In Search Of Vanished Ages

Field trips to fossil localities in California, Nevada, and Utah

By Inyo

A view across the middle Miocene Barstow Formation on California's Mojave Desert. Here, limestone concretions that occur in rocks deposited in a freshwater lake system approximately 17 million year-ago produce exquisitely preserved, fully three-dimensional insects, spiders, water mites, and fairy shrimp that can be dissolved free of their stone encasings with a diluted acid solution—one of only a handful of localities worldwide where fossil insects can be removed successfully from their matrixes without obliterating the specimens.

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Dedicated to my parents who introduced me to the glories of nature

Chapter 1

Fossil Plants At Aldrich Hill, Nevada

The Great Basin wilds of west-central Nevada are rich in productive fossil plant localities. While they are probably not as well known to amateur fossil plant hunters as the classic Paleocene through Late Miocene (roughly 64 to 5.3 million years ago) leaf-bearing sites of Oregon, Idaho, Washington, Montana, Colorado and Wyoming, the Nevada fossil plant deposits continue to yield many excellently preserved paleobotanical remains.

One of the more interesting and paleontologically rewarding leaf and seed-yielding areas lies near Yerington (the county seat of Lyon County) at Aldrich Hill. Here can be collected some 35 species of ancient plants from what geologists call the middle Miocene Aldrich Station Formation, a geologic rock unit dated at roughly 13 to 12.5 million years old. Among the many fossil plant remains found at Aldrich Hill are complete, carbonized leaves from an evergreen live oak, in addition to many conifer winged seeds and even giant sequoia foliage. It is indeed a special place to visit, an isolated region in the Great Basin "outback" where the Bureau of Land Management still permits the hobby collecting of fossil plant remains--a situation that could change literally overnight, by the way, should commercial collecting interests begin to raid the stratigraphic section, desecrating the integrity of the exposures and destroying in the process the great scientific value of the locality. Fortunately, Aldrich Hill remains accessible to the general public, and folks interested in collecting fossil plants there for personal use only may continue to visit, remembering of course that such specimens gathered must be neither sold nor bartered--activities which would constitute a clear violation of the rules and regulations established by the Bureau of Land Management for visitors to America's public lands.

All of the fossil plants--including evergreen live oak leaves, spruce winged seeds, conifer needles, alder cones, and giant sequoia/big tree foliage--occur in the tan to reddish-brown and cream-colored diatomaceous to tuffaceous mudstones and shales of the middle Miocene Aldrich Station Formation exposed on the north side of Aldrich Hill. Excellent outcrops of the plant-bearing strata can be examined along the main wash which trends generally east-west across the northern side of Aldrich Hill. Additional productive fossiliferous exposures can be found in the minor erosion gullies that dissect the north slope of the hill. It should also be pointed out that virtually every outcrop of diatomaceous mudstones and shales in the Aldrich Hill district yields fossil plant material in varying degrees of relative abundance, from very rare to common, although the prominent and accessible exposures along the north side of the hill have in a historical sense provided collectors with the majority of paleobotanical remains.

When fossil hunting at Aldrich Hill, as at most other fossil leaf and seed-yielding localities, try to cover as much terrain as possible in search of the most productive layers. Split heaps of the shales with the blunt end of a geology hammer whenever you stop for a "look-see." Some folks prefer to use the pick end of a geology rock hammer, though this technique actually decreases the likelihood of splitting with precision the blocky diatomaceous mudstones and shales; too, a number of collectors prefer a roofer's or brick-layer's-style hammer, with a wide narrow blade, which theoretically splits shales with great effectiveness. Such a hammer probably works well with very soft, classically fissile shales, but the tool lacks any kind of "punch," or heft, for cleaving bulkier and more compacted mudstones and shales. The upshot: the blunt end of a traditional geology hammer splits the Aldrich Station Formation diatomaceous shales and mudstones quite nicely. Remember, of course, to wear safety goggles, or some manner of eye protection while splitting the mudstones and shales.

Although nowhere abundant, the fossil plant impressions in the Aldrich Station Formation are nevertheless common and even obvious at several horizons in the diatomaceous material. Watch for their pale to dark-brown, carbonized coloration on the tan to reddish-brown and cream-colored rocks. Associated with the leaves, winged seeds, and twigs are conspicuous oval specimens roughly one-half to one inch in diameter. These fossils represent the internal molds of fresh water clam shells; the actual shell substance has long since been dissolved away, as the siliceous mudstones and shales were evidently a poor medium of preservation for the tests of pelecypods.

If a microscope is available, you can, in addition to finding the plants and clams, examine the remains of an especially prolific fossil type at Aldrich Hill--the diatom. This is a microscopic photosynthesizing single-celled plant which during the geologic past contributed its resistant siliceous remains in vast numbers to the plethora of paleohistory in the rocks, particularly in west-central Nevada in rocks of Middle through Late Miocene age (roughly 17 to 5 million years ago). The scientific extraction of diatoms for paleobotanical study is a dangerous operation, involving as it does the use of several powerful acids, among them hydrochloric, sulfuric and hydrofluoric--potent brews that if not handled properly can cause frightful or even life-threatening burns. It is a process only an expert should attempt. Fortunately, though, you can get an adequate and general view of diatoms simply by powdering a small amount of diatomaceous matrix on a glass microscope slide and then examining the residues under moderate to high powers of magnification. Most of the diatoms from the Aldrich Hill district resemble minute boxcars and discs.

Excluding the numerous species of diatoms identified from the Aldrich Station Formation, some 35 species of fossil plants have been described from the exposures at Aldrich Hill--a fossil deposit first investigated scientifically in the early 1940s by the late paleobotanist

Daniel I. Axelrod during one of his geological reconnaissance investigations in Nevada. Axelrod eventually published his paleobotanical, paleoecological, and geological conclusions concerning the Aldrich Hill paleoflora in a monumental paleobotanical monograph, where he additionally describes in detailed scientific fashion three more important Nevada fossil floras (Middlegate Formation, Chloropagus Formation, and Desert Peak Formation). All of the fossils from Aldrich Hill occur in the Aldrich Station Formation, as named by Axelrod in his treatise, a geologic rock unit originally considered transitional Miocene-Pliocene (about 10 million years old by the geologic time scale then in fashion--as recalibrated, the Miocene-Pliocene is now established at roughly 5.3 million years ago), but now considered Middle Miocene in geologic, or approximately 13 to 12.5 million years old.

The Aldrich Station paleoflora shows quite a variety in its composition. The five most commonly collected specimens are, in decreasing order of relative abundance: (1) winged seeds from three varieties of spruce--*Picea sonomensis* (by far the most abundant representative of the paleoflora), whose seeds appear identical to the modern Brewer Spruce (*Picea breweriana*) of the Klamath region of northwestern California and adjacent Oregon; an extinct spruce that Axelrod called *Picea lahontense*--a conifer whose seeds cannot be compared with any known living spruce, although they do show a general similarity to those produced by a few modern "larger-coned" spruces of eastern Asia, chiefly China; and a presumed extinct spruce called *Picea magna*, whose winged seeds resemble those produced by the living tiger-tail spruce, *Picea polita*, a conifer now native to the volcanic soils of Japan; (2) fragmental and occasional complete, intact leaves from an evergreen live oak called *Quercus pollardiana*, a species that is practically identical to the modern maul oak, also called canyon live oak, *Quercus chrysolepis*, presently native to the moist western slopes of the Sierra Nevada and the Coastal Ranges of California; (3) leaves from a species of cottonwood, *Populus payettensis*, whose fossil foliage matches leaves produced by the living Narrowleaf Cottonwood, *Populus augustifolia*; (4) foliage/twigs of giant sequoia, *Sequoidendron chaneyi*, that match very well with those produced by the living Sierra Redwood/Big Tree, *Sequoiadendron giganteum*, which is now restricted solely in natural habitat to a narrow, moist belt along the western slopes of the Sierra Nevada in California; and (5) leaves from a species of willow referred to as *Salix payettensis*--its foliage appears very similar, if not identical to leaves produced by the modern willow *Salix exigua*, a rather widespread variety that goes by many common names, such as Coyote Willow, sandbar willow, or even Narrowleaf willow. The nine next most-common specimens encountered are: Catalina ironwood, Mountain alder, an extinct water oak, California buckeye, black cottonwood, an extinct cottonwood, zelkova, Arizona ash, and Cedar elm. Rarer occurrences include such varieties as sugar pine, white fir, Ponderosa pine, Douglas-fir, Western Red Cedar, Western

hemlock, California sycamore, serviceberry, Oregon grape, California coffeeberry, coralberry, Japanese pagodatree, birch-leaf mountain mahogany, and a Horsetail.

The vast majority of fossil plants recovered from the middle Miocene Aldrich Station Formation at Aldrich Hill show a demonstrable resemblance to their modern analogs still living today. For example, the humid cooler-weather conifer elements in the paleoflora (spruce, fir, pine, giant sequoia) have their closest contemporary counterparts in the Sierra Nevada and Cascade Mountains regions of western North America. As a matter of fact, there is a direct relationship postulated between the overall composition of the Aldrich Hill Miocene flora and modern-day plant associations present in the giant sequoia forests of the western slopes of the Sierra Nevada in California--specifically, the spectacular Sierra Redwood groves at Calaveras Big Trees State Park and Sequoia National Park.

Based on the known climatic requirements of present day plant counterparts of the fossil flora, the Aldrich Hill district some 13 to 12.5 million years ago had quite a different environment than the arid juniper-sage-Pinyon pine associations observed there today. For one thing, rainfall was approximately 25 to 30 inches per year, distributed in both winter and summer months. This is fully 15 inches more than the area receives today, with almost all of the effective precipitation now occurring during wintertime as snow and rain. Temperatures today also show much greater extremes than what can be inferred for the moderate Middle Miocene days, when freezing conditions were extremely rare and summer highs normally ranged around 85 degrees. This contrasts dramatically with today's regular winter weather patterns that mimic Arctic-style extremes and summer peaks to over 100 degrees Fahrenheit. Elevations at the sites of deposition were in all likelihood slightly higher than the 6,000 to 6,700 feet we observe today in the Aldrich Hill district--probably an elevation between 7,000 and 7,500 feet for those Middle Miocene times is not out of the question.

In addition to telling us something of the climate of the geologic past, the Aldrich Hill fossil plant bonanza also reveals a striking gradual change in both the local paleogeography and the associated plant communities. In the earliest phases of their deposition, the fossil plants reveal that the ancestral Aldrich Hill region was a broad valley within which sprawled one or more fresh water lakes of perhaps moderate to large size; the diatoms preserved in the Aldrich Station Formation suggest that the lakes were rather cool and deep and well within the range of normal mineral content. Occasionally, though, volcanic activity from distant areas contributed layers of ash and pumice to the accumulating diatomaceous sediments. The adjacent slopes supported a thick mixed conifer forest consisting of white fir, Ponderosa pine, Brewer spruce, Douglas-fir, Western Red Cedar, Western hemlock and giant sequoia, along with a subordinate deciduous grouping of alder, poplar, cottonwood, willow, elm, zelkova, Japanese pagodatree, and coralberry. Living on the more exposed slopes were

evergreen live oak, serviceberry, California buckeye, cottonwood and ash. Yet, higher in the geologic section at Aldrich Hill, in rocks younger by hundreds of thousands of years, the fossil plants prove that the geography had changed significantly. In place of a widespread conifer forest with only minor areas of woodlands surrounding a great lake basin, there had developed a vast hilly woodland where only a few interfingers of forest penetrated from the higher slopes surrounding the lake basin of deposition. Replacing big tree, spruce, pine and other conifers as dominants were evergreen live oak, mock locust, California buckeye, coralberry, mountain mahogany and serviceberry--a paleoenvironment that was much more xeric in nature than that suggested by plant communities which had preceded it. Here rare forest elements were white fir, Ponderosa pine, western hemlock and giant sequoia. Also present in the forest association were such species as alder, hollygrape, Catalina ironwood, cottonwood, poplar, elm, willow and zelkova. The once thriving forest grouping of conifers and deciduous varieties appears to have survived in the upland regions, descending into the dominant evergreen live oak territory only under especially favorable conditions.

Today, the sedimentary rocks at Aldrich Hill provide proof that roughly 13 to 12.5 million years ago an extensive giant sequoia forest reigned over what is presently an arid Great Basin land of sage and juniper and Pinyon pine. Along with the big trees grew such plant varieties as Brewer spruce, Ponderosa pine, white fir, Western hemlock, evergreen live oak, and an array of deciduous kinds--a scene that closely resembles the modern-day humid western slopes of California's Sierra Nevada in the vicinity of Calaveras Big Trees State Park east of Angels Camp, where two groves of mighty Sierra Redwood continue to thrive in a setting of pristine grandeur. Within the diatomaceous mudstones and shales of the middle Miocene Aldrich Station Formation can be found direct evidence of that ancient Big Tree forest, the beautifully preserved carbonized impressions of plant remains covered over by the sediments in a long-vanished lake--leaves and seeds and conifer foliage which only await a patient, dedicated fossil hunter to bring to their first light of day in many millions of years.

Chapter 2

A Visit To Ammonite Canyon, Nevada

Introduction

All Ammonite Canyon localities presently reside on BLM-administered territory (United States Bureau of Land Management)--a conservation category also commonly called public lands. This is a long-held and well-understood American legal status that affords unauthorized amateur paleontology enthusiasts an opportunity/privilege to collect within the confines of Ammonite Canyon reasonable amounts of common invertebrate fossils, without first securing from the BLM a customary special use permit. Without that permit, vertebrate remains encountered on public lands must be left where found (taking photographs of vertebrate fossils is not yet illegal, though).

Unfortunately, that special land status could literally change overnight, without any degree of advance warning. The undeniable scientific fact of the matter is, Ammonite Canyon remains a world-famous fossil-producing region that hosts perhaps the most complete Late Triassic through Early Jurassic--approximately 205 through 195 million years ago--ammonite succession in the world; that is, paleontologically significant species of ammonoids (Triassic types) and ammonites (Jurassic and Cretaceous) are stacked directly atop one another in distinct layers--called "zones" by stratigraphers--just as they were deposited through roughly 10 million years of sedimentary accumulation. Too, the rich and inclusive Mesozoic Era cephalopod assemblage is exceptionally well exposed in a stark Great Basin Desert setting--no vegetation covers the ancient strata--permitting accessible opportunities to study in great scientific detail one of our planet's major mass extinction of plants and animals--the paleobiologically traumatic Triassic-Jurassic boundary extinction of roughly 202 to 198 million years ago. Indeed, not a few professional paleontologists consider the area worthy of a World Heritage designation.

Probably that most restrictive of strictures is not likely to come to pass anytime soon--if at all, actually. On the other hand...the BLM could at any arbitrary moment decide to place Ammonite Canyon into a special conservation category called an Area Of Critical Environmental Concern (ACEC, for short).

And make no mistake about it: This will most certainly happen should commercial collecting interests begin to desecrate through illegal mechanized gathering of fossil specimens the priceless stratigraphic integrity of the Mesozoic Era geologic section. Also, if ammonites and other invertebrates from Ammonite Canyon begin to appear for sale with egregious

frequency via the Internet, or at various rock, gem, and fossil shows around the United States--and world for that matter--the Bureau of Land Management will then, with obvious legal precedent, have reasonable justification to close Ammonite Canyon to all but trained professional paleontologists. This is because, according to the laws regarding fossil collecting, paleontological specimens gathered on public lands shall neither be sold, nor bartered (in legal argot, generally understood to mean traded); such specimens are intended solely for personal hobby use only.

The upshot here is pretty much this: Should a clear pattern of collecting abuse develop, Ammonite Canyon, because of its abundant association of marine invertebrate fossils that span the important Triassic-Jurassic Period extinction boundary--it is, indeed, one of the best exposed and most reliably fossiliferous localities on Earth in which to study the traumatic end-time Triassic mass extinction and eventual recovery of paleo-ecosystems during the succeeding Jurassic Period--will most certainly be closed to all unauthorized amateur paleontology enthusiasts.

Field Trip To Ammonite Canyon, Nevada

Several years ago, during my first trip to Buffalo Canyon, Nevada--a locality that yields abundant and well-preserved Middle Miocene leaves and seeds some 15 million years old--I happened to learn of a tremendous Triassic-Jurassic Period, Mesozoic Era fossil-bearing area in the Great Basin Desert of Nevada.

It's often strange how such things come about. I was camped along the dirt access path, in the heart of the fossil plant-yielding district, when a four-wheel-drive vehicle came bounding around the bend in the distance; it was approaching fast, churning up billows of dust. While camped in isolation there in Buffalo Canyon, I had not seen another human being in three days and nights, so naturally I was surprised to encounter another explorer of the sparsely populated Basin And Range outback.

It came to pass that that individual maneuvering his vehicle across the terrain was a field geologist employed by a local gold exploration company. He'd been sitting "on top of a rich strike" for some five days, taking core samples and assessing the mineral potential of the find--a huge gold field in which the precious metal was disseminated through the country rock in microscopic particles. He even showed me a typical sample of the ore, an improbable-looking bluish-gray mud through which, I was soberly assured, the gold was liberally distributed. I had to take his word for it, of course, since there was obviously no distinctive luster to identify the gold content.

When I told the geologist that I was seeking fossil leaves in the middle Miocene Buffalo Canyon Formation, he expressed an interest in finding a few plant specimens of his own. We then hiked over to a nearby fossiliferous outcrop and must have spent a half-hour or so picking through the diatomaceous (composed primarily of the microscopic photosynthesizing single-celled plants called diatoms) siltstones and shales.

While we were digging, he rather matter-of-factly asked if I had ever visited Ammonite Canyon, a "world-class ammonite collecting locality," he said, where Late Triassic (roughly 205 to 200 million years old) and Early Jurassic-age (about 199 to 195 million years ancient) strata yield an abundance of beautifully preserved fossils, including beaucoup, bountiful extinct cephalopods. I admitted that I hadn't heard of the place, but would certainly appreciate directions to it.

Back at camp, the geologist tried his best to remember the specific route to Ammonite Canyon, but his memory failed him. The best that he could recall was that "Ammonite Canyon" was the informal name of the area he'd received on "good authority" from several folks in his profession who'd actually visited the site.

My enthusiasm waned significantly. The revelation that this information concerning Ammonite Canyon was only hearsay knocked most of the wind out of my sails.

Still, the phrase "world-class ammonite collecting locality" continued to bounce around in my brain, from time to time, over the next few years. Perhaps, I reasoned at last, the geologist I'd met in Buffalo Canyon had not exaggerated the claims made by his acquaintances. Maybe the line of evidence was more direct than I had originally determined it to be. After all, such geologists were trained men of science, presumably not given to imprecise observations. My reflective analysis told me that the information was probably reliable, but there was obviously one additional problem to solve: Where in the world was Ammonite Canyon?

I had nightmares that this would turn into a tangled, involved search. The geologist's original description that Ammonite Canyon was but an "informal name" could conceivably lead to endlessly frustrating avenues of speculation. For example, every major mountain range invariably contains innumerable gulches, canyons, draws and washes, most of them unnamed. And, since Ammonite Canyon was admittedly a popular, unnamed geographic designation for one of these defiles in the mountains, I figured that I might have a difficult time tracking it down.

And so, I began research preparations with an inspired dedication akin to attempting to locate the famous (or infamous, if you will) Lost Dutchman's Mine in Arizona--or, perhaps even formulating for possible submission my own crazy, convoluted plot for the "National

Treasure" film franchise. I purchased maps. I drove to the nearest available university library to copy off reams of scientific literature pertaining to my search for Ammonite Canyon. I contacted several rockhounding clubs across the United States for geographic details. I emailed all the major university geology departments in Nevada. Zilch. Nada. No direct leads.

I was genuinely dispirited. At this point I was wholly prepared to abandon the research project when the inspired idea arrived one morning after a bracing cup of coffee that perhaps I ought to try to contact the geologist who'd originally alerted me to the existence of Ammonite Canyon in the first place. That I still had in my field notebooks a reference to that individual, his name--and even the mining company he'd worked for--was in itself a minor miracle. Still, there was no guarantee of a favorable outcome. Perhaps that helpful geologist had already moved on--no longer worked for the same mining outfit. Too, I indeed recollected that when pressed for details the individual had been unable to come up with directions.

It was worth a try, I decided. Off went an inquiry, mailed to the mining company. Perhaps with a little additional prodding, the geologist--or even somebody at that mining corporation--might be able to provide me with explicit directions to this mysterious Ammonite Canyon.

Thus, it came to pass that I simply had to wait with at least a modicum of appropriate patience. But, when not a few weeks passed without any kind of response...well, my enthusiasm for the project began to dissipate once again--until, that is, one eventful afternoon when amidst the usual bills and unsolicited advertisements I spotted a rather inconspicuous envelope from an address I instantly recognized: that mining company I had contacted regarding the geologist who'd first mentioned to me this place called, colloquially, Ammonite Canyon.

With great anticipation I ripped open that envelope to find a very welcomed letter. It seems that my original inquiry never actually made it to the geologist I'd met back in Buffalo Canyon. Somebody at the mining company had with superior initiative taken it upon himself to answer my burning question: Where in the world was Ammonite Canyon?

And when I read the exact directions to Ammonite Canyon, I practically laughed out loud; turns out that, in a delicious delirium of irony, I'd already driven directly past the turnoff to it during that initial journey to--you guessed it...Buffalo Canyon.

That following spring, I loaded up my trusty vehicle with all sorts of fossil finding equipment, plus the obligatory water and supplies, and lit out for the adventure. I already knew the directions to the correct mountain range, of course; the tricky part was locating the correct dirt road that veered from asphalt to Great Basin Desert wilderness--a typical unimproved desert trail that winds its way across an alluvial fan, ever so gradually upward toward the looming presence of a fossil-rich Nevada mountain range directly ahead. Anticipation and excitation increase exponentially as one gains elevation, headed toward the mouth of the canyon in the distance.

It's a mountain range packed with beaucoup geology and paleontology--an awe-inspiring spectacle consisting over 10,000 feet of Mesozoic-age limestones, shales, and dolomites jumbled together through geologic time as if rotary-beaten. The sedimentary rocks exposed there belong to the middle through upper Triassic Luning Formation; the upper Triassic though lower Jurassic Gabbs Formation; the lower Jurassic Sunrise Formation; and the lower through early middle Jurassic Dunlap Formation. The range also contains extensive Cenozoic Era volcanic intrusives and extrusives, primarily rhyolites, rhyodacites, quartz latite welded tuffs, and tuffs of Late Miocene through Pliocene geologic age, some 10 to three million years old--in addition to Cretaceous quartz monzonites and albite granites approximately 90 million years old. Many of the Miocene-Pliocene igneous rocks have been appreciably enriched in copper minerals, and there are several extensive prospects back in Ammonite Canyon that reveal colorful specimens of azurite and malachite--blue and green varieties of copper carbonate, respectively.

The most fossiliferous sedimentary rocks in Ammonite Canyon belong to the upper Triassic-lower Jurassic Gabbs Formation (205 to 198 million years old) and the lower Jurassic Sunrise Formation (197 to around 193 million years ancient). In addition to the fossil ammonoids (the Triassic ceratites types) and ammonites (Jurassic-Cretaceous ammonites varieties) that occur within several limestone layers in the thick Mesozoic sequence, there are also not a few other kinds of macro and micro-invertebrate animal remains well-represented in the Ammonite Canyon exposures. These include: corals (both colonial and solitary scleractinian kinds--the type of coelenterate that replaced the tabulate and rugose corals, which went belly-up, extinct, at the close of the Paleozoic Era some 252 million years ago); brachiopods; pelecypods; and gastropods--in addition to numerous species of diminutive invertebrates (usually lumped together under the category "micro-invertebrates") such as radiolarians, foraminifers, ostracods (a minute bivalved crustacean), microgastropods, micropelecypods, and even the last known conodonts in the geologic record (of latest Triassic geologic age--that is, a minute tooth-like food gathering calcium phosphate apparatus from an extinct lamprey-eel like organism; such conodont denticles are nevertheless unrelated to modern jaws), whose preservation is excellent considering the locally geologically disturbed nature of the sedimentary rocks in which they occur.

Most of the shales of the Sunrise Formation, for example, have been altered through stressful metamorphism to a special brand of rock geologists call hornfels; hence, fossil remains tend

to be rather poorly preserved there--except for one particularly fossil-rich shale zone rather low in the stratigraphic section that indeed yields plentiful casts and molds of many species of ammonites. On the other hand, the limestones, sandy limestones and sandstones of both the Gabbs and Sunrise formations have usually survived the millions of years of unkind heat and pressure, yielding many fossils in a superior state of preservation.

One of the better representative fossil-bearing localities occurs not far from the prominent mouth of Ammonite Canyon. Here, the steep slopes immediately north of the dirt trail consist of abundantly fossiliferous coarsely crystalline, dark brown limestones of the upper Triassic portions of the upper Triassic-lower Jurassic Gabbs Formation. Among the commonly observed forms present are brachiopods, pelecypods, gastropods, and corals. Unfortunately, ammonites are not plentiful here, although I did manage to locate three specimens during my first visit, including one giant some six inches (15 centimeters) in diameter (*Acestes gigantogaleatus*, perhaps?). It came from outcrops of limestone way above the canyon floor, though, where admittedly the best collecting can be done.

One doesn't need advanced mountain-climbing skills to ascend the limestone slopes, but extreme caution should be taken. The footing is, to say the least, unreasonably treacherous; wear reliable, comfortable footwear--preferably good-quality hiking boots--and take your time to spot the safest place to plant each step. The numerous excellently preserved fossils will wait for you. They've been around approximately 203 million years at this particular locality and will remain in place for a few more minutes at least, so there is certainly no need to rush to locate them, placing you in a precarious and potentially dangerous situation.

As I learned from the geological literature I had eagerly consumed, this is a classic collecting site, well-known to the pioneering geologists and paleontologists of the 1800s. It has also been visited by hordes of both amateur fossil enthusiasts and professional paleontologists alike since at least the early 1900s. As a consequence, the fossil beds have suffered appreciable attrition, and the once unbelievably abundant ammonoid and ammonite specimens--astoundingly well-preserved in many instances--have been depleted, stored away in private collections and museum cabinets around the world. There are obviously many fabulous fossil-bearing layers throughout Ammonite Canyon, but this single site, outcropping along the main road through the canyon not far from its mouth, is certainly one of the most easily accessible and richly fossiliferous exposures known. It is hoped that visitors to this exceptional site will take but a representative sampling of paleontological material, leaving the integrity of the 203-million-year-old Late Triassic faunal association intact.

Immediately northeast of the first fossil locality, the road cuts through a narrows in the reddish-brown conglomerates and fanglomerates of the lower to early middle Jurassic Dunlap

Formation, roughly 180 million years old. The Dunlap deposits were apparently laid down in a terrestrial paleo-environment after the lower Jurassic Sunrise Formation sea had receded, probably as alluvial outwash carried by rivers and streams from the surrounding ancestral mountains millions of years ago, a Mesozoic range that was uplifted and completely worn away before the first widespread flowering plants appeared in the geologic record some 120 million years ago.

Somewhat farther up Ammonite Canyon, beyond the unfossiliferous narrows eroded in the lower middle Jurassic Dunlap Formation, the Gabbs and Sunrise formations are much better exposed. Here, marine fossils are indeed plentiful in both geologic rock units, but they tend to occur only in a few restricted zones, principally throughout a 95-foot-thick section of the Gabbs Formation, slightly above the middle--an interval of brownish-colored shaly and sandy limestone preserved in individual layers six inches to two feet thick. This is the well-known and famous "Member Three" of the Gabbs Formation, a member that yields abundant ammonoids, pelecypods, gastropods and brachiopods. One noteworthy aspect of this particular faunal association is that the fossil species recognized from it are almost identical to those that occur in similar Late Triassic rocks in the Mediterranean region.

Two other traceable cephalopod-rich horizons occur in the Gabbs Formation. One lies near the base of the 400-foot-thick unit, in the very oldest rocks; the other can be found just below the noted middle Member Three, in black to grayish-purple weathering limestones typically four inches to two feet thick. All three zones yield important species of ammonoids, including such key Late Triassic forms as: *Arcestes gigantogaleatus*; *Arcestes nevadanus*; *Chloristoceras crickmayi; Chloristoceras marsh*i; *Chloristoceras shoshnensis*; *Pacites* sp.; and *Rhacophyllites cf debilis*--plus, a curious nautiloid cephalopod called *Pleuronautilus*. The older of the two zones has been correlated (that is, it's the same geologic age) with a major mollusk-bearing section in the Santa Ana Mountains of southern California.

At a stratigraphic point roughly 56 feet (17 meters) below the base of the overlying (and younger) lower Jurassic Sunrise Formation--within the Gabbs Formation--there is recorded in the rocks at Ammonite Canyon a traumatic event of worldwide import--the classic end-time Triassic event, a great mass extinction some 199.6 million years ago. That's when, over an unbelievably brief period of geologic time--only 10,000 years, perhaps--some 20 percent of all marine life died out, and up to half of all terrestrial animal life disappeared, as well. The numerous paleo-ecological niches then left vacant famously ushered in the dawn of "Jurassic Park"--when dinosaurs began to dominate our planet's terrestrial domains during the Jurassic and succeeding Cretaceous Periods. Stratigraphers continue to rave, proclaim with considerable conviction, that the well-exposed marine stratigraphic section developed in

Ammonite Canyon remains one of the world's thickest, most complete, and reliably fossiliferous exposures of rocks dating from the day of end-time Triassic doom.

In Ammonite Canyon, the geologic transition from Late Triassic to Early Jurassic times lies within the upper (younger) phases of the Gabbs Formation. The precise boundary between the Triassic and Jurassic Periods has been placed by Mesozoic Era specialists at the first occurrence of two key ammonite species--*Psiloceras tilmanni* and *Psiloceras spelae*.

Directly above the Gabbs Formation lies the lower Jurassic Sunrise Formation, whose lowermost (oldest) brownish sandy limestones and younger shales yield a true abundance of ammonites and other invertebrate remains. Key species of cephalopods from the lower limestones include such ammonites as: *Caloceras peruvianum*; *Chloristoceras minutum*; *Kammerkarites* sp.; *Neophylites* sp.; *Nevadaphylites* sp.; *Odoghertyceras deweveri*; *Pleuroacanthites mulleri*; *Psiloceras marcouxi*; *Psiloceras pacificum*; *Psiloceras polymorphum*; and *Transipsiloceras transiens*. Also present in the oldest limestone zones of the Sunrise Formation are numerous nicely preserved solitary scleractinia corals not yet formally described in the scientific literature, plus several species of rynchonellid brachiopods, pecten-style pelecypods, and various gastropods. Higher in the Sunrise section--in strata approximately 193 million years old (mid Sinemurian Stage of the Early Jurassic Period)--several species of ammonites occur as casts and molds through several tens of feet of pale purple-weathering shales.

Almost all of the fossil-bearing layers in the Gabbs and Sunrise Formations closest to the main road have been heavily prospected over the years. I had better luck when I hiked away from the primary wash, up any of the minor gulches and gullies that intersect it. Virtually all of my Early Jurassic ammonite finds, for instance, came from a single narrow nondescript dry wash, above Ammonite Canyon road, in a localized exposure of transitional Gabbs-Sunrise strata.

Be advised once again, though. The ammonoids and ammonites are far from common at the surface anymore. Because the extinct cephalopods are such prized paleontological items, sought by many collectors throughout the world, don't expect to step out of your vehicle and load up on perfectly preserved specimens. This just isn't going to happen. One almost needs to acquire a "sixth sense" about where to look for ammonites--attempting to out-guess the competition, as it were.

Although ammonoids and ammonites are no longer exceptionally abundant, the other "less glamorous" Mesozoic marine invertebrates remain plentiful. Brachiopods, pelecypods, solitary corals, colonial corals (found only within late Triassic strata at Ammonite Canyon), and gastropods are frequently overlooked, or ignored, by eager prospectors bent on locating

the famed Ammonite Canyon coiled cephalopods, and many exquisitely preserved forms weather free for the taking from their calcium carbonate matrixes.

While hiking along the gravel road through Ammonite Canyon, one will likely observe relatively common chunks of colorful blue-green copper minerals scattered about. These have been washed down from volcanics and geologically altered Mesozoic-Cenozoic rocks that outcrop farther up the canyon. As a matter of fact, at one point in time a prestigious mining company decided to claim a significant portion of Ammonite Canyon for future copper exploration. Don't worry, though. At last check, they haven't closed off the canyon just yet, though visitors will have to obey all private property rights should such formal mining operations ever commence.

Ammonite Canyon instantly became one of my favorite fossil localities. Here is a remote region in a rugged strata-jumbled range in Nevada, where wonderfully preserved ammonoids, ammonites, brachiopods, corals, pelecypods, and gastropods can be found in a classic Great Basin Desert setting--Mesozoic-age specimens some 205 to 195 million years old, the preserved remains of invertebrate animals that span the world-famous end-time Triassic mass extinction.

Few places on Earth record such a well-exposed, accessible, and inclusively fossiliferous marine Triassic-Jurassic-age transition period. With a single step, one can actually move 100,000 years in geologic time: from the end-time latest Triassic 199.7 million years ago, to the very beginning of the succeeding Jurassic Period 199.6 million years ancient, when fully one-fifth of all marine life no longer existed and roughly half of all animals on land had vanished.

Chapter 3

Fossil Insects And Vertebrates On The Mojave Desert, California

Preface

Visit two world-famous paleontologic localities situated on California's vast Mojave Desert. They're from what geologists call the middle Miocene Barstow Formation. And--they're 17 to 13.4 million years old.

One specific site within the Barstow Formation is without question among the most unusual fossil-bearing areas on earth. Not only does it yield many species of insects, but also lots of spiders, water mites, fairy shrimp, ostracods (a small bivalve crustacean) copepods (a minute crustacean often called Cyclops), cladocerans (tiny crustaceans commonly called "water fleas"), and even diatoms (a microscopic single-celled plant), as well--all of which can be dissolved whole and intact, in three-dimensional form, from their calcium carbonate (limestone) concretion encasings. It is one of only a handful of places on the planet where fossil insects can be removed without damage from their matrix.

A second geologic district in the Barstow Formation provides vertebrate paleontologists with one of the most significant terrestrial records of Middle Miocene animal life in North America--a place rich with the remains of extinct horses, camels, pronghorns and proboscideans, among many other mammalian varieties. It is, in fact, the type locality for what geologists, paleontologists and stratigraphers call the Barstovian Stage of the Middle Miocene, roughly 16 to 12.5 million years old--an epochal stage of North American Cenozoic Land Mammal Biochronology with which all other time-correlated rocks in North America are compared.

Introduction

This field trip's all about paleontological discovery on California's Mojave Desert. Here's a chance to visit two world-renowned fossil localities in the middle Miocene Barstow Formation--dated through rigorously sophisticated radiometric techniques at 19.3 to 13.4 million years ancient.

First off, visit what many paleontology enthusiasts call Fossil Insect Canyon. It's a special place that yields an astounding diversity of exceptionally well-preserved insects, arachnids, crustaceans, and plants from a roughly 19 to 17 million year-old lake system, whose sediments accumulated under still incompletely understood geochemical conditions, permitting in not a few examples internal organ preservations. The fossils lie encased within

calcium carbonate (limestone) concretions as mineralized, fully three-dimensional specimens, usually replaced by a variety of cryptocrystalline quartz called chalcedony (silicon dioxide), celestite (strontium sulfate), gypsum (calcium sulfate) and calcite (the crystal mineral manifestation of calcium carbonate), primarily; that is, the "Barstow bugs" are not carbonized compressions or impressions lying along the bedding planes of fissile shales, the classical way most fossil insects have been kept "alive" through geologic time. This is one of only a mere handful of localities on earth where three-dimensional fossil insects can be removed whole and intact from the matrixes within which they have been preserved through geologic time.

In order to extract, recover, the scientifically invaluable remains, which sometimes reveal delicate internal organs preserved intact, a special diluted solution of acid must be used to dissolve away the calcareous matrix; recommended acids include formic, acetic (glacial acetic, not the kind found in vinegar), or muriatic---in other words, commercial grade hydrochloric. The fossils can then be found within the insoluble residues left behind by the chemical reaction. In all, upwards of 50 species of freshwater arthropods have been identified from Fossil Insect Canyon, a place many paleontologists call a Konservat Lagerstätte. This is by definition a sedimentary deposit that "exhibits extraordinary completeness or richness," preserving for study "lightly sclerotized and soft-bodied organisms or traces of organisms that are not otherwise preserved in the usual shelly and bony fossil record."

Next, for additional important exposures of the middle Miocene Barstow Formation, head on over to what's colloquially called Fossil Bone Basin. It's a prolific vertebrate fossil-bearing area, extensively studied since the early 1900s by any number of paleontologists representing universities and museums throughout the world. Abundant mineralized (often silicified, replaced by silicon dioxide) animal specimens identified from Fossil Bone Basin include just about every manner of Middle Miocene mammalian critter imaginable, from horses to proboscideans to rodents, and everything in between--plus birds, tortoises and fresh water mollusks (gastropods and pelecypods). Significant botanic remains include diatoms (microscopic single-celled plant), carbonized leaves, and petrified woods. In Fossil Bone Basin the list of mammal species is quite extensive, indeed, and continues to grow each year as university and museum personnel repeatedly head out to the bone-bearing badlands for successive seasons of discovery. As a matter of fact, the Barstow Formation within Fossil Bone Basin is the type locality for the Barstovian Stage (North American Cenozoic Land Mammal Biochronology) of the Middle Miocene Epoch, technically 15.9 (OK, call it 16 million years, rounded off) to 12.5 million years old. All geologically time-equivalent strata in North America are compared and evaluated for their specific paleontological content with the Fossil Bone Basin sequence.

Collecting Status

OK--now it's time to talk about collecting legalities, restrictions and such. First of all, without first obtaining a special use permit issued by the United States Bureau of Land Management (BLM), removing any manner of fossil specimen from Fossil Bone Basin is strictly forbidden, verboten. Such a permit, by the way, is distributed solely to fully qualified scientists, with at least a B.S. degree from an accredited university, who seek to undertake research projects that can be verified as authentic and scientifically justifiable by the petitioned authorities. But, then again, not to worry too much: In a fortunate richness of happenstance--taking photographs of fossil vertebrates, when found in situ in the ancient sediments, is not yet illegal. The bone-bearing badlands remain open for public inspection, and many vertebrate fossils continue to weather out of the middle Miocene Barstow Formation. Documenting the specimens in situ with a camera is keen fun, indeed.

Fossil Insect Canyon presents a rather different situation. At the fossil-bearing area, when last checked, the United States Bureau of Land Management (BLM) still retains official jurisdiction over territory designated as federal public lands. This means that unauthorized amateur paleontology enthusiasts may continue to collect on such public lands, for personal and hobby-recreational use only, reasonable amounts of the insect-bearing calcareous concretions. Such items, naturally, must never be bartered (generally interpreted as trading specimens), or sold, for that matter.

On the other hand, one must take this much under advisement: While the BLM continues to manage public lands, much of Fossil Insect Canyon in actual fact still remains under formal mineral claim by a prominent mining company; hence, numerous productive localities known to yield fossiliferous concretions occur on, technically, private property. In the past, though, the mining company has graciously allowed hobby enthusiasts unrestricted access. Needless to report, that friendly attitude could change overnight should vandalism, graffiti, littering, or the commercial raiding/destruction of the concretion zones commence. Without belaboring the point, commercial collectors must stay away, or with certifiable certainty only those with credentials of university accreditation will have access to the wonders of Fossil Insect Canyon. To stay on the safe side, individuals interested in visiting Fossil Insect Canyon must consult the most up-to-date public lands maps to determine the boundaries of territory administered by the BLM--and then, restrict fossil-hunting activities only to public lands within the canyon. Of course, given its profoundly unique paleontological importance, Fossil Insect Canyon certainly qualifies a priori as a candidate for federal protection--possibly a national monument. It is, for example, by every scientific comparison, as paleoentomologically significant as Florissant National Monument in Colorado--probably the most well-known

fossil insect-yielding site in the world. That Fossil Insect Canyon, as of now, remains accessible to the general public is in itself a minor miracle, of sorts. Always watch for changes in collecting status, naturally.

Just an addendum to the above--I do indeed find it rather ironic that my introduction to Fossil Insect Canyon's paleontological mysteries came when, as a youngster with my folks on a weekend camping trip to the Mojave Desert, I happened to visit a rock shop (long since out of business, gone belly-up) situated near the fossiliferous canyon and saw for sale there several of the distinctive insect-bearing concretions.

Health Advisory

And now for the obligatory words of caution. Endemic to the Mojave Desert of California and southern Nevada, including the Las Vegas, Nevada, region by the way, is Valley Fever. This is a potentially serious illness called scientifically, Coccidioidomycosis or "coccy" for short; it's caused by the inhalation of an infectious airborne fungus whose spores lie dormant in the uncultivated, harsh alkaline soils of the Mojave Desert. When an unsuspecting and susceptible individual breaths the spores into his or her lungs, the fungus springs to life, as it prefers the moist and dark recesses of the human lungs (cats, dogs, rodents and even snakes, among other vertebrates, are also susceptible to "coccy") to multiply and be happy. Most cases of active Valley Fever resemble a minor touch of the flu, though the majority of those exposed show absolutely no symptoms of any kind of illness; it is important to note, of course, that in rather rare instances Valley Fever can progress to a severe and serious infection, causing high fever, chills, unending fatigue, rapid weight loss, inflammation of the joints, meningitis, pneumonia and even death. Every fossil enthusiast who chooses to visit the Mojave Desert must be fully aware of the risks involved.

Part 1--Field Trip To Fossil Insect Canyon, California

Look to the deep distance in Barstow, California, some 140 miles (225 kilometers) northeast of Los Angeles. All around is the botanically austere, often environmentally harsh Mojave Desert. The burnt reds and browns of the looming mountains appear to be mostly volcanics, a heat-warped jumble of solidified fire-rock, lava, that poured over this part of the earth during what geologists call the Tertiary Period of the Cenozoic Era, 65 to two million years ago. And, as most fossil enthusiasts understand, volcanic rocks are relatively unlikely sources of paleontologic specimens.

Luckily, tucked away among the rugged recesses of a mostly volcanic mountain range, within a reasonable driving distance of Barstow, is a place many seekers of paleontology colloquially

call Fossil Insect Canyon. That's where the eroded badlands of an approximately 19 to 17 million year-old lake yield exquisitely preserved arthropod and plant fossils in a world-famous geologic rock unit known appropriately enough as the middle Miocene Barstow Formation: it's a varied assemblage of insects; spiders; water mites; fairy shrimp; ostracods (a tiny bivalve crustacean); copepods (a minute crustacean, of which Cyclops is the most recognizable freshwater species), cladocerans (small crustaceans often called "water fleas"); Chara (a large green algae that superficially resembles a vascular plant); and even diatoms (a microscopic single-celled plant), all preserved in exceptional three dimensional detail--and, the fossils can be extracted whole and intact from the ancient rocks within which they reside. In all, upwards of 50 species of fresh water arthropods have been identified from Fossil Insect Canyon, a place many paleontologists call a Konservat Lagerstätte. This is by definition a sedimentary deposit that "exhibits extraordinary completeness or richness," preserving for study "lightly sclerotized and soft-bodied organisms or traces of organisms that are not otherwise preserved in the usual shelly and bony fossil record."

As a matter of fact, Fossil Insect Canyon is one of only a mere handful of localities on Earth where fossil insects can be removed from their matrix without any loss of detail. Probably the best-documented, competing example is paleoanthropologist Louis B. Leaky's description in 1952 of an Early Miocene (between 24 and 18 million years old) fauna near Lake Tanganyika, Africa; in that case, the insects had been preserved within a sequence of volcanic ash. Leaky and crew panned the volcanic layers repeatedly, as if searching for gold nuggets in a stream, and extracted many insect remains preserved as calcite (the crystal mineral manifestation of calcium carbonate) molds of the original critters. In the case of the well-known, spectacular amber arthropod assemblages of the Baltic, Dominican and Colombian areas, it is usually impossible to reliably remove fossils from the hardened tree resin without destroying them, although recent studies with amber from India and Lebanon, for example, suggest that such a process might be regularly feasible. Despite the fact that amber insects are merely desiccated, gossamer-like veneers of their once-living forms, they indeed reveal remarkable external detail of the original animals.

These paleontological specimens from Fossil Insect Canyon occur in calcareous (composed primarily of calcium carbonate) concretions that are present within a rather narrow horizon in the middle Miocene Barstow Formation. The insects, associated arthropods, and diatoms can easily be set free by immersing the stones in a diluted acid solution. The fossil fauna accumulated under unique, still incompletely understood geochemical conditions that allowed, in not a few instances, delicate soft-tissue internal organ preservations.

It should be pointed out, of course, that the vast majority of Barstow specimens are minute, from around .5 millimeter (one-fiftieth of an inch) to 8 millimeters long (roughly a third of an

inch), although the occasional dragonfly larvae can range up to approximately 37 millimeters (inch and a half). For this reason, in order to study in full detail such magnificent preservations, folks interested in actively pursuing the paleontology of Fossil Insect Canyon should certainly invest in at least an inexpensive microscope.

For many decades now the fossil-bearing district has provided popular desert recreation. Although regional governmental authorities no longer maintain the dirt road through Fossil Insect Canyon, where visitors now proceed at their own risk along an archetypically neglected desert trail subject to pot-holes, jagged rocks and major flash-flood wash-outs, loads of Mojave Desert adventurers still manage to find their way to the isolated environs--where those who do arrive encounter an obvious major travel restriction. Under the Bureau of Land Management's Off Road Vehicle Program, travel by automobile must be confined to already existing roads and trails. And use caution when scouting by foot around the multitude of old mines and prospects that penetrate the canyon topography. They are completely unsafe. Never enter them under any conditions. In fact, the locals say that their major rescue problem arises from unsuspecting hikers and trail bike riders who fall into the abandoned shafts.

Carry out all garbage, even if trash cans have been provided. There are no regular refuse hauls and sudden high winds can blow someone's waste all over the canyon. Target shooting is permitted, but always choose soft, eroded slopes at which to fire. Many hillsides in the canyon contain abundant volcanic and agate talus too hard to risk a dangerous ricochet.

Remember, this is true desert terrain and all camps in Fossil Insect Canyon are dry--no water or wood is available. These items will have to be brought with you. Summer temperatures exceed 100 degrees most everyday (ah, yes, but it's a dry heat, as "they" say...), winter weather turns quite cold, and sudden high winds can spring up without warning all year-round. The most comfortable times for visiting the canyon are from mid to late Fall and early to mid-spring. Less adventurous folks can find lodging and food in either Barstow or Victorville.

Once within the confines of Fossil Insect Canyon, having braved the unimproved dirt road in a reliable four-wheel drive vehicle, or at the very least a rugged, dependable truck, paleontology-minded explorers concentrate their attention on the middle Miocene Barstow Formation. Here, it's a varicolored sedimentary sequence exposed in wildly eroded badlands fashion below the immediately overlying (and hence, younger) reddish-brown volcanic rocks--igneous material completely devoid of fossil specimens, of course. The volcanics have been dated at around 17.1 to 16.8 million years and belong to an extrusive brand of solidified lava

geologists call dacite. The fossiliferous concretions occur in the sedimentary beds just below the overlying dacites.

Credit for discovering the first fossil insect specimen from Fossil Insect Canyon goes to a most-observant geologist, indeed, with the United States Geological Survey (USGS). In January of 1954 he picked up two odd-shaped concretions, one of which had the segmented body of a dragonfly larva partially exposed. This specimen, along with the apparently unfossiliferous stone, was brought to the attention of a USGS paleontologist, who exposed the complete insect through acid etching. When the second sample, without any obvious signs of fossils, failed to yield anything significant, the entire project was about to be abandoned. Then it was learned that a colleague with the USGS had independently collected concretions in the general vicinity of the original discovery with a few of processing them for diatoms (microscopic single-celled plants). Several of these items were obtained and dissolved in a bath of dilute formic acid. This second batch of residues included a water beetle larva, the second fossil insect recovered from the Barstow Formation. With interest in the project now renewed, one of the scientists hurried back to Fossil Insect Canyon to collect several hundred more concretions; all were run through the acid process and produced numerous beautifully preserved insects, spiders, and fairy shrimp. And so began the concretion "Gold Rush" to Fossil Insect Canyon.

Today, the fascinating fossil-bearing concretions can still be found in relatively common numbers, although certainly not in the profusion I can recall from but a few years ago. Innumerable representatives of universities, museums, colleges, rockhound clubs, mineral clubs and fossil clubs, as well as individual private collectors have visited Fossil Insect Canyon over the years, so most of the concretion horizons bear evidence of former human presence, in the form of trenches, holes, and quasi-sophisticated mining-style operations. Nonetheless, even after such concerted searchings, the concretions continue to weather out of the microlaminated greenish shales in the upper 30 meters (100 feet) of the middle Miocene Barstow Formation. Concretions are, in addition, most often found just below the contact with the overlying reddish-brown dacite volcanics, in the vicinity of numerous abandoned mines and exploratory prospects (for commercially saleable minerals) that penetrate the canyon's topography. Despite the years of fossil-hunting attrition--several private collectors and professional paleontologists alike report keeping upwards of 25,000 concretions for their projects--the original productive sites continue to provide the best places for concretion gathering.

Throughout the canyon corridor, only the lower and middle portions of the middle Miocene Barstow Formation have been exposed through the tireless powers of erosion. So, here the Barstow's roughly 19 to 17 million years old. It consists of approximately 457 meters (1,500

feet) of interlayered lacustrine (lake-deposited) brown shale, greenish siltstone, white-weathering limestone, conglomerate, limy sandstone, tan volcanic tuff, ledge-forming gypsum--and, finally, at the very top of the geologic section, three separate zones of insect-bearing calcareous concretions within the uppermost 30 meters (100 feet) of greenish microlaminated shale, just below the overlying volcanic dacites. All three concretion zones occur only within those extremely fine-grained, geologically youngest microlaminated shales, which reveal on average roughly 25 double annual bands (varves) per 2.5 centimeters (one inch). At that incremental rate of sedimentary deposition, the concretion-precipitating period of middle Miocene Lake Barstow (a name coined by a major "Barstow bug" researcher, by the way) lasted some 30,000 years. Each distinct concretion horizon is one meter (3.28 feet) to three meters thick and bears four individual layers of arthropod-yielding concretions. One additional calcium carbonate concretion layer produces no arthropod body parts, but does yield abundant fairy shrimp coprolites. Underlying the Barstow in Fossil Insect Canyon is the unfossiliferous, primarily pyroclastic-volcanic Pickhandle Formation of late lower Miocene age, around 19.4 to 19 million years old. Recent geological reconnaissance suggests that the lower layers of the Barstow Formation in Fossil Insect Canyon interfinger with the dominantly volcanic Pickhandle section and were therefore deposited contemporaneously, at least in part, as Pickhandle volcanic activity subsided.

The Barstow Formation calcareous concretions formed under still incompletely understood geochemical conditions, although one recent scientific analysis of their diagenesis arrived at some interesting conclusions. The investigators decided that concretion development initiated as a result of abundant decaying organic matter in the Miocene paleo-ecosystem--a ripe combination of putrefying fecal material, cyanobacteria (blue-green algae), aerobic bacteria, anaerobic bacteria, aquatic arthropods and plants, primarily. As this "rot sludge" released carbon dioxide (CO_2) and ammonia (NH_3), alkalinity increased locally in the pore waters. But, that was still not enough geochemistry to stimulate concretion growth. According to the investigations, something else was needed to boost the alkalinity level to a critical point--and that special catalyst was probably the element boron. Since the fossiliferous concretions lie in close stratigraphic proximity to bedded ores of borates, the scientists speculated that perhaps the periodic introduction of boron to the ecosystem, through local hot springs, brought alkalinity to the proverbial tipping point. That final boron boost then produced a necessary rise in carbonate ion concentration, which in turn facilitated precipitation of calcium carbonate (limestone) concretions that trapped and preserved the remarkable Barstow arthropod fauna. It is an elegant solution to the problem, indeed. Calcium carbonate concretions that yield three-dimensional insects, amenable to acid treatment for their removal, are found only within a restricted geographic area of California that bears bedded ores of borates. Without boron--no "Barstow bugs." It was that "simple," perhaps.

Whatever the eventual explanation might be, the concretions probably developed in at least an above-normal saline lacustrine environment--but, not necessarily one of extremely high brine alkalinity. Appreciable saline content is proved by the sudden appearance of zeolites--defined mineralogically as microporous aluminum silicates--in the microlaminated shales that yield the concretions. Used widely as water purifiers, in cat litter and in manufacturing laundry detergent, zeolites generally form naturally from the reaction of volcanic glass with connate water trapped during sedimentation in saline, alkaline lakes. Shales both above and below each concretion zone lack zeolites, suggesting that for many thousands of years, until occasional concretion-forming episodes occurred, Lake Barstow existed within an average range of alkalinity without significant contributions of volcanic ash. Also, because the regularly bedded microlaminated shales lack the element iron and show no signs of bioturbation, the concretions likely grew within dysaerobic conditions (extremely low oxygen content). And, finally, rapid fluctuations of the lake's water level, which introduced on a sudden plentiful mineral solutes from the surrounding countryside, as well as depriving the lake of sediments (when water levels dropped rapidly, for example), could have contributed substantially to the preservation of the middle Miocene Barstow arthropod fauna. This comports well with the observation that the seasonal layered laminations (varves) of shales within each concretion-bearing zone actually become dramatically thinner than those shales both above and below the fossil horizons, pointing to probable cyclic pulsations of prolonged sediment starvation combined with concomitant concentration of alkaline constituents through evaporation, ultimately contributing to concretion development in the presence of zeolites derived from occasional influxes of volcanic ash.

That significant evaporation took place during concretion growth is proved by two independent analyses of oxygen isotopes contained in the concretions. Both scientific studies demonstrated that the specific ratios of oxygen isotopes observed could have developed only under conditions of gradual and then, eventually, an almost complete evaporation of the lake waters. Additionally, concretions successively higher in the geologic section (proceeding up the geologic column to younger zones) at Fossil Insect Canyon bear distinctive carbon isotope signatures that point to a progressive increase of decaying vegetation during Lake Barstow's history. This agrees well with practical field experience at Fossil Insect Canyon, where many collectors remark that the uppermost concretion zone smells "funkier," more distinctly fetid than the older two horizons--the primary reason being that the youngest concretions contain more "aromatic" petroleum.

Of course, classically, such calcium carbonate concretions precipitate when mineral matter accumulates in the pores of sediments around a nucleus or center, such as a silicified organism; and, they develop after the sediments are deposited because the bedding planes of the formation within which they lie pass through them. In polished cross-sections, concretions from Fossil Insect Canyon reveal distinct alternating dark and white bands (layers), the latter composed almost entirely of minute fairy shrimp fecal pellets (coprolites); the three-dimensional fossil arthropods occur not only at the center of the concretions, but also scattered randomly throughout them in a horizontal bedding orientation. Clearly, it would seem, the concretions developed after many layers of sediments containing arthropods had already been deposited; sediments both above and below concretions observed in-place (not weathered out) are distorted from their natural horizontal planes of deposition to conform to the rounded concretion preserved within the shales. This provides compelling evidence that the concretions originally grew within the sediments, expanding and warping the soft layers above and below them during development--not as calcareous accumulations that poked their "heads" above water before their compete burial. Some concretion centers display small mineral crystals, or even vacant spaces, presumably where droplets of petroleum migrated during concretion development.

Not content with the standard models, several investigators have proposed alternate physical processes to explain the Barstow Formation concretions. One possibility offered is that the concretions represent miniature oil reservoirs, that perhaps calcium carbonate precipitated when stimulated by incipient oozings of petroleum, derived from decaying aquatic arthropods, fecal material, and cyanobacteria (blue-green algae), primarily; in this scenario, boron plays a significant role as a catalyst for petroleum migration to the concretions. Another line of thought holds that the concretions are actually stromatolites, not classically created through cyanobacterial activity, but rather by an unknown, presumably extinct organism adapted to the unique geochemistry of such boron-precipitating Middle Miocene lake systems in what is now the Mojave Desert of southern California; the specific champion of this hypothesis points to the fact that each concretion is an entity unto itself--not a member of a vast algal mat. A more recent proposal suggests that the fossil-bearing concretions can be identified as "coproherms," calcareous accumulations that enveloped aquatic arthropod poop (fecal material derived from fairy shrimp and water-living insects, mainly). Favoring this line of thought is that most concretions in cross-section reveal alternating bands of calcite and fairy shrimp fecal pellets. Perhaps cyclic, repeated local concentrations of dying fairy shrimp, and other aquatic arthropods in ever-evaporating, oxygen-depleted, mineral-charged waters finally helped alter to a critical point--after many such successive death struggles--the lake's geochemistry, now allowing calcium carbonate precipitation around pockets of entire masses of layered coprolites, simultaneously

preserving the remains of insects, arachnids, crustaceans, diatoms, and *Chara* (green algae) already stratified in the bottom muds from past death cycles. Another creative explanation postulates that concretion growth was stimulated by water beetle larvae, which actually leave the water to pupate, excavating distinct spherical, oval or pyriform cells (slight depressions) up to 5 centimeters (2 inches) or more in diameter in the shoreline muds. That's the general size and shape of many Barstow Formation concretions; such larval cell depressions could have provided ready-made spaces for calcium carbonate precipitation after fluctuations of the water level flooded the excavations. An additional idea is that the green algae *Chara* stimulated concretion growth; modern *Chara* characteristically grows in hard-water alkaline lake conditions, and calcium carbonate regularly precipitates around their branching structures. Perhaps prolific fragments of *Chara*, already accumulating in calcareous layers, were the ultimate loci of concretion formation. Lower in the Barstow Formation, in strata geologically older than the insect-bearing concretion zones, localized fossil *Chara* deposits form what lithologists describe as phytoherms--that is, rounded, roughly spherical masses of tangled *Chara* branching structures preserved in place in strata dated at approximately 19 million years old.

Within the 13 distinct concretion-bearing beds, the fossiliferous oddities are typically 6 millimeters (quarter-inch) to 64 millimeters (two and a half inches) in diameter and weather out in a variety of shapes: spheres, hemispheres, discs, cones, "derby hats," and even mammillary types. Each kind may yield one or more fossil specimens. One concretion in my collection produced no fewer than 12 beautifully preserved specimens. On the other hand, some of the calcium carbonate precipitates are, of course, fossil-free. There is no sure way to determine which concretions are fossiliferous, so it is best to keep all that are found. The percentage that contain fossils will depend on which of the 13 concretion horizons is explored. For example, the lower and uppermost nodule zones produce significantly fewer arthropod remains than the middle horizon. Although abundant agate, gypsum, and volcanic talus often litter the concretion-bearing hillsides, the stone paleo-tombs themselves are quite distinctive. They typically show concentric lamination on their weathered exteriors and will fizz when tested with a dilute acid solution, as they are composed primarily of calcium carbonate. In addition, when found in place in the shales, the hemispherical varieties typically have a flattened surface up and a rounded side down.

Collecting the insect-bearing concretions is certainly not difficult. As a matter of fact, it is a most enjoyable and educational experience to sit on a hillslope overlooking the variegated badlands, to dig a bit here and there, placing the strangely contoured concretions in any handy container. They've been around some 17 million years and, even if a few should crack

while in transit it really doesn't matter because they have to be dissolved in acid in order to obtain the prize fossils they contain.

Once you've collected a "few" nodules and taken them home, you are ready for a most important step: dissolving them in a dilute acid solution. It should be pointed out that, although some collectors prefer acetic acid (glacial, not that found in white vinegar, which works way too slowly and imparts too many impurities to the chemical reaction), my experience shows that dilute formic acid, five parts water to one part acid, serves better. A number of "Barstow bug" aficionados advocate, instead, dilute muriatic acid--that is, commercial grade hydrochloric, available at any home improvement emporium. Both the mixing of the acid and dissolving of the nodules must be done in glass or plastic basins. When diluting the acid, never pour water into the acid; this could cause a sudden overheating of the mixture with a resulting splattering of the acid-laden solution. The full strength acid should be poured into the pre-measured water. Safety goggles must be worn at all times! Be careful!

The exact method used to dissolve the concretions is an individual decision. Possibilities range from sophisticated scientific laboratory procedures available mostly to university personnel to those less efficient but more accessible. I've found that lining a medium-sized casserole dish with aluminum foil gives all the space to dissolve about five or six medium-sized paleo-prizes. It is, among other things, more efficient to work with relatively smaller amounts of the insoluble residues, from which the silicified fauna is extracted. Fill the basin to the brim; leave the brew uncovered; be sure to conduct the dissolving operation where there is good ventilation and nothing is nearby that would be corroded by the fumes. The chemical reaction that takes place between the calcium carbonate and the acid generates a pungent stench. Added to the malodorous emanations is a distinctive fetidness that arises from the small amounts of petroleum released from the bubbling concretions. All in all, it is a pretty stinky situation. If only a few medium-sized concretions are set into reaction, the dissolving will take only a few hours to complete. Often, though, the process will require more than an overnight period. Experience soon will show one how many concretions can be dissolved completely by a given volume of acid solution.

After the concretions have been thoroughly dissolved, neutralize any remaining active acid with sodium bicarbonate and then carefully dispense with the spent solution, obeying all local and federal regulations regarding the disposal of such hazardous material. Now, carefully and gently rinse the residues with fresh water. This is to prevent caking due to by-products of the chemical reaction, which can obscure key characteristics of the fossils. When the residues have dried completely, the fossils are ready for study. At this point, even an inexpensive microscope will come in handy, because the vast majority of specimens range in size from a little less than one millimeter (less than one twenty-fourth inch) to around 8

millimeters (a third of an inch) long. A stereoscopic dissecting microscope works especially well, but for some the cost may be prohibitive. Transfer small portions of the insoluble residues to a clean sheet of colored construction paper. As most of the fossils are the color of opaque glass, the contrast in color makes them easier to spot. Then, scan them with a hand magnifying glass of ten or more power. If the microscope in use has a black metal plate, one's efficiency in spotting the fossils can be greatly increased. The silicified fossils that are found can be moved to special microfossil slides for storage and study by lightly touching them with a fine-pointed dampened artist's brush. These microfossil slides usually come in two basic types and can be procured from a commercial laboratory supply house. Each is the size of a standard glass microscope slide, but they are usually made of cardboard. One variety traditionally has separate compartments in the shape of circles; the others are either square or rectangular shaped. The microfossil specimens are placed in these compartments. If these particularly useful slides are not available, the fossils from the Barstow Formation can be secured to regular glass microscope slides by applying a minute amount of well-diluted white glue (so that the glue does not obscure the specimen). Ingenuity is the name of the game here. Manner of storage of such fragile microfossils is purely an individual decision, quite obviously.

The Barstow Formation fauna of Fossil Insect Canyon consists of five dominant varieties, all of them exclusively aquatic in habitat--they constitute, as a matter of fact, fully 98 percent of all fossil finds. By far, the three most abundant forms found are: pupae belonging to a midge (adults infrequently found), *Dasyhelea austalis antiqua*, a variety whose closest living relative is *Dasyhelea australis australis*, now found on the islands of Isles Juan Fernando, approximately 400 miles west of Santiago, Chile--the pupal period for midges lasts only five to seven days, and within the Barstow concretions every stage has been preserved, even up to adults caught forever in time emerging from their pupal cases; larval predacious water beetles, *Shistomerus californense* (adults rare), of a species most closely related to the modern *Deronectes striatellus*, today widely distributed throughout the southwestern United States; and fragmentary remains of a fairy shrimp (adults common, though mostly complete specimens extraordinarily rare), called scientifically *Archaebranchinecta barstowensis*, whose closest living relative is *Archaebranchinecta pollicifera*, now native to the mountains of Bolivia and Peru, around Lake Titicaca; their fragmentary presence here is in itself remarkable, as fairy shrimp have absolutely no genuine hard parts to begin with. The abundant fairy shrimp in Lake Barstow also contributed enormous quantities of minute coprolite pellets to the calcareous concretions, discrete fecal rods only a fraction of a millimeter long (much less than one twenty-fourth of an inch). Often such pellets are so abundant that they form successive, multiple layers within Barstow concretions. Two additional dominants in the Barstow concretions remain far less commonly recovered: a

species of dragonfly (larvae only) that most closely resembles the Caribbean dragonfly, *Orthemis ferruginia*; and larval water mites, called scientifically *Protoarrenurus convergens*, which is most like the living genus *Arrenurus* of world-wide distribution.

Much rarer paleontological specimens recovered in three-dimensional glory from the calcium carbonate concretions at Fossil Insect Canyon include: two additional species of midges (pupae and adults); black flies/gnats (pupae and adults); mayflies; aphids; book lice; rove beetles; termites; true bugs; thrips (at least three species); flower beetles; carrion beetles; rove beetles; ants, leafhoppers (three species); grasshoppers (larval forms); parasitic wasps; springtails; bush crickets; stink bugs; psyllids; mantidflies; butterflies (based on two species of caterpillars); mosquitoes; bee flies; bees; termites; ostracods (a minute bivalved crustacean); copepods (a tiny crustacean; Cyclops is the best know freshwater genus); cladocerans (a small crustacean often called "water fleas"); and jumping spiders (more than one species). In all, upwards of 50 species of fresh water arthropods have been identified from Fossil Insect Canyon. Plant remains identified include 5 species of diatoms (microscopic single-celled plants), mosses and moss spores, *Chara* branches and spore cases, plus unidentified twigs, leaves and seeds.

The fossils are typically preserved by opaque white to crystal clear chalcedony quartz, although some specimens seem impregnated with a reddish organic compound of unestablished chemical structure. Other replacing minerals are celestite (strontium sulfate), gypsum (calcium sulfate), calcite (crystalline form of calcium carbonate, seen only in dragonfly larvae that have been exposed by weathering), analcite (a zeolite of sodium aluminum silicate structure formed by volcanic ash reacting with alkaline lakes waters), and bassanite (a saline evaporite, consisting of calcium sulfate--it was identified at Mount Vesuvius, interestingly enough). One of the remarkable features of these fossils is the fact that the internal organs of some of the animals have been preserved intact--particularly the brains and trachea of larval water beetles, *Shistomerus californense*; internal structures of dragonfly larvae (*Orthemis* sp.--a type now known from the Caribbean); and unhatched adult midges still in their pupae. Thus, the "Barstow bugs" are certainly not internal mineral fillings, or molds of the original animals. Mineral replacement took place soon enough after death or in such a perfected chemical environment that in many instances the internal organs never disintegrated.

Through the decades, several formal, professional scientific analyses of the Barstow fauna prove conclusively that all concretion horizons yield mainly immature varieties of arthropods that lived most of their lives in water: a dominantly aquatic assemblage, indeed, characterized by larvae and pupae of midges, larval water beetles, larval dragonflies, larval water mites, and immature and adult fairy shrimp; terrestrial, non-aquatic creatures are of

course well-represented by adults, and actually account for a greater number of species than the purely water-thriving forms. It's just that such adult specimens constitute but two percent of the total takes, so that on average, for every 100 fossils recovered from the concretions, only 2 will be an adult.

Additionally, distribution of both immature stages and adults in the fossil fauna is such that, for the most part, adults are more common in the easternmost Barstow Formation exposures of Fossil Insect Canyon, while the midge pupae seem highly concentrated in the westernmost outcrops. Perhaps the explanation, offered by one particularly paleo-perspicacious Barstow investigator, is that prevailing winds blew from east to west during concretion formation. That meteorological scenario would theoretically blow many more adults into the eastern waters of Lake Barstow, and then drive the poorly motile midge pupae toward the western end, where sometimes great numbers are encountered, fused together as if they had formed extensive sheets on the surface, prior to preservation. Perhaps supporting this idea is that the more actively mobile predacious water beetle larvae ("water tigers") can be found in evenly distributed numbers throughout Fossil Insect Canyon, arthropods apparently unaffected by winds or mild currents.

In an immature state, present-day aquatic insects and hatching fairy shrimp dominate the fauna of fresh-water basins during late winter or springtime. So the inference is that an assemblage deficient in adults was dependent on seasonal chemical conditions in the bottom muds of the ancient lake which favored preservations. Adult water beetles and water mites, for example, were obviously present during other times of the year, but were not preserved because some strangely restricting conditions in their environment were not then favorable for concretion formation--conditions most likely associated with unique bottom mud geochemistry. Or, perhaps adults, for whatever reason, were simply less amenable to preservations in the concretions. It's entirely possible that adults have been replaced by calcite or some other mineral which dissolves away during acid treatment for removal. Barstow concretion adult ostracod remains, for example, have been identified only from their exceptionally well-preserved soft tissues (a unique occurrence for ostracod specimens); their distinct bivalve shell covering dissolves away during an acid bath, leaving only a telltale imprint pattern in the residues, proving to researchers that the shell was there, prior to the acid dunking.

Speaking of which...somebody needs to deploy a virtual, digital thin-sectioning technique, whereby the concretions are "sliced" into micro-thin sections and then assembled through computer technology into a three-dimensional display of the cuttings--so that one may actually peer into a concretion from every conceivable angle, without ever having to dissolve it away. In other words, run them through synchrotron imaging, or even a CAT scan, if at all

possible. Among many exciting scientific observations imaginable, one could then view every species of arthropod preserved within, not having to worry whether the acid bath destroyed something organic--plus, learn with unambiguous certainty how each individual fossil specimen is orientated within the concretion.

In an attempt to better understand Lake Barstow's paleo-environmental Middle Miocene times, many "Barstow bug" investigators draw a modern comparison with Soap Lake in central Washington, although not a few folks find California's Mono Lake a better present-day analog, not to mention Borax Lake in southeastern Oregon, for that matter--which, incidentally, remains the sole place in North American where, today, boron actually precipitates into a lake system. Found living at Soap Lake, in a highly alkaline environment, are larval water beetles, fairy shrimp, and pupae of aquatic insects amazingly similar to species recovered from Fossil Insect Canyon's concretions. So it is indeed possible that relative concentrations of alkalinity controlled the fossil fauna's variety. This also agrees with the mineralogical evidence. The fossiliferous concretions occur in association with barites (barium sulfate), celestites (strontium sulfate), borates (ores of boron) and gypsum (calcium sulfate)--all of which signify a decidedly briny, concentrated alkaline environment. It should be pointed out, though, that Lake Barstow never existed within a classically defined desert, so the comparison with modern major hydrologic systems in the American arid west is probably not convincingly analogous. Whatever environmental factors caused significant evaporative processes during Middle Miocene times in what is now Fossil Insect Canyon, deposition under conditions akin to Recent (within the past 11,000 years) deserts can probably be eliminated.

Alternately, it is entirely possible of course that for most of its existence, for thousands upon thousands of years between concretion growth cycles, Lake Barstow was a perfectly average freshwater basin, with normal variations of alkalinity. Then, as the waters gradually evaporated, or perhaps became poisoned by borates and a combination of mineral solutes infused into the hydrologic system from thermal springs and/or volcanic activity, fewer creatures could tolerate the increasingly saline-alkaline conditions, flying away, escaping to live another day, until finally even the hardiest of inhabitants--the fairy shrimp, water beetle larvae and midge pupae, predominantly, eventually succumbed, many of which fortuitously found their way into calcareous concretions, silicified, preserved in crystalline three-dimensions for millions of years.

Such a grand cyclic repetition of arthropod preservations--there are 13 distinct, individual beds of fossil-bearing concretions, stacked one atop another in normal stratigraphic relations, separated by many meters (one meter equals 3.28 feet) of unfossiliferous shale--necessitates a causative agent, some primary generator of concretion precipitation that every several

thousand years or so captured vast numbers of delicate arthropod remains. That unifying explanation has never been satisfactorily delivered.

But, an intriguing proposal involves regional emplacement of silver ore.

On the Mojave Desert, within a reasonable distance of Fossil Insect Canyon, lies a famous silver-producing district. The ore bodies were mined extensively in the late 1800s and yielded unfathomable riches from numerous bonanza bodies situated in rocks hydrothermally altered at relatively shallow depths 17 million years ago. The volcanic dacites that outcrop in the immediate area are 17.1 to 16.8 million years old, and the specific age of the dacite that caps the Barstow Formation in Fossil Insect Canyon is 16.8 million years old. By the laws of geological superposition, the underlying Barstow Formation is therefore older. Between the youngest concretion horizon and the overlying dacite are several meters of barren Barstow sediments. Probably that uppermost concretion bed in the Barstow Formation is around 17 million years old. And that age coincides with a dramatic up-welling of super-heated silver-bearing fluids--and dacite extrusive lavas--from deep in the earth, bringing with them any number of associated minerals, including boron, barium and strontium--all of which could have been expelled into ancient Lake Barstow through thermal springs during occasional pulsations of ore and lava upwards through the crust. During that specific period of silver ore emplacement, lasting several thousands of years, Lake Barstow could have on occasion coincidentally evaporated enough to concentrate the minerals--most importantly, boron--the proposed necessary catalyst for Barstow concretion growth. Or, perhaps the dacite extrusive eruptions themselves, cyclically timed to hydrothermal silver pulsations, repeatedly killed all life in the Middle Miocene lake.

Whatever the triggering mechanism might have been for their formation, those concretions have provided an unprecedented opportunity to gaze backward in geologic time to a complete three-dimensional insect world that can literally be held in one's hand. Paleoentomology has never been quite the same since that January, 1954, discovery of the Barstow Formation arthropods in Fossil Insect Canyon.

The fossil arthropods, diatoms (microscopic single-celled plants) and *Chara* (green algae) inform much about the paleo-environment of the ancestral Mojave Desert province some 17 million years ago. Straightaway, of course, it is important to remember that during Middle Miocene times the modern Mojave Desert did not exist. The North American deserts we recognize today did not develop until the end of the Ice Age Pleistocene Epoch roughly 11,000 years ago. Taken as a whole, what the paleo-treasures in Fossil Insect Canyon show is that the temperatures ranged from hot to mild, with moderate aridity and nearby humid microclimates. Rainfall probably was in the neighborhood of 15 to 25 inches per year (38.1 to

63.5 centimeters), and that distributed substantially in both the summer and winter months. Today, Barstow--a number of miles distant from the fossil district, though still considered representative of Fossil Insect Canyon weather conditions--receives roughly 5 inches per year (12.5 centimeters). The thrips, aphids, true bugs, leafhoppers, grasshoppers, and ants show that the surrounding countryside was likely predominantly grassland, although there were scattered patches of woodlands, or even extended savannas, as evidenced by the carrion beetles, termites, and flower beetles. Most of the terrestrial insects lived in grassy plains and meadows or in weedy patches along the shores of the lake.

The evidence from Lake Barstow's terrestrial insects jibes with what can be inferred from paleobotanical data--a grassy plains region in the lowland lake basin, with scattered patches of woodlands, giving way at higher elevations to a greater diversity of botanic life. Although no fossil leaves occur in the shales at Fossil Insect Canyon, a famous locality in the Tehachapi Mountains along the western border of the Mojave Desert province provides a valuable insight into probable Middle Miocene plant communities at slightly higher elevations surrounding Lake Barstow. This so-called Tehachapi Flora occurs in the lower stratigraphic intervals of the Bopesta Formation, dated radiometrically at 17.1 million years old--practically the same geologic age as the Barstow Formation arthropod fauna. It preserves in fine detail, within a bed of lithified volcanic ash, fossil leaves from a variety of trees and shrubs whose modern-day relatives grow in the riparian habitats, oak woodlands and subtropical scrub associations of southwest Texas, southern New Mexico, southeastern Arizona, southern California, and northern Mexico.

By studying the Tehachapi paleobotanical record, the Cenozoic scene in the vicinity of Lake Barstow becomes clearer. Around the watercourses thrived Miocene species of sycamore, cottonwood, willow, maple, hackberry, avocado, and palm; their living representatives now live in the summer-wet regions of the southwest United States and northern Mexico. Higher up along the slopes grew an oak-pine woodland consisting of Miocene ancestors of canyon live oak, Engelmann Oak, Nuttall's scrub oak, Arizona White Oak, Arizona Cypress, Mexican Pinyon Pine, New Mexican Locust, Fremont's mahonia, Mexican madrone, and Texas madrone, among others. The overall composition of the fossil flora suggests a climate of mild, frost-free winters and ample summer rainfall.

The aquatic Barstow arthropods add even more detail to the story. They indicate a shallow warm-water lake, poorly oxygenated, sometimes covered in thick blankets of blue-green algae (cyanobacteria). This is proved by the profusion of midge pupae, which require algae-choked conditions to thrive. Modern midge larvae and pupae cannot tolerate salinities (NaCl) above 14 percent, and the presence of non-biting *Dasyhelea australis antiqua* midges shows low oxygenation. Adult predacious water beetles and their larvae generally prefer stagnant

bodies of water, such as ponds and lakes, or slow-moving streams; as a biological family, the Dystiscidae (predacious diving water beetles) are quite tolerant of wide variations in salinity, though a few species can be eliminated with only minor changes in salt levels. The adult water beetles are strong flyers and are known to flee habitats affected by drought. Fairy shrimp can withstand great variations of salinity, and in fact require a minimum NaCl level of 3 percent, but curiously the species identified from the Barstow concretions most closely resembles a type now native to temporary shallow pools in high-Andes bofedal peatlands near Lake Titicaca, Bolivia and Peru; their amazing abundance in the Middle Miocene lake proves there were no endemic predators present--in other words, fish. Fairy shrimp require water temperatures above four, to possibly six degrees centigrade (39 to 43 degrees Fahrenheit) and cannot survive sub-alkaline waters below a pH level of 6.8 (anything above 7.0 is alkaline), though some species easily withstand extreme pH readings of 9.5. Generally speaking, fairy shrimp and water mites prefer pH levels between 7.0 and 7.5 (only mildly alkaline). According to one scientific report, the ostracods (minute bivalve crustacean)--preserved as unique, unprecedented soft-tissue mineral replacements--suggest a permanent saline-alkaline lake, "in shallow, poorly mixed, dysaerobic waters, with a salinity between 3 and 14% NaCl and a pH greater than 6.8." Likewise, two of the five diatom species identified from the Barstow concretions point to a saline-alkaline lake system, although admittedly the other three diatoms recovered remain equivocal regarding relative saline concentrations. The presence of *Chara*, a large species of green algae that superficially resembles vascular terrestrial plants, demonstrates that Lake Barstow's waters were at least 4 centimeters (slightly over an inch and a half) to twenty meters deep (65 feet), and occasionally hard-alkaline.

In general, it seems that the Middle Miocene climate during the formation of the insect-bearing concretions was mild, somewhat warmer, and probably more humid than that of the southern California coast of today.

Because so many different species of organisms have been recovered from the concretions, it has been possible to piece together a representative food chain that existed in and around ancient Lake Barstow some 17 million years ago. In the lake itself: diatoms, cyanobacteria (blue-green algae), and *Chara* (green algae) photosynthesized all the food they needed from sunlight; mayflies, fairy shrimp, and the larvae and pupae of midges and mosquitoes fed on blankets of blue-green algae; ostracods and water fleas filtered detritus and scavenged the remains of fallen arthropods, while copepods (*Cyclops*) ate microscopic single-celled animals; dragonflies hunted midges, mosquitoes, and mayflies; water mites parasitized the midges; and water beetle adults and larvae ate midges, mayflies, mosquitoes, dragonfly larvae, copepods, and water fleas. On the shore and amid the surrounding countryside: book lice,

rove beetles, termites, true bugs, aphids, bees, bee flies, bush crickets, butterflies, stink bugs, psyllids, and springtails (technically, not an insect--a Collembola arthropod) fed on decaying matter, fungi, flowers, shrubs, and trees; flower beetles, parasitic wasps, and mantidflies consumed aphids, thrips, true bugs, ants, leafhoppers, and springtails; grasshoppers ate the grass; and jumping spiders preyed on the ants.

Each of the insects, arachnids, crustaceans, and diatoms appears to have had its day. Now preserved in exceptional detail by a combination of minerals--most commonly chalcedony, gypsum, and celestite--they are a source of wonder and of vital scientific information about a long-vanished age.

As you travel up Fossil Insect Canyon road into the heart of this great fossil field, you too may consider the origins of the color-splashed, geologically important rocks there. And, on a hot summer's day, up by a fossiliferous concretion-bearing bed with the powerful stillness and starkness of the Mojave Desert all around you, it is easy to believe that there are more insects in the stones you are collecting than in all the land around you.

Part 2—Field Trip To Fossil Bone Basin, California

Within a reasonable driving distance of Barstow, seeming to appear out of nowhere in the midst of California's vast Mojave Desert, is a beckoning desert road that leads to one of the great terrestrial, land-laid vertebrate fossil-bearing areas in North America--a place many paleontology enthusiasts call Fossil Bone Basin, where abundant mineralized mammalian skeletal elements occur in variegated sedimentary strata carved through the ceaseless powers of erosive creativity into bold badlands roughly 19.3 to 13.4 million years old. This is the world-famous middle Miocene Barstow Formation, which appropriately enough is the type locality for the Barstovian Stage of the Miocene Epoch, deposited 15.9 to 12.5 million years ago. Every earth scientist in North America compares, contrasts, and evaluates vertebrate fossil evidence from all geologically time-equivalent rocks with the Barstow Formation exposures at Fossil Bone Basin, where some 66 species of mammals have been identified, including extinct three-toed horses, camels, pronghorns and proboscideans, among many others. Indeed, the list of fossil mammals continues to grow, as each field season in the Barstow beds seems to yield something significant, something that causes vertebrate paleontologists to reassess previous conclusions.

The general area known colloquially as Fossil Bone Basin holds a special place in the paleontological and geological history of the Mojave Desert. It is a region in which scientific institutions from all across America (and world, for that matter) have collected at one time or another--ever since 1911 when H. S. Mourning, a private paleontology enthusiast from Los

Angeles, sent to University California Berkeley (UCB) student John R. Suman a hundred or so fossil vertebrates he'd found in what today is sometimes called Fossil Bone Basin. Suman immediately directed that collection to the legendary vertebrate paleontologist John C. Merriam at UCB, who identified the specimens as teeth and foot bones from two species of extinct three-toed horses, genus *Merychippus* (one of which in the early 2000s was redescribed and renamed in honor of Suman*, Scaphohippus sumani*); horn fragments from a pronghorn, *Merycodus*; and loads of miscellaneous camel skeletal material, probably representing at least two distinct species.

Mourning's collection certainly sparked an intensified interest in trying to unravel the historical geology of the Mojave Desert province. After collecting abundant material from the bonanza beds at Fossil Bone Basin, UCB paleontological expeditions once again lit out into the desert under Merriam's direction, this time searching for additional vertebrate fossil-yielding areas. And the scientific crews were remarkably successful. Merriam's "fossil posse" next investigated a rich vertebrate deposit from the Late middle Miocene Dove Spring Formation exposed in the El Paso Mountains at today's Red Rock Canyon State Park. It's a rock deposit Merriam and associates then knew as the Ricardo Formation, a now obsolete geologic designation for an instantly recognizable, dramatically-exposed unit--since used as a backdrop for any number of Hollywood films, television shows and commercials--that continues to yield the internationally appreciated Ricardo Fauna. By the 1930s, almost all of the major bone-bearing Cenozoic Era fossil localities (65 million to 11,000 thousand years ago) scattered across California's Mojave Desert had been discovered, including most famously: the upper Pleistocene Manix Lake Beds; the upper Pleistocene Rogers Lake Beds (now in Death Valley National Park); the lower to middle Pliocene Coso Mountains Fauna; the late middle Miocene Avawatz Mountains fauna; the late middle Miocene Copper Canyon Formation (contains perhaps the greatest concentration of the best-preserved Tertiary Period mammal trackways in North American; now in Death Valley National Park); the middle Miocene Bopesta Formation fauna; and the Oligocene Titus Canyon Formation fauna (now in Death Valley National Park). A supplemental important fossil vertebrate find on the Mojave Desert came in 1950, when Richard H. Tedford and R. Shultz discovered the significant Paleocene Goler Gulch Fauna.

But by far the most abundant and well preserved vertebrate fossil material from California's Mojave Desert has been recovered from the Barstow Formation at Fossil Bone Basin. As a matter of fact, the Barstow yields one of the largest, most complete terrestrial Miocene vertebrate faunas ever described from North America. In addition to the pioneering work conducted by crews from the University California Berkeley (which still supports on-going research), representatives of many museums and institutions of higher learning continue to

frequent the Barstow badlands--among them the Natural History Museum of Los Angeles County, where as a youngster I was allowed access to the innermost vertebrate paleontology catacombs after I'd donated several quality fossil vertebrates I'd picked up during a weekend desert outing with my parents to the late middle Miocene Dove Spring Formation, El Paso Mountains, outside of Red Rock Canyon State Park. There, I vividly recollect drawer after huge drawer of beautifully preserved vertebrates from the Barstow Formation; bountiful, showy horse teeth and a seemingly infinite variety of ornate pronghorn horns, in particular, captured my attention. Other museums actively excavating Barstow bone treasures include the San Bernardino County and Raymond Alf museums. Among the many universities still researching Barstow mysteries, probably the University California at Riverside pursues the bones most regularly.

In the history of paleontological research at Fossil Bone Basin, certainly the most protracted collecting was undertaken by the Frick Laboratory of the American Museum of Natural History. Beginning in 1923, Childs Frick and personnel began what can accurately be described as an extended field campaign. Frick led the first teams from 1923 through 1930, then handed over the reins to J. Wilson (1930-37), who in turn relinquished his lead role to C. Falkenbach (1940), followed by T. Galusha (1950-'52). During the first full field season, paleontologists happily learned that they didn't have to rely solely on surface prospecting for specimens--that, fortuitously, the Barstow Formation was amenable to quarrying, and the digs were given colorful, informal names; in all, Frick's crews worked over 25 unique, specific vertebrate fossil quarries, most of them paleontological bonanza bodies, producing in many instances amazing concentrations of mineralized mammal material.

Unfortunately, Frick and his subsequent replacement teams can easily be accused of having been less than scientifically meticulous in their collecting procedures, and this inattention to geological detail threatened, for a time, to tarnish their legacy. For example, in the published documentation of their finds, Childs Frick--the man in charge--gives no geographic or even reliable stratigraphic evidence to help tie together the exact localities and age significance of his many fossil quarries. At first blush, it seemed all their work had been for naught--essentially meaningless. True, they had described many new species of animals from the Barstow beds, but by apparently neglecting to give their specimens an accurate point of reference in the stratigraphic section, they had ostensibly perpetrated a disservice to science. Thus, when the United States Geological Survey (USGS) conducted its extensive mapping projects in the Mojave Desert from 1950 through 1955, it was impossible to adequately identify the many evidences of Frick's digs--they were, in effect, just so many holes in the ground, a frustrating guessing game.

Partial redemption was slow in coming for Frick. When vertebrate paleontologists finally gained access to Frick's voluminous field notes, they discovered that Frick and personnel had actually continued to follow faithfully for many years an outdated stratigraphic subdivision of the Barstow Formation, originally formulated by a geologist in 1911. It wasn't until 1950-'52, near the conclusion of their field work, that a member of the team actually decided to map Fossil Bone Basin; his results agreed well with a definitive field mapping project by a USGS geologist many years later.

Results of subsequent geological mapping projects in Fossil Bone Basin prove that the vertebrate fossil-bearing middle Miocene Barstow Formation is approximately 1,000 meters thick (3,280 feet) and can conveniently be divided into three distinct subunits, or members. The oldest unit is called the Conglomerate Member, around 200 meters in thickness (656 feet), and is best exposed around the scenic one-way loop trail that penetrates some of the most spectacular outcrops of the Barstow Formation. It's chiefly a gray-green conglomerate composed of granitic debris, grading into conglomerate and reddish sandstones to the south. Studies of directional clast orientations within the Conglomerate Member suggest that deposition flowed from the north and south, and then migrated to the southwest; geologists estimate that the ancestral Fossil Bone Basin probably was no wider than eight miles. A lithified layer of volcanic tuff near the base yielded a radiometric date of 19.3 million years. At the top of the Conglomerate Member, in a layer of volcanic tuff radiometrically calibrated between 16.5 and 16.3 million years, the first vertebrate fossils appear in the Barstow section; it is a tantalizing paucity of remains, but an extinct three-toed horse, an oreodont (an extinct artiodactyl; even-toed critter, sort of a cross between a pig and a sheep, but actually more related to a camel), a camel, and a pronghorn constitute the main take. The Conglomerate Member, with its coarse conglomeratic detritus, certainly suggests deposition under very high-energy conditions, probably the result of high-gradient watercourses rushing off dramatic extremes in nearby topography.

Above the Conglomerate Member lies the Middle Member, a full 530 meters (1,739 feet) of fluviatile (river-deposited) conglomerate, conglomeratic sandstone and finer-grained lacustrine (lake) sandstones and shales dated at 16.3 to 15 million years old; the conglomerate probably came in from sources to the south and southwest, while the finer-grained sediments flowed in to a much deeper section of the basin from the east and northeast. The Middle Member is best exposed from points near the one-way scenic loop trail, eastward to the vicinity of the primitive Bureau of Land Management (BLM) campground. Two major tuff beds in the section yielded radiometric dates of 15.8 and 15.2 million years--an interval of geologic time, incidentally, that coincides nicely with deposition of what could well be the single richest deposit of Miocene marine vertebrates in the world--

the Sharktooth Hill Bone Bed in the middle Miocene Round Mountain Silt member of the Temblor Formation, southern San Joaquin Valley, California; the Sharktooth Hill Bone Bed accumulated 15.9 to 15.2 million years ago. In the Middle Member of the Barstow Formation, the first abundant and well preserved vertebrates occur; they are concentrated within three separate, successively younger faunal divisions, and obvious evidences of abandoned fossil quarries, presumably dating from the Childs Frick expeditions of 1923 to the early 1950s, can be studied while hiking dry washes that penetrate the boldly sculpted Barstow exposures.

The fantastically fossiliferous youngest Upper Member extends 270 meters (886 feet) above the Middle Member to the very top of the Barstow sequence. It's primarily a fine-grained interval of lacustrine (lake-deposited) shale, mudstone and claystone, with subordinate coarser-grained sandstones and conglomeratic material to the west and southwest. The mudstone-claystone deposits came in from the north and east sectors, but the sandstone and conglomeratic fluviatile constituents could have flowed basinward from the west and southwest. Two volcanic tuff beds in the section, plus a sandstone layer near the very youngest horizon bear radiometric dates of 14.8, 14.0, and 13.4 million years, respectively. Roughly 15 to 13.4 million years old, the Upper Member is best exposed along dry washes several miles removed from the scenic one-way loop trail.

For folks wishing to visit the bone-bearing badlands, remember once again of course that removing vertebrate fossils from Fossil Bone Basin without a special use permit issued by the Bureau of Land Management is not allowed. The permit, by the way, is provided solely to trained personnel (with a minimum B.S. degree), representing either an accredited university or an officially recognized established museum, who seek to undertake scientifically justifiable research projects that can be verified as authentic by the petitioned authorities: Even professional vertebrate paleontologists must submit formal requests in proverbially triplicate, 20-page single-spaced format. But this is really not too discouraging for private paleontology buffs, because you can still hunt for fossil vertebrates there to your heart's content--with a camera in hand, of course. Instead of taking home the actual physical specimen, you can have loads of fun doing the next-best-thing: capture its image either on film, or with a digital device, just as it lies exposed in the Barstow sediments, 16.3 to 13.4 million years old. There are certainly many more bones yet to be found; do not became disheartened, as new material continues to come to light with each passing season. For example, in the chiefly mudstone-claystone facies of the Upper Member vertebrate fossils are often still astonishingly common, even after all those decades of scientific quarrying and surface collecting.

Most representative outcrops of the highly fossiliferous Upper Member can be explored several miles removed from the scenic one-way loop trail and the excellent BLM campground.

Here, along primitive jeep trails that follow the sinuous courses of dry packed sand Mojave washes (visitors must remain on already established road and trails within Fossil Bone Basin), fossil seekers enter a paleontological paradise consisting of roughly 900 feet (around 270 meters) of greenish to tan tuffaceous mudstones and claystones, from which obvious 15 to 13.4 million year-old mammalian vertebrate remains continue to weather free. Some of the more prolific, sensational sites in this area were given informal, memorable names by the pioneering paleontologists--names based on the prevalence of specific kinds of fossil critters common to individual beds: camels, carnivores and rodents, for example.

One particularly rich, world-famous fossil rodent locality was discovered during the spring of 1922. While camped amidst the Upper Member, Pirie Davidson--a noted vertebrate paleontologist--in the company of legendary fossil collectors Annie Alexander and Louise Kellogg (working under the auspices of John C. Merriam of UC Berkeley)--happened upon an undistinguished mudstone hill about four to five feet high. Plastered all over that localized exposure were abundant jaws and teeth of many small mammals, including chipmunks, pocket mice, deer mice, and shrews. For years, that lone little fossil hill provided successive teams of technicians many seasons' worth of paleontological pleasure, the paleo-teams carefully excavating the Miocene matrix for readily identifiable tiny jaws, teeth, and post-cranial elements. On a related note, a year later, in 1923, Pirie Davidson actually named a new species of camel from the Barstow Formation in honor of its finder, Annie Alexander--*Alticamelus alexandrae*.

There is really no special, magical technique for locating vertebrate fossils. Simply try to explore as much territory as possible. It usually helps to begin prospecting at the bases of hills, since all things being equal, gravity and such, bones that erode out of the sediments will in all likelihood tumble downslope. Try to find the little gullies and dry rivulets where water has created erosion gullies that might have exposed fossils. Hike slowly and deliberately upslope, watching for any telltale bone fragments. Whenever several fragments or splinters occur together, there's a good bet that you are near one of the fossiliferous zones in the Barstow Formation. Sometimes digging in the general vicinity of an especially rich concentration of fossil fragments helps to uncover quality specimens, the complete skeletal elements, teeth and jaws from the numerous species of extinct animals that lived in the ancestral Mojave Desert district all of those millions of years ago...although, technically, without a BLM permit, even digging for specimens is not allowed within the confines of Fossil Bone Basin. One might do well to remember this technique, though, when accompanying a professional paleontologist who's secured a permit. Whatever fossil-searching method is used, be sure to document with a GPS device (Global Positioning Satellite) the locations of your finds. This will help vertebrate paleontologists accurately identify your specimens when

you return to civilization, since such specialists often require precise stratigraphic data to make a genus-species determination; not only that, but if you've found something genuinely remarkable, worthy of further study, scientists can then use your co-ordinates to go back and recover the mineralized remains.

Generally speaking, a significant vertebrate fossil find is either, obviously, a complete bone, tooth, jaw, or skull--or, alternately, any specimen which has an articulating surface preserved; for instance, a ball or socket joint from a limb bone. Such remains are readily identifiable by an expert in vertebrate paleontology, although many scientists who specialize in the study of recent mammals (biologists)--or even archeologists, for that matter, should have little trouble stating the general type of critter involved--camel, horse, pronghorn, or proboscidean, for example.

What you'll find in the Barstow badlands is a fossil vertebrate fauna composed of three dominantly abundant forms. In decreasing order of relative prevalence they are: the teeth, jaws, skulls, and post-cranial bones from (1) four species of extinct three-toed horses; (2) six species of camels; and (3) at least four species of pronghorns (horns frequently found, as well).

But, that's not all, naturally. Fossil Bone Basin's exalted reputation among vertebrate paleontologists lies in its remarkable diversity of Middle Miocene terrestrial life. Some 66 species of mammals have been described from the fossil beds; indeed, that's enough material for researchers to conclude that the specific ratio of predators to prey in the Barstow fauna is highly reminiscent of a present-day east African savanna. A few species are extremely rare, of course, their formal scientific descriptions based on perhaps fewer than a mere handful of specimens--but, in general, investigators agree that, among the more common specimens collected, the remains of smaller animals constitute a significant percentage of finds. Several years ago, for example, one expert attempted to erect a faunal zonation of the Barstow Formation based on the presence of four key species of rodents. That idea fell out of favor very quickly, though (as well it should have). Still, remains of smaller Barstow mammals continue to intrigue scientists. Diminutive Middle Miocene dwellers recognized from Fossil Bone Basin include: one kind of bat; two species of shrews; a hedgehog; one rabbit; four species of pocket mice; two species of squirrel; one chipmunk; four species of mice; and one New World mole. An additional larger rodent identified was a beaver.

Among the larger animals recovered from the Barstow Formation, herbivores assume true dominance. And, the most common herbivores encountered are three species of the extinct three-toed horse Scaphohippus, a Barstow type originally called *Merychippus*, but officially renamed in the scientific literature in the early 2000s. Scaphohippus is directly ancestral to

the modern horse; it stood about three to five feet high at the shoulder (a little less than a meter to 1.5 meters), and like earlier horses in the geological record it still possessed three toes, though the outer two had now become vestigial, never again reaching the ground. *Scaphohippus* had relatively high-crowned teeth, suggesting an adaptive ability to masticate tough vegetation, possibly grasses. Another notable horse observed is *Megahippus*, which stood only slightly smaller than a modern horse; *Megahippus* had lower-crowned teeth, though, and probably fed on the softer vegetation of shrubs and trees.

Based on the sheer numbers of fossils recovered, camels are the second-most commonly observed vertebrate remains in the Barstow Formation. At least 6 separate species have been identified, all of varying shapes and sizes. Smallest of the lot was *Paramiolabis minutus*, which stood only two feet high at the shoulder (60 centimeters); probably it resembled in behavior and size a present-day small deer. *Protolabis* was one of several kinds of medium-sized camels, with a life-style and appearance apparently more like a modern deer than a current camel. *Aepycamelus* on the other hand was a long-legged, long-necked fellow of giraffe-like lifestyle and size, adapted to browsing on vegetation higher up in the trees.

Next in relative abundance were several small artiodactyl (even-toed) horned animals, usually referred to as pronghorns--most only slightly larger, perhaps, than a modern fawn. Among these, *Mercycodus*--with its distinctive pair of forked horns--was by far the most common; such specimens are certainly prolific, and vast numbers of Barstow Formation *Merycodus* horns have likely found their way to any number of vertebrate paleontology departments throughout North America. *Rakomeryx* grew to the size of a modern impala, bearing two long, curved horns. Other pronghorn genera include *Merriamoceras*, which displayed diminutive moose-like horns; and *Ramoceras*, with curious tripod-configured horns.

Several additional herbivores ranged through the Barstow savanna, though they were preserved in far fewer numbers than the three dominants. For example, only a single rhinoceros is known from Fossil Bone Basin, called scientifically, *Aphelops*; somewhat smaller and more slender than the modern Sumatran rhinoceros, *Aphelops* also possessed longer legs, an anatomical adaption that suggests that it might have been able to run faster than its present-day analog. Among the peccaries identified, *Dyseohyus* is best known; in appearance and behavior, all Barstow peccaries probably resembled today's javelina of the southwestern United States. Another group of plant eaters, the oreodonts--a curious mammalian experiment often categorized as a cross between a pig and a sheep (though they were more closely related to a camel)--were on their way to eventual extinction during Miocene Barstow times. In the Oligocene of North America, though, particularly South Dakota, oreodonts are among the most abundant fossil mammals reported; a single tapir-like oreodont called *Brachycrus* occurs in the oldest vertebrate-producing Barstow Formation horizon. Its teeth

were adapted to grinding softer deciduous vegetation along the watercourses. The largest herbivore documented from Fossil Bone Basin is the proboscidean *Gomphotherium*, which grew slightly smaller than a modern elephant; such proboscideans first appear in the geologic record in North America approximately 15 million years ago. Supplementing the significant Barstow *Gomphotherium* skeletal material are many nicely preserved trackways; in the Middle Member of the Barstow Formation, exposed along the one-way loop trail, several reworked, water-laid volcanic tuffs beds reveal easily recognizable *Gomphotherium* steps, helping ichnologists determine how the animal behaved in life.

Preying on the plant-eaters was a great diversity of carnivores. The most commonly encountered in the field belong to members of the dog subfamily Borophaginae; modern dogs reside within the subfamily Caninae--so, as many scientists note, the relationship is somewhat comparable to that of chimpanzees (Barstow dogs) to modern humans (present-day dogs). The Barstow borophagine canids came in a wide variety of shapes and sizes, with habitats and behaviors that anticipated present-day wild canine activity. *Cymarctus*, for example, was analogous to the fox, while *Tamarctus* and *Aelurodon* more closely resembled coyotes and the gray wolf, respectively. *Cynarctoides* looked and behaved like the modern mink or fisher, and *Protepicon* was the famous Barstow "hyaenoid dog," with a shortened muzzle and powerful jaws adapted for scavenging and crushing bones--perhaps seeking the marrow within.

Another group of Barstow predators resembled an unusual cross between a bear and dog. The chief example was a true carnivorous terror of Middle Miocene times, *Amphicyon*--commonly called a "bear-dog," as it occupied an adaptive morphological position between modern dogs and bears. This bad boy resembled a modern grizzly bear--and probably filled an ecological niche similar to today's bears--but its more streamlined body and slightly longer legs likely permitted the creature to run down even the largest of prey. *Hemicyon* was the so-called "running bear" of its age. More like a modern dog than a bear in overall morphology, though, *Hemicyon* was stockier and slightly larger than a gray wolf. It walked on its toes instead of a flat-footed gait and first appears in the North American geological record roughly 15 million years ago.

Along with the dogs and bear-dogs lived a number of mustelids--that is, for example weasels, badgers, minks and wolverines. Virtually identical to minks or weasels were *Miomustella* and *Plionictus*, while *Brachypsalis* grew to nearly wolverine size and probably had a similar lifestyle.

Among the Barstow cats, two types are quite representative. *Nimravides* was a saber-tooth cat from the older family Nimravidae, not a member of the modern Felidae which, first

appearing in the fossil record approximately 15 million years ago, includes all true cats. In size, *Nimravides* was somewhere between a lynx and a cougar. The most common true cat in the Barstow fauna is *Pseudaeluris*, which in most morphological characteristics resembles a modern cougar.

In addition to the many mammals, paleontologists have also recovered several other kinds of specimens from the Middle Miocene strata of Fossil Bone Basin. These include: a tortoise; birds (most famously a hawk and flamingo); freshwater mollusks (gastropods and pelecypods); 24 species of diatoms (microscopic single-celled plant)--plus, such important macroscopic botanic remains as fossil leaves from a buckthorn and two varieties of evergreen oak--and, petrified woods representing palm, juniper, and poison oak.

The environment suggested by the multitude of fossils and the sedimentary rocks within which they occur is quite illuminating. In general, the Miocene climate was certainly cooler and less arid, with perhaps 15 to 25 inches (38.1 to 63.5 centimeters) of annual precipitation delivered during both summer and winter months. Vegetation surrounding the lake basin of deposition probably resembled modern oak-juniper woodlands now common to southern Arizona and northern Mexico, where summer monsoonal precipitation develops; abundant lush deciduous plants grew along the watercourses, ponds and springs, providing nourishment for many Barstow herbivores whose lower-crowned teeth were adapted to process softer plants; a greater variety of conifers (fir, pine and spruce) probably thrived at slightly higher elevations. A palm preserved in the Barstow beds is in many key botanic characteristics close to a variety that now grows in northern Mexico. Too, the ratio of Barstow Formation herbivores to the specific diversity of predators suggests that savannas (ecosystems where trees are sufficiently spaced so that the canopy remains open) similar to those in modern east Africa dominated certain portions of the terrain. Diatoms (microscopic single-celled plants) preserved in the vertebrate fossil-bearing section of the Barstow Formation, 16.3 to 13.4 million years ago, point to cool, clear lake waters whose normal freshwater alkalinity was interrupted on occasion by evaporative periods and enormous quantities of volcanic ash ejecta which, eventually reworked by erosion and redeposited as firm mudflats, provided a perfect medium (analogous to wet concrete) to preserve the trackways of horses, camels, pronghorns, gomphothere proboscideans, and bear-dogs. The trackways are now found along the tilted and folded bedding planes of those lithified volcanic tuffs. That such an abundance of well-preserved vertebrate material lies within reworked tuff beds and tuffaceous mudstones suggests that perhaps periodic episodes of cataclysmic volcanism repeatedly devastated successive landscapes over the course of approximately three million years, cyclically wiping out vast herds of herbivores and their predators. Flooding then fortuitously delivered carcasses and myriads of disarticulated

skeletal elements to the ash-laden lakes and watercourses, where the silica-rich environment guaranteed faithful mineral replacements of the bones.

Today, 16 to 13.4 million years later, the animals once entombed in the volcanic slush of a Miocene lake weather out in stony profusion on a vast desert under conditions of extreme aridity--as low as five inches (12.5 centimeters) of precipitation per year, on average. It is a land most comfortably visited during mid to late fall and early to mid-spring. Expect sudden high winds and great fluctuations of temperatures year-round, though, since Fossil Bone Basin lies in the midst of the great Mojave Desert and unpredictable meteorology is, well, predictable in a paradoxical sense. Remember, too, that Fossil Bone Basin is a federally protected region. This means that the removal of any fossil specimens without a BLM special use permit is absolutely forbidden.

Of course, the way to get around this regulation is to bring along a camera and capture your fossil game in situ as it comes to light in the ancient Barstow Formation sediments, the mineralized remains of a Miocene animal that played out its life in savannas and oak-juniper woodlands among an association of predators and prey reminiscent of modern east Africa.

Chapter 4

Fossil Plants At Buffalo Canyon, Nevada

Buffalo Canyon lies in the heart of the arid Great Basin physiographic province a number of miles from Fallon, Nevada, home to the US Navy's Top Gun fighter pilot program. This is a land characterized by three widely distributed botanic species: sagebrush, juniper, and pinion pine. But roughly 15.5 million years ago, during Middle Miocene geologic times, the present-day fossil locality was the site of a large fresh-water lake around which flourished a great variety of plants, including but of course not limited to--spruce, fir, pine, ash, maple, zelkova, willow, and evergreen live oak.

Today, common to abundant carbonized leaf and seed impressions from over 50 species of trees and shrubs, along with commercially mineable quantities of diatomite (a microscopic photosynthesizing single-celled plant), can be found in the sedimentary layers deposited in that ancient lake. Not only that, but several diatomite beds in the immediate vicinity of the plant-bearing locality have been changed to prized opal through the geologic forces of heat and pressure, a geologic process that has created abundant, colorful material for hobby, recreational lapidary use.

All of the fossil plants occur in the diatomite member of the middle Miocene Buffalo Canyon Formation, a regional badlands-forming deposit originally named by geologist K. L. Barrows in 1971.

Credit for discovering the fossil plant-bearing beds at Buffalo Canyon goes to a Mrs. Beulah Buckner, who came across the productive diatomaceous beds during a rockhounding excursion in either the 1940s or very early 1950s. After she eventually directed writer Harold O. Weight and his wife Lucile to the locality, Mr. Weight wrote up an article on the subject of fossil plants in Buffalo Canyon for a noted national publication, in which he named one of the primary fossil-bearing sites Fossil Leaf Hill.

Interestingly enough, many years later, completely unaware of Mr. Weight's earlier published documentation of the Buffalo Canyon fossils, I happened to re-discover that same leaf and seed-bearing locality and decided to call it Fossil Leaf Ridge. The thought of course occurred to me at the time that probably loads of folks have independently "discovered" and named that identical prolific plant-yielding site over the decades

The most efficient way to locate fossil plants here is to split the soft shales along their natural bedding planes. Use the pick end of a geology rock hammer or a broad putty knife to split the poorly indurated, often crumbly sedimentary material. If you should happen to accidentally

fracture a fossil specimen, use Duco Cement or some other fast-drying, reliable glue to mend the break. But try to be especially careful not to crack the fossils. Attempting to glue pieces of diatomaceous shale back together is usually a messy, delicate chore. Several coats of glue applied along the fractured surfaces may be required to get the job done, since the porous, powdery rocks often soak up glue like the proverbial sponge.

Not every sedimentary rock layer in the area is fossiliferous--as a matter of fact there appear to be many more barren horizons than plant-bearing ones. But, generally speaking, if you can find the fine-grained, whitish diatomaceous shales that outcrop in proximity to narrow beds of blue-gray volcanic ash, your chances of finding superior fossil plant specimens will increase dramatically. The "paper shales" observed in parts of the section closely resemble the plant and insect-bearing shales exposed in Fossil Valley, Nevada, and Florissant, Colorado--noted insect-yielding deposits of world-wide renown--although I've yet to locate anything significant in the Buffalo Canyon paper shales, save for a few poorly preserved leaf fragments. Still, those finely laminated shales may well be worth some special explorations. Excellent specimens could yet show up in them, due to the fact that they lie in such close stratigraphic proximity to the plant-bearing beds higher in the geologic section. Adding to the paper shales' potential interest is the fact that a graduate student on a field trip to Buffalo Canyon uncovered an exquisitely preserved dragonfly wing--the very first fossil insect reported from the middle Miocene Buffalo Canyon Formation.

The shales in the Buffalo Canyon Formation grade upward into geologically younger tan to gray clays and sandstones bearing five distinct beds of lignite, a brownish-black coal whose alteration of the original vegetal constituents has proceeded farther than in peat but no so far as in subbituminous coal. All five layers of the lignite have been analyzed for possible uranium content, but only two of the beds showed any potential economic interest, averaging 0.052 to 0.1 percent uranium. The ashy-gray mudstones in this part of the geologic section frequently yield abundant remains of reeds from a species of cattail, a scouring rush.

Taken together as evidence, the lignites and fossil cattails indicate ponded, swampy conditions during deposition of the younger phases of the middle Miocene Buffalo Canyon Formation. The regularly bedded diatomaceous shales lower in the section--rocks which represent the older periods of deposition--were likely laid down in a large lake whose shoreline supported a dense growth of deciduous hardwood trees and shrubs such as maple, birch, ash, cottonwood, willow, serviceberry, hawthorn, Oregon grape, bitter cherry, currant, rose, and sparkleberry. Slightly higher slopes bordering the basin of deposition were covered by a rich mixed conifer forest of fir, larch, spruce, cypress, hemlock, maple, alder, birch, black locust, elm, zelkova, serviceberry, hawthorn, Oregon grape, bitter cherry, and mountain ash. On the more exposed, drier south and west-facing hillsides the mesic vegetation graded into

an evergreen woodland consisting of madrone, mountain mahogany, cypress, stopper, juniper, Catalina ironwood, and evergreen live oak.

The Buffalo Canyon fossil flora was famously analyzed by the late paleobotanist Daniel I. Axelrod in an informative monograph. Axelrod concluded that the fossil floral association most closely resembles conifer-deciduous forests now living in three widely separated areas of the United States: the Klamath Mountains of northwestern California; the Adirondack Mountains of eastern America; and the Porcupine Mountains of Michigan.

Based on the environmental preferences of modern analogs of the fossil flora, Axelrod decided that precipitation in the ancestral Buffalo Canyon Basin was approximately 35 to 40 inches per year, a figure that contrasts radically with the scant 15 inches delivered there today--and most of that amount is in the form of winter snow. A major difference in the rainfall patterns 15.5 million years ago was that storms dropped significant amounts of precipitation during both the winter and summer months--enough rain during those seasons, as a matter of fact, to account for such sensitive indicators as elm, birch, hickory, black locust, and zelkova in the local fossil record.

Temperatures were also apparently much more moderate some 15.5 million years ago. For example, terrain in proximity to today's fossiliferous Buffalo Canyon Formation experiences an average June-July temperature of some 77 degrees, but the associations of fossil plants now found there prove that 15 million years ago the average monthly reading for that specific time of season could not have been any higher than 63 degrees. And while today's average January temperatures range downward to a frigid, arctic-style 10 degrees, the mid-Miocene plants demonstrate that 15.5 million years ago a typical January mean would have been a rather chilly, but tolerable 37 degrees.

Such a major change in Buffalo Canyon's precipitation and temperature averages over geologic time suggests that elevations there were significantly different some 16 to 15 million years ago. Cogitating this perplexing problem, Axelrod studied in great detail the environmental requirements for today's analogs of species found in the Buffalo Canyon Formation to determine that the plants likely accumulated at an elevation of roughly 4,200 feet; today, the fossil site lies at an altitude of 6,060 feet, suggesting, according to Axelrod's analysis, that the region has undergone an uplift of approximately 1,900 feet since Middle Miocene times 15.5 million years ago.

But, that was not the end of the "uplift" story. Far from it. Eventually, the late paleobotanists Howard E. Schorn and Jack A. Wolfe, along with several other scientists working the problem independently, applied sophisticated geophysical, geochemical, and Climate Leaf Analysis

Multivariate Program methodology (CLAMP) to conclude that the present-day Great Basin region of eastern California (Death Valley region), Nevada, southeastern Oregon, southern Idaho, and extreme western Utah stood just as high, if not higher, during Middle Miocene times than it does today. Accordingly, when all the evidence from disparate avenues of analysis finally came together, Schorn and Wolfe proposed that the Buffalo Canyon Formation plants accumulated at an elevation of roughly 9,000 feet, that in actual fact the entire Cenozoic Era Great Basin region--the so-called Nevadaplano--had remained a vast high plateau region for most of the Early to mid-Tertiary Period (Paleocene, Eocene, Oligocene, and Early to Middle Miocene Epochs), until at last that Nevadaplano gradually dropped, collapsed, to its modern-day elevations by 13 million years ago through geologic extensional stress and concomitant block faulting which helped create the modern Great Basin geography.

Today, roughly 15 million years after Buffalo Canyon Lake ceased to exist, dried up, some 54 species of fossil plants remain in the rocks to tell their fascinating paleobotanical tales of a time before the Nevadaplano high plateau had completely collapsed. The two most conspicuous, and abundant, forms encountered in the Buffalo Canyon Formation are intact leaves from an evergreen live oak, *Quercus pollardiana*--a species that is practically identical to the living maul oak now native to the western foothills of the Sierra Nevada, Cascade Mountains and Coast Ranges of California--and leaves from a birch*, Betula thor*, whose vegetation is identical to the modern paper birch. Other less commonly observed specimens include the leafy twigs of cypress, a juniper, in addition to the leaves of cattail, four species of cottonwood, six species of willow, an alder, three additional species of birch, a hornbeam, a hickory, a black walnut, two more species of oak, an elm, a zelkova, two species of holly grape, a water lily, a hydrangea, four species of currant, a Catalina ironwood, three species of bitter cherry, a rose, a mountain ash, a leadplant, a black locust, a tropical cypress, a madrone, a stopper, two species of ash, a sparkleberry, and a snowberry. Also present, but rarely recovered, are the winged flying seeds of two species of fir, one species of larch, three species of spruce, two species of pine, one species of Douglas-fir, one species of hemlock, and five species of maple.

During my last extended exploration of the Buffalo Canyon Formation, I spent a couple of productive days opening a modest-sized fossil quarry. The digging was good. Among my keepers were several nice birch leaves, winged spruce seeds, a few relatively rare *Zelkova* leaves, and many nice evergreen live oak leaves. A few years later I made a brief stopover to check out my quarry, which had lain dormant all that time. Unfortunately, I found it had been obliterated by heavy rains. All that was left to mark the site of my past digs were several large slabs of shale I remember having yanked out while attempting to expose a particularly

fossiliferous layer upon which were plastered some fine specimens of oak leaves. The slabs of shale had been washed way down slope into a newly formed natural gully far removed where I had dug--the result of intense, short-lived rampaging runoff that had taken advantage of the softer sedimentary rocks there, cutting into them with potent ease: acts of inexorable erosive power on full display here. I spent a couple of hours digging in the same general area as my original quarry and was pleased to learn that the fossil plants were still "alive and well;" they could still be found there, much to my delight.

All of the collecting sites are presently accessible: as far as I am aware, no federal or private ownership collecting restrictions exist. Still and all, conscientious fossil aficionados will nevertheless opt to conduct common sense due diligence to determine the current legal accessibility of the fossil locality before visiting. And, of course, should commercial collecting parties begin to raid and desecrate the fossil plant localities, the Bureau of Land Management will most certainly close the fossil leaf-bearing district to all but professional paleontologists.

It should be pointed out, perhaps, that eventually, after several years of conducting occasional visits to the much-productive district, I decided to donate practically all the fossil plants I'd recovered from the middle Miocene Buffalo Canyon Formation to a major museum's archival paleobotanical fossil repository. As a general rule, all particularly well-preserved plant remains collected from the area should be brought the attention of a professional paleobotanist; who knows, perhaps you have uncovered a species that is new to science!

A field trip to Buffalo Canyon, Nevada, will provide visitors with something out of the ordinary: a chance to collect a large selection of nicely preserved Middle Miocene plant remains, plus an abundance of very colorful specimens of common opal, as well. As you dig into the fossiliferous diatomaceous shales of the middle Miocene Buffalo Canyon Formation, you will bring fossil leaves and winged seeds to their first light of day in some 15 million years, species which tell of a time when the plant life in this part of arid Nevada resembled the modern-day rain-rich Klamath Mountains of northwestern California and the humid, moist forests of the Adirondack and Porcupine Mountains of the northeastern United States.

Chapter 5

Ordovician Fossils At The Great Beatty Mudmound, Nevada

Beatty lies 115 miles north of Las Vegas along Highway 95 in Nye County, Nevada. It is the lone surviving member of the once-illustrious Bullfrog Mining District founded in the early 1900s. The nearby ghost town of Rhyolite, some two miles east--one of the most photogenic abandoned mining towns in the entire West--was also a member of this short-lived yet important silver-producing region, where stock speculation far outdistanced mineral exploitation as the liveliest, though riskiest venture to undertake. Today the gaunt brick-building carcasses of Rhyolite roast in the summer sun while Beatty flourishes near the entrance to Death Valley National Park, one of America's most-visited natural treasures.

In addition to serving as a jumping-off point for visitors to Death Valley, Beatty is also the staging area for a truly remarkable fossil locality--the great Middle Ordovician mudmound/bioherm on the flanks of the mountains in the vicinity of town--a geologically and paleontologically fascinating unstratified pod-shaped accumulation of calcium carbonate, limestone, some 1,000 feet in length around which (and within the core of which) profuse invertebrate animal remains can be found. From a distance, the mountains within which the fossil locality lies appear to be an inhospitable moonscape of a place--a virtually barren upthrusting of desert rocks that overlook the Nevada Atomic Test Site to the immediate east; such a juxtaposition of locales--a direct reminder of our nuclear age in such proximity to a world-class Ordovician-Period fossil site where many extinct animals lie entombed in the rocks--only serves to provide a greater aura of intrigue and mystery to a locality that contains such a wealth of prehistory to study.

While apparently sparse in plant life, the great Beatty mudmound more than atones for this botanic deficiency with its fantastic abundance of Middle Ordovician fossils in a geologic rock formation geologists call the Antelope Valley Limestone. Here can be found a wealth of excellently preserved invertebrate animal remains some 470 million years old, including echinoderms, sponges, bryozoans, ostracods (tiny bivalved crustaceans), pelecypods, gastropods, trilobites, conodonts, cephalopods, and brachiopods. All of the specimens, save the conodont elements, have been thoroughly silicified--that is, replaced by the mineral silicon dioxide--so the fossils can be dissolved out of their limestone matrix without damage using a dilute solution of acid. To find the conodonts, by the way, micropaleontologists usually use gentle organic acetic acid.

The Beatty mudmound/bioherm is such a wonderfully fossiliferous and paleontologically impressive place that a Public Interest group nominated it for special protection by the

Bureau of Land Management. If that designation eventually comes to pass, the Beatty mudmound will most certainly become off-limits to all amateur fossil hunters; only those with degrees from an accredited university or personnel representing an officially recognized museum will then be allowed to collect fossils there.

Not only can Ordovician fossils be found in abundant in the vicinity of Beatty, but significant mineral exploration and exploitation is likewise quite prevalent. For example, a few miles southeast of Beatty is the Daisy Fluorspar Mine, a private claim once owned by J. Irving Crowell, Jr. and his son. The Daisy Mine was discovered in 1918 and produced continuously from 1927 through the early 1960s. Total production up to that date was approximately 100,000 tons. Considerably more has probably been mined since then, one ought to presume, as the Daisy Fluorspar Mine is likely one of the single greatest sources of fluorspar in the history of Nevada. The ore bodies occur as hydrothermal replacements in dolomites of the upper Cambrian (500 million years old) Nopah Formation; cinnabar--mercury sulfide--has also been reported from the Daisy Mine, primarily as thin red stringers between fluorite and bands of calcite.

Fluorspar, of course, is simply the commercial term used for fluorite, the mineral form of calcium fluoride, which is the primary source of the element fluorine and fluorine compounds. Mineralogically speaking, fluorite has a Mohs hardness of 4.0, a specific gravity of 3.01 to 3.25 and a vitreous luster. It is usually found in shades of white, yellow, rose and crimson-red, violet blue, sky blue, brown, wine yellow, greenish blue, and violet blue.

And, naturally, fluorspar has numerous important commercial applications. For example, on average the manufacture of steel requires from three to 12 pounds of fluorite for every ton of the finished product. It was also used to manufacture the fluorocarbon compounds that found their way into refrigerants, aerosols, solvents, and plastics. As an important additive to glass, ceramics and enamel, fluorite improves strength--in addition to imparting a greater luster and transparency. And in the aluminum industry, a healthy 150 pounds of fluorite are required to produce a single ton of the metallic aluminum from the raw ore bauxite.

Another area of rather serious mineral exploration is the Telluride Mine district, several miles southeast of Beatty. Significant trace concentrations of the elements antimony, arsenic, cadmium, copper, gold, lead, molybdenum, silver, and zinc have been reported there, initiating several years ago a hot claim-recording rush. The old Telluride Mine itself--for which the district was named--is curiously enough a noted mercury deposit, discovered in 1908. Up to 1943 production from the mine had amounted to 72 flasks of mercury. It was active once again in 1956, but there is no available report of the total take. The mercury occurs as cinnabar sparsely disseminated through opal and chalcedony of a steeply dipping bed of

dolomite in the Devonian (419 to 359 million years ago) Fluorspar Canyon Formation. Another working, the Tip-Top Mine located 600 feet north of the Telluride deposit, reportedly yielded 100 flasks of mercury up to 1944.

Many folks who visit the Beatty region are of course interested primarily in the mineral content of the famous district, and there are loads of places to hunt for fascinating crystals and ores of various metals; but if one's main focus (read: obsession) is paleontology, then one is in for a special treat, because the great Beatty mudmound/bioherm is a genuinely remarkable specific Ordovician fossil site. Interestingly enough, the huge pale-gray mudmound accumulation can actually be spotted along the mountainsides from a distance of many miles, most notably from roughly 20 miles away on the eastern side of Daylight Pass near the eastern entrance to Death Valley National Park along State Route 374.

But, to gain a more detailed appreciation of the mudmound's dimensions, one must stand near the base of it. From that up-close-and-personal vantage point, the bioherm/mudmound is wondrously prominent and impressive--a massive pale gray body of limestone exposed along the skyline of the mountains, a rather uncommon geological structure that truly dominates the view: it's a great pod-shaped accumulation of calcium carbonate some 270 feet thick and 1,000 feet long, by far the largest, best preserved and most dramatic of the three Ordovician mudmounds exposed in this same general region of Nevada. The other two known bioherms occur over on the neighboring A.E.C. Nuclear Testing Site, an area obviously off-limits to unauthorized explorations.

The scientific significance of the bioherm was first recognized in 1960 by geologists H.R. Cornwell and F.G. Kleinhampl during their geological mapping of the district. They brought it to the attention of United States Geological Survey paleontologist Reuben James Ross, Jr., an expert in Ordovician-age brachiopods and trilobites, two of the more abundant fossils groups present. To help analyze the paleontology of the bioherm, Ross assembled a superior team of fossil specialists, each of whom identified fossil specimens in his particular field of expertise. Among those who helped identify the Ordovician remains from near Beatty were Ellis Yochelson (gastropods), Jean Berdan (ostracods), John Hudle (conodonts), John Poleta Jr. (pelecypods), Rousseau H. Flower (cephalopods), and James Sprinkle (echinoderms). Ross concluded that in general the fossil fauna from the Beatty bioherm closely resembles fossil assemblages from similar Middle Ordovician limestone structures in Quebec and Newfoundland. An interesting aspect of preservation of the fossils is that many of them are encrusted with a special form of sparry calcite, which many geologists and paleontologists believe is algal in origin.

All of the fossils at the Beatty mudmound occur in the oldest sections of the middle Ordovician Antelope Valley Limestone, roughly 470 million years old. The specimens are restricted to sporadic, productive pockets within the core of the mudmound and to, more abundantly, the medium gray to olive-gray and olive-brown shaly limestones along the flanks and directly above the mudmound itself. Several of the limestone beds consist almost entirely of the fragmental remains of echinoderm debris, a type of rock geologists call encrinite. Notable among the fascinating echinoderm finds are the mysterious and enigmatic parablastoids, strange types that are confined to strata of Middle Ordovician age; their small isolated plates are sometimes quite common in the limestone beds that flank the mudmound—a special irresistible occurrence that attracts echinoderm enthusiasts worldwide to the great Beatty bioherm. Still other calcium carbonate layers contain prolific quantities of brachiopods, most of which are rather tiny, measuring roughly eight to 12 millimeters long. Trilobites are also excellently represented by upwards of 20 genera, although their preservation leaves much to be desired. They are for the most part fragmental, consisting of isolated pieces of the head shield, thorax and tail. Sometimes the sharp spines that were attached to the cephalon and body are all that remain to help identify a species of trilobite. Less common constituents include nautiloids, pelecypods, ostracods, bryozoans, sponges, algae, gastropods, and conodonts.

The conodonts are a fascinating fossil type. Measuring on average only one to three millimeters long, conodonts are minute jaw-like specimens that for over a century were thought to have come from worms or even some extinct, primitive species of fish. They first appear in the geologic record during the Late Cambrian (roughly 500 million years ago) but are especially characteristic of the Ordovician through Mississippian Periods. Even though they persisted well into the Triassic Period of the Mesozoic Era--the age of reptiles--most conodonts had become extinct by the close of the Permian Period 252 million years ago.

Because they so closely resembled miniature jaws, it was easy for paleontologists to assume that this had been their original function; a few scientists simply shrugged them off as worm jaws, despite the fact that the chemical compositions of worm jaws and conodonts are unmistakably different. Talk about a fossil that got no respect! More serious investigators theorized that they might have belonged to the gill apparatus of several extinct species of fish. Another nice try. Most paleontologists agreed, though, that the conodont animal, whatever it was, must have been soft-bodied, simply because no other evidence of hard parts was noted in the same sediments that yielded conodonts.

Nobody had seriously expected to find the actual conodont animal--after all, a hundred-plus years of collecting couldn't be wrong--but at last, it appeared, that somebody had actually made the incredible discovery. It came in 1968 in the Little Snowy Mountains of Montana.

Here, in the fine-grained shales of the transitional Late Mississippian and Early Pennsylvanian deposited 323 million years ago, the mystery for short spell at least appeared to be resolved once and for all. What scientists had recovered from the Montana locality was a small fish-shaped chordate (it seemed to possess a primitive spinal cord, although this was more like a partial notch just behind the head), that had a single fin on its back for stability and a tail fin for swimming. Based on the first 24 carbonized outlines of the body cavity unearthed, the purported conodont animal averaged a little less than 12 millimeters in length. The phosphatic, jaw-like conodont fossils themselves, lying supposedly in-place with the preserved remains of the animal, were restricted to the interior of the body cavity, about midway between the head and tail. Scientists immediately conjectured that the conodont structures served a dual function: to circulate water currents through the body and act as sieves.

But, something was wrong with the entire scenario. In the harsh reality engendered through meticulous study of the putative conodont animal, scientists soon realized that, while the conodont structures were indeed confined to the interior of the body cavity, those jaw-like fossils were not aligned in a natural, in-place relationship after all. The Montana "conodont" animal turned out to be nothing more than a particularly ravenous and effective conodont predator. Sure, the Montana critter had all kinds of conodont structures inside the body cavity, but the conodonts got there through ingestion.

Back to square one. Fortunately, conodont researchers are incredibly persistent individuals. And that never-quit attitude eventually paid off: In 1982, Dr. E. N. K. Cradlesong finally discovered the actual conodont animal in Carboniferous (the European equivalent of the Mississippian and Pennsylvanian Periods combined) rocks in Scotland. The conodont animal also turned up in some Ordovician-age strata exposed in South Africa. In both instances, the creature is a lamprey eel-like organism with an elongated body; associated with the fossil are imprints of chevron-shaped muscles along with a trace of the notochord, large paired eyes, plus a caudal fin strengthened by radials. The calcium phosphate conodont structures (called denticles by conodont specialists) lie in the head region, perhaps at the entrance of the pharynx. Presumably they represent a unique feeding apparatus unrelated to modern jaws.

The Beatty bioherm exposures are the westernmost outcrops of the middle Ordovician Antelope Valley Limestone, a rock formation named for Antelope Valley in central Nevada. Age-equivalent limestones and dolomites exposed throughout the mountains bordering Death Valley are referred to as the Pogonip Group. However, these carbonate rocks are virtually barren of common fossil remains; the most widespread specimen encountered is a large gastropod called *Palliseria robusta*, the very same species found at the type locality of the Antelope Valley Limestone and at the Beatty mudmound.

Rocks of the Pogonip Group in the Death Valley district are almost everywhere dolomitized and recrystallized due to hydrothermal alteration, so it is no wonder that there is such a paucity of paleontology (not so in western Utah, though, where lower through Middle Ordovician strata lumped into the Pogonip Group yield abundant, beautifully preserved fossils). A more direct correlation of rocks exists with the middle Ordovician Badger Flat Limestone exposed in the Inyo Mountains, California. The Badger Flat yields abundant brachiopods, echinoderms and trilobites, several species of which are identical to those that occur in the Antelope Valley Limestone at the Beatty bioherm.

The mudmound/bioherm occurs in oldest layers of the Antelope Valley Limestone, as do the other two somewhat smaller bioherms exposed in the neighboring Nevada Test Site. The bioherm is a massive unstratified mound of pure calcium carbonate within the core of which noticeable invertebrate fossils are sporadically abundant. An unusual type of cavity is also present within the mudmound, a structure that contributes up to 20 percent of the mass--stromatactis (flat-bottom cavities with irregular tops that are filled with fibrous calcite); geologists remain puzzled just how these kinds of cavities developed in the mudmound, but a plausible explanation, offered by geologist Adam D. Woods, is that stromatactis formed as a result of "fluids migrating upwards through the mound from below" during "dewatering" of the underlying sediments.

Yet another fascinating geophysical structure at the Beatty mudmound is the so-called zebra limestone development--an incredibly thick cyclic repetition of tightly laminated calcium carbonate strata that has defied a definitive explanation. An early idea was that zebra limestones were created by monstrous algae mats, which helped bind the limestones together into such a distinctive and baffling laminated condition; that seemed reasonable, a working hypothesis one might say, but the latest conclusion is that zebra limestones at the Beatty mudmound probably formed by shear failure, or as professor Adam D. Woods says, "possibly even through fluid flow after much of the mound was lithified, and the stromatactis network became 'plugged' with cement."

The Ordovician mudmounds/bioherms were large mounds of calcite mud whose initial deposition occurred in waters probably not more than 100 feet deep. Their surfaces were evidently held together by mats of algae, which in turn helped trap and bind additional mud, causing the mass to grow. At no time did these bioherms rise above the surface of the water. They were, in effect, huge underwater sand dunes--or more accurately termed "mud dunes," if you will, able to trap calcareous sediments driven by the prevailing sea currents. The mudmound near Beatty probably developed scores of miles from the ancient Ordovician shoreline in seawater shallow enough to allow monstrous algae mats to flourish and enormous quantities of animal life to thrive along the flanks of the mound. A competing idea

that the mudmound developed in waters deep enough to permit frozen methane gas to help "sculpt" it is here rejected outright.

Because the abundant Beatty mudmound fossils are completely silicified, the specimens are amenable to acid treatment for removal from their limestone matrix. Many fossil collectors are perhaps familiar with the use of diluted hydrochloric acid to process silicified fossils entombed in limestone. In the hands of a knowledgeable, especially cautious worker, hydrochloric acid--one of the most potent acids known--is probably not an overly hazardous material. For processing a bulk of rock within a short period of time, no other acid works quite as well. Still, this writer does not like to work around it, and many other collectors have echoed the same sentiment. The fumes are toxic, even lethal; the slightest mishandling can cause frightful burns, and delicate fossils often don't stand a chance under the vigorous dissolution of the matrix. Not only that, but one can never recover the calcium phosphate conodont fossils while using hydrochloric acid. For these reasons, using one of the less-potent organic acids, either acetic or formic, seems preferable. This is not to say that such acids do not require the same kind of caution that hydrochloric demands. It's just that should you happen to accidentally spill some acetic or formic acid on bare skin, you have a much better chance of preventing serious burns by washing immediately and repeatedly with cold water.

An effective brew is concocted using a 20-percent solution of formic acid: five parts water to one part acid. When diluting it, always remember to pour the acid into the premeasured volume of water, never the other way around, an act that could result in dangerous splattering due to a sudden overheating of the solution. Use only plastic or glass basins for the dissolving; and wear safety goggles at all times while working around acid! When all the rock is finally dissolved, carefully dispose of the spent acid solution--in compliance with all public safety laws--then rinse the remaining residues repeatedly with fresh water to prevent caking of the fossils by residual compounds formed during the chemical reaction between the calcium carbonate and the acid. Let the residues dry and then transfer them to a clean sheet of paper. Use tweezers to remove observed fossils for storage.

While in the neighborhood, visitors to the Beatty mudmound/bioherm district might want to combine fossil seeking with a trip to nearby Death Valley National Park. The Visitors Center, resort, and Death Valley Museum at Furnace Creek are only 38 miles from Beatty--a quick "fossil's throw" away by vehicle. Along the way, though, you may want to take a detour through Titus Canyon, whose turnoff lies six miles east of Beatty along State Route 374. This is an ultra-scenic one-way route that winds through a narrow passage in the Grapevine Mountains, eventually connecting with California State Route 178 in the heart of Death Valley, 18 miles south of Scotty's Castle. Along the path through Titus Canyon, you can examine the Oligocene Titus Canyon Formation, around 29 million years old, a thick

accumulation of muds, sandstones and conglomerates that entombed the remains of many species of extinct animals, including rodents, a dog, a horse, a titantothere, a rhino and oreodonts. The assemblage of vertebrate fossils is indicative of a lush green environment, well-watered, a scene that probably resembled a modern-day tropical forest--direct fossil evidence that creates one of the most startling contrasts imaginable: present-day Death Valley, synonymous with sand and heat and aridity, was once a luxuriant forest in which a multitude of animals thrived.

Springtime and mid to late autumn are customarily considered the most comfortable times to visit this Great Basin Desert land. At an elevation of 3,284 feet, Beatty stays a little less hot in the summer than its sizzling neighbor Death Valley, but the difference, measured in five to ten degrees at the most, is arguably negligible, although the higher altitude certainly contributes to a much-welcomed cooling during the evening hours.

Beatty, of course, offers the usual ingredients of civilization--motels, restaurants, service stations, a grocery store, shops, and that fascinating institution: gaming. It is in fact a very friendly place to visit. The community makes an excellent jumping-off point for explorations of Death Valley and the great Beatty mudmound/bioherm.

The Bullfrog silver boom of the early 1900s brought Beatty to life. Now it is tourism to Death Valley, gaming, and the reliable arrival of motorists passing through along Highway 95 that contribute to the prosperity of the town--an economy apparently safe, for the time being at least.

Yet, one thing is for certain. Should Beatty eventually become a ghost town, joining its Bullfrog neighbor Rhyolite in silence, that great bioherm in the vicinity of town, visible from Daylight Pass near the eastern entrance to Death Valley some 20 miles away, will continue to rise majestically above the desert floor, its 470 million-year-old fossils emphasizing the mutability of man's designs.

Chapter 6

Fossil Plants And Insects At Bull Run, Nevada

Introduction

Take a virtual field trip to a famous 37 million-year-old fossil locality in Nevada where many excellently preserved winged seeds and needles from conifer trees, plus fossil insects can be collected from what geologists call the upper Eocene Chicken Creek Formation. Explore the fossil remains of an essentially pure montane conifer forest--one of the few such paleobotanical associations yet described from the Tertiary Period of North America.

Field Trip To Bull Run, Nevada

An excellent region in which to prospect for a wide variety of nicely preserved plant and animal fossils is the Bull Run Basin district, Nevada. Here can be found winged flying seeds (or samaras, botanical terminology) and fascicles (bundles of needles) from several species of conifers, ostracods (a minute bivalved crustacean), freshwater gastropods, plus rather common carbonized insect larvae. The paleontological specimens occur in the upper Eocene Chicken Creek Formation, whose fossiliferous horizons have been dated by radiometric means at some 35 to 37 million years old. Although the region is quite remote, well off the proverbial beaten track, Bull Run Basin nevertheless remains quite popular among amateurs and professional paleobotanists alike, owning to its virtually unique abundant association of Late Eocene conifer remains that demonstrate clearly that some 37 million years ago this portion of the Great Basin district supported an essentially pure montane conifer forest.

I first learned of this particular fossil-bearing district, by the way, from a citation in a United States Geological Survey Bulletin. Here is a partial quote of that original citation: "Discussion of potassium-argon ages of some western Tertiary floras. Sample of Chicken Creek Formation is from a 20-foot bed of biotite rhyolite ash 5 feet above uppermost of 10 florules that comprise the Bull Run Flora. Radiometric age of 35.2 million years indicates this florule is basal Chadronian or transitional Eo-Oligocene and the florules stratigraphically below it are Duchesnean or latest Eocene." Note that according to the current Geologic Time Chart referenced most paleontologists, the Oligocene Epoch of the Tertiary Period began about 34 million years ago (well...that would of course be 33.9 million years ago, if one requires unerring exactitude)--hence, the fossil floras preserved in the Chicken Creek Formation can faithfully be assigned to the late portions of the Eocene.

Many fine fossil plant localities occur in the Bull Run District. Exposed here are extremely fine-grained, dark-greenish shales and mudstones bearing common winged seeds and

fascicles from many species of conifers, including fir (*Abies*), pine (*Pinus*), spruce (*Picea*), larch (*Larix*), hemlock (*Tsuga*) and cypress (*Chamaecyparis*)--all of which can be collected from the upper Eocene Chicken Creek Formation, named by the late paleobotanist Daniel I. Axelrod in an unpublished manuscript. Rarer finds, comprising less than 1 percent of the fossil flora--over 8,000 plant specimens have been taken from the Chicken Creek Formation by paleobotanists for study--include the leaves of alder, birch, zelkova, Oregon grape, maple (samaras are also found), willow, and cottonwood.

Much digging and splitting of the shales will be required to find the best representation of fossil plant specimens. Since the fine-grained sedimentary rocks accumulated in the deepest portions of the ancient Late Eocene lake, plant structures transported there by storm waters far from the shoreline were preserved in the muds and silts only under the most favorable circumstances. This means that many shale beds are barren of botanic specimens, while others, without any apparent differences in lithology from the rocks lacking fossils, yield significant concentrations of conifer winged seeds and associated fascicles, or small bundles of needles that originally were attached to the branches. A moderate amount of picking through the shales and mudstones should soon help you determine which horizons will provide enough fossil specimens to allow a successful quarrying operation. Even though the conifer seeds and fascicles are rather small, they are nevertheless readily identifiable in the sediments, carbonized an attractive brownish-black on the dark green shales.

Some collectors thrive on the opportunity to open up a fossil quarry in a productive plant-bearing region, choosing to concentrate their efforts at one or perhaps two favorable locations. Other fossil plant seekers prefer to "hit and miss," as it were, hiking over the outcrops and collecting specimens from surface exposures. Both methods will net many well-preserved remains here, but if you choose to undertake a major quarrying excavation, be sure to open up your fossil pit at a site well-removed from the main dirt roads. While it is certainly permissible to dig a bit in the roadcuts, be careful not to probe through a great quantity of shales, tossing the debris back onto the roads.

When last in the region, I spent but a partial day splitting shales at Bull Run and was able to secure an excellent selection of well-persevered seeds and fascicles from several species of conifers, primarily spruce and fir. During a number of previous visits, I enjoyed whacking (a genuine paleobotanical term denoting enthusiastic wielding of a rock hammer) into the shales at a supremely productive quarrying excavation were I invariably managed to recover a satisfying number of beautiful plant specimens--although admittedly my glory hole of paleontological gold had begun to produce progressively fewer paleontological structures not soon before I decided to explore elsewhere.

The fossil floras from the upper Eocene Chicken Creek Formation--there are no fewer than ten stratigraphically separate fossil plant-bearing horizons exposed at Bull Run Basin--have yet to be described in a formal scientific monograph; however, the late paleobotanist Daniel I. Axelrod had the area under serious study for several years. Axelrod gave a brief analysis of the flora in one of his many published paleobotanical monographs. He noted that the fossils from the youngest horizons in the Chicken Creek Formation were comprised of fully 99.5 percent montane conifers. Based on the known environmental requirements of living representatives of the fossil flora, the average year-round temperature during Late Eocene times was somewhere between 53.5 and 53 degrees Fahrenheit, an effective temperature gradient that suggests that the fossil species lived close to subalpine conditions, or more specifically in the montane conifer forest zone. Axelrod estimated that 37 million years ago the plants lived at an elevation of some 4,000 feet--today, the area lies at slightly over 6,000 feet in the midst of the arid Great Basin Desert. Yet, according to Axelrod the local paleogeography alone is apparently not enough to explain why the Chicken Creek plant community was essentially a pure conifer forest; a moderate elevation of 4,000 feet during the Late Eocene would seem an insufficient reason to account for the rarity of deciduous trees and shrubs in the fossil record. According to Axelrod, the explanation was that a pronounced overall cooling trend during Bull Bun Tertiary Period times influenced the kinds of plant communities that supplanted those found in older sections of the Chicken Creek Formation, which yield a wider variety of species.

Eventually, though, scientists gathered much more information on the paleo-environment and related paleo-elevations of the Early Tertiary Period. For example, the late paleobotanists Howard Schorn (former retired Collections Manager of fossil plants at the University California Museum of Paleontology) and Jack Wolfe (former member of the United States Geological Survey), among others, demonstrated through a combination of geophysical data and sophisticated leaf character analyses (a reliable methodology in which such factors as size, shape, and ratios of entire to serrated margins of leaves are compared to approximate paleo-elevations during the geologic past) that throughout Eocene, Oligocene, and early Middle Miocene geologic times the ancestral Great Basin existed as a vast high plateau region that likely stood as high, if not higher than most of the present-day Nevada mountain peaks; hence, Schorn and Wolfe suggested that the Chicken Creek Flora likely accumulated at elevations well over 8,000 feet. Then, by 13 million years ago, through extensional geologic forces which helped create the modern physiographic province we observe today, the Great Basin had dropped to roughly its present elevations during the middle portions of the Miocene Epoch.

In addition to conifer winged seeds and occasional leaves, fossil insects can also be recovered from the upper Eocene Chicken Creek Formation. Most of the insect specimens occur in the greenish-brown fissile shales which, happily for the collector, erode in platy slabs from the exposures, a mode of weathering that has produced abundant material through which to search for elusive paleontological remains--in this case, winged conifer seeds and insects carbonized an aesthetically pleasing dark brown on the paler-colored matrix.

While insect exoskeletons are common to abundant (at least they used to be; loads of paleoentomology enthusiasts have with ebullient excitement swarmed over the productive shale exposures throughout the decades) in several of the shale layers at Bull Run, the exact identification of them remains in doubt. Since no wings or legs can be observed on the insect fossils, it is assumed by most collectors that they represent some sort of immature arthropod stage, or instar, perhaps a variety of fly larvae similar to types sometimes noted in oil shales of the famous Eocene Green River Formation of Colorado, eastern Utah, and Wyoming (some of the sedimentary beds in the Chicken Creek Formation have also been identified as oil shales). There are no museum-quality insect finds here, unfortunately, and the fact that the localized exposures still exist and have apparently survived hordes of collectors over the years testifies to the fact that most visitors simply content themselves with a few select samples of insect-bearing shale and then move on to other sites. The conifer samaras are far rarer in the insect-bearing sections, but the specimens, when found, appear to be significantly larger than their counterparts at places where only plants constitute the paleotological association.

The Chicken Creek Formation is decently exposed at Bull Run. Visitors would be advised to conduct reconnaissance of all outcrops encountered. A few of the more marly sedimentary rock types in the area yield abundant tests of the minute bivalved crustaceans called ostracods. Genera identified from the Bull Run Basin include *Cadonia*, *Tuberocyprise* and *Cypridopsis*. It is illuminating to note that modern *Cadonia* ostracods inhabit quiet freshwater lakes, where they typically creep and burrow in the silts and muds. Even though none of the ostracods found in the Chicken Creek marl beds is particularly well preserved, their fragmental and occasional complete shells often constitute a large proportion of the strata in which they occur. Such ostracod accumulations cannot properly be termed coquinas, although their concentration in the sedimentary rocks is such that a casual inspection might lead to this conclusion. Also, coiled freshwater gastropods of the genus *Planorbis* can be found in a few of the more ledge-forming outcrops of carbonaceous shales; such specimens are not particularly abundant, though.

An interesting sidelight is that the Chicken Creek Formation was originally called the Upper Miocene Humbolt Formation; geologists now conclude, of course, that the Bull Run strata

belong to the Late Eocene Epoch. The initial age determinations were based on suites of fossil plants collected from horizons not officially calibrated by radiometric isotope techniques. All of the conifers and deciduous varieties first studied from the Bull Run Basin in the early 1960s appeared diagnostic of the Middle Miocene age, or roughly 15 to 13 million years old. When radiometric measurements were finally used on volcanic rocks both immediately overlying and underlying the fossiliferous sequence, paleobotanists were surprised to learn that the Chicken Creek beds could be accurately bracketed between 42 and 35 million years old. And, since the vast majority of the fossil florules in the Bull Run district occur in the sedimentary section roughly 600 feet below the rhyolite ash bed which gave a radiometric age of 35 million years, most paleobotanists believe that so the so-called Bull Run Flora is on the order of 37 million years old, or Late Eocene in geologic age.

Traditionally speaking, the most comfortable times for visiting Bull Run Basin are from mid-spring through mid-fall. A few hardy souls brave the winter--invariably local collectors from surrounding Great Basin territories who must contend with such arctic-style meteorology on a regular basis--but for most temperate-climate residents the prospect of experiencing subzero temperatures combined with frequent lacerating winds tends to chill the paleontological enthusiasm somewhat.

Bull Run Basin lies right in the middle of the sparsely populated Great Basin Province, many miles from the nearest community where mechanical or medical assistance can be found. It is imperative that visitors to the district observe the traditional rules of backcountry travel. Now, depending on the creativity of the person suggesting the necessary precautions to observe, the list of "traditional rules" varies from a few trenchant admonitions to an unwieldy didactic tome. Since I regularly conduct my paleontological excursions in an average-sized four-wheel drive vehicle, I have little room to carry with me a redundancy of emergency supplies. I prefer to keep matters uncomplicated: 10 gallons of water; two or three days' worth of provisions; spare fan belts; heavy-duty blanket and trusty Antarctica jacket (purchased during my stay in Kansas several years ago during chill factors of minus 35 degrees); hydraulic jack and lug wrench; insect repellent (most frequently used emergency item--one particular species of biting gnat--"black fly"--common to Nevada devastates my system); battery-operated radio; flashlight; and various officinal preparations such as aspirin, rubbing alcohol, and a topical antibiotic. I also have citizens-band radio capabilities, but have never had the need to broadcast an emergency plea.

As a member of the inspiring Great Basin physiographic province, Nevada today holds many fascinating fossil plant and animal localities--paleontological sites that tell tales of more temperate climates in the geologic past, many millions of years ago when forests of moist green thrived around extensive pristine lakes whose slowly accumulating sediments now lie

exposed in a setting of pastel aridity. In the Silver State of Nevada, at Bull Run Basin, fossil enthusiasts may dig into the hardened muddy remnants of what existed here some 37 million years ago: a great body of fresh water around which grew luxuriant stands of spruce, fir, pine, larch, hemlock, and cypress--a pure montane conifer forest, one of the few such botanic associations recorded in the Cenozoic rocks of North America. It must have been a scene which rivaled modern Lake Tahoe in the high Sierra Nevada: a shimmering expanse of cold deepness reflecting skyward the pitch-scented density of conifer green.

Chapter 7

Field Trip To The Copper Basin Fossil Flora, Nevada

Introduction

Visit a remote fossil leaf locality in Nevada where some 42 species of 40-million-year-old plants have been identified from the upper Eocene Dead Horse Tuff. Find superior examples of carbonized leaves preserved in sedimentary rocks that contain substantial quantities of volcanic ash.

Field Trip To Copper Basin, Nevada

Fossil enthusiasts looking for a remote and scenic area in which to find an abundance of well-preserved leaves, seeds, and twigs might want to try Copper Basin in Nevada. It's a famous paleobotanical locality that yields up some of Nevada's most reliably spectacular fossil plant remains.

The fossil site lies within a geologic rock formation called the Dead Horse Tuff, which is upper Eocene in age, dated by radiometric means at some 39 to 40 million years old. For the most part the Dead Horse Tuff is an unfossiliferous unit of pyroclastic debris, a crystal vitric tuff ranging in mineral composition from a biotite rhyolite to a biotite hornblende latite some 5,200 feet thick. But near the middle of the extensive accumulation of solidified volcanic ash--the remnants of a series of devastating explosive eruptions throughout Late Eocene times--minor interbeds of tuffaceous shales yield a treasure-trove of beautifully preserved deciduous leaves, conifer and maple samaras (winged flying seeds), and conifer foliage (primarily twigs, though cones and cone scales have been reported). The leaves in particular are typically preserved as bountiful carbonized impressions, organic tissues compressed through geologic time to shades of dark brown to black on a pale reddish-brown matrix.

And because they are so spectacularly preserved, ranking as some of the finest examples of fossil plants in all the state of Nevada, many Dead Horse Tuff specimens have begun to appear in the inventories of commercial fossil dealers throughout the Western states. This is of course illegal activity, since no fossil specimen collected on public lands may be either sold or bartered; and the Copper Basin locality definitely lies amidst such a Bureau of Land Management-administered region. Accordingly, commercial collectors must stay away from Copper Basin, or the entire fossil-bearing area will most certainly be closed down to all but professional paleobotanists representing either an accredited university or museum.

The usual admonitions may sound familiar to many regular travelers of the Great Basin, even laughably repetitious perhaps, but it is critical to remember that Copper Basin lies well off the proverbial beaten track. This is what the locals call the southeastern sector of "Owyhee Country," a sparsely populated Great Basin outback, if you will, where immediate medical or mechanical assistance is nonexistent. You may be able to find a ranch house somewhere out there, but don't count on it in a dire emergency. So, in order to assure a safe and enjoyable visit, those planning to visit the fossiliferous exposure of Dead Horse Tuff at Copper Basin must do so only in a reliable four-wheel-drive vehicle--or, at the very least, a rugged pickup truck whose tire tread can be trusted to carry you over lonesome stretches of semi-maintained and unimproved dirt roads subject to washboarding, potholing, and sudden washouts. You should also expect to encounter a variety of jagged rocks that tend to ruin even the toughest of tire treads: keep your speeds moderate to slow; there is nothing worse than blowing out more than one tire during a backcountry trek.

Once within the deep backcountry, still many a mile from Copper Basin, visitors will have an opportunity to observe the old site of Charleston, formerly one of the most isolated and lawless mining towns in all of Nevada. Nothing remains now to mark the site, save perhaps a couple of crumbling wooden buildings, but in a broader historical perspective Charleston has much to offer. Its general history has been discussed by many Nevada ghost town enthusiasts, including such notables as Stanley W. Paher and the inimitable Nell Murbarger, who in her classic work *Ghosts of the Glory Trail* gives a riveting account of one of the last lynchings to take place in this part of the Great Basin--it happened in Charleston.

The story has been told many times over; I hesitate to attempt another rendering of it here, but as I have already suggested the subject, I might as well join the prodigious body of folk who have already related the tale. Bear in mind that nobody has yet written the definitive account of what happened in Charleston in the 1880s. The general idea is that one George Washington Mardis, a Bible-thumping Old Testament preacher who gave stentorian sermons to his favorite burro "Sampson" made more-or-less regular trips from Charleston to a rather distant community for supplies. Prior to one his scheduled journeys, a local Chinese miner gave him $250 in gold to deliver to the community in payment of a debt.

Mardis obliged--but it was the last favor he would ever do for anyone on this earth. The next day miners from Charleston found his wagon and team of horses abandoned along the road, below town. In the dry, dead brush nearby they also came upon his remains, riddled with bullet holes. Apparently word had spread to the local criminal element (and there was no short supply of that commodity in Charleston) that Mardi was carrying with that extra gold worth 250 spondulix. A few of the miners at the scene of the crime decided to take a look around, playing amateur sleuth, to see what might turn up.

When one of them spotted near the body the tracks of a barefooted individual bearing six toes on the left foot, the search for the perpetrator immediately turned to the Chinese quarter in Charleston. The logic went something like this: Nobody, the investigators averred, but a person of Chinese ancestry would possibly go around without shoes in that harsh, unforgiving Nevada climate. Thus, a vigilante posse swooped down on Chinatown, yanking slipper after slipper from the left feet of everyone they happened to encounter. Eventually, after running through scores of normal feet, they came upon one lone male who exhibited that distinctive and incriminating extra toe.

The case was closed. They gave the six-toed individual two full days to devise any possible alibi; when none was forthcoming, the man was swiftly convicted on circumstantial evidence. The next day a suitable length of rope was procured and fashioned into the hangman's noose. And with most of the population of Charleston looking on--or taking part, as some accounts of the execution suggest--George Washington Mardis' murder case came to an inevitable ending.

Once beyond Charleston, having successfully maneuvered to Copper Basin through additional inspiring expanses of pristine sagebrush paradise, one is well-ready for some paleobotanical investigations--AKA: let's start digging.

The best way to find fossils at Copper Basin is to split with great care the partially silicified reddish-brown to creamy-white ashy shales of the Upper Eocene Dead Horse Tuff. Remove large chunks of the shales from the outcrop and, using either the pick or blunt end of a geology hammer (or even a broad putty knife, though a selection of large and small chisels would be a better idea here), forcefully rap the shales along their natural bedding planes. Usually, they will split with surprising ease to reveal a rewarding assortment of carbonized plant remains.

Some 42 species of fossil plants have been identified from the Dead Horse Tuff at Copper Basin. The most abundant forms encountered are fragmentary and complete leaves belonging to a species of alder called *Alnus jarbidgiana*.

In decreasing order of abundance, the nine next most-common remains include: an extinct redwood, *Sequoia affinis* (which is closely related to the modern coast redwood of northwestern California); leaves, from a tanbark oak; seeds, cone scales, and twigs from a spruce; twigs from a second type of spruce; leaves from an Oregon grape; samaras and twigs from a fir, *Abies cuprovallis*; leaves of a second species of alder, *Alnus cuprovalis*; and leaves from a sassafras, *Sassafras ashleyi*.

Also present, but rather rarely found, are such varieties as cypress, hawthorn, plum yew, pine, maple, rhododendron, *Prunus* sp. (four species), eastern wahoo, buckeye, larch, willow, tree sparkleberry, madrone, currant, ocean spray, rose, and leadplant.

It may come as no surprise to students of paleobotany that the first scientist to collect at Copper Basin was none other than the late Dr. Daniel I. Axelrod, who for decades was one of the better-recognized paleobotanists in the world. After learning of the locality through a private collector in Elko, Nevada, Axelrod and his field assistant James F. Ashby made their first visit to Copper Basin in the spring of 1939. Axelrod said that they made only a small collection of plants on that date, due to the fact that the ground was still way too damp from the thawing snow pack of the previous winter. Subsequent visits in the summers of 1956, '59, and '61 through '63 netted a total of 5,343 specimens from the Upper Eocene Dead Horse Tuff--all of them now housed in the archival paleobotanical collections at the University California Museum of Paleontology.

Eventually, Axelrod published his findings in a formal peer-reviewed paleobotanical treatise, monograph. That's where he concluded that the fossil flora most closely resembled a number of modern conifer forests present in the western United States--among them the coast redwood and spruce-hemlock forest of northwestern California, in addition to the spruce-larch forests of the northern Cascade and Rocky Mountains. He also saw some obvious relationships to the spruce-fir and regional conifer-deciduous hardwood forests of the eastern United States and their similar, counterpart, forest-type associations in China and Japan.

Based on the environmental preferences of modern analogs of species identified from the Dead Horse Tuff, Axelrod suggested that the Copper Basin Flora originated from a conifer-hardwood deciduous forest that lived close to the zone of montane conifers. Initially, Axelrod estimated that elevations at the site of deposition were probably in the neighborhood of some 3,600 feet; today the fossil site lies at 7,150 feet in a region regularly hit with wintertime weather extremes reminiscent of an arctic environment. Yet, approximately 40 million years ago the Late Eocene climate could best be described as cool-temperate, with roughly 50 to 60 inches of rain per year--and that well distributed throughout the summer. There was no snow, except on the higher peaks surrounding the basin of deposition. The average yearly temperature was somewhere around 51 degrees, with mean temperatures for the warmest and coldest months of the year at around 58 and 44 degrees, respectively.

It's interesting to note that Axelrod's Copper Basin paleo-elevation analysis went pretty much unchallenged for many years, until eventually the late paleobotanists Howard Schorn and Jack A. Wolfe, among numerous other investigators, concluded through several avenues of

independent scientific research (including a rigorous, sophisticated leaf character analysis study) that the entire ancestral Great Basin region—the vast area that includes present-day Death Valley in eastern California, almost all of Nevada, extreme southeastern Oregon, southern Idaho, and western Utah (Millard County, in particular)--likely existed during later Eocene times as a broad plateau that stood as high, if not higher, than those elevations observed today. Schorn and Wolfe therefore estimated that the Copper Basin Flora accumulated at elevations roughly the same as what's seen there today--in other words, around 7,200 feet. Eventually, though, through geophysical strains of extension and block faulting, by Middle Miocene times some 13 million years ago elevations throughout the Great Basin had collapsed, dropped, to around the same as today's heights.

It was certainly a different world at Copper Basin some 39 to 40 million years ago--a broad lake basin within which volcanic ash periodically mixed with the fallen debris from deciduous plants and conifers to form a richly fossiliferous horizon in the Dead Horse Tuff. Today, collectors pry apart the hardened tuffaceous muds on a weathered ridge some 7,150 feet high in the glorious isolation of Nevada, finding a wealth of beautifully preserved fossil plants--a direct link with an age when a now extinct variety of coast redwood towered above thickets of alder, and the harshness of modern winters was yet to come.

Chapter 8

Trilobites In The Nopah Range, Inyo County, California

One of the more prolific producers of trilobites in the Mojave Desert-Great Basin region of eastern California is the lower to middle Cambrian Carrara Formation, a sedimentary rock deposit that has yielded more than 95 species of trilobites distributed among 38 genera. The Carrara was first described in the geological literature from excellent and characteristic exposures in Carrara Canyon at Bare Mountain, a few miles south of Beatty, Nevada, where metamorphosed carbonates in the youngest periods of sedimentary deposition yielded vast quantities of high-grade commercially exploitable marble, productive deposits that were extensively mined in the early portion of the 20th century. By a curious twist of fate, though, the Carrara Canyon outcrops of the Carrara yield few identifiable fossil remains. Trilobites are virtually nonexistent there, save for a few poorly preserved fragments of the exoskeleton, such as spines and free cheeks from the cephalon, or head shield. It is therefore a very disappointing region to explore, at least in a paleontological sense.

More productive exposures can be visited in the Funeral Range of eastern California--that impressive looming hulk that guards the eastern borders of Death Valley National Park. The problem here, obviously, is that unauthorized fossil collecting within the borders of the national park is not permitted. Yet, such classic sites as Echo Canyon, Titantothere Canyon and Pyramid Peak--all tucked away within the rugged and wild Funeral Range--continue to lure amateur fossil seekers, curious to observe in situ, with hands obediently kept off the rocks, the beautiful trilobites preserved along the bedding planes.

In western Nevada, most of the classic trilobite-bearing beds in the Carrara Formation occur on the Atomic Energy Commission Nuclear Test Site, which lies east of Highway 95 from the vicinity of Scotty's Junction all the way south to Las Vegas. Paleontologists privileged enough to gain access to the site report beautiful trilobite specimens, some of them complete, from a number of Carrara Formation exposures at Striped Hills, Jangle Ridge, and the Spectre Range.

In addition to Carrara Formation exposures lying within Death Valley and the nuclear test site, amateur fossil collectors face yet another obstacle. Much of the Mojave Desert is presently a federally protected wilderness area, a national monument, or a national monument. For example, one of the more frequently visited outcrops of the Carrara used to be Eagle Mountain, south of Death Valley Junction (just east of the Death Valley National Park border), where abundant, identifiable trilobites had been collected for decades. The locality now lies within the federally designated Eagle Mountain Wilderness and it is completely off limits to any manner of unauthorized collecting.

Another broad band of productive trilobite-bearing Carrara Formation exposures can be visited in the Nopah Range, Inyo County, California. While it's true that most of the Nopah Range has been swallowed up by the bureaucratically established Nopah Wilderness, there is still one productive place where trilobites continue to occur on public lands--all from a single unit of slightly metamorphosed shale that is uppermost lower Cambrian in geologic age (or roughly 518 million years old). The locality lies in the Nopah Range and has attracted much attention from many amateur fossil enthusiasts, since this particular site represents one of the few accessible places remaining in all the southwest where unauthorized exploration of the Carrara Formation is allowed to take place.

As one gazes to the Nopah Range slopes in the vicinity of the fossil site, the Carrara Formation is the conspicuous recessive interval that in an idealized stratigraphic evaluation is some 1,200 feet thick. In practical field experience, though, when measured completely from top to bottom, the Carrara is considerably thicker than that due to faulting and repetition of some of the sedimentary beds. The formation lies between two massive layers of widely differing lithologies--a dark bluish carbonate layer at the top called the middle to upper Cambrian Bonanza King Dolomite, and pale brown to dark brown quartzite below representing the lower Cambrian Zabriskie Quartzite. The Carrara is such a distinctive unit in the field, a varied mixture of tan, brown, and greenish shales interbedded with several massive beds of bluish to gray-blue limestone, that it can be followed with ease throughout the Nopah Range. But don't touch anything within the Nopah Wilderness (a detailed map delineating the geographic extent of the Nopah Wilderness can be obtained from the BLM). At the trilobite locality, the Carrara Formation can be observed lying below the massive bluish carbonate accumulations of the middle to upper Cambrian Bonanza King Dolomite. The Bonanza King yields few trilobites, but is known to contain locally abundant oval algal structures called *Girvanella* signifying deposition in a warm, shallow Paleozoic Era sea.

Throughout its area of outcrop, the Carrara can be separated into nine easily distinguished stratigraphic subunits, or members. The youngest member, just below the overlying Bonanza King Dolomite, is the Desert Range Limestone. It can be recognized from afar due to its distinctive lithologic mixture of thin-bedded black silty limestone interbedded with orange dolomitic partings. The Desert Range is noted producer of *Glossopleura* trilobites, representing a Middle Cambrian geologic age, but almost all of the productive beds lie on the nuclear test site in western Nevada.

Immediately below the Desert Range Limestone is the Jangle Limestone Member, which is the uppermost, or youngest of the three major carbonate units in the Carrara Formation. It's characterized by one to as many as five massive limestone layers separated by thin argillaceous partings. In the Grapevine Mountains of eastern California, the Jangle yields a

diverse and abundant Middle Cambrian trilobite fauna consisting of *Mexicella grandoculus*, *Mexicaspis radianis*, *Nyella climlimbata*, *Ptarmiganoides hexantha*, and *Volocephalina connexa*. Exposures of the Jangle Limestone Member in the Nopah Range yield only sparse trilobite fragments and occasional algal nodules of the *Girvanella* variety. The algal structures are usually referred to by sedimentologists as oncolites, and were theoretically formed by direct precipitation of calcium carbonate from Cambrian sea-waters, unlike modern algal bodies from the Bahamas that develop directly through accretionary capturing of the surrounding oceanic muds.

In descending order of geologic age, the next oldest unit in the Carrara is the Pahrump Hills Shale Member. It consists of a heterogeneous accumulation of red-and-green mudstone, tan siltstone, silty limestone, and dolomite. Typically, the lowermost exposures produce abundant invertebrate tracks and trails preserved on the bedding planes of an orange-brown siltstone, while strata higher in the section often yield abundant oncolites embedded in a cryptalgal limestone. Even though the Pahrump Hills Shale reveals abundant trace fossils--including problematic trilobite feeding grooves, scratch marks, and profuse tracks clearly allied with arthropodal life movements--trilobite fossils are scarce to nonexistent at most outcrops. The most productive trilobite-bearing sites include the Grapevine Mountains in California and the Groom, Desert, Spectre and Belted ranges in western to central Nevada. Trilobites identified from those localities include *Albertelloides rectinmarhinatus*, *Caborcella pseudaulax*, *Caborella reducta*, *Chancia venusta*, *Kootenia germona*, *Pachyaspis gallagari*, *Pagetia resseri*, *Sysacephalus obscurus*, *Volocephalina connexa*, *Zancanthoides* sp., *Albertellina aspinosa* and *Elrathina antiqua*. All of the specimens suggest a middle Cambrian age for the Pahrump Hills Shale Member.

Underlying the Pahrump Hills Shale is the Red Pass Limestone Member, named for Red Pass, which lies roughly three-quarters of a mile east of Titantothere Canyon in Death Valley National Park. The Red Pass is easily distinguished in the Carrara section since it forms a prominent carbonate cliff face in a section dominated both above and below the interval by more recessive-weathering shales. Limestones in the Red Pass produce invertebrate tracks and trails, in addition to occasional oncolites, sometimes found in a superior state of preservation. Thin sections of the algal material yield actual filaments from the original critter, an extinct species of blue-green algae. Other varieties of fossil remains are generally rare, occurring only in the uppermost and lowermost layers. These include such trilobites as *Kochaspis augusta*, *Kochaspis lilian*, *Kochiellina groomensis*, *Kochielina janglensis*, *Plagiura extensa*, *Plagiura vetracta*, *Plagiura cercops* and *Schistometopus* sp. Paleontologists agree that the Red Pass Limestone Member is entirely Middle Cambrian in geologic age.

Lying directly below the Red Pass Limestone, in conformable fashion--that is, there were no apparent breaks in sedimentary deposition--is perhaps the most reliably fossiliferous unit in all the Carrara Formation--the fabulous Pyramid Shale Member, which was named for Pyramid Peak in the eastern sector of Death Valley National Park. Until 1994, when the California Desert Protection Act became law, Pyramid Peak could be found outside Death Valley National Monument. The prominent geographic landmark, and productive fossil locality, presently resides within the boundaries of Death Valley National Park: Fossil collecting there is obviously illegal without prior authorization from the Death Valley National Park Resources Division. If you think that you might possibly qualify for a collecting permit (a minimum B.S. degree from an accredited institution of higher learning is necessary, in addition to a valid research project that can be verified through independent investigation by the petitioned authorities), contact the DVNP Resources Division.

Not only is the Pyramid Shale Member fossiliferous at its type locality, but trilobites can be found at most of its exposures throughout the deserts of eastern California and western Nevada. It is in fact the most fossiliferous unit in the Nopah Range and is the member within which the trilobite locality discussed here occurs in the Nopah Range--although, it should be noted that not all investigators agree with this assessment. Professor Matthew J. James of Sonoma State University, California, for example, believes that the fossils found in what's here called the Pyramid Shale Member actually occur in either the older Echo Shale and/or Eagle Mountain Shale Member of the Carrara Formation; so do several dedicated trilobite hunters, as well. In either case, the fossils also show up near the main locality, within the Nopah Wilderness, but don't even think about keeping anything found there, because that area is presently under federal jurisdiction and administered by the Bureau of Land Management: it is therefore completely off-limits to unauthorized collectors. Be sure to have an up-to-date, accurate map of the Nopah Wilderness while exploring the Nopah Range for trilobite localities.

It should be noted that there is nothing in the original language of the Wilderness Act (circa 1964) that specifically allows hobbyists to excavate for minerals, fossils, or any other natural resources within a designated wilderness area. The final approval to collect on wilderness lands likely rests with the individual BLM ranger in charge of his or her district. Therefore, always check with the local district ranger before collecting within a wilderness region: some rangers, for example, may permit only surface collecting within their particular jurisdiction, such as what's allowed to take place within the Southern Inyo Wilderness at Union Wash near Lone Pine, California, where many freely eroded species of Early Triassic ammonoids can be gathered from surface exposures only--no digging into the bedrock is allowed there without a special use permit, which is issued only to professional paleontologists and

geologists conducting formal, technical research projects. Wilderness areas administered by the U.S. Forest Service (in national forests, for example) are completely off-limits to any kind of unauthorized collecting--don't even bother to ask.

At the Nopah Range fossil trilobite locality, the specimens occur in greenish shales and maroon siltstones interbedded with a minor amount of barren quartzite and limestone in the lowermost 30 feet of the Pyramid exposures. Trilobites are relatively common at this site, appearing as fragmentary portions of the arthropod's original exoskeleton: Cephalons, thoracic segments, and infrequent pygidia constitute the primary finds. Extended periods of assiduous hunting--that is, several hours spent splitting shales along their natural bedding planes of deposition (the blunt end of a rock hammer works best, in combination with a selection of well-tempered chisels for the more massive chunks one might yank out of the outcrops)--may net a complete specimen or two, but don't count on it. There are no guarantees of perfect trilobite remains from an Early Cambrian locality. The fragile exoskeletons of the earliest trilobites in the fossil record tended to disassociate quite easily upon the death of the animal, or during the periodic molting process, when the arthropod discarded its outgrown cover for an external shield more suitable to its larger size. Typical Early Cambrian trilobites identified from the Pyramid Shale at the Nopah Range site include *Olenellus clarki; Olenellus gilberti*, and *Olenellus multinodus*. Higher in the section, trilobites become exceedingly rare, although the following Middle Cambrian forms have been recognized from the Groom and Belted ranges in western Nevada: *Poliella lomataspis*, *Sysacephalus longus*, *Oryctocephalus nyensis*, and *Pagetia* sp.

The Pyramid shale can be traced throughout the Nopah Range. While fossil-prospecting outside the boundaries of the Nopah Wilderness, simply watch for the greenish shales and maroon siltstones sandwiched between two massive layers of bluish limestone. Fossil prospectors here will likely observe numerous trenches in the Pyramid shales all along the Nopah Range, where it is permissible for amateurs to collect.

For the past number of years, a noted trilobite specialist has studied a key section of the Carrara Formation in the Nopah Range, a specific site that the paleontologist, in a guide book to the various Cambrian stratotypes in the Great Basin, proclaimed produced "not uncommon" perfect trilobite specimens. An examination of that locality, which lies at the top of the proposed Dyeran Stage of the lower Cambrian Waucoban Series (in strata older than the Pyramid Shale), proved conclusively to this writer, at least, that that specific stratigraphic section contains trilobites of no greater excellence of preservation, or even abundance, than at the fossil site mentioned here; the specimens are still virtually one-hundred percent fragmental at the study site, though one must suppose that if one could dedicate hundreds of man-hours to splitting shale there, one might turn up a stray perfect trilobite or two,

eventually. Indeed, that geologic section turned out to be a major disappointment. Of course, this statement will only serve to further drive the curiosity of many a fossil seeker, who will strive to track down the locality to determine on his/her own whether trilobites preserved there are in a better grade of preservation: be forewarned, though--you'll just have to trust the writer on this one.

The fossiliferous Pyramid Shale Member lies in sharp stratigraphic contact directly above the underlying Gold Ace Limestone Member. The bulk of the Gold Ace is an oncolite-bearing microspar limestone, an extremely fine-grained carbonate unit that was originally deposited in a shallow oceanic setting as a lime mud. Some bedding planes yield abundant fragmental trilobites, mostly unidentifiable, though sections at Titantothere Canyon in Death Valley National Park have yielded *Olenellus puertoblancoensis*, *Olenellus howelli* and *Olenellus* sp., all of which demonstrate an Early Cambrian age for the Gold Ace Limestone Member.

The next oldest unit in the Carrara Formation is the Echo Shale Member, named for its distinctive occurrence in Echo Canyon, Death Valley National Park. It's a predominantly green micaceous platy shale, uniformly unfossiliferous, except for one rare occurrence at Titantothere Canyon, where paleontologists identified a lone trilobite, *Olenellus clarki*. What's intriguing about this specific member in the Carrara, though, is that its lateral correlative shale unit is none other than the spectacular lower Cambrian Latham Shale, exposed in the Providence and Marble Mountains of San Bernardino County, California. The Latham Shale has probably produced more trilobite specimens than any other lower Cambrian formation in the western states. The once heavily visited fossil trilobite quarry in the Marble Mountains is justifiably world famous, although the area now lies in the federally established Mojave Trails National Monument, an officially protected place in which unauthorized collectors must keep their hands off the trilobites.

Next-oldest of the nine Carrara members is the Thimble Limestone Member, first described at Thimble Peak on the west side of Titantothere Canyon. The Thimble is chiefly an argillaceous dolomitic limestone that weathers to shades of orange, brown, and black. Some limestones in its northwesternmost exposures yield abundant fragments of echinoderms, hyolithids (a diminutive conical lophophorate that bears a distant relationship to brachiopods), and trilobites. At a few localities, abundant identifiable trilobites have been recovered, including *Bristolia anteros*, *Bristolia brisolensis*, *Bristolia fragilis*, *Olenellus clarki*, *Olenellus euryparia*, *Olenellus fremonti*, *Olenellus howelli*, *Olenellus puertoblancoensis*, *Peachella brevispina*, and *Peachella iddingsi*. It is also interesting to note that the trilobite-bearing portions of the Thimble Limestone Member probably correlate with at least part of the Latham Shale, as well. Unfortunately, the Thimble Limestone is not recognized in the Nopah Range, where the

overlying Echo Shale and older Eagle Mountain Shale Members combine to form an undifferentiated sequence.

The oldest unit in the Carrara Formation, lying directly atop the lower Cambrian Zabriskie Quartzite (which yields vertical trace fossil worm borings paleontologists usually call *Skolithus*--generally considered a member of the Phylum Phoronida, or the Horseshoe Worms) in stunning fashion, is the aforementioned terrigenous Eagle Mountain Shale Member. This is a slope-forming silty shale unit that weathers out in shades of green and gray-brown. It was named for its typical exposures at Eagle Mountain, a few miles north of Shoshone, where it reaches its greatest topographic development. Though generally unfossiliferous, the Eagle Mountain Shale has nevertheless produced two identifiable trilobites, *Olenellus arcuatis* and *Olenellus cylindricus*, from green micaceous shales in the lowermost few feet of the sections exposed at Echo Canyon and Titantothere Canyon.

The single best reference work dealing with the Carrara Formation is *Physical Stratigraphy and Trilobite Biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the Southern Great Basin*, United States Geological Survey Professional Paper 1047, by Allison R. Palmer and Robert B. Halley, published in 1979 (at last check, still available from the USGS). In addition to naming and precisely detailing all nine members of the Carrara Formation, Palmer and Halley also describe and figure every one of the 95-some species of trilobites thus far identified; it is, indeed, a monumental contribution to paleontology and stratigraphy. As the authors note, the Carrara Formation is not richly fossiliferous, but it yields the most complete representation of Early to Middle Cambrian trilobites yet described from North America.

Not only is the Nopah Range trilobite site quite productive, but an added bonus for collectors is that it remains easily accessible. Everybody's still welcome to visit it, as long as the area continues to remain free from litter, graffiti and vandalism. The BLM reserves the right to close the place down without advance warning, and they will most certainly do just that if visitors abuse their privileges here. With so many exceptional fossiliferous exposures of the Carrara Formation already closed due to Wilderness and California Desert Protections acts—not to mention their inclusion in national monuments--it would be a shame to lose yet another, this time to our own boorish behavior.

Chapter 9

Field Trip To A Vertebrate Fossil Locality In The Coso Range, California

Introduction

Visit the Coso Range Wilderness in Inyo County, California, west of Death Valley National Park at the southern end of California's Owens Valley, where vertebrate fossils some 4.8 to 3.0 million years old can be observed in the Pliocene-age Coso Formation: It's a paleontologically significant place that yields many species of mammals, including the remains of *Equus simplicidens*, the Hagerman Horse, named for its spectacular occurrences at Hagerman Fossil Beds National Monument in Idaho; *Equus simplicidens* is considered one the earliest known members of the genus *Equus*, which includes the modern horse and all other equids.

Please note that fossil collecting is not allowed within the designated Coso Range Wilderness, except by special permit issued by the Bureau of Land Management--a permit given only to individuals who matriculated from an accredited university with a minimum B.S. degree, or represent a museum whose credentials meet the necessary standards of excellence.

Field Trip To The Coso Bone-Bearing Badlands

An inviting route to Death Valley National Park is State Highway 190 out of Olancha in California's southern Owens Valley. Not only is this a much-scenic and reliably accessible pathway to one of the world's favorite haunts, but it also places visitors within convenient striking distance of a most fascinating vertebrate fossil locality in the federally established and administered Coso Range Wilderness--an area no longer accessible to motor vehicles, of course, though it's still wide open for inspection by foot and other non-mechanized means.

Perhaps not a few folks remain unfamiliar with this particular area, and I can surely see why. You just can't spot the bone-bearing beds from the asphalt and, besides, it's more than probable that many a traveler has their eyes fixed on the ever-looming and impressive hulk of the Panamint Mountains up ahead--the range which guards the western side of Death Valley, proper.

The Cosos are that at first blush nondescript piece of territory off to the east and southeast as you speed along the southern fringes of Owens Lake between Highway 395 and the intersection with State 136 to Keeler. They are primarily of igneous origin, born of fire and brimstone, the savage spewings of explosive Cenozoic Era molten lavas in combination with Mesozoic Era batholithic instrusive granites--as unlikely a source of fossil specimens as one

could be excused for believing. Yet, tucked way back in the rugged Coso recesses lie the eroding badlands of an ancient lake system which yields up many fossil bones.

The vertebrate remains that await discovered in the Coso Mountains come from the appropriately named Coso Formation, which is upper Miocene to upper Pliocene in geologic age, dated with considerable radiometric confidence at 6.0 to 3.0 years old. And all fossil specimens described from the Coso Formation derive from a restricted sequence some 4.8 to 3.0 million years old. This means that statigraphically speaking the Coso mineralized skeletal material falls within the range of what vertebrate paleontologists call the Blancan Stage of North American Land Mammal Age chronology--that is to say, a geologic interval roughly 4.75 to 1.80 million years ago. Indeed, the Pliocene Coso Formation yields up one of the premiere Blancan Stage mammal localities in all the US West.

Petrological analysis demonstrates that the Coso hydrologic-volcanic system deposited a composite aggregate of roughly 500 feet of arkosic sandstones, shales, claystones, diatomite (a variety of rock composed almost entirely of diatoms, a photosynthesizing microscopic single celled plant), air fall volcanic ash, and basalts in a relatively localized lacustrine (lake) basin influenced by subordinate fluviatile (stream) and alluvial conditions that contributed substantial detrital constituents to the continuously operating three million-year regime of sedimentary-igneous accumulations--all subjected on occasion to geophysically stressful extensional (pulling apart of a portion of the earth's crust) and block-faulting forces.

Significantly, near the conclusion of its depositional history--between four and three million years ago--the Coso Formation starts to record a dramatic influx of clastic-detrital debris now eroding with sudden onslaught from a fault-controlled uplift and eastward rotational tilting of the eastern front of the central to southern Sierra Nevada--a still-active and fully on-going creative geologic process that continues to fashion the great elevations and breathtaking contrasts in topographic relief so spectacularly characteristic of the eastern face of the Sierra Nevada; the northern Sierra of course (Donner Pass area, northward) has stood at approximately the same height as present since at least the Early Middle Eocene Epoch some 48 million years ago.

Geologist J. R. Schultz was the first scientist to investigate this fossil fauna. He led experienced field technicians from the California Institute of Technology on two extensive expeditions to the Cosos, the first in the winter of 1930-'31, then another during the summer of 1936. Schultz eventually published his geological and paleontological findings in: Schultz, J. R., 1937, *A late Cenozoic vertebrate fauna from the Coso Mountains, Inyo County, California*, Carnegie Institute of Washington Publication 487, pages 75-109. Among his many fossil mammal descriptions were meadow mice, rabbits, hayenoid dogs, very large grazing horses--

one of which was eventually recognized by paleontologists as the world-famous Hagerman Horse (one of the oldest members of the genus *Equus*, which includes all modern horses and other equids)--peccaries, slender camelids, and a short-jawed mastodon. Additional Coso Formation fossil material, secured by teams of professional paleontology explorers who succeeded Schultz's ground-breaking investigations, includes undescribed ostracods (a minute bivalved crustacean), algal bodies (stromatolitic developments created by species of blue-green algae), diatoms (a microscopic single-celled photosynthesizing single-celled plant), fish, a vole (the famous *Cosomys primus*, named in honor of its occurrence in the Coso Mountains), a large-headed llama, a bear--and, prolific quantities of pollen, palynological specimens that add invaluable paleobotanical information to the Coso story.

The Pliocene Coso Formation pollens come from what paleobotanists call the Haiwee Florule, situated near the shores of Haiwee Reservoir approximately five miles south of the Coso Range vertebrate fossil locality. They were recovered from brownish siltstones in the lower portions of the Coso Formation by the late paleobotanist Daniel I. Axelrod and W. S. Ting through sophisticated--and extraordinarily dangerous--laboratory procedures, involving the use of perhaps the most potent/unforgiving acid known to exist, hydrofluoric acid, whose efficient destructive activity on human tissue is so rapid and overwhelming that permanent damage to epidermis, muscles, and nerves occurs before one even feels any degree of discomfort or pain after skin exposure. Published documentation of that palynological study can be found in the scientific paper, *Late Pliocene Floras East of the Sierra Nevada*, by D. I. Axelrod and W. S. Ting, University of California Publications in Geological Sciences volume 39, number 1, issued November 7. 1960.

The extensive fossil flora that Axelrod and Ting collaboratively examined from the Pliocene Coso Formation includes such conifers as: Incense Cedar; White Fir; Grand Fir; California Red Fir; Bristlecone Pine; Jeffrey Pine; Sugar Pine; Singleleaf Pinyon Pine; Western White Pine; Lodgepole Pine; Ponderosa Pine; Douglas-Fir; Western Hemlock; and Giant Sequoia--in addition to the following angiosperms: White Alder; Water Birch; Hazelnut; Blue Elderberry; Pacific Dogwood; California Black Oak; Interior Live Oak; Silk Tassel Bush; Black Walnut; Bush Poppy; Snow Bush; Deer Brush; June Berry; Rock Siraea; Thimbleberry; Coyote Willow; Pacific Willow; White Squaw Current; Red Prickly Currant; Kellog Sierran Currant; Sierra Gooseberry; California Slippery Elm; and Zelkova.

Axelrod and Ting concluded that the overall paleo-environmental aspect of the Coso Formation Haiwee Flora most closely resembles today's Sierran pine-fir forests along the moist western slopes of California's Sierra Nevada. Based on the known annual precipitation totals necessary to sustain modern examples of such luxuriant forest vegetation found in the fossil flora, Coso Pliocene times experienced an estimated minimum of 35 inches of rain per

year--whereas today the area lies within what geographers categorize as the Mojave Desert-Great Basin transition zone, which in the vicinity of the Coso fossil occurrences receives a scant three to five inches of rain per year, with soaring summer temperatures that frequently exceed 110 degrees Fahrenheit; in forested Sierran regions where modern-day members of the fossil flora now grow, temperature rarely exceed 85 degrees F.

While fossil pollens lie preserved in older horizons of the Coso Formation, all the vertebrate remains occur within a rather narrow zone in the upper part of the Coso sedimentary deposits; they are found in a buff-colored arkosic (composed primarily of the mineral feldspar) sandstone which weathers into subangular chunks. Often, the mineralized mammalian material can be found already weathered out of the sandstone and in the softer claystone a few feet below the sandstone. The fossil-bearing horizon shows up within most of Pliocene exposures of the Coso Formation, so there is a lot of territory to explore. Schultz's original bone localities lie about two and a half miles from State Route 190; reaching them now involves strenuous hiking through rugged, desolate desert terrain. "In the old days," though, one could negotiate a four-wheel drive vehicle up a system of packed sand desert washes, through magnificent outcrops of the bone-bearing Coso Formation, to within a quarter mile or so of the Schultz fossil quarry. As a matter of fact, with the aid of "trusty" CJ5 and CJ7 jeeps, I managed to thread my way back to the familiar box canyon parking spot several memorable times before the Coso Range became a protected wilderness region--a federally mandated designation which means, naturally, that without a special BLM permit you can't keep anything you find there (paleontological, or otherwise)--except in a camera.

Although many Coso bones observed in surface exposures will be fragmental, that doesn't necessary indicate that what you've found can't be identified, eventually. In addition to occasionally encountering isolated-scattered occurrences of complete teeth and associated jaws, watch out, too, for such ostensibly insignificant specimens as fractured limb sections and other assorted incomplete post cranial skeletal elements that reveal a crucially preserved articulating surface (a ball or socket joint, for example). These are prize finds, indeed, paleontologically speaking, as experts in vertebrate paleontology should be able to determine exactly what kind of animal they came from. There are certainly a good many fossil bones waiting to be found and subsequently photographed where they reside in situ in their sandy to clay-rich sedimentary environment. Probably the most efficiently productive method is to locate the fossil-bearing bed (it will tilt with the moderate dip of the sedimentary rocks, and often it occurs on a precipitous hill-slope--so be careful), then hike it out for as long as it is traceable. Some extensions of the bone horizon are quite prolific, while others seem pretty much barren.

All the way around, this is a great area in which to get some exercise.

Though not necessarily during summer times, one must observe with at least a modicum of sagacious deference to the months of June through September in this part of the Northern Hemisphere, when daytime temperatures regularly exceed 105 degrees. More comfortable--and physically safer--hiking weather in this geographical transition zone between the northwestern Mojave Desert and westernmost Great Basin is traditionally encountered during mid to late autumn and mid-spring.

Still and all--speaking of good old hot summertimes--I must admit that my first acquaintance with the Coso bones was during a particularly ultra-thermal early July. This was a number of years ago, when I resided in coastal southern California. This was a number of years ago, before the Coso Range became off limits to off-road vehicles. This was a number of years ago, before the Coso Range became the Coso Wilderness.

The preliminary circumstances: My father and I wanted to escape the dismal, fog-bound coast of Santa Barbara. We wanted to get out into the desert in the worst way possible. Thus, we turned deaf ears to weather reports of 100-plus degrees on the Mojave Desert.

Because when Coso paleo-urges strike...well, there's no turning back.

At the crossroads in Olancha, at a filling station, somebody was talking about 108 in the shade. That somebody was assessing the conservative side of the situation. I was inhaling fire, it seemed. Somebody else, the service attendant, would only shake his head when I pointed, with what could have easily been interpreted as braggadocious indifference to the brutal elements and the imminent dangers they could present, down the road in the direction of Death Valley in reply to his inquiry as to our destination.

At what our maps indicated was the correct intersection of State Route 190 with a dry wash a number of miles beyond Olancha, I idled the CJ5 jeep. No matter that the heat from the engine overpowered the stifling furnace of the Mojave. We re-checked our maps; and then decided to take yet another look at them. This was the place all right, and the wash leading off into the Coso Mountains invited us onward; not to mention the obvious that the potential bone bonanza up ahead was a prime motivator. I got the jeep down in the middle of the wash with the four-wheel drive already engaged, primed for any kind of sandiness we might encounter.

We should have been so lucky as to get stuck in some mere sand.

What happened--and that within sight of the bone-bearing badlands we had traveled some 250 miles to explore--was somewhat more than we had expected. Smoke on a sudden came billowing from beneath the hood, and the nauseating pungency of electrical wires on fire

became intense; this, just before the jeep jerked to a halt, cold. We leaped to the situation with canteens in hand, flipping open the hood to already charred remains of wires--and we doused what we could. Then I ran with hectic unsteadiness back to the rear of the jeep where we kept our extra water supply. The five gallon container felt like a bag full of air as I plunged its contents to the flames, dousing them repeatedly until only sickening smoldering remained.

So what did we do next? Consternate? Curse? Nope, we took a hike (fossil mania has its prerogatives). Just up ahead a few hundred feet began the badlands exposures of the Coso Formation. And it was with not a little anticipation that we struck out to them with our remaining full canteens, leaving behind for the moment that dead-in-the sand jeep. We crisscrossed those ancient rocks while following the bone-bearing bed, and the paleontological zeal propelled us further in that glaring, brutal heat than I could have possibly foreseen.

But broken down jeeps wait for every man. A sobering mechanical analysis of the predicament proved that the wiring had been fried to a crisp when the horn mechanism had jarred loose, shorting out the system: too many bumpy roads too many times taken. Aided and abetted by the recollection of some basic electrical knowledge garnered from a recent workshop (studying diagrams and such from the jeep's manual from the curbside at home), we figured pretty quickly that we could safely bypass the obvious tactic of securing assistance when stuck out in the boondocks all alone, where nobody in the world who knows where you are is there to lend a hand--in other words, yelling and yelling like crazy at the top of your lungs. No, this was too easy.

We chose to resort to a plan of action which in theory we had only heard about; this entailed an electrical trick usually quite controversial, but one worth trying under the circumstances. It was decided that if we were ever to get out of that wash alive we would have to "hot wire" the contraption.

The prospects did not excite us much. What if an officer of the law should wander by and catch us in the hot wiring act? Perish the thought! Yet, we persisted and pursued and made it back to tell the tale.

And the moral of this story? Don't toot your horn too often about how you can brave the desert elements, I suppose.

We maneuvered the jeep back to Santa Barbara the same way it got to the Cosos to begin with--towed behind an Open Road camper/RV, and later on down the line (with some creative electrical finagling) we finally got a brand new wiring harness installed, and the four

wheel drive "contraption" was by all indications good as new, and good to go: A new-and-improved jeep that actually managed survive numerous additional deep desert backroad adventures.

To all who visit the Coso badlands, don't be surprised if someday you happen to spot a four-wheel drive vehicle stranded along State Route 190, hood raised, the driver nowhere to be seen. If this is the case, simply follow the boot prints in the sand up a dry desert wash into the Cosos until you come upon a fossil hunter, nose bent to the ground, examining a 4.8 to 3.0 million year-old mammal bone.

Chapter 10

Plant Fossils In The Dead Camel Range, Nevada

In the Dead Camel Range near Fallon, Churchill County, Nevada, paleobotany enthusiasts have had, for decades, an enjoyable and educational experience fossil-prospecting for 12.6-million-year-old plant remains in a sedimentary rock deposit geologists call the middle Miocene Desert Peak Formation. The popular paleontologically significant site lies at an elevation of 3,900 feet on the slopes of an unnamed dry wash whose erosive power through the ages has exposed a series of fossiliferous siliceous shales, occasionally interbedded with intrusive volcanic basalt and basaltic tuffs. Despite the fact that the sedimentary sequence has been invaded through time by such disruptive volcanic activity, the oldest shale accumulations in the Desert Peak Formation, or those beds exposed lowest in the local stratigraphic section, have continued to provide both amateur plant seekers and professional paleobotanists alike with an abundance of nicely preserved leaves from a variety of deciduous trees and evergreen live oaks, in addition to samaras (winged seeds), needles and twigs from several types of conifers.

In all, paleobotanists have identified some 22 species of ancient plants from the middle Miocene Desert Peak Formation. The flora list includes such varieties as evergreen canyon live oak, European aspen, paper birch, Utah juniper, white fir and Giant Sequoia--all of which contrast dramatically with the desert extremes of the Fallon district today. The fossils provide incontrovertible evidence that 12.6 million years ago an extensive oak-juniper woodland thrived near the lower reaches of a mixed conifer forest in a region subjected to intermittent volcanic activity.

The famous fossil plant locality frequented by paleobotany enthusiasts in the Dead Camel Range has remained open to hobby inspection for many decades now; when last field checked, the Miocene plants still occurred on public lands administered by the Bureau of Land Management (a significant portion of the Dead Camel Range does happen to lie within the boundaries of the Fallon Naval Air Station). This means that visitors were able to collect, for personal use only, a wonderful selection of Middle Miocene fossil plants, specimens that must never be bartered or sold. Then too, collectors had to be careful not to abuse their privileges here. The operative attitude one had to bear in mind was that the noted Dead Camel Range fossil plant site remained open to the public only because the local landowners, across whose property visitors needed to pass in order to reach the region, recognized the great recreational value of their vast desert surroundings. They encouraged visitors to experience the rewards of back-country explorations amidst the challenging austerity of the Great Basin Desert while continuing to maintain a stern vigilance over the natural domain.

Had a clear pattern of disregard for property emerged, rest assured that the paleobotanical treasures in the Dead Camel Range would not only have become off limits to all amateur fossil collectors, but also to every visiting desert enthusiast, in general.

The Dead Camel Range flora occurs in the basal portion of the middle Miocene Desert Peak Formation--a geologic rock unit dated by radiometric methods at 12.6 million years old. It consists of around 500 feet of thick-bedded siliceous shale (in beds one to five inches thick, on average) that weathers to shades of yellowish-brown, brownish-red and maroon. Unweathered beds of the fossiliferous fine-grained shales often reveal a pale olive-green coloration. The shale frequently disintegrates through erosion to form rubble-strewn slopes, a characteristic style of weathering which masks the true lithologic nature of the underlying strata. Interbedded with the sedimentary rocks are a few minor volcanic contaminants--basalt flows and basaltic tuff--which have locally metamorphosed the shales, sometimes obliterating any fossil material they might have originally contained. Though this is not always the case. Some of the better-preserved fossil plant remains actually occur in highly altered shales, demonstrating here at least that fossil plants can often withstand a great degree of geologic stress and survive to tell their fascinating paleobotanical tales.

The fossil-bearing shales are clearly of lacustrine origin (deposited in a lake), and the plants that were preserved in them most likely accumulated near the shoreline. There is little evidence to support the idea that currents carried the ancient plant specimens far from the margin of the lake into which they were swept by repeated storm waters over the course of tens of thousands of years, at the very least. If they had truly been preserved through the action of lake currents, the plant material would certainly be found as scattered, rare remains throughout the sedimentary deposit, not as a complete fossil flora concentrated within a relatively narrow shale horizon.

At the primary fossil locality situated along the unnamed dry wash in the Dead Camel Range, the fossil plants are fairly common. They are typically preserved as pale brown to dark reddish-brown impressions that stand out in bold contrast on a paler-colored matrix of yellowish-brown to pale olive-green shale. But, as the sedimentary deposits are traced away from that principal accumulation of Middle Miocene plants, collectors learned that the once-productive shale rapidly turns barren of organic remains: all fossils simply disappear due to the mysterious nature of sedimentary deposition some 12.6 million years ago. The fossil locality apparently corresponds to a favorable position along the bottom of the ancient Middle Miocene lake, where plant debris--transported/swept into the waters from the surrounding countryside--was buried rapidly by tons upon tons of inflowing mud and silt: organic tissues were obviously covered completely before any significant decay could begin.

To locate the best-preserved fossil plants in the Dead Camel Range, the highly indurated siliceous mud within which they lie hidden had to be successfully split, revealing the Middle Miocene treasures to their first light of day in some 12.6 million years. This certainly involved a lot of paleontological dedication and patience, not to mention hard work, but the ultimate reward of many perfect, complete evergreen live oak leaves and an occasional conifer samara, among other botanic types, created a burning anticipation for an encounter with the distant geologic past.

The basic idea was to first remove large chunks of potential leaf-yielding shale from the Desert Peak Formation exposures, then, using a good quality geology hammer (the steel must be tempered properly or the metal will spall off with shrapnel-like ferocity, potentially inflicting serious injuries), one proceeded to strike the shale chunks along their natural bedding planes, where the mud and silt had accumulated layer by layer to form sedimentary rock. If nothing significant popped out at you, another try with a different piece of shale could reasonably be expected to net an excellent specimen or two. The quality specimens were indeed present there, even if it took a measure of dedication to recover them. One needed to remember that this was an old and famous fossil locality--a favorite of rockhounding locals from the Fallon and Reno areas, in particular. The upshot was that after decades of intensive collecting by amateurs and professional paleobotanists alike, it was indeed remarkable that the Fallon site continued to yield such a reliable selection of fossil plant specimens.

The history of collecting in the Dead Camel Range goes all the way back to the first half of the 1900s. In the summer of 1936, two amateur collectors from Fallon, Laura Mills and Ray Alcorn, brought fossil leaves from the Dead Camel Range to the attention of Ralph W. Chaney, one of the more renowned paleobotanists of the 20th century. After making a preliminary assessment of the find, Chaney handed the project over to Daniel I. Axelrod. Several weeks later Axelrod accompanied Mills and Alcorn to the discovery site, or what has since become known as the primary fossil locality along an unnamed dry wash in the Dead Camel Range. They collected a modest supply of fossil plants at that time--a large enough selection, at least, for Axelrod to determine that the area demanded a formal paleobotanical interpretation, preferably in a scientific monograph. Mills and Alcorn knew that they had discovered a productive fossil plant horizon. When they learned of the genuine scientific importance of it, they generously presented Axelrod with the extensive collection of fossils they had already taken from the locality, a collection that amounted to several hundred specimens according to Alcorn.

Axelrod returned to the Fallon site several times over the succeeding years, accompanied either by his wife Nancy Robinson Axelrod or his long-time field companion, Robert E. Smith

(who in addition to digging, helped maintain accurate records of the plant taxa recovered). In time, they had amassed an exhaustive collection of some 1,390 specimens from the Desert Peak Formation--enough fossil material to allow a definitive paleobotanical treatise on the subject. Axelrod eventually published his findings concerning the Dead Camel Range plants in a monumental scientific monograph in the 1950s.

All told, Axelrod described 22 species of fossil plants from the Dead Camel locality. The most common specimens he encountered were fragmentary and complete leaves belonging to an evergreen live oak, called scientifically *Quercus pollardiana*. It is identical in every major delineating leaf characteristic to the living canyon live oak, or maul oak *Quercus chrysolepis* now native to California's mountainous regions, namely: western slopes of the Sierra Nevada; Coast Ranges; San Gabriel Mountains, and Klamath Mountains. Maul oak also extends into western Nevada, southwestern Oregon, southwestern New Mexico, Arizona, and northern Mexico. Even though the oaks appear indistinguishable, most American paleobotanists give the Miocene variety a different scientific species name in order to emphasize the great distance in geologic time between the fossil and modern species of the same plant. European paleobotanists on the other hand prefer to retain the modern scientific names for fossil species which appear identical to those still living.

After canyon live oak, in decreasing order of relative abundance the next eleven most common forms encountered in the middle Miocene Desert Peak Formation were: interior live oak (*Quercus wislinoides*); an extinct water oak (*Quercus simulata*), related to the modern White Oak; the Brewer spruce (*Picea sonomensis*); Giant Sequoia (*Sequoiadendron chaneyi*); White Fir (*Abies concoloides*); Oregon grape (*Mahonia reticulata*); a Lemmons willow (*Salix knowltoni*); a second species of Mahonia--Leatherleaf Mahonia (*Mahonia marginata*); Pacific madrone (*Arbutus matthesi*); Arizona ash (*Fraxinus alcorni*), named after Ray Alcorn, who made many of the early collections from the Dead Camel locality; and Ponderosa pine (*Pinus florissanti*). The 10 rarest species found included a Black cottonwood (*Populus eotremuloides*); a sandbar willow (*Salix payettensis*); California nutmeg (*Torreya nancyana*); the paper birch (*Betula thor*); Curlleaf mountain-mahogany (*Cercocarpus linearfolius*); Utah juniper (*Juniperus nevadensis*); Japanese scholar tree (*Sophora spokanensis*); western redcedar--which is in reality a cypress (*Thuja dimorpha*); a European aspen (*Populus subwashoensis*); and the common cattail (*Typha lesquereuxi*).

The Dead Camel paleobotanical remains record an oak-juniper woodland community near the lower reaches of a mixed-conifer forest, similar to modern plant associations that inhabit the western flanks of the southern Sierra Nevada in California. Paleobotanist Daniel I. Axelrod believed that the fossils accumulated in a rather regional, localized lake basin into which streams dumped detritus from a terrain dominated to the south by rhyolite cones of

moderate elevations. That kind of ecological setting, he reasoned, permitted coniferous varieties usually restricted to the uplands to descend the cooler, moister north-facing slopes and enter the fossil record along with evergreen live oaks and species of deciduous trees and shrubs that preferred the lowlands. Plant varieties nearest the shoreline and along the bordering stream courses included Arizona ash, Black cottonwood, sandbar willow and water oak. Drier, sunnier sites at slightly higher elevations supported a widespread oak-juniper woodland dominated by canyon live oak, interior live oak, Utah juniper and Pacific madrone. And the nearby forest community included specimens of white fir, Brewer spruce, Ponderosa pine, canyon live oak and Giant Sequoia/Big Tree.

Axelrod concluded that the Dead Camel Range flora received approximately 25 inches of rain per year. This is in glaring contrast to the scant six or seven inches delivered annually to the area today, almost all of it falling during the winter months. Yet, 12.6 million years ago there was certainly ample summer rainfall over the ancestral Fallon basin--at least enough to support such sensitive botanical indicators as paper birch, Oregon grape and Japanese scholar tree. Middle Miocene times were probably mild and comfortable, with a frost-free season ranging from seven to eight months; today, the frost-free season barely lasts four months, and the Fallon district experiences extended episodes of wicked winter chilling.

That remarkable contrast in environments is on display in the rocks of the Dead Camel Range near Fallon, Nevada. Here, along a narrow dry gully in the middle of the Great Basin Desert (a land of brutal weather extremes and austerity of plant life) is direct proof of what once existed in this part of west-central Nevada some 12.6 million years ago: The lake-originated shales exposed by the powers of erosion contain the preserved evidence of an extensive oak-juniper woodland that intermingled with a rich mixed-conifer forest. It was a paleo-landscape in which canyon live oak thrived in proximity to white fir and western red cedar and Giant Sequoia.

Today, the volcanic peaks of the Dead Camel Range rise above the fossil locality: rugged, barren outcroppings of solidified lava that postdate the accumulation of fossil plants in the Desert Peak Formation below. There are no trees atop the summits, neither can a single variety be found along their slopes--yet, the shadows they cast across the tortured desert landscape cross a place where old sediments hide an age of green.

Chapter 11

A Visit To The Early Cambrian Waucoba Spring Geologic Section, California

Introduction

Journey to the northwestern sector of Death Valley National Park to explore one of the great Early Cambrian fossil localities in North America--the Waucoba Spring Geologic Section in Death Valley National Park, first studied by legendary Cambrian fossil specialist C. D. Walcott in the late 1890s.

Please note: Fossil collecting is prohibited within the boundaries of Death Valley National Park, except by special permit from the National Park Service--a special use permit given solely to individuals with a minimum B.S. degree from an accredited university who seek to undertake research that can be fully verified and corroborated by the National Park Service. No fossil can be collected from the world-famous Waucoba Spring geologic section in Death Valley National Park without such a permit.

Field Trip To The Waucoba Spring Geologic Section, California

Relatively few localities on Earth record the important Precambrian-Early Cambrian transition period--a fascinating and truly mysterious interval some 550 to 509 million years ago, when abundant animal life with shells or a hard external covering first appear in the geologic record.

One of the best places to study this crucial boundary between two major geological Eras (Precambrian and Paleozoic) is the Waucoba Spring district some 35 miles southeast of Big Pine, California, on the eastern slopes of the Inyo Mountains, a locality that now lies within the northwestern border of Death Valley National Park (as of 1994, when the Desert Protection Act became law). Here can be found the classic Waucoba Spring geologic section, first measured and described by legendary Cambrian specialist Charles Doolittle Walcott in the 1890s.

Walcott is of course most famous for discovering the middle Cambrian Burgess Shale fauna of Canada, an extraordinary assemblage of soft-bodied organisms also recognized from a specific Early Cambrian site in China. But Walcott was vitally interested in all aspects of the Cambrian Period, and his detailed analysis of the Waucoba Spring geologic section elevated the site to the status of type reference section for the Waucoban Series of the lowermost Cambrian (542 to 509 million years ago). This means that all age-equivalent strata in the world are correlated with the Waucoba Spring rocks.

Not only is the important Precambrian-Cambrian boundary well exposed near Waucoba Spring, but the sequence is amazingly fossiliferous for strata of such profound antiquity. Among the diverse fossil types that can be observed in situ at Waucoba is the archaeocyathid, an extinct invertebrate animal that secreted a conical to cup-shaped shell typically one-quarter to two inches long--among the earliest reef-forming animals on Earth, it was likely an early calcareous sponge, although not a few archaeocyathid purists still prefer to call it a unique organism with no known modern analogs, deserving of its own scientific Phylum. There are also worm trails, miscellaneous invertebrate tracks and trails (probably from annelids and trilobitic arthropods), *Salterella* (an early experiment, now an extinct member of the Phylum called Agmata, with a small tusk-shaped shell roughly a quarter inch long), algal *Girvanella* bodies, brachiopods, and trilobites. Most of the fossil material is surprisingly well-preserved, and there is even one specific site where perfect, intact trilobite carapaces can be observed. Please note of course that the Waucoba Spring geologic section presently resides within the borders of Death Valley National Park. One must not remove fossil specimens within the park's boundaries without formal, written approval from the National Park Service personnel.

To reach the Waucoba Spring geologic section, first travel to the intersection of Highway 395 and State Route 168 in Big Pine, Owens Valley, California. Turn east on route 168 and proceed 2.4 miles to Death Valley Road (to Saline Valley, Eureka Valley, and Scotty's Castle). Turn right here.

At the 2.3 mile mark from the SR 168, look to the north of the road (left) and you will begin to see impressive badlands carved in sedimentary rocks deposited in ancient Lake Waucoba--a dominantly detrital sequence of calcareous silts and sands and water-laid volcanic tuffs that accumulated 2.63 to 2.06 million years ago during the Late Pliocene and Early Pleistocene.

In the 1890s, C.D. Walcott, on his way to the Early Cambrian rocks exposed farther southeast, discovered an abundance of freshwater snail fossils from several beds in the Plio-Pleistocene section. For those interested in researching the original reference to the molluscan assemblage, Walcott's paper appears in the Journal of Geology, volume 5, 1897. In 2012, a scientific examination of the Waucoba Lake Beds--their formal geologic name (though some folks prefer "Waucobi Lake Beds")--disclosed numerous species of ostracods (a minute bi-valve crustacean), as well.

When you have driven 13.5 miles from the SR 168, turn right on Waucoba-Saline Road. This path can be followed all the way through Saline Valley, just inside the westernmost boundary of Death Valley National Park. It is for the most part a well-graded dirt road, although the

Whippoorwill Canyon area a few miles up ahead tends to be rocky and rutted--a condition one would expect to encounter on a dirt route through such a defile in the mountains.

At the 8.1 mile point from Death Valley Road, Waucoba-Saline Road begins to cut through one of the oldest recognizable sedimentary rock formations in North America: the Wyman Formation. The dark-brown to gray-brown exposures along either side of the path consist of heat and pressure-altered sandstones and siltstones. Some portions of the formation have been changed to quartzite through the eons of tortuous metamorphism. From a distance, these Wyman rocks have a suspicious volcanic aspect: a blocky, basalt-like tone and style of outcropping. Closer examination, though, reveals the obvious sedimentary nature of the material; the strata reveal the characteristic layered bedding and fine-grained composition of altered sandstones and siltstones.

No animal remains have been recovered from the Wyman Formation. At this point in the local stratigraphic section you are standing thousands of feet below the first occurrence of olenellid trilobites, which in a traditional sense used to define the beginning of the Cambrian Period and the Paleozoic Era. Not any longer, though. The Precambrian-Cambrian boundary is now defined as either (1) the appearance of a trace fossil called *Treptichnus pedum* (feeding trails of a supposed annelid), or (2) a distinctive negative carbon isotope excursion in the sediments at the boundary. Rarely do the two defining occurrences--biological and geochemical--occur together, but there's one place in Death Valley National Park where such a unique combination of defining events can be studied. It's in Boundary Canyon near Daylight Pass, along the road to Beatty, Nevada, in the lower member of the Wood Canyon Formation.

Unicellular organisms and algae most certainly lived here during Wyman time--nearly a billion or so years ago--but due to intense metamorphism any trace of their former existence has long since been obliterated. Still and all, a relatively few pure limestone pods have been reported in the Wyman. If such rocks could be located in the predominantly detrital terrigenous terrain, one would naturally expect a greater opportunity to discover some of the oldest identifiable animal fossils on Earth.

At a point 13.8 miles from Death Valley Road, the path starts to slice through scenic Whippoorwill Canyon. Rocks exposed here belong to the upper Precambrian Reed Dolomite and the Upper Precambrian-Lower Cambrian Deep Spring Formation, roughly 560 to 542 million years old. In contrast to the predominantly detrital Wyman Formation, these two rock units contain relatively high percentages of carbonates, rocks composed of calcium carbonate and magnesium carbonate (dolomite) precipitated on the floors of vast shallow seas.

Near the very top of the Reed Dolomite, in strata transitional with the younger Deep Spring Formation, scientists have found one of the earliest evidences of a widespread variety of animals with shells. Most of the described specimens are minute, measured in millimeters (about one-twenty-fourth of an inch). But they represent such identifiable forms as worm tubes and primitive mollusks. I have personally scoured the Whippoorwill Canyon area for fossils but have yet to find any there. The worm-tube/primitive mollusk horizon occurs in the same formations at Mount Dunfey in neighboring Esmeralda County, Nevada. It also shows up in the Westgard Pass region several miles east of Big Pine. Even so, this is an excellent place for paleontological explorations. It is one of the most significant geologic regions in all the world. Because most of the sedimentary material exposed here is miraculously unaltered, there is great potential for the discovery of the oldest identifiable animal with a shell.

For two miles the Waucoba-Saline Road carves through the Precambrian strata of Whippoorwill Canyon. All along this route you move gradually upsection--that is, as you proceed south the rocks become progressively younger in geologic age. The base of the section bearing the oldest layers of the classic Waucoban Spring section, as defined by pioneering paleontologist Walcott, occurs in transitional rocks of the Late Precambrian-Lower Cambrian Deep Spring Formation and the overlying lowermost Cambrian Campito Formation. This world-famous change from the Precambrian to the Paleozoic Era lies directly to the east of the Waucoba-Saline Road, 16 miles from the Death Valley Road junction. To the left of the road you will note typically blocky weathering black to brownish quartzites and shales of the Andrews Mountain member of the Campito Formation, within which some of the oldest olenellid trilobites have been recovered. The fossils are by no means common here--they are, indeed, frustratingly rare: one lone occurrence discovered by a very lucky paleontologist, although supplemental evidence exists to conclude that perhaps that specimen came from much younger strata; the trilobite was recovered from a wash and could have been transported to the site of discovery. Outcrops of the Andrews Mountain member in neighboring Esmeralda County have yielded a few identifiable trilobite specimens.

After examining exposures of the Campito Formation here, proceed one additional mile to the turnoff to Waucoba Spring, where you will be within a short hiking distance of fossiliferous Early Cambrian strata in the Waucoba Spring geologic section. Waucoba Spring, proper, lies approximately one-half mile west of Waucoba-Saline Road, 17 miles south of the intersection with Death Valley Road.

The spring is an old and famous watering hole for the local fauna, including feral burros whose presence in the Death Valley region has generated much controversy. Some investigators claim the burros foul critical watering holes and scare off more sensitive creatures such as bighorn sheep. Others exonerate the asses, pointing out that they have just

as much right to exist in the wild as any indigenous creature and charges that they are solely to blame for the ruination of the ecology are absurd.

During my first visit to the Waucoba a number of years ago, I recall having observed quite a few burros. They'd halt right in front of a moving vehicle, staring inscrutably ahead. Subsequent trips to the Waucoban wilds disclosed a dramatic drop in the observable burro population. I do not know whether natural selection has been weeding out the weak or artificial measures have been employed--such as periodic thinning of the paces/herds by gunfire.

Excellent representative exposures of the classic Early Cambrian Waucoba Spring section described by Walcott lie to the east of Waucoba-Saline Valley Road. To reach the fossil-bearing exposures it is necessary to hike approximately a quarter of a mile to the nearest hillslope, directly east of the turnoff to Waucoba Spring. This slope is composed of the greenish shales and quartzites of the Montenegro Member of the Campito Formation, within whose detrital rocks can be seen worm trails, invertebrate tracks (many made by trilobites, but also several types that have not yet been positively identified) and trilobite head shields, or cephalons (complete specimens rather rare). Another region in which to hunt for the oldest reasonably common trilobites in the geologic record is over in neighboring Esmeralda County, Nevada, where several Montenegro Member sections yield many complete *Fallotaspi*s trilobites, along with several other spectacularly preserved Early Cambrian trilobites.

As you continue to hike in a generally southeasterly direction along the hillside, the greenish shales and quartzites give way to geologically younger gray-blue to buff-brown archaeocyathid-bearing limestones of the Poleta Formation. Most of the extinct calcareous sponges range from a half-inch to two inches in length, and quite a number of archaeocyathid fragments have weathered out of the rocks. A few of the more densely packed clusters of archaeocyathids observed in the limestones are likely the preserved remains of primitive, localized reefs.

All of the trilobites within the Poleta Formation occur in the younger gray-green shales which lie directly on top of the archeocyathid-bearing limestone. In addition to the trilobites, perfect specimens of which remain elusively infrequent in the extensive deposits of shale, abundant worm trails and invertebrate tracks can also be seen. These fossiliferous shales are in striking stratigraphic contact with the older archaeocyathid limestone, and the lithologic contrast is so distinctive that it can be traced with assurance throughout the Waucoba Spring district and western Great Basin, in general (northern Inyo County and western Esmeralda County, Nevada).

Additional superior fossil material can be observed in place from the next-youngest geologic rock unit in the Waucoban section, the Harkless Formation. Abundant worm trails and invertebrate tracks, salterella (diminutive tube-like to roughly conical shells secreted by an extinct animal of unestablished zoological affinity), and a few species of archaeocyathids are characteristic of the formation, which outcrops roughly three-quarters of a mile to one mile directly east of the Waucoba Spring turnoff. The Harkless is chiefly a terrigenous unit of gray shale and siltstone, interbedded with brownish quartzites. Minor lenticular blue-gray limestones in the youngest phases of deposition often yield large archaeocyathids, some up to nine inches in length.

Expect to conduct extended periods of hiking in order to examine all of the fossil material present in the Waucoba geologic section directly east of the turnoff to Waucoba Spring. The trilobites in particular are seldom even common at any one locality. They are usually confined to the greenish shales of the Poleta Formation, several feet above the archaeocyathid-rich limestones.

A better place in which to observe in situ trilobites lies farther south, in much younger exposures of the Early Cambrian Waucoba Spring geologic section at Algae Ridge, where the Lower Cambrian Mule Spring Limestone contains abundant fossil remains of a species of cyanobacterial blue-green algae called *Girvanella*.

The Mule Spring limestone contains the highest concentration of fossil algae of any Cambrian formation in the Great Basin. It is estimated that in some horizons *Girvanella* algal bodies constitute fully 40 percent of the limestones by volume. At Algae Ridge these fossil remains are certainly locally prolific, appearing in the blue-gray rocks as oval to circular black concretionary structures roughly one-quarter to three-quarters of an inch in diameter.

The Mule Spring Limestone marks the very top, or youngest part of the Waucoba Spring geologic reference section. Above it lies the middle Cambrian Monola Formation whose prominent exposures can be seen about a mile and a half to the south, near where the dramatic expanse of Saline Valley commences.

The prime trilobite locality lies on Algae Ridge in the lower Cambrian Saline Valley Formation. Prior to December 1994 this site was open to hobby fossil collecting, lying as it did outside the boundaries of Death Valley National Monument. Please note that it now lies within the borders of Death Valley National Park. Look and touch, but don't keep anything you find there--unless it's a photograph of a fossil specimen, of course.

At the fossil site one can examine abundant trilobite head shields, plus occasional perfect, intact specimens. During my last visit to the site before it was assimilated by the national

park system, I was fortunate to find three complete, whole trilobites--a powerfully exhilarating and rewarding experience, to be certain. Perfect specimens were surprisingly common here interestingly enough--a fact that helped set this specific Early Cambrian fossil site apart from most others.

The Waucoba Spring district is a rugged and pristine land. It is also out in the middle of nowhere, miles from civilization. This means that adventurers traveling to the region must make certain that their vehicles are in perfect working condition and carry with them extra food, plenty of water, spare fan belts (and know how to change one!) and protective clothing. In short, take all necessary precautions to ensure a safe experience.

Most of my Waucoba Spring trips were during the early spring, mainly in early to mid-April. I'm not presuming to suggest that this is the most comfortable time of the year there, but by way personal experience I recall one August spell that turned into pure vapor lock of the brain--soaring daytime temperatures even up in Whippoorwill Canyon at elevations over 7,000 feet--and a brief stay in December practically froze my toes off.

The Waucoba district certainly contains one of the greatest Early Cambrian stratigraphic sections in the entire world: the classic Waucoba Spring section first described by C.D. Walcott in the late 1800s. Except for development of the graded Waucoba-Saline Road and a few additional minor off-road-vehicle trails, the region likely appears much the same as it did in 1897 when Walcott first passed through. The Precambrian-Early Cambrian transition exposed here records the preserved remains of plants and animals that lived in this part of what is now the Great Basin some 600 to 510 million years ago--a time so distant, so primordial that it echoes back to a moment when the Spirit moved over the face of the waters and said, "Let there be light."

Chapter 12

Fossils In Millard County, Utah

Field Trips To Wheeler Amphitheater And Fossil Mountain

Part 1—Wheeler Amphitheater

Millard County in western Utah is world-famous for its Early Paleozoic fossil localities--a vast, sparsely inhabited area that holds numerous prolific paleontologic places of Middle Cambrian through Early Ordovician geologic age some 509 to 470 million years old. Indeed, this eastern Great Basin Desert region could well hold the best preserved and most complete succession of 509 to 485 million year-old Middle to Late Cambrian trilobites in the world. The renowned Wheeler Amphitheater locality in particular--also called Antelope Spring--in the House Range attracts eager paleontology enthusiasts year-round to an extraordinarily productive commercial fossil quarrying operation, where for a reasonable fee visitors may collect common, complete trilobites from the middle Cambrian Wheeler Shale, around 505 million years old; these include prodigious numbers of stunning specimens of a genus-species scientists call *Elrathia kingii*, probably the single most readily recognizable trilobite variety on earth. It is indeed a world-class fossil district.

While Cambrian trilobites continue to draw fossil seekers to these breathtakingly beautiful Great Basin environs, there are numerous additional sensational paleontologic localities scattered across Millard County.

Probably the best of the lot is Fossil Mountain in the informally designated Ibex District. Here can be found a veritable treasure trove of wonderfully preserved invertebrate fossils dating from the Early Ordovician age of approximately 485 to 470 million years ago. Among the fossil groups documented from Ibex are algae, brachiopods, bryozoans, corals, cephalopods, conodonts, echinoderms, gastropods, graptolites, ostracods, pelecypods, sponges, and trilobites. Preservation of the brachiopods in particular rivals that of the Midwest region of the United States--specimens universally regarded as the most exquisitely preserved Late Paleozoic (Pennsylvanian, and Permian Periods) organisms in the world. Around 3,500 feet of lower Ordovician sedimentary rocks are exposed at Ibex, and the material is for the most part unmetamorphosed by the geologic forces of heat, pressure, and hydrothermal alteration--pervasive processes that have invariably obliterated much ancient animal life in Paleozoic Era strata exposed throughout the western United States.

An excellent place to begin a Millard County paleontology adventure is of course Wheeler Amphitheater in the House Range, or as many fossil aficionados prefer to call the rich region:

Antelope Spring. That's where the fabulous middle Cambrian Wheeler Shale attains its ultimate geological and paleontological development, where quite conveniently that successful commercial fossil dig allows visitors to come on in and collect for a reasonable fee any number of whole, perfect trilobite carapaces.

The history of fossil collecting at Wheeler Amphitheater probably begins with the prehistoric Ute Indians, who archaeologists aver used not a few of the extinct arthropod trilobites as amulets to help repel injury during battle. But there is no doubt that a Henry Engelmann, who accompanied geologist J. H. Simpson on the very first earth science expedition to Millard County in the mid-19th Century, made the initial historic recorded trilobite find at Antelope Spring in 1859. Simpson eventually provided paleontologist/geologist Fielding Bradford Meek with the Wheeler Amphitheater trilobites Engelmann had collected during the Utah explorations--specimens that Meek described for the first time in a peer-reviewed scientific paper in 1876, shortly before his death. In the early 1870s geologist G. K. Gilbert, aware of Engelmann's fossil discoveries, visited Antelope Spring and measured upwards of 2,300 feet of iddle Cambrian strata, collecting in the process numerous trilobites subsequently identified and described by famous Cambrian paleontologist C. D. Walcott, who during expeditions to Wheeler Amphitheater in 1903 and 1905 not only recovered additional abundant fossil material, but also measured the entire Middle to Late Cambrian sequence exposed in the general vicinity--a sedimentary succession now known to contain the following geologic rock formations: middle Cambrian Howell Limestone; middle Cambrian Dome Limestone; middle Cambrian Swasey Limestone; middle Cambrian Wheeler Shale; middle Cambrian Marjum Formation; middle Cambrian Weeks Limestone; upper Cambrian Orr Formation; and upper Cambrian Notch Peak Formation (uppermost part is lower Ordovician). Walcott officially named what's now universally recognized as the world-famous middle Cambrian Wheeler Shale in a scientific paper in 1908. After Walcott's contributions, the proverbial paleontological flood gates open on scientific exploration of the House Range and its incomparable Middle to Late Cambrian geologic section; scientific research papers now abound.

At Wheeler Amphitheater, only a rather narrow 17-foot thick section in the upper portions of the middle Cambrian Wheeler Shale produces significant concentrations of fossil remains. This is the precise interval that's presently mined commercially for paleontologic specimens, having operated more or less continuously since the late 1960s when an enterprising entrepreneur recognized that, fortuitously, the richest trilobite horizon occurred in an easily accessible valley or "amphitheater" on Utah state-owned lands, which could legally be leased for natural resource exploitation.

While collecting within that specific 17-foot thick zone of optimal trilobitic presence, fossil seekers catch on pretty quickly that despite the common occurrence of exceptionally well preserved trilobite exoskeletons in the rocks--most often discarded arthropod molts, shed each time the animal underwent a spurt of growth (identical to modern arthropod insects, crabs, and spiders who during growth cycles regularly drop their old body armor for newer external coverings)--only three species pop up with any kind of regularity. These include *Elrathia kingii* (the most famous trilobite in the world), *Asaphiscus wheeleri*, and *Peronopsis interstricta*. Much rarer trilobite finds invariably constitute carapaces of *Bolasidella housensis*, *Alokistocare harrisi*, and *Olenoides nevadensis*. Excluding casual surface collecting atop the numerous spoils piles, searching for prize specimens others might have left behind or overlooked (a method that often discloses excellent material, by the way), the most efficient collecting method is to attempt to spit sizable shale chunks along their original planes of sedimentary deposition with a geology rock hammer/pick. An optional technique involves utilizing a selection of well-tempered chisels in combination with the rock pick.

What you'll find in both instances is that with a gentle, firm rapping the trilobites tend to pop out of the rocks whole and complete, often in an essentially perfect state of preservation. This unusual style of fossil occurrence developed when dolomite (magnesium carbonate) precipitated in the trilobite carapaces, forming in effect "trilobite nodules" that only await a patient collector to crack them free. Practical experience has demonstrated here that on average most collectors find anywhere from 10 to 20 exceptional trilobites in a four-hour period; the majority of trilobites unearthed range from under an inch to two inches in length. Occasionally a few specimens could reasonably require special prepping with perhaps an abrasive air scribe, to remove sedimentary particles that obscure key features of the trilobites, although in actual fact most finds need little more than a careful washing with water and a toothbrush. Sometimes, though, it's aesthetically appropriate to retain trilobites in their natural state of preservation--still residing along the bedding planes of the middle Cambrian Wheeler Shale, where they dropped to a tropical sea floor accumulating silty detrital particles some 505 million years ago.

At that distant Middle Cambrian date, today's Wheeler Amphitheater existed as unlithified marine muddy ooze at rather shallow depths several miles off the northwestern coastline of an ancient continent geologists call Laurentia--the paleo-precursor to what eventually became North America--then situated slightly north of the equator in what's today the southern Bay of Bengal, between India and Thailand. Over the course of geologic time, continental drift has carried the once-tropical trilobite beds northeastward thousands of miles into the temperate latitudes of present-day North America, where they now outcrop within the eastern reaches of the Great Basin Desert.

Within the House Range geographic province, paleontologists have identified some 35 species of trilobites from the middle Cambrian Wheeler Shale, although such extinct arthropods aren't the only fossil varieties waiting to be found. Also present in less frequent numbers are brachiopods; echinoderms, including an eocrinoid ("dawn crinoid") called *Gogia*; Phyllocarids (a bivalve crustacean with only two known living members)--including the extinct *Brachiocaris* and *Pseudoarctolepsis*; such early siliceous sponges as *Diagonella*, *Choia*, and *Chancelloria*; an early Chelicerate (horseshoe crabs, sea spiders, and arachnids are living members) called *Esmeraldella*; *Naraoia*, a so-called trilobitomorpha, or "soft-bodied trilobite"; *Anomalocaris*, the largest predator of the Cambrian seas; annelids (the worms), including famous *Wiwaxia*, which was first described from the astounding middle Cambrian Burgess Shale of Canada; and 20 species of non-mineralized arthropods unrelated to trilobites--in other words, soft-bodied animal remains rarely encountered in the fossil record.

In general, the soft-bodied fauna occurs in sedimentary layers where skeletonized animals remain absent; why this is so puzzled investigating paleontologists, until a sophisticated taphonomic analysis of the Wheeler Shale fossil beds disclosed that *Elrathia* trilobite-dominated biofacies accumulated under dysaerobic conditions (low oxygen levels) that allowed frequent bioturbation (organisms burrowing through the unconsolidated muds)--facilitating rapid decomposition of soft tissues in the presence of greater oxygen content--whereas the non-mineralized (soft-bodied) creatures were preserved when decay-inducing bacterial activity and bioturbation became restricted by anoxic sediments lacking oxygen.

I first visited Wheeler Amphitheater a number of years ago during a three-week summer vacation with my parents to eastern Nevada and western Utah. From our base camp at Baker Creek Campground in Great Basin National Park, Nevada (campsite #16, by the way--elevation roughly 7,500; Great Basin NP is a terrific place to visit when exploring the world-class paleontology of Millard County) we headed out to classic Wheeler Amphitheater in dad's old ruggedly reliable 1979 American Motors Corporation (AMC) CJ7 jeep he'd purchased in Olathe, Kansas. I recollect that we gassed up in Baker, Nevada, grabbed a few snack items and associated carbonated beverages (AKA, sodas), then moved out into the brilliant early eastern sun along a lonesome stretch of asphalt. Probably we spotted no more than three or four vehicles during the entire journey through timeless expanses of eastern Great Basin Desert. As navigator and lead research archivist for the Millard trek, I kept all pertinent road maps and scientific documents close at hand, prepared for quick inspection should contingency referencing become necessary.

What I remember distinctly is that we found the correct turnoff to Wheeler Amphitheater without difficulty. Easily spotted, indeed. After maneuvering along a system of surprisingly well-graded dirt roads through stupendous isolation, we reached our desert destination

bursting with keen anticipation of a joyful paleontological adventure. We were not disappointed. For the next four hours or so we moved about the commercial quarry with a fevered zeal, splitting 505 million year-old middle Cambrian Wheeler Shale to find within several excellently preserved *Elrathia kingii* trilobites that popped out of their muddy matrixes whole and intact with but a gentle rock hammer tapping. This was discovery ecstasy.

505 million years earlier we would have been floating atop a warm, shallow sea off the northwest coast of North America's ancestral continental mass situated slightly north of the equator at the southern end of today's Bay of Bengal, between India and Thailand. With living trilobites below us, the sun shines roughly four percent dimmer than at Wheeler Amphitheater in a sky whose atmospheric carbon dioxide levels exceed an approximated 4,000 parts per million--at least ten times higher than CO2 readings of earth's last 100 Recent years--and average temperatures approach 77 degrees Fahrenheit, 27 degrees higher than a little over a half billion years hence. A look shoreward from the Cambrian sea discloses a landscape devoid of vegetation and animal life--an Early Paleozoic scene reminiscent of portions of the Great Basin Desert, as observed from a distance in a moving vehicle through Millard County to Wheeler Amphitheater some 505 million years later.

Part 2—Field Trip To Fossil Mountain

After visiting classic Wheeler Amphitheater to sample an amazing concentration of trilobites in the middle Cambrian Wheeler Shale, it's time for a rendezvous with Fossil Mountain in the Ibex District--a regional Millard County locale named for a European wild goat in the 1890s by English immigrant Jack Watson, who established a post office on property he homesteaded a few miles north of what later became known as Fossil Mountain, proper.

The abundant fossil organisms at Ibex and Fossil Mountain occur in the roughly 485 to 470 million years-old lower Ordovician Pogonip Group, an association of six distinct and easily identifiable geologic rock formations. This major stratigraphic succession can be traced throughout western Utah and extreme eastern Nevada (the Pogonip Group of eastern California is composed of several different formations), but nowhere is it as fossiliferous as in the Ibex area, where silty carbonate beds several feet thick often consist of nothing but exceptionally well preserved brachiopods, gastropods, ostracods, trilobites, or echinoderms--each animal type characteristically contributing its specific remains solely to an individual shell bed, to the exclusion of all other invertebrate varieties. Such technically termed monotypic shell beds are extensively developed in the Pogonip at Ibex's Fossil Mountain, and the fossil-saturated ledges can be followed for considerable distances.

I had long heard reports of the remarkable paleontologically prolific formations of the Ibex District--had even viewed stunning brachiopod specimens from the lower Ordovician Kanosh Shale exposed there. Nevertheless, dubiety existed. I was dutifully skeptical of the reportedly extensive, bountiful fossil occurrences. Several times in the past I'd been given "reliable" information about a rave-review region, only to find out that it could not live up to its advance billing. A fossil dealer at a mineral show once touted Ibex, talking on and on about the unbelievable abundance of fossils available there, but at the time I was busy researching another specific locality and his credible recommendations went over my head.

At a rock shop in Calico Ghost Town, in California's Mojave Desert a few miles east of Barstow, the proprietor made a special point of showing off his Millard County specimens, including chunks of brachiopod material from Ibex that were beyond belief. By now my interest in the region was solidifying, but there just didn't seem to be any spare time to get away and properly explore the place.

When at last I finally made the trip to Ibex, I was not disappointed. As the well-worn saying goes, you have to see it believe it. The rocks are relatively flat-lying, in a horizontal bedding orientation, and erosion has created natural ledges along these bedding planes. Fossil hunters can simply hike along the strike of the strata--in other words, along the horizontal direction of the rock layers--and pick of free-weathered fossils at will, in addition to innumerable quality chunks of fossil-bearing limestones and shales.

From personal experience, I can recall few Paleozoic Era localities that have yielded such a profusion of excellent forms. Midwestern exposures certainly come to mind. While I was residing in eastern Kansas a number of years ago, I had the great fortune to explore several of the abandoned rock quarries in the area. These have penetrated Late Pennsylvanian limestones and shales approximately 305 million years old, in which a mind-boggling diversity of beautiful specimens can be found. One quarry just a few miles outside of town came to be my very favorite--the single finest Pennsylvanian Period fossil-bearing site from which I have ever collected.

If that quarry happens to rank as the best Pennsylvanian fossil locality, then there is no doubt that Fossil Mountain at Ibex is the finest Ordovician Period fossil-yielding area I have visited. It is true, of course, that I have yet to explore the famous Ohio Ordovician outcrops.

Although Fossil Mountain of Ibex lies within a proverbial no man's land--parched desert many miles from the nearest center of population (that would be Delta, Utah)--the fossil-bearing area is rather easily reached via a system of well-maintained dirt roads. Still, this no place to become stranded. Make certain that your vehicle is in perfect working order. Carry a well-maintained emergency first aid kit, extra food, and plenty of water: The traditional rule stresses that one must possess at least one gallon of water per person per day in reserve for the duration of an expected dry-camping expedition. And notify local authorities in Delta--or, Baker, Nevada, if one is traveling to Millard County from directions west--of your destination and how long you plan to stay. But be sure to contact them when returning to civilization, so they won't organize a rescue operation unnecessarily. While in the neighborhood of Baker in White Pine County, eastern Nevada, by the way, consider a visit to Great Basin National Park--established October 27, 1986; beaucoup scenic wilderness adventures await, and Baker Creek Campground at an elevation of roughly 7,500 feet makes a most comfortable base camp during summer visits.

Those of us who travel the desert regularly sometimes develop a lazy attitude toward these important reminders. I freely admit that I have on occasion broken the rules of safe and sane backroads travel conduct. Just call me lucky so far. So, don't do as I do--as the saying goes--do as I say.

Note, too, that Ibex's Fossil Mountain presently lies within the proposed King Top Wilderness area. A formal federal wilderness designation means that at the very least only surface collecting of fossil specimens is allowed--do not dig into the exposed strata; pick up and keep only what you find already lying atop the ground. Before proceeding into the wilds, check with the local Bureau of Land Management office (BLM) to determine the latest land status. If the region eventually goes the route of a federally protected wilderness, unauthorized amateur collectors will likely incur additional restrictions on their hobby fossil-finding activities. Obey all rules and regulations. For example, fossils collected on America's public lands (administered by the BLM) must never be sold or bartered--in legal argot, generally agreed by common convention to mean that you can't trade for specimens, either. Watch for BLM signs along the way that detail the latest official public lands status.

After negotiating a system of decently maintained dirt roads through several lonesome miles of classic Great Basin Desert terrain, one arrives at excellent exposures of the lower Ordovician Lehman Limestone--the first prominent and easily accessible outcrops of the paleontologically prolific Pogonip Group one encounters within view of looming Fossil Mountain, now less than two and a half miles away. The rugged slopes to the right of the dirt trail (north) consist of blue-gray-weathering arenaceous limestones in which moderately common brachiopods, ostracods (a small bean to pea-shaped bivalve crustacean), and gastropods occur. Yet another paleontological point is that the first corals in the local Ordovician Ibexian stratigraphic record happen to appear in the Lehman Limestone.

This is an advantageous place to become acquainted with the regional style of rock outcropping and fossil occurrences in the Fossil Mountain/Ibex District. You will note that the limestone layers here are essentially flat-lying, in what geologists call a horizontal bedding attitude. Considering the extreme geologic age of the Lehman Formation--some 470 million years old--the lack of metamorphism and related deformation of the Ordovician strata is absolutely astonishing.

The Lehman limestones tend to form prominent ledges, while the shale partings have been eroded back in recess. This is the distinctive geomorphological characteristic of all the exposed Early Paleozoic rock formations in the Ibex District. Not every carbonate layer here is fossiliferous but, rather, the specimens occur in specific zones or horizons throughout the sequence. Some beds yield only ostracods, while others are packed with brachiopods, echinoderms, trilobites, or gastropods.

The Lehman Limestone is the youngest of the six geologic rock formations included in the geographically widespread lower Ordovician Pogonip Group--roughly 485 to 470 million years old--which reaches its most abundant and reliably diverse fossil development at Fossil Mountain and the surrounding Ibex area. In descending order of geologic age, this significant grouping of strata includes first the Lehman Limestone, then the Kanosh Shale, the Juab Limestone, the Wah Wah Limestone, the Fillmore Formation, and the House Limestone. In general, all Pogonip rocks but the House Limestone yield plentiful fossils. This is not to say that the House is a disappointing unit; it's just that its ledges of silicified trilobites are more difficult to spot in the field.

After examining the Lehman Limestone outcrops, one continues along the primary dirt road to another branching dirt trail. Which way to go to get to Fossil Mountain is now no longer even a question. At this point Fossil Mountain--the primary fossil-bearing locality in the Ibex District--looms to your immediate northwest, a great pyramid-shaped protuberance composed of a conformable (i.e., without any breaks in time in the geologic history of sedimentary deposition) sequence of lower Ordovician through Middle Ordovician-age strata capped by the erosion-resistant middle Ordovician Eureka Quartzite (not a member of the Pogonip Group)--a massive accumulation of heat and pressure-altered sandstones that are in large part responsible for the protection of the fossiliferous limestones and shales below. They have prevented the erosion of the less-resistant Ordovician rocks in much the same manner that a small pebble resting atop a glob of mud will keep the mud mound intact through a rainstorm, while soil exposed to the brunt of the storm easily washes away.

Immediately below the brilliant white Eureka Quartzite capstone on Fossil Mountain are two additional rock formations geologists exclude from the early Ordovician Pogonip Group: The

darker band below the quartzite peak is the middle Ordovician Crystal Peak Dolomite; and that bold, steep cliff face composed of alternating white and brown bands is the middle Ordovician Watson Ranch Quartzite, underlain in turn by a narrow, prominently protruding limestone ledge belonging to the lower Ordovician Lehman Limestone, the youngest member of the Pogonip Group. According to several official geological measurements, Early to Middle Ordovician-age rocks in Millard County accumulated to an aggregate thickness of some 3,500 feet.

At the intersection with the north-south trending dirt road that leads over to Fossil Mountain, you will note to the right of the road a magnificent exposure of the middle Ordovician Eureka Quartzite--the same geologic interval that caps Fossil Mountain. This is certainly one of the most widespread Early Paleozoic Era rock units in all the Great Basin Desert. It has been recognized as far away as eastern California, in the mountains surrounding Death Valley National Park.

For decades, scientists have speculated on the original environment of deposition of the Eureka Quartzite, an unusually thick bed of heat and pressure-crushed sandstone. Many models have been analyzed, but no one explanation seems to answer all the questions.

The main problem for geologists is to satisfactorily account for such a massive, persistently uniform zone of practically pure metamorphosed sandstone that occurs over thousands of square miles. It hasn't been easy. After much debate on the subject, earth scientists remain puzzled and intrigued, although recent investigations seem to show that the Eureka Quartzite accumulated some 465 million years ago as clean, well-sorted beach sand along the shores of a shallow sea during the middle portion of the Ordovician Period.

If this is true, the Eureka Quartzite could well represent one of the oldest identifiable Early Paleozoic terrestrial rock deposits in North American.

A short drive beyond the Eureka Quartzite exposure brings you directly in front of the place you want to visit.

Before you arises Fossil Mountain, one the great early Ordovician fossil-bearing sites in existence. It was named--and first popularly publicized--sometime between 1910 and 1920 by Frank Ashel Beckwith, a cashier at the first established bank in Delta, Utah, who spent considerable spare time exploring the fossil wonders of Millard County. Among a shipment of Early Ordovician invertebrate fossils that Beckwith donated to the US National Museum (part of the Smithsonian Institution in Washington D.C.), a selection of brachiopods became the first paleontologic specimens from Fossil Mountain ever formally described in the scientific

literature (1936 and 1938); mysteriously, though, the paleontologists who wrote up the papers failed to credit Beckwith as the donor.

A short walk toward Fossil Mountain will place you on the ledge-forming, dark-blue silty limestones of the Wah Wah Limestone. Silicified trilobites, algae-sponge patch reefs, conodonts (a minute feeding apparatus, unrelated to modern jaws, from an extinct eel-like organism--seen only in the insoluble residues of carbonates dissolved in a dilute solution of acetic or formic acid), graptolites, gastropods, brachiopods, solitary sponges, nautiloid cephalopods, and cystoid echinoderms constitute members of a large and diverse fossil assemblage.

The Wah Wah Limestone in the vicinity of Fossil Mountain is about 235 feet thick. It is traceable southward from the parking area for a little over a mile, and fossils can be collected throughout this entire area of outcrop.

As in the Lehman Limestone explored earlier, the Wah Wah specimens (yes, the Wah Wah is colloquially called "The George Harrison interval, where all things Ordovician must pass"...) tend to occur in distinct zones. This means that productive, fossiliferous horizons are separated by several feet of barren limestone and shales. The trick, naturally, is to locate these fossil-rich ledges, then follow them as they arc about the hillsides.

As you ascend the slopes of Fossil Mountain, the Wah Wah Limestone grades into the younger Juab Limestone, which consists mainly of medium-gray arenaceous limestone that forms ledges up to four feet thick. There are also minor interbeds of tan shale in the sequence.

Despite the fact that the Juab is a relatively thin geologic unit--only 160 feet at most--many fossil types are well-represented. Brachiopods, gastropods, cephalopods, trilobites, conodonts, solitary sponges, and graptolites are especially characteristic of the formation.

Directly above the Juab Limestone lies the next-youngest formation, which also happens to be the most fossiliferous lower Ordovician Pogonip Group unit of them all--the fabulous Kanosh Shale. Simply continue your hike upward along any of Fossil Mountain's numerous erosion gullies and you will soon intersect the unmistakable olive-brown to chocolate-brown shales that tend to form slopes and protruding ledges.

Here you will discover a profusion of fossils--especially orthid-type brachiopods which form beautiful museum-quality shell beds (also called monotypic beds); these are accumulations of prodigious quantities of a single species of brachiopod, only, that typically form a great percentage of the rocks in which they occur. Free-weathered brachiopods are abundant, as

well--a superior selection of plentiful pedicle and brachial valves, plus fully articulated specimens with both valves preserved intact.

Researchers suggest that such Kanosh Shale monotypic shell beds developed under supremely stressful paleo-environmental conditions, probably when Early Ordovician marine saline levels rose to critical concentrations, initiating "brachiopod blooms." The brachs reacted to the increasingly intolerable alteration of a once-salubrious sea geochemistry with adaptive creativity; they opted to over-reproduce in sudden spurts, saturating the Ordovician sea floor with great numbers of their kind, ensuring that at least a few would persist and endure. On occasion, though, the periodic prolific brachiopod blooms were ultimately overcome by rapidly deteriorating conditions that proved fatal, and so entire beds composed mostly of their multitudinous valves built up on the sea floor.

Other fossil groups well represented in the Kanosh Shale include ostracods--which often form their own impressive monotypic shell beds--gastropods, bryozoans, cephalopods, pelecypods, graptolites, echinoderms, sponges, conodonts, and trilobites. Many Kanosh Shale bryozoans and echinoderms originally inhabited what paleontologists call hardgrounds: that is, sections of the Fossil Mountain sea floor created when Early Ordovician storm waves exhumed abundant inorganically precipitated calcareous nodules, forming discrete and extensive beds of so-called "marine pavement." Upon these newly developed areas early echinoderms (often, a rhipidocystid eocrinoid) found a favorable environment to proliferate, contributing when they died vast numbers of disassociated ossicles (also called "stems" or columnals) and holdfasts--the minute, bulbous attachments that allowed the animals to anchor themselves--to the ever-thickening cemented substrate. Repeated echinoderm death cycles created ever-expanding space for an even more diverse echinoderm fauna to thrive, atop which, eventually, several species of bryozoans came along to help colonize the hardgrounds areas, as well. These were the first known bryozoans in the fossil record to inhabit hardgrounds, which are also known from the preceding Cambrian Period that ended some 10 million years before the Kanosh Shale began to accumulate, a time prior to 485 million years ago when only echinoderms contributed to hardground developments on the Early Paleozoic sea floors. So scientifically fascinating are the Fossil Mountain examples that paleontologists and geologists from all around the world travel to Millard County, Utah, to study the classic Kanosh Shale hardgrounds.

This is a formation absolutely packed with wonderfully preserved fossil material. Like others before me, I could rave on and on about the excellence displayed here, the diversity of Early Ordovician animal groups and the quality of their preservation, but you too will just have to see it to believe it. The Kanosh Shale, with its fantastic brachiopod and ostracod shell beds, early echinoderm-bryozoan hardground developments, and prolifically diverse free-

weathered invertebrate animal fauna, ranks as one of the most important paleontologic exposures in North America. To collect here is an exhilarating, uplifting experience--one I will never forget.

The older Fillmore Formation and House Limestone are not exposed on the immediate slopes of Fossil Mountain, but typical fossiliferous outcrops can be found not far from the parking area. There, the Fillmore is roughly 1,600 feet thick, consisting of interbedded conglomerate, olive-gray to greenish shale, fine-grained limestone, and occasional lenticular algae-sponge patch reefs; other fossils present include graptolites, trilobites, brachiopods, conodonts, gastropods, echinoderms, and cephalopods. Oldest of the Pogonip Group formational subunits, the lowermost Ordovician House Limestone yields silicified trilobites and brachiopods through approximately the upper third of 500 feet of finely crystalline limestone in beds two to four feet thick.

My first visit to the Ibex District provided me with an extraordinary collection of Early Ordovician invertebrate animal specimens. I only wish I could have stayed longer.

While exploring the gullies and dry washes at Fossil Mountain, I felt incredibly privileged to be collecting from such a remarkable series of fossil-bearing geologic formations. They were deposited some 485 to 470 million years ago in a warm shallow sea then situated astride the equator--a deep time tropical ocean that teemed with burgeoning Early Paleozoic Era life.

That varied life of the Early Ordovician has now been preserved in splendid detail at Fossil Mountain, where neither the ravages of erosion nor the brute force of metamorphism has harmed the ancient animals. They now reside in the limestones and shales of a vanished age--kept alive in their death for nearly half a billion years, longer than the human mind can comprehend. The abundant and beautifully preserved fossils at Ibex give us a rare glimpse back in time to a unique association of animal life that will never exist again.

Chapter 13

A Visit To Fossil Valley, Great Basin Desert, Nevada

Introduction

Journey to Fossil Valley, a world-famous desert district situated in Nevada's Great Basin geomorphic province that contains the most complete and diverse terrestrial (land-laid) fossil record of Miocene life yet discovered in North America--and perhaps the world, as a matter of fact--a genuinely spectacular paleontological place that produces from what earth scientists call the middle Miocene Esmeralda Formation an astounding association of well-preserved fossil material some 16 to 10 million years old, including: insects (preserved in exquisite detail along the bedding planes of very thinly stratified sedimentary rocks commonly called "paper shales"); plants (leaves, seeds, flowering structures, conifer needles and foliage, diatoms--a microscopic single-celled photosynthesizing aquatic plant that constructed silica "shells"/frustules--pollens, and petrified woods); stromatolitic, cyanobacterial blue-green algal developments; mollusks (gastropods and pelecypods); ostracods (a bivalve crustacean); mammals; birds; fish; amphibians; turtles; and arachnids (spiders).

Indeed, it's quite likely that no other place on the planet provides a better opportunity to study such a rich, essentially complete paleo-community of terrestrial Miocene plants and animals.

Field Trip To Fossil Valley, Nevada

It's often called Nevada's paleontologic crown jewel of the Neogene (on the geologic time scale, roughly 23 to 2.58 years ago). A place that yields North America's single best fossil representation of terrestrial, land-laid Miocene plants and animals from a time interval of approximately 16.4 to 10.5 million years ago; too, arguably no other land-deposited Miocene geologic area on earth rivals its combined organismal diversity and preservational preeminence.

That would of course be Fossil Valley, situated in the Great Basin Desert geomorphic province. Its exalted reputation among students of paleontology lies in its unusually complete record of later Cenozoic Era life kept in an overall exceptional state of preservation for roughly 16 million years in what geologists, stratigraphers, and paleontologists all call the middle Miocene Esmeralda Formation. Documented organic specimens discovered from Esmeralda Formation exposures in Fossil Valley, Nevada, include a practically unprecedented, unparalleled, multiplicity of excellently preserved forms that contribute to an essentially

complete paleoenvironmental biota. Among the numbered: insects (preserved in exquisite detail along the bedding planes of very thinly stratified sedimentary rocks commonly called "paper shales"); arachnids (spiders); plants (leaves, seeds, flowering structures, pollens, conifer needles and foilage, diatoms--a microscopic single-celled photosynthesizing aquatic plant--and petrified woods); blue-green algal stromatolite developments--concentrically laminated dome-configured structures precipitated by cyanobacterial activity; mollusks (gastropods and pelecypods); ostracods (a minute bivalved crustacean); fish, amphibians, reptiles, birds, and mammals.

Within Fossil Valley, the middle Miocene Esmeralda Formation is roughly 600 meters thick (1,970 feet) and ranges in geologic age from 16.4 to approximately 10 million years old. Twelve major fossil horizons between roughly 16.4 to 10.5 million years ancient lie stacked atop one another in mostly conformable, successive stratigraphic relations--which is to say that deposition of the Esmeralda here was pretty much continuous, with few significant interruptions in sedimentary accumulation. For organized, nomenclatural ease of stratigraphic descriptions, geologists have separated Fossil Valley's Esmeralda Formation into seven subunits, or members, which reflect distinct depositional lithologies that can be mapped across wide areas of rock outcropping.

Initiation of the Miocene Fossil Valley lake basin begins around 17 million years ago with right-lateral fault displacement associated with extensional geophysical stresses that accompanied incipient formation of the Great Basin geomorphic province. Oldest Miocene rocks in Fossil Valley are paleontologically barren volcanic andesites, overlain by a dacite breccia (also devoid of fossil material) dated at around 17 million years old. Member One of the Esmeralda Formation interfingers with and overlies the breccia interval, consisting of some 100 to 150 meters (320 to 490 feet) of, in ascending order (oldest to youngest): dark-colored mudstone and shale; light-colored siltstone, sandstone, and calcareous sandstone; and blue-gray volcanic-clastic sandstone. Member One's mudstones and siltstones preserve the earliest fossil leaves in the Esmeralda Fossil Valley sequence, approximately 16.4 million years ancient, in addition to several geologically younger ostracod coquinas composed almost entirely of the minute (typically, around 1mm long) bivalve crustacean sometimes colloquially called a "seed shrimp" (though the ostracod is not directly related to a shrimp). Bountiful freshwater mollusks (gastropods and pelecypods) occur locally in the calcareous sandstone facies, while abundant silicified petrified wood (replaced by the mineral silicon dioxide) plus mammalian teeth and post cranial skeletal elements often commonly weather free from the coarser sandstone horizons; reptile and amphibian bones also occasionally occur in the same interval. The mollusks, ostracods, petrified woods, reptiles, amphibians, and mammals have been dated to roughly 15.4 to 15.1 million years old.

Above the primarily clastic Member One lie additional detrital deposits assigned to the middle Miocene Esmeralda Formation--the fabulous, world famous "paper shales" of Member Two--roughly 55 meters (180 feet) of laminated, exceedingly thin bedded brown to dark-gray siliceous shales that bear beautifully preserved insects, arachnids, leaves, winged conifer seeds, conifer needles and foliage, flowering structures, pollens, bird feathers, and complete fish skeletons some 14.5 million years old.

Lying directly above the paper shales of Member Two is Member Three's 90 meters (295 feet) of mostly white to buff-colored mudstone and shales, all of which represent deposition in the center of the Fossil Valley basin. Fossil plants, fish scales, and ostracods occur in several of the sedimentary layers.

Next youngest sequence is Member Four, which just happens to be the most widespread unit exposed throughout Fossil Valley's Esmeralda Formation stratigraphic complex. Its extensive regional area of outcropping, as a matter of fact, helps paleogeographers estimate a maximum size for the ancestral Fossil Valley basin--the conclusion: eight kilometers wide (five miles) by 16 km long (10 miles). Member Four consists of approximately 45 meters (147 feet) of white to cream-colored diatomaceous shales, diatomaceous mudstones, and blue vitric volcanic ash layers. The diatomaceous sediments are composed of myriads of diatoms--microscopic single-celled photosynthesizing aquatic plants that secreted an opaline silica "shell," technically called a frustule.

Separating Member Four from the younger Member Five is a minor erosional unconformity, marked by a prominent soil profile that developed on Member Four's predominantly diatomaceous deposits before additional sedimentary accumulations commenced. Above the buried soil profile lies around 140 meters (460 feet) of buff to brown and gray-colored siltstones, sandstones, and a rather thin-bedded pebble conglomerate. An important Early Clarendonian Stage mammalian vertebrate fossil locality some 13 million years old occurs just above the base of Member Five's buried soil horizon; elsewhere, the unit produces isolated fish bones and occasional mollusks (gastropods and pelecypods).

Fully conformable above the bone-bearing Member Five, without erosional break in the continuous regimen of fluviatile sedimentary deposition, is the gradationally younger Member Six--about 40 meters (131 feet) of blue volcaniclastic sandstone (contains weathered volcanic constituents) with subordinate layers of interbedded buff to brown and blue-gray sandstone. Member Six yields significant concentrations of several species of Clarendonian mammals in strata approximately 12 million years old.

Youngest geologic unit in Fossil Valley's Esmeralda Formation is Member Seven, whose base is marked by a persistent 2.5 meter-thick layer (8 feet) of white biotite volcanic tuff dated through radiometric measurements at 10.7 million years old. Above that horizon rests about 90 meters (295 feet) of volcaniclastic siltstones and sandstone, with lesser admixtures of volcanic ash that as a mappable lithologic group undergo a persistently consistent color change throughout Fossil Valley. Approximately the lower 50 meters is white to light gray-colored siltstone, followed by 20 meters of pale green siltstone and then 20 meters of pale pink sandstone. Many classic Late Clarendonian Stage vertebrate fossil localities around 10.5 million years old occur in the upper half of Member Seven.

Among Fossil Valley's numerous significant paleobiological representatives, its exceptionally well preserved insects (and occasional arachnids--spiders) probably attract the most consistent scientific and popular attention. Worldwide, paleoentomologically productive deposits that yield so many readily identifiable, exquisitely detailed fossil specimens remain fantastically rare occurrences, indeed. Fossil Valley's world-famous "bugs" occur of course in the middle Miocene Esmeralda Formation, but remain restricted to the so-called "paper shale" deposits of Member Two--layers of shale so thinly bedded that each individual stratum is classically no thicker than a proverbial sheet of paper--dated through radiometric techniques at around 14.5 million years old. Petrographic analysis of the insect-bearing paper shales proved that the fossiliferous detrital deposits consist almost entirely of finely eroded grains of cristobalite, a high temperature polymorph of silica--meaning that it bears that same chemical structure as silica ($SiO2$), but in a different molecular crystal arrangement.

And what a veritable treasure trove of supremely well preserved freshwater arthropodal fossils the paper shales contain. A representative sampling of insect specimens includes: gall gnats, fungus gnats, midges, jumping plant lice, fulgorid bugs, true bugs, damsel bugs, beetles, metallic wood borers, mayflies, march flies, moths, dragonflies, crickets, termites, aphids, butterflies, mosquitoes, fruit flies (hoverflies), Crane flies, leaf-miner flies, bibionid flies, bees, yellow jackets, ichneumon wasps, lacewings, leaf hoppers, and ants. Dipteran flies and gnats comprise approximately fifty percent of the Esmeralda Formation's paleoentomological fauna, while members of the Hymenoptera (exemplified by ants and ichneumon wasps) make up around twenty-five percent; the remaining insectan content percentage is composed of, primarily: Hemiptera (lacewings); Coloeptera (beetles); Ephemeroptera (mayflies); Odonta (dragonflies); and Lepidoptera (moths and butterflies).

A general "rule of thumb," as it were, is that Fossil Valley produces a predominantly diminutive fossil insect assemblage; an observation that naturally leads one to the tempting working hypothesis that specimens recovered from the paper shales accumulated in rather deep, anoxic waters (severely oxygen-depleted), far away from near-shore areas where

turbulence and greater decay-inducing oxygen content would tend to obliterate delicate arthropodal tissues of larger insects recently cast to the waters. On the other hand, one must note that numerous examples of Fossil Valley Diptera (flies and gnats, in particular) would appear to have been flung forcefully to a fine-grained surface, preserved as they are in quasi-smashed, contorted death positions--suggesting that at least a percentage of the unfortunate arthropods met their demise when blown to the sticky vast mudflats of a moist playa floor.

Another taphonomic explanation for Esmeralda Formation freshwater arthropod preservations involves the influence of mucus. Call it the "paleo-spit" idea, if you will. What researchers perspicaciously observed was that elsewhere in the world many exceptionally preserved fossil insects often tend to occur in the presence of microbial films produced by diatoms (Colorado's famed Florissant fossil insect association, for example). That is to say, investigators concluded that diatoms, during periods of overstimulated bloom, "exuded" a sticky mucus-like substance which helped slow the invariably rapid decomposition of insects adhering to it, until the arthropods could be buried by a protective layer of lake bottom mud, or volcanic ash.

But of course, many of Fossil Valley's insects required plants to survive.

Paleobotanically important leaf, seed, and conifer foliage impressions from Fossil Valley come from two primary horizons separated by several millions of years of geologic time. The older fossiliferous layer is preserved in mudstones and siltstones approximately 16.4 million years old, while the younger localities lie within the world-famous paper shales dated at around 14.5 million years ancient. Plant species recovered from the older 16.4 million year-old stratigraphic interval resemble in great part vegetation varieties that contribute to the lush deciduous forests of the eastern United States. Estimated precipitation during that particular period of Middle Miocene time was probably as high as 100 centimeters per year (39 inches)--with reliable patterns of summer rainfall, as well--a decidedly mesic paleoenvironment, well-watered, that encouraged the proliferation of a healthy broadleafed canopy. Representative floristic material secured from the older plant-bearing horizon includes--common specimens of alder, birch, walnut, persimmon, Eugenia, Kentucky coffeetree, Malus (related to the apple), a member of the genus *Prunus* (which includes plums, cherries, peaches, nectarines, apricots and almonds), *Photinia* (yet another species that some call the Christmas berry), black walnut, poplars, hawthorn, Chinese scholar tree, barberry, gooseberry, whitebeam, tassel bush, lobed red oak, stone oak, an extinct water oak, elm, zelkova, sycamore, and maple--in addition to such conifers as fir, spruce, and hemlock; average year-round temperatures likely never exceeded 10 degrees Celsius. (50 F).

At around 15 million years ago, ancestral western North America in general began to experience a dramatic shift in climatic conditions. By 14.5 million years ago, for example, average year-round temperatures had dropped approximately three degrees Celsius to 7 degrees C (44 degrees F), and summer rainfall patterns had all but dried up; annual precipitation probably fell from the previous highs of 100 centimeters (39 inches) to 75 centimeters (29) inches per year. This rather rapid (geologically speaking) alteration of paleoenvironmental patterns pretty much eliminated from Fossil Valley most of its once-dominant broadleafed deciduous plant life. In the younger 14.5 million year-old fossil flora above the older zone, no deciduous hardwoods of eastern alliance that characterize the 16.4 million year-old plant bed have been recovered. Replacing the many Esmeralda exotic hardwoods that now inhabit eastern United States forests was a botanic biota now represented by many evergreen dicotelydons and conifers. Commonly observed fossil plant remains identified from the younger Esmeralda Formation paper shales include--giant sequoia (foliage), Alaskan cedar, hemlock, spruce, fir, false cypress, larch, pinyon pine, juniper, manzanita, black cottonwood, mountain cottonwood, quaking aspen, Himalayan aspen, American aspen, willows, evergreen live oaks, oceanspray, mockorange, serviceberry, Catalina ironwood, mountain mahogany, toyon (sometimes called Christmas berry), buckthorn, squaw apple, silverberry, coast silk-tassel, oregon grape, elderberry, soapberry, pepper tree, hickory, mountain ash, locust, curl-leaf sumac, and madron. In many floristic respects, the younger Esmeralda Formation plants begin to resemble in a general trend the associations of shrubs and trees now found growing along the western slopes of California's Sierra Nevada.

In addition to the bountiful, exquisitely detailed leaves, seeds, conifer foliage, and flowering structures preserved along the natural bedding planes of mudstones, siltstones, and thinly bedded shales in Esmeralda Formation members One and Two, rather common to abundant petrified woods can also be found concentrated in localized, so-called mini-petrified forests throughout the coarser-grained fluviatile (river-deposited) sedimentary sections of Esmeralda Member One. Much of the woody material is nicely silicified--that is, replaced by the mineral silicon dioxide--although not even a smidgeon of it has been definitively identified, let alone formally described in the scientific paleobotanical literature. Casual inspection, though, leads not a few investigators to believe that much of the petrified could well derive from giant sequoia trunks.

Thriving in the lakes that once lapped the now mineralized trees is a fascinating group of minute organisms that provides students of the middle Miocene Esmeralda Formation with one of the more prolific paleontologic occurrences yet known from Fossil Valley Basin--the diatom, a microscopic photosynthesizing single-celled plant, allied biologically with

phytoplanktonic algae, that secretes a "shell" composed of opaline silica (the mineral silicon dioxide)--a diatom home technically termed a frustule. Though micropaleontologists often recognize diatom fossil remains under moderately high powers of magnification as isolated cells of varying intricate shapes and sizes, the tiny plants were still quite capable of forming chains or links, mimicking a multicellular organism. They first appear in the geologic record during the Early Jurassic, approximately 185 million years ago, but molecular clock calculations (genetic DNA analyses) and sedimentary evidence point to an earlier established presence in the Triassic Period. Since roughly 100 million years ago, beginning in the Cretaceous Period (age of dinosaurs, or course), diatoms have pretty much owned the so-called silica cycle, flourishing in both marine and freshwater habitats while contributing throughout the Late Cretaceous Period and succeeding Cenozoic Era myriads of their frustules to the ever-accumulating fossil record; indeed, during Miocene times throughout ancestral Nevada diatoms occasionally formed impressive deposits of commercially exploitable diatomite, a sedimentary rock type composed almost entirely of diatoms. At Fossil Valley, within the middle Miocene Esmeralda Formation, diatoms accumulated in several punctuated, successively stratified geologic horizons distributed between irregularly spaced barren layers denoting dramatic diatom kill zones precipitated by periodic air-fall volcanic ash, which paradoxically provided plentiful dissolved silica for additional diatom "colonies" to become established--until, that is, yet another pyroclastic episode devastated diatom reproduction dynamics.

Fossil Valley has provided micropaleontology investigators with some 109 diatom species. Characteristic Esmeralda Formation examples include--*Anomoeoneis lanceolata*, *Anomoeoneis nyensis*, *Anomoeoneis turgida*, *Fragilaria crassa*, *Stauroneis debilis*, *Surirella spicula*, *Cestodiscus cedarensis*, *Cestodiscus fasciculatus*, *Cestrodiscus stellatus*, *Pinnularia esmeraldensis*, and *Tetracyclus radiatus*. Diatom specialists note that the presence of a number of diagnostic pelagic and littoral forms demonstrates that Fossil Valley Lake's deeper waters were at times eutrophic (biologically productive), low in salinity (probably between 0 and 5 parts per thousand), clean, and generally alkaline. Still and all, diminishing frequencies of *Tetracyclus* (a cold water diatom) in successively younger stratigraphic intervals certainly suggests an overall shallowing of Fossil Valley Lake over geologic time. Most diatom assemblages from the Esmeralda Formation yield species whose living members now dominant saline and brackish lakes, paleontologic evidence which likely explains the presence of a normally marine genus in the freshwater Fossil Valley collections--*Cestodiscus*. A minor introduction of alkaline-loving members of the diatom genera *Pinnularia* indicates that periodically, at least, Fossil Valley Lake's pH levels could have gone greater than 7.0. For the Esmeralda Formation stratigraphic section containing *Coscinodiscus miocaenicus* and *Coscinodiscus grobunovii* diatoms, a geologic age of 15 to 12 million years is suggested.

Also living throughout the Fossil Valley Lake hydrologic system were untold numbers of freshwater mollusks and ostracods (a tiny bivalve crustacean), whose often well preserved remains now lie encased in Esmeralda Formation strata approximately 15 to 14 million years old.

Among Fossil Valley's prolific freshwater molluscan assemblage, some 34 species of gastropods and pelecypods have been identified from the middle Miocene Esmeralda Formation--four clams and 30 snails, all told. Most occur in the calcareous sandstone and silty limestone layers of Member One, often developing widespread coquinoid associations where the matrix is composed almost entirely of whole and broken shells. The most abundant varieties recovered include four species of rather diminutive pelecypods distributed within the genera *Pisidium* (two species) and *Sphaerium* (two species)--often referred to colloquially by malacologists as "fingernail clams"--in addition to the following gastropods: *Vorticifex* (six species); *Valvata* (three species); *Viviparus* (two species); and *Goniobasis* (three species).

The fossil freshwater mollusks inform paleolimnologists and paleoecologists much about ancestral Fossil Valley's middle Miocene lacustrine and fluviatile conditions. For example, *Vorticifex* sp. belongs to the freshwater gastropod family Planorbidae, the planorbids (technically categorized as an "aquatic pulmonate gastropod mollusk" that breaths air), whose living representatives often find their way into aquariums under the common name "ramshorn snails" (admittedly, of course, not all gastropods advertised as aquarium-ready "ramshorns" are actually planorbids). During Esmeralda times some 15 to 14 million years ago, *Vorticifex* snails likely lived in vegetation-rich waters no deeper than 15 feet; their extant representatives remain manifestly happy at depths of about six feet.

Another gastropodal dominant is *Viviparus* sp. (family Viviparidae), which interestingly enough uses a gill to respire. It's a relatively large, exclusively freshwater mollusk (grows up to two and a half inches long) that tolerates a wide range of habitats: ponds, rivers, streams, marshes, backwaters, and permanent bodies of water of varying depths. In North America, recent *Viviparus* species remain restricted to areas east of the Rocky Mountains at latitudes below 52 degrees. Dispersal in an ecosystem is likely achieved by active molluscan movement through water channels, with rafting a theoretical possibility that's never actually been witnessed. Diet is exclusively herbivorous; the snails feed on vegetation growing in the silty and sandy bottoms. An additional observation is that *Viviparus* gives live birth to its young, although all youngsters hatch inside the female snail's body and emerge only when environmental conditions are optimal (technically, a process called ovovivipary).

A third freshwater gastropod common to Fossil Valley's Esmeralda Formation exposures is *Goniobasis* sp., which is the extinct molluscan equivalent of the living genus *Pleurocera*

(family Pleuroceridae) now native to eastern North America; a related genus called *Juga* resides in the US west. It's often mistaken for a *Turritella* marine gastropod because of its characteristic high-spired morphological configuration. The Eocene Green River Formation, for example, produces plentiful silicified layers of *Goniobasis* snails, usually marketed under the name "turritella agate." *Goniobasis* was a gill breather that could generally tolerate varying degrees of salinity and even adverse turbulent waters.

The fourth Fossil Valley Esmeralda Formation gastropod dominant is *Valvata* sp. (family Valvatidae)--an operculum-bearing snail that possesses a gill attached only by the base so that it forms a structure like a feather outside the shell when fully extended. Modern *Valvata* species almost exclusively inhabit large, permanent bodies of water such as rivers and lakes. And they're also almost universally intolerant of waters with a pH level below 7.0; hence, the presence of *Valvata* indicates with invariable high probability an alkaline lake chemistry.

Fossil Valley's freshwater pelecypodal preservations consist of two forms, both members of the family Sphaeriidae--*Pisidium* and *Sphaerium*. Living members of the Shaeriidae inhabit a wide range of conditions, from shallow to deep waters, but generally prefer depths less than 6 feet. Although sphaeriids like slightly alkaline environments, *Sphaerium* has nevertheless been reported from waters with a borderline acidic pH of 6.0. Too, they'll tolerate just about any kind of substrate--except bottom areas composed of rocks or clay; that they will not abide.

The ostracods from Fossil Valley Esmeralda exposures are numerous, indeed. Often colloquially called "seed shrimps," ostracods are minute (typically around 1 millimeter long, but often as small as 0.2mm) bivalve arthropod crustaceans, not directly related to shrimps, that today inhabit both marine and freshwater environments; they first appear in the geologic record during the Early Ordovician Period, approximately 485 million years ago. Scientific investigators usually consider them accurate, sensitive indicators of water chemistry, depth, and temperature. They also provide earth scientists with a superior utility to help calculate the relative geologic ages of rock formations in which ostracods occur. In Fossil Valley Lake, they were obviously gregarious organisms, multiplying with efficient overpopulating explosiveness when the proper environment conditions arose--commonly contributing to the sedimentary accumulations impressive zoned coquinoid associations. Within the middle Miocene Esmeralda Formation some 35 ostracod species have been described. Typical forms include *Pactolocypris cancellatus*, *P. pactolensis*, *P. biprojectus*, *Heterocypris blairensis*, *Kassinina microreticulata*, *Advenocypris concinnus*, *Procyprois gracilis*, *Hemicyprinotus ionensis*, *Eucypris fingerrockensis*, *Cypricercus mineralensis*, and *Dongyingia lariversi*, *Dogelinella coaldalensis*, *Disopontocypris hendersoni*, and *Cypridopsella esmeraldensis*--an informative selection of fossil crustacean material that suggests that Fossil

Valley Lake, during periods of ostracod accumulations, probably experienced pronounced pulsations of saline-dominated, brackish water paleolimnological fluctuations.

Not only are innumerable Middle Miocene plants and invertebrate animals preserved at Fossil Valley Basin, but the backboned kinds get in the act in a big way, as well.

Vertebrate fossils recovered from the middle Miocene Esmeralda Formation at Fossil Valley include fish, amphibians, a reptile, birds, and mammals. The fossil fish occur as isolated bones, scales, and often common complete skeletons in the world-famous paper shale horizon of Esmeralda Formation member Two, approximately 14.5 million years old. Two major types predominate: an undescribed salmonid, which is related to salmon, char, and trout--probably its closest living relative is the Dolly Varden trout--and a Chub called scientifically *Gila* sp., a member of the Cyprinidae family (minnows, chubs, European daces, carps, and chars are other examples). Additionally, some years ago a paleontologically fortunate member of the United States Geological Survey found a pharyngeal arch that resembles the hardhead, a member of the Cyprinidae now native to California; that specimen has never been formally described in the scientific literature, though. Amphibian skeletal elements identified are indistinguishable from the living Couche's Spadefoot toad native to parts of southeastern Colorado, southern Oklahoma, western Texas, New Mexico, southern Arizona, southeastern California, northern Mexico, and the Baja peninsula; its scientific name is *Scaphiopus alexanderi*, named for famed fossil hunter and naturalist Annie Alexander who collected it from the middle Miocene Esmeralda Formation. One undescribed alligator snapping turtle was mentioned among Esmeralda finds in the late 1950s. Numerous bird feathers have been secured from the paper shale deposits, as well--among them, identifiable specimens belonging to a golden eagle, a burrowing owl, a turkey vulture, and a pinyon jay.

The Middle Miocene mammals from Fossil Valley are many, and varied. They typically occur in two major Esmeralda Formation horizons--an older vertebrate accumulation specific to the Barstovian Stage of the Miocene Epoch that dates from approximately 15.4 to 15.1 million years ago--and then a younger bone interval from the Clarendonian Stage, somewhere around 13.5 to 10.5 million years old. Both faunas supply vertebrate paleontologists with some of the most iconic Miocene mammals that ever walked the earth.

Older of the two vertebrate associations occurs in overbank fluviatile deposits associated with Member One of the middle Miocene Esmeralda Formation. Here can be found a paleontologically satisfying representative cross-section of land life that roamed ancestral Middle Miocene Fossil Valley a little over 15 million years ago. Among the many significant mammals, for example, was a group of interesting insect-eaters--a hedgehog-like critter; a shrew; a mole; a curious extinct ground-dwelling insectivore (*Arctoryctes*); and a bat.

Diminutive rodents and lagomorphs (hares-rabbits-pikas) also resided at Fossil Valley during Barstovian Stage times: the faunal listing includes: two kinds of squirrels; two extinct squirrel-like animals; two beavers; a kangaroo rat; and an extinct rabbit-like creature.

Carnivores were nicely represented, as well. Examples of meat-eaters from the older Esmeralda Formation horizon include: an extinct bear-dog (*Tamarctus*); an extinct hyena-like dog (*Aelurodon*); a fox; a ring-tailed cat; and an unspecified member of the Mustelidae, which includes otters, badgers, weasels, martens, ferrets, minks and wolverines.

Larger Barstovian-age Fossil Valley herbivores attempting to evade the carnivores amounted to a diverse lot, indeed. Obligate vegetation munchers described from the oldest Middle Miocene Esmeralda Formation section include: an extinct elephant-like gomphothere proboscidean; three different species of extinct three-toed horses (one *Hypohyppus* and two *Merychippus*); a rhinoceros; two camels; an extinct three-horned ruminant (a Palaeomerycid); and two extinct pronghorns (*Merycodus*).

The geologically younger Fossil Valley vertebrates occur in Esmeralda strata deposited during the Clarendonian Stage of the Middle Miocene, a mammal-producing section dated at roughly 13.0 to 10.5 million years old. That's where important bone-bearing beds lie positioned through many hundreds of feet of Esmeralda Formation members Five, Six and Seven. And the faunal list is quite inclusive: an extinct shrew-like insectivore (*Limnoecus*); two kinds of squirrels; four members of the Heteromyidae rodent family--three extinct pocket mice (*Perognathus*) and an extinct critter closely related to the pocket mouse (*Cupidinimus*); a giant kangaroo rat; a beaver; a deer mouse; a rabbit; a bear-dog (*Tamarctus*); a fox; two species of a bone-crushing hyena-like dog (*Aelurodon*); a member of Mustelidae family, which includes badgers, otters, weasels, martens, ferrets, minks, and wolverines; an extinct cat (*Psudaelurus*)--an ancestor of today's felines and pantherines as well as the extinct saber-tooths; an extinct felid carnivore (*Sansanosmilus*) commonly called a false saber tooth cat; two kinds of elephant-like gomphothere proboscideans; five types of extinct horses--the last browsing horse in North America (three-toed *Megahippus*), two species of three-toed grazing horses (*Neohipparion* and *Hypohippus*), and two species of the single-toed grazer *Pliohippus*; a rhinoceros; three types of camels; and an extinct pronghorn (*Mercycodus*).

Today, while visiting Nevada's Great Basin Desert, it is perhaps difficult to imagine Fossil Valley as an extensive verdant lake basin teaming with luxuriant trees and shrubs and grasses and abundant animal life within the midst of such an unimaginably vast expanse of arid, ecologically austere territory dotted with creosote, shadscale, and additional botanically specialized compact spinescent types adapted to prolonged periods of scant precipitation--less than five inches per year, on average.

But the eroding rocks of the middle Miocene Esmeralda Formation prove the case: This is a land dominated by the good dust of deep time, by the weathered sedimentary particles from a geologically hardened hydrologic system that disappear into the infinite distance as an incessant desiccated wind whips across stone outcroppings of a 17 to 10 million year-old lake--each gone grain further releasing gradually to view the paleontologic wonders for which Fossil Valley is appreciated worldwide--a unique, complete paleo-biota of Middle Miocene organisms retained in an exceptional state of preservation: the leaves, the conifer winged seeds and needles and foliage, the petrified woods, the pollens, the diatoms, the stromatolites, the gastropods, the pelecypods, the ostracods, the fish, the amphibians, the turtles, the birds, the mammals--and the insects, whose delicate winged varieties often seem so life-like that they appear ready to fly away from the water-born sedimentary layers upon which they've lived for fourteen and a half million years.

Chapter 14

High Inyo Mountains Fossils, California

An unusual fossil locality occurs east of Owens Lake, near the crest of California's Inyo Mountains--a place many fossil enthusiasts call the Chainman Shale site, where 325-million-year-old ammonoids can be found along the same bedding planes that yield fossil shark teeth and terrestrial plants. The paleontological remains have been preserved in what geologists refer to as the upper Mississippian Chainman Shale, a geographically widespread marine rock deposit (its type locality—where it was first named and described in the technical literature--is over in eastern Nevada), almost everywhere slightly metamorphosed, that also contains several species of pelecypods and brachiopods, in addition to a peculiar orthocone nautiloid cephalopod called *Bactrites*, or in more colloquial language the "darning needle" fossil because of its sharply elongated, needle-like appearance in the rocks.

The Inyo Mountains fossil horizon lies in the vicinity of Cerro Gordo, an abandoned mining camp that produced beaucoup spondulix worth of silver, lead, and zinc during the latter half of the 1800s (that would be many millions of dollars). It is now a picturesque ghost town preserved in what is euphemistically termed a state of "arrested decay." Years ago, before the question of legal ownership of the property had been settled, the multi-hued pulverulent mine tailings surrounding the town used to furnish collectors with such relatively uncommon mineral varieties as caledonite (a copper-lead sulfate), linarite (lead-copper sulfate), and leadhillite (a lead-sulfate-carbonate), in addition to excellent examples smithsonite (a zinc carbonate) that often rivaled specimens from the famous Kelly Mine in New Mexico. But those days are now a distant memory in the minds of older mineral enthusiasts. Today, every last square inch of Cerro Gordo is privately owned, and mineral collecting within its posted boundaries is strictly forbidden without the owners' prior approval. For details about how to secure a permit to collect mineral specimens at Cerro Gordo, contact the regional office of the Bureau of Land Management in Ridgecrest, California. In the past, though, only "fully accredited individuals" have had success in finagling the essential legal documentation.

Not only is the Cerro Gordo fossil site a productive and scenic area to explore, it is also a place of great paleontological importance. As one of only three known Carboniferous (the European equivalent of the Mississippian and Pennsylvanian Periods combined) ammonoid localities in all of California, it is also the only such example currently accessible to amateur fossil buffs. The other two occur in Death Valley National Park (officially established in 1994), near the famous Racetrack in the northern sector of the vast park--now, with the assimilation of many thousands of acres of adjacent wilderness lands, larger than the entire state of Connecticut--where rocks of varying shapes and sizes apparently slide in mysterious secrecy across a wide desert playa. The traditional explanation was that during winter, when nobody was around to see the phenomena occur, preferably in the dead of night, fierce wind gusts--upwards of 100 miles per hour--pushed the rocks across slippery playa muds when they were saturated by rare episodes of Death Valley precipitation.

In actual fact, both Death Valley sites are extensions of a single phenomenally productive cephalopod-bearing horizon in the upper Mississippian Perdido Formation. Each yields innumerable ammonoids that characteristically weather out whole and intact, although many of the cephalopodic remains reveal obvious signs of degradation to their exteriors caused by the ceaseless abrasive weathering in the harsh desert elements. Even so, numerous specimens still retain their original suture lines--that is, the distinctive growth line of the junction of a cephalopod's shell with the inner surface of its shell wall, which paleontologists use to identify the genus and species of all shell-bearing cephalopods, both living and extinct.

Even though the Cerro Gordo locality fails to yield free-weathering specimens, its ammonoids and associated brachiopods, pelecypods, terrestrial plants and shark teeth are, nevertheless, common to abundant in the slightly metamorphosed detrital deposits of the upper Mississippian Chainman Shale. They are preserved as attractive reddish-brown limonitic casts and molds of the original 325-million-year-old organisms, set on a matrix of pale-to medium-gray slaty shale. The majority of ammonoid specimens are rather diminutive, with diameters of generally 10 millimeters or less (smaller than .40 of an inch). So, be sure to carry with you a good-quality magnifying glass. Their preservation is fair to excellent--very surprising when you consider the degree of metamorphism the matrix was unavoidably subjected to in the geologic past. When the Sierra Nevada began to buckle upward during the Late Jurassic Period, many relatively incompetent shale beds in the Inyo Range underwent moderate to severe alteration. That the ammonites and associated goodies in the Chainman Shale escaped this ravaging assault was indeed a miraculous occurrence.

Prior to their having survived obliteration by powerful geologic processes, the Chainman Shale organisms were deposited at the muddy bottom of a rather deep, warm-water Paleozoic sea some 325 million years ago. Now they lie at elevations of 8,800 to 9,000 feet near the crest of the great Inyo Range near Cerro Gordo ghost town. The ride up to the site along the precipitous western flanks of the Inyo Range is a hair-raising adventure. The jeep trail climbs over a mile in a mere seven or eight miles...although the vast majority of that amazing ascent takes place within a distance of only three or four miles. Needless to say, only those with a reliable four-wheel-drive vehicle should consider accepting the challenge.

It doesn't hurt to be in at least moderate physical condition, either. Once within striking distance of the fossil ammonoids and shark teeth, you will have to hike at elevations approaching 9,000 feet. For those unaccustomed to exertion at high altitudes, serious consequences can result--not the least of which is altitude sickness, a debilitating condition caused by prolonged oxygen deprivation.

The turnoff to the Chainman Shale fossil bonanza lies along the eastern side of Owens Lake--an essentially dry saline depression most of the year (occasional heavy runoff from the mountains during spring sometimes results in a big shallow pond that evaporates quickly)--near Keeler, where Cerro Gordo Road intersects State Route 136 13.5 miles southeast of Highway 395. Check your pulse at this point and get a grip!

The adventure begins at a modest 3,800 feet or so, with billows of irritating saline dust rising from "Owens Lake." Within just a few miles (when hairpin turns spiral upward and upward), you might reconsider having stayed behind in what had previously seemed the inhospitable Owens Lake below, and even find yourself obsessing on the flatness of it--that wonderful level expanse with no sheer drop-offs on either side.

Turn east on Cerro Gordo Road. Here you leave civilization behind. You will be striking though a great wilderness: a geological wonderland comprised of thick geologic rock deposits, in which many kinds of Paleozoic Era fossil remains can be recovered. Mainly these include fusulinids, brachiopods, corals, bryozoans, and crinoid fragments from the middle Pennsylvanian Keeler Canyon Formation and the lower Permian Owens Valley Group. Also exposed in the area surrounding Cerro Gordo is the lower Mississippian Tin Mountain Limestone (358 million years old)--a noted producer of corals and crinoids in particular from massive reef-like carbonate accumulations in its youngest phases of sedimentary deposition.

During the first 2.2 miles of four-wheel drive travel, you pass through Pleistocene (roughly 2.5 million to 11,000 years ago) to recent fanglomerate--extensive accumulations of eroded debris from every sedimentary and volcanic outcrop in the Inyo Mountains. Limestone cobbles in the alluvial material sometimes contain abundant fusulinid tests; however, because the host deposit consists of weathered rock out of its normal stratigraphic position, the best that can be said regarding its geologic age is that any fusulinid found within it probably came from either the Keeler Canyon Formation or the Owens Valley Group. These are the only rock units in the Inyo complex known to contain the distinctive wheat-shaped test secreted by an extinct single-celled animal.

At 2.2 miles from State Route 136, Cerro Gordo Road begins to slice through the lower Permian Owens Valley Group, which is roughly 285 million years old. Here, the Owens Valley is composed of several sedimentary lithologies, including silty fusulinid-bearing limestone, lenticular organic limestone (within which brachiopods, corals, crinoids and bryozoans can be

found), calcareous shales, sandy limestone, limestone-mud breccias, and relatively pure limestones. Fossil remains are not abundant in the Owens Valley exposures along Cerro Gordo Road. But farther southeast, in the Darwin District of Inyo County, profuse fusulinids, brachiopods, and corals have been reported.

For 1.4 miles Cerro Gordo Road passes through dramatic exposures of the lower Permian Owens Valley Group. Then it intersects an unnamed terrestrial accumulation of Middle Triassic (220 million-year-old) volcanics and sedimentary rocks approximately 2,200 feet thick. The volcanic facies includes andesite flows, breccia, and tuffs of gray, red and purple; among the sedimentary constituents are shale-sandstones and conglomerates of gray, red, green and purple. None of the land-laid Triassic exposures is fossiliferous, though.

After cutting through the thick Middle Triassic terrestrial sequence for 1.5 miles, Cerro Gordo Road penetrates the marine lower Triassic Union Wash Formation (roughly 248 million years old), some 1,800 feet thick. Unlike its classic fossil-rich outcrops in Union Wash northeast of Lone Pine, the exposures along Cerro Gordo Road bear only rare, fragmental ammonoids representing the genus *Ussuria*. The cephalopods occur in brownish-gray silty limestones some 50 feet thick, along with abundant minute gastropod molds and infrequent pelecypodal lenses. The Union Wash Formation is wonderfully exposed for 0.8 mile, forming craggy reef-like ridges and colorful slopes composed of thin-bedded shales in hues of pale greenish-gray, light gray, yellowish-orange, and slightly greenish-yellow.

At a point 5.9 miles from State Route 136, Cerro Gordo Road intersects the middle Pennsylvanian Keeler Canyon Formation (roughly 310 million years old). It's approximately 2,200 feet thick, a predominantly carbonate-shale sequence in which the arenaceous to argillaceous limestones often yield crinoid material and abundant tiny fusulinids that for the most part are only moderately well preserved. Typically, the shale interbeds are totally barren of paleontology--yet, from a perspective of casual inspection they seem so inviting, appearing eminently suitable for the preservation of many varieties of Paleozoic organisms. Persistent investigations of them may eventually reveal something truly remarkable.

For the next 1.1 miles, the Keeler Canyon Formation outcrops in prominent fashion along both sides of the road, affording easily accessible exposures for fossil explorations. Abundant small fusulinids and occasional disarticulated crinoid stems occur at irregular intervals throughout the carbonate sequence. At a point 7.0 miles from State Route 136, the Middle Pennslyvanian strata rest in a prominent fault contact against the older upper Mississippian Chainman Shale (about 325 million years old).

The first Chainman outcrops encountered consist of smooth slopes underlain by dark gray to black carbonaceous shale and blocky-weathering argillite (a heat-and-pressure-altered clay shale), with subordinate interbeds of fine-grained sandstone and limestone. Periodic roadcuts during the next 1.3 miles--all the way up the remainder of the grade to Cerro Gordo Summit--reveal unfossiliferous brownish-red to dark gray argillites and characteristic thin-bedded, often cleavable black shales.

The fabulous Paleozoic Era fossils occur in grayish-black, slightly fissile shales of the upper Mississippian Chainman Shale at a lone isolated locality that lies in the vicinity of Cerro Gordo Summit; even though fossil specimens are quite common at the specific site, preserved through roughly 50 feet of well exposed strata, collectors will still have to watch carefully for the invariably small ammonoid casts and molds. On the other hand, common fragments of mature specimens demonstrate that the largest varieties here could grow to approximately 60 millimeters across (two and a third inches).

The most abundant ammonoid represented at the Chainman Shale site is *Cravenoceratoides nitiloides*, a type originally described from a locality near Yorkshire, England. Less commonly observed species of ammonoids include *Cravenoceras nevadense*, *Cravenoceras richardsonianum*, and *Eumorphoceras bisulcatum*.

A second variety of cephalopod occasionally encountered is *Bactrites*, referred to in scientific terms as an orthocone nautiloid cephalopod. *Bactrites* is in reality more closely related to the modern chambered nautilus than are the extinct ammonoids and ammonites, whose coiled morphologic aspects bear only a superficial resemblance. Paleontologists identify cephalopodic affinity not by the rough similarity of exterior shell designs but, rather, by the unique suture signature they happen to bear.

Based on their distinctive suture patterns, all ammonoids and ammonites can be classified into three separate orders: goniatitic (species with nonserrated sutures, generally considered the most primitive varieties)--the kind found in the Chainman Shale; ceratitic (sutures with serrated lobes); and ammonitic (very complex suturing--usually referred to as the most advanced order of ammonites--and the only order that can properly be termed an ammonite; the goniatitic and ceratitic types are necessarily called ammonoids). The goniatites first appear in the geologic record during the Devonian Period, some 370 million years ago; they persisted all the way up to the great dying at the conclusion of the Permian Period (when trilobites finally disappeared, as well), 252 million years ago. During the Permian Period both ammonoid and the ammonite varieties became common. But by Triassic times (252 to 201 million years ago), only the ceratitic forms proved particularly successful. Then they, too, died

out at the conclusion of that geologic period, leaving only the ammonitic types, the ammonites proper, to carry on the cephalopodic heritage.

Throughout the Jurassic Period (201 to 145 million years ago) ammonitic ammonites thrived, becoming increasingly complex and numerous in the oceans of the Mesozoic world. They persisted right up to the close of the Cretaceous Period (66 million years ago), becoming extinct along with all the sensational terrestrial giants of that age--the dinosaur.

In addition to the cephalopods, the molluscan class Pelecypoda is well represented in the Chainman exposures. The pelecypods here are typically much larger finds, easily spotted as reddish-brown limonitic impressions and silvery sheens--original lustrous shell material may be present some instances--on the darker grayish shales. Two of the more common varieties present include *Caneyella wapanachensis* and *Caneyella richardsoni*, each of which is frequently found preserved intact with both valves splayed open along the hinge line.

Not only are invertebrate fossils common in the Chainman outcrops, but fascinating fossil shark teeth can also be collected. For the most part, they occur as limonitic casts and molds, stained a pleasing reddish-brown on a grayish shale matrix, barely a few millimeters in length. One collector, though, has reported finding a three-quarters inch beauty with a distinctly serrated edge. Just what variety of shark they came from is anybody's guess, but it is quite exciting to come across an obvious tooth resting next to an ammonoid along the same bedding surface...a splendid fossil occurrence, indeed. Of course, gathering and keeping any kind of vertebrate fossil on public Lands is usually considered verboten, forbidden; but most folks understand that collecting shark teeth--the vertebrate equivalent of a common invertebrate fossil such as a brachiopod or coral, for example (specimens one is permitted to keep on BLM administered territory)--is not in the same category as removing, say, dinosaur remains, or even mammalian skeletal elements from public lands, activities that are universally not allowed since such specimens are considered "rare" and of vital importance to the scientific community.

Also present in the carbonaceous shales are common to abundant poorly preserved terrestrial plants, most of which were likely derived from a nearby coal-swamp paleoenvironment. The most readily recognizable forms resemble slender algal structures preserved as faint fragmentary outlines of vermiform configuration. The second group consists of branching stems and flat, straight impressions of rushes and ferns.

Lying directly above the fossiliferous grayish shales is an inconspicuous three-foot layer of silty limestone. Most often, a thick talus overburden of weathered shales masks its presence, but careful inspection of the narrow horizon usually discloses a wonderful variety of

Paleozoic invertebrate remains--including the corals *Triplophyllites* and *Chaetetes*; a fenestellid bryozoan; a trilobite (*Proetus missouriensis*); a gastropod (*Pleurotomaria brazeriana*); and the following brachiopods: *Spirifer* (two species), *Composita lewisensis*, *Productus* (two species), *Diaphragmus elegans*, and *Dictyoclostus* sp.

Such brachiopods, bryozoans and corals all add dramatically to the sensational plethora and variety of fossil specimens that can be recovered from the Chainman Shale locality, situated in the westernmost Great Basin along the crest of eastern California's Inyo Mountains, in the vicinity of Cerro Gordo ghost town.

While today's fossil specimens lie at an altitude of roughly 9,000 feet, during Late Mississippian geologic times they would have been buried perhaps thousands of feet below sea level by detritus eroded away from already long-vanished mountains. Now, in the rarefied atmosphere of the high Inyo Mountains, fossil collectors become deep-sea divers of the Paleozoic Era, plunging far below the surface of the eons to explore layers of lithified muddy ooze, to search for ancient animal life that once took in oxygen from many fathoms below earth's surface some 325 million years ago.

Chapter 15

Early Cambrian Fossils In Western Nevada

Introduction

Visit a remarkable, prolific 518-million-year-old fossil locality situated several miles north of Death Valley National Park in Esmeralda County, Nevada--the Gold Point fossil site, where paleontologists have recovered the single largest assemblage of Early Cambrian trilobites yet described from North America; here's an opportunity to collect at least 12 species of trilobites, abundant salterella (the "ice cream cone-shaped" fossil), archaeocyathids (extinct calcareous sponge), brachiopods, algal remains, plus numerous varieties of annelid and arthropod tracks and trails--a truly diverse assemblage of Early Cambrian fossil remains from the famous lower Cambrian Harkless Formation.

Field Trip To Early Cambrian Fossils In Western Nevada

One of the great Early Cambrian trilobite localities in the western United States can be found in Esmeralda County, Nevada, a number of miles north of Death Valley National Park. It's a ne plus ultra paleontological place where invertebrate paleontologists have identified at least 12 species of trilobites from a series of terrigenous and carbonate strata mapped as the lower Cambrian Harkless Formation, some 518 million years old--a specific fossil locality, as a matter of fact, that has yielded the single largest assemblage of Early Cambrian trilobites yet described from North America.

Thus, it is a unique and scientifically invaluable area--still accessible to amateur fossil aficionados, by the way, primarily because the exceptional extinct arthropod fauna has already been described in detail by a noted Cambrian trilobite specialist, who published his findings in a United States Geological Survey professional paper in the 1960s.

Nevertheless, the wonderful arthropod horizon remains a geologically sensitive place. Visitors to the region must respect its vulnerable existence, understanding that if commercial collecting parties begin to desecrate the stratigraphic integrity of the exposed strata--ripping the fossiliferous rocks from their primordial resting grounds by mechanized means--officials with the Bureau of Land Management (BLM) will have no recourse but to close the entire district, preventing interested amateur collectors from experiencing the exhilarating rewards of paleontological discovery here; of course, it is not likely that commercial collectors would favor the Gold Point area, anyway, since complete, perfect trilobite specimens are so rarely recovered--a not unexpected situation when dealing with the majority of Early Cambrian fossil localities world-wide. Needless to report, commercial collectors must stay away;

otherwise, only those with certificates of university accreditation will be allowed to keep what they find.

The Gold Point locality lies in the vicinity of Gold Point in Esmeralda County, Nevada--several miles from still another exceptional paleontologic place--a renowned regional sedimentary protuberance from whose Late Precambrian rocks paleontologists have identified one of the earliest known assemblages of shell-secreting animals on Earth. The specimens occur in dolomitic carbonates transitional between the Precambrian Reed Dolomite and the Deep Springs Formation and apparently represent varieties of primitive worm tubes occasionally observed in correlative deposits in Mexico, Russia, and Namibia.

What's particularly intriguing about this Late Precambrian site is that the curious annelid tubes, only a few millimeters long in most instances, apparently occur in rocks approximately a full thousand feet below the first appearance of olenellid trilobites in the local stratigraphic section--extinct arthropods that in a traditional geologic context used to define the base of the Cambrian System--now recognized as roughly 541 million years old, not 570 million years ancient as had been held for most of the 20th Century.

Even though the ancient annelid tubes lie within reasonable proximity to the celebrated Gold Point trilobite beds, the exposed sedimentary material lying between the two areas is not in its original stratigraphic succession; that is to say, one cannot expect to encounter between the two areas an uninterrupted series of sedimentary layers representing a reliable transition from the oldest periods of deposition to the youngest. The explanation is that potent earth forces during the Cenozoic Era, roughly 66 million years ago to present, block-faulted vast quantities of intervening strata, creating a jumbled messy mass of exposed rock deposits that only exacting geologic field mapping can hope to unravel.

Fortunately for folks with paleontological zeal, the disruptive geologic upheavals did not obliterate all of those wonderful Early Cambrian plants and animals that once thrived here in the primordial timelessness of the geologic past. In addition to the prized trilobite exoskeletons--most commonly found as disarticulated, isolated cephalons and thoracic segments--the Gold Point locality also yields a wide assortment of interesting fossil organisms. These include such extinct species as archaeocyathids (cup-to conical-shaped creatures whose morphological aspect resembles a cross between a coral and a sponge--they were for decades considered members of a unique Phylum of animals, but closer scrutiny suggests that they are more closely allied with the sponges, and so today most paleontologists categorize archaeocyathids as an extinct variety of calcareous sponge) and *Salterella* (an ice-cream-cone to tusk-shaped specimen roughly 6 to 8 millimeters long that many investigators originally conjectured represented one of the earliest examples of a

cephalopod--sort of a distant ancestor of the ammonite--but more detailed analyses concluded that it was most likely a unique animal deserving of its own zoological Phylum called Agmata, a group that never survived beyond Early Cambrian times)--in addition to annelid trails, arthropod tracks, algal bodies (the widespread *Girvanella*, a peculiar rounded concretionary specimen characteristic of pure, uncontaminated limestones deposited during latest Early Cambrian times in what is now the Great Basin), and brachiopod casts and molds.

All of these specimens occur in strata originally mapped as the lower Cambrian Harkless Formation, although the shales and shaly limestones that yield the trilobites certainly resemble correlative rocks known as the Saline Valley Valley Formation, whose type locality (the place where a geologic rock formation was first described in the scientific literature) lies over in the Waucoba Spring area in northwestern Death Valley National Park. The informally named Waucoba District used to be a rewarding area to explore for Early Cambrian fossils. Needless to report, the entire district, since 1994, has been included in the national park system and is therefore presently off-limits to any manner of unauthorized collecting.

The fossiliferous sections at the Gold Point locality are composed of alternating brownish shales, reddish-brown limy shales, orange-brown limestones, greenish-orange shales and dark-gray limestones (indeed, a rather colorful outcropping of various rock lithologies.). Almost all of the trilobites occur in the thin interbeds of dark-gray limestones that outcrop intermittently along the hillsides.

This is certainly a classic Early Cambrian fossil locality. Even though the vast majority of trilobite specimens will be both fragmental and rather small--most cephalons range from one-quarter to one-half inch in diameter (or, 6.3 to 12.7 millimeters in metric measurement)--the sheer abundance and diversity of arthropod remains in the rocks here is truly phenomenal and inspiring. Trilobite varieties identified include *Paedeumias granulata*, *Wanneria walcottana*, *Bonnia caperata*, *Olenoides* ssp, *Ogyopsis batis*, *Goldfieldia pacifica*, *Stephenaspis* sp., *Stephenaspis avitus*, *Zacanthopsis* sp., *Zacanthopsis contractus*, *Zacanthopsina eperephes, Syspacephalus*, and four additional species as yet undescribed.

Credit for discovering this remarkable trilobite-bearing district goes to two geologists with the United States Geological Survey. They came across the site during reconnaissance for a geological field mapping project. In 1960, a USGS paleontologist happened to examine fossil material collected from the Gold Point site. By all accounts, the extraordinary suite of trilobite specimens immediately "floored him," as it were, and led to his identification of the largest single assemblage of Early Cambrian trilobites yet described from North America.

It should be pointed out right about now that although the Gold Point arthropods have already been formally documented in the scientific literature, a number of additional trilobite localities in Esmeralda County remain under formal paleontological investigations--hence, not even a hint of their approximate occurrences can be divulged at this time, at least not until they have been described in monographic detail by the paleontologists involved in the investigations. Indeed, I have been sworn to secrecy (under penalty of torture by a trilobite's pygidium) not to reveal at least three other world-class Early Cambrian fossil sites within western Nevada--places that yield a plethora of identifiable trilobite specimens, including not a few perfect, completely intact exoskeletons.

Once at the Gold Point fossil site, most collectors concentrate on the many fine trilobite fossils they find along the more moderately inclined, easily negotiated slopes. This is certainly acceptable behavior, an individual choice of course, but additional trilobite-yielding horizons can be discovered all along the axis of the Gold Point region, within the more rugged topography. Also, a wider variety of fossil remains can be sampled, including: archaeocyathids (restricted to thin carbonate horizons interbedded with the shales); worm trails and undetermined arthropod tracks (present locally on greenish quartzitic sandstones and shales); brachiopod molds and casts (usually observed on reddish-brown shales); blue-green algal bodies (roundish *Girvanella* concretionary specimens in grayish-blue massive limestones); and *Salterella* (seen in orange-brown shaly limestones at irregular intervals--locally quite abundant, forming coquinas in which the carbonate matrix is composed almost entirely of the 6 to 8 millimeter long ice-cream-cone-shaped specimen).

Although none of the non-trilobite specimens is overly abundant here (except for the *Salterella*, which is locally quite prolific), their presence in a least moderate numbers this low in the lower Cambrian Harkless Formation makes the moderate hiking required to find them a most memorable and rewarding field experience. Of course, not every outcrop in the Gold Point fossil zone will yield something remarkable, but there is definitely enough 518-million-year-old paleontology available to keep even the most jaded explorer in fossil ecstasy.

Here is an important fossil locality that gives us an opportunity to look back in geologic time to the surprising diversity and complexity of an Early Cambrian sea, some 518 million years ago. That so many biologically successful creatures should have thrived so long ago, and through the eternity of eons, seems to defy all that we believe to be law. Yet, when we hold in our hands the incontrovertible evidence of a creature with eyes in the rocks: a trilobite's eyes that gaze back into our own from ages past, we finally come to realize that those 518 million revolutions around the sun can no longer separate us.

Chapter 16

Field Trip To The Kettleman Hills Fossil District, California

Back in 1940, the United States Geological Survey (USGS) issued Professional Paper 195 by W.P. Woodring, Ralph Stewart and R.W. Richards, entitled: *Geology of the Kettleman Hills Oil Field*, with the subtitle *Stratigraphy, Paleontology, and Structure*. That's still pretty much the definitive geological and paleontological statement on the Kettleman Hills region. It's a classic work of science that continues to draw inquisitive paleontology enthusiasts/sleuths to university reference libraries all across America, seeking information on what kinds of fossils can be collected there--and just where such magnificently preserved material can be found.

For that data, you need to thumb all the way to back of the paper, through all of those stunning black and white photographs of Kettleman Hills fossils--all of those perfectly preserved sand dollars and pectens and clams and snails and such that truly boggle the mind and catch one's attention, holding it for lengthy periods of time, delaying the search for the exact localities from which the specimens came. When you finally get to the back of Professional Paper 195, one half expects to learn that most of the fossils likely came from no more than a dozen or so localities, 20 to 30 at most, perhaps (I am speaking from experience--this was my grand delusion, at least)--and so, it comes as a pleasant shock to learn that the Kettleman Hills district, an area roughly 20 miles long by 4 miles wide situated some 80 miles northwest of Bakersfield in Kings County, California, contains 370 registered fossil localities in the Pliocene (5.3 to roughly 2.5 million years old) Tulare, San Joaquin and Etchegoin Formations (in descending order of geologic age--that is, from youngest to oldest)--an amazing array of invertebrate, vertebrate and even floral fossil remains that includes pectens (scallop shells), clams, gastropods, oysters, mussels, fish, land mammals, marine mammals, sand dollars, diatoms and even terrestrial plants, among others.

Of course, the majority of those 370 specific fossil localities are no longer accessible to the general public; many remain closed due to legal liability issues incurred by local property owners, while others were obliterated long ago through the vagaries of time. Most Kettleman Hills paleontolgical places of interest, still potentially open for inspection, currently lie on private property. That means, naturally enough, that if you've failed to secure the essential preliminary formal written permission from the proper authorities (the legal property owners), don't even think about wandering off the main asphalt paths to seek out potential fossil-bearing places. One will likely face certain prosecution if one misbehaves here.

The three specific sites described here provide a representative sampling of the kinds of fossils that can be found in the Kettleman Hills area, as each is loaded with abundant,

sensationally preserved specimens. At last field check, only one of the localities requires advance written documentation from the local oil corporation.

Probably the best of the lot, in terms of overall specimen variety and quality of fossil preservation, is what many paleontology enthusiasts refer to as--in an affectionate, colloquial sense-- "The Zone." The fish remains, pectens, oysters and sand dollars found there occur in the middle Pliocene San Joaquin Formation, which is roughly three million years old, and the Upper Pliocene Tulare Formation, around two and a half million years ancient. It lies back in the Kettleman Hills on private property, so permission must be secured from the oil company branch office. Usually, though, that is not a problem. In any event, the bottom line here is: You certainly must possess written approval from the oil corporation folks before visiting "The Zone" locality.

Averaging 10 to 20 feet in thickness, the fossiliferous "Zone" horizon is a sequence of gray to tan silts and sands exposed for a length of a half to three-quarters of a mile--it is, in fact, an amazingly fossiliferous extension of the famous Pecten Zone in the middle Pliocene San Joaquin Formation. And it is crammed almost everywhere one happens to look with perfectly preserved scallops, oysters and sand dollars, primarily, whose original shell material has been preserved intact.

In addition to the wonderful invertebrate animal assemblage here, one is also advised to stay alert for occasional beaver teeth--vertebrate remains that invariably, while on public lands, one must leave alone, never collect except by formal written permission from the Bureau of Land Management; but there, you happen to fossil hunt on private property belonging to the oil folks, and if you've successfully garnered the essential written documentation from their branch office (let's hope that you have; one needs to carry the paper at all times while on oil company land, or risk almost certain detention by the local law enforcement authorities while they decide whether to cite you for "simple" misdemeanor trespass, or perhaps even criminal trespass), you have secured the right to keep whatever fossils you happen to find, including vertebrate remains usually off-limits to unauthorized individuals.

At "The Zone" locality, the sand dollars measure on average from a half-inch to two inches in diameter, although many are quite minute--what you might call "sand pennies," if you will--in the neighborhood of no more than a quarter-inch across. All such echinoid occurrences here are referable to one or two species of the genus *Dendraster*, mainly *Dendraster coalingaensis*. The scallop, or pecten shells are striking, attractive specimens whose ribbed exteriors are of course very distinctive and identifiable in the sediments; most of them belong to the species *Pecten coalingensis*. An added collecting plus here is that the majority of fossils either weather out of the San Joaquin Formation already intact, or can be dug out without any degree of pain or strain. All that's needed to put the finishing, cleaning touches on them is a gentle scrubbing in water with an old toothbrush.

In addition to the pectens, oysters, sand dollars and beaver teeth teeth, another fossil type can be also found in the same general area of "The Zone" locality--fish remains. The specific horizon in which they occur has been mapped as the upper Pliocene Tulare Formation, which is about 2.6 million years old. Geological and paleo-limnological analyses demonstrate pretty convincingly that the Tulare is a fresh to brackish water deposit that incorporates sedimentary facies which record the final drying up of the last great inland sea to cover the present-day Central Valley of California--a sea that throughout the Tertiary Period of the Cenozoic Era (66 to roughly 2.5 million years ago) had at times stretched from Redding (northern California) all the way south to the vicinity of Bakersfield (southern California).

The Tulare Formation of the Kettleman Hills just happens to yield the largest fauna of fresh water Pliocene mollusks of any rock deposit on the US west coast. Some 33 varieties of pelecypods and gastropods have been described from it, though only a few species come from this particular spot near the The Zone. Several miles south of The Zone locality, though, a second Tulare area of exposure yields abundant and well preserved fresh water mollusks.

But here at "The Zone," fish remains are the thing--unusual paleo-items colloquially called "bulbous fish growths" by field geologists who've mapped the geology, structure and stratigraphy of the Kettleman Hills. These are the fossilized bony tumors which evidently afflicted many of the fish during Tulare times. Most specimens are similar to observed types that attack the skeletons of modern weak-fish, cod (specifically the hakes), angel fishes and even catfish. No other fossil locality, save the Kettleman Hills, is known to yield these kinds of paleontological preservations. They are present in fair numbers in the tan silts and sands, most appearing as rounded "bulbous" masses that reveal obvious bony structure on their worn exteriors. A few, though, show a definite resemblance in both shape and size to Brazil nuts. This "bulbous fish growth" zone is perhaps 30 feet thick at the most and trends generally south to southeast for a distance of approximately three-quarters of a mile. The fossilized bony tumors weather free from the easily eroded sediments and presented no difficulty to collect.

While "bulbous fish" growths dominate the Tulare exposures at "The Zone" site, much better preserved pelecypods and gastropods from the Upper Pliocene Tulare Formation occur several miles south in what local geologists call the Middle Dome district of the Kettleman Hills ("The Zone" area lies in what's referred to as the North Dome, by the way). Here, innumerable freshwater gastropods and pelecypods weather out whole and perfectly preserved. And because they're so exceedingly fragile, special care must be taken to prevent

damage to them. Probably a good idea is to place the mollusks in a plastic sandwich bag for safe transport back home for a closer inspection. Also present here, in the more indurated (hardened) layers of sandstone, are relatively common specimens of brackish water mussels, most of which occur in an excellent state of preservation. Almost all of the 33 species of freshwater mollusks identified from the Tulare Formation can be collected from this single locality. An obvious distinctive feature of the assemblage is that in general the fossil clams and snails are decidedly diminutive, many no larger than a quarter-inch in length. For this reason, a good-quality hand lens of ten power or better is useful when studying the external details of your finds.

A third accessible and highly fossiliferous locality in the Kettleman Hills occurs several miles south of the Tulare locality; this one's within the Upper Mya Zone of the middle Pliocene San Joaquin Formation, a place that yields innumerable three million year old pelecypods, many with both valves preserved intact. It occurs in what's called the South Dome area of the Kettleman Hills. Consisting almost entirely of estuarine clams dominated by *Mya dickersoni* and *Macoma affinis*, the pelecypodal fossils here are conspicuously abundant, although several intervals reveal only fragmental material. Still, many nice specimens of clams with both valves preserved can be secured by using attentive care and extra patience. Even though it's limited in aerial extent--the fossil-bearing layers outcrop for only a tenth of a mile or so--this isolated exposure of San Joaquin Formation sediments in the Upper Mya Zone provides a maximum of clam-shell density, with *Macoma* and *Mya* liberally distributed throughout the brown clays.

Now's probably a pretty good time to warn about a major health risk while collecting fossils in the Kettleman Hills.

It's what's commonly called Valley Fever--a potentially dangerous condition caused by inhalation of an infectious airborne fungus. Not only are the Kettleman Hills affected, but the entire surrounding southern San Joaquin Valley is also infested with the fungal spores which cause Valley Fever, or what the medical community calls Coccidioidomycosis. While most active cases of the illness resemble a slight touch of the flu, or even a minor cold, a small percentage of those infected do indeed go on to develop severe medical complications such as pneumonia, meningitis and even death; a particularly devastating, chronic form of "coccy" mimics the debilitating symptoms of tuberculosis and lung cancer, requiring months of recuperation and rehabilitation. On the other hand, a significant percentage of those exposed to the fierce fungus show absolutely no symptoms of any kind of infection.

In the southern Great Central Valley of California, there is obviously no sure way to avoid exposure to coccy. For one, it resides everywhere in the uncultivated alkaline soils of the

southern San Joaquin Valley (it's also endemic to California's Mojave Desert, San Fernando Valley, Santa Clarita Valley, and Coachella Valley--not to mention central to southern Arizona, parts of New Mexico, southern Utah, west Texas, and southern Nevada), and when the winds kick up, throwing dust everywhere, one is almost certain to come in contact with the feared spores. Fortunately, coccy is difficult for most folks to catch (individuals with compromised immune systems seem most vulnerable), and only a minuscule number of those who actually develop active symptoms progress to the most severe complications.

This is all something to consider when stirring up dust at the Kettleman Hills fossil localities, where in deference to coccy's potential virulence many collectors choose to wear surgical masks while excavating specimens.

If contending with Valley Fever fungal spores was not enough, visitors to the Kettleman Hills experience even more obstacles to paleontological nirvana. Although fossil collecting in the Kettleman Hills can be done year-round, a couple of seasons in California's Central Valley are notorious for, one, taxing bodily comfort and, two, interfering with driving safety. Summertimes, for example, are invariably ultra-hot--downright savagely hot, as a matter of fact--with daytime temperatures more like extreme desert conditions than any other geographic comparison that comes to mind. And there is no shade to speak of in the hills, except for rare oven-tolerant shrubs maybe two feet high at most. These are fine for shading the head when lying flat on one's back, when prostrate, but rather puny for providing overall precautionary protection from the elements. And while winters are usually mild, with regular seasonal rainy patterns and tolerable temperatures, a particularly impenetrable fog traditionally inhabits the Great Central Valley during December and January--the infamous Tule Fog. It clamps down tight on the entire San Joaquin Valley region for days on end, at times reducing visibilities to zero. Needless to report, driving during the reign of the Tule Fog is hazardous and harrowing. And the Kettleman Hills, lying on the west side of the Central Valley, do not seem to be exempt from these fogged conditions. Proceed at your own risk then.

When collecting in the Kettleman Hills, be sure to obey all the rules and regulations. Obtain written permission from the oil company officials where necessary, and don't enter private property without the owner's say-so. Of the three fossil localities described here, only "The Zone" requires permission from the oil corporation folks.

Happy collecting in the Kettleman Hills. But bring along a hat and plenty of water in the summer. And a searchlight during December--you never know when you might want to try to find the end of your own nose in the Tule Fog.

Chapter 17

Trilobites In The Marble Mountains, Mojave Desert, California

There are quite a number of popular rockhounding and fossil-bearing areas on the vast Mojave Desert, but one site in particular consistently attracts a great deal of attention. This is the classic Marble Mountains fossil quarry presently situated in Mojave Trails National Monument, San Bernardino County, California (officially authorized and established on February 12, 2016), where the BLM (Bureau of Land Management) continues to allow the casual collection of reasonable amounts of common invertebrate fossils--a designation that here includes trilobites; for fossil sites that occur on private property, visitors must first secure explicit permission from the land owners.

Here in the Marble Mountains abundant and well-preserved fossil trilobites can be found dating from the early Cambrian geologic age, or roughly 518 million years old--some of Earth's most ancient identifiable animals with hard parts--those wonderful arthropod trilobites that as a group survived for nearly 300 million years before their eventual extinction just prior to the rise of the dinosaurs some 245 million years ago.

The fossil trilobites in the Marble Mountains occur in a greenish to rusty-brown, platy-weathering shale called the Latham Shale, a detrital rock formation dated as lower Cambrian on the geologic time scale, or roughly 518 million years old. The Latham was named in 1954 by geologist John C. Hazzard for its excellent exposures on the western slopes of the Providence Mountains near an old and famous miner's cabin approximately 40 miles north of the Marble Mountains site--a specific place within the Providence range that is now off-limits to unauthorized collectors due to its inclusion in a federally protected wilderness area (one often needs a special Bureau Of Land Management permit in order to collect legally within a federally administered wilderness region). Throughout its "type locality," in the region around the cabin where it was first described in the geologic literature, the formation is at least 60 feet thick and contains an abundant fauna of Early Cambrian trilobites and brachiopods. At the classic trilobite quarry in the Marble Mountains, the Latham Shale averages around 50 feet in thickness and is also loaded with fossilized carapaces of trilobites, brachiopods, a siliceous sponge, a soft-bodied coelenterate (perhaps a jelly fish of some sort), an echinoderm and a mollusk or two. Virtually all of the trilobite specimens found at the old quarry--and in other exposures of the Latham outside wilderness boundaries, as well--were fragmental, although a few extraordinarily fortunate individuals reported that a whole, perfect fossil popped out at them from the shales.

The main reason there are so few complete, intact trilobite specimens to be found in the Latham--and at other early Cambrian sites, for that matter--has to do with the original fragility of the animal's exoskeleton. In actual life, trilobites possessed a thin outer covering composed of chitin--a hard, horny substance protecting the delicate soft-bodied organism within. While this material can be preserved in the rocks for millions of years, the problem is that the primitive Early Cambrian trilobites--among the oldest known animals with hard parts--had loosely attached body segments. Thus, the head, thorax (middle portion) and tail tended to separate very easily upon the animal's death. Also, trilobites molted throughout their lives, periodically shedding their chitinous external covering in much the same way their modern-day relatives, insects, crabs, scorpions and pill bugs regularly shed their own exoskeletons during the molting process. The result was that the trauma of the molting often caused the already free-moving body segments of the trilobite to disassociate and break off, to be scattered by the sea currents.

All the trilobites found in the Latham Shale belong to a single significant family of trilobites called Olenellidae, or as they are more commonly called, olenellids. These were marvelously specialized arthropods, well adapted--for a time, anyway--to their life of burrowing in the muds of the shallow marine shelves along the margins of the Early Cambrian land masses. Perhaps their most fascinating feature was their set of compound eyes, consisting of numerous minute calcite crystals in a closely packed arrangement, called scientifically a holochroal eye. It's not known for certain just how clearly the earliest trilobites were able to focus these eyes, but there is little question that, at the very least, they were able to distinguish adequately between predator and prey in their marine habitat. Mysteriously, though, the olenellids never survived beyond the Early Cambrian, roughly 510 million years ago. Why they became extinct has never been fully explained, although the most logical idea is that, ultimately, they were ill-equipped to wage a successful struggle for life in their increasingly competitive environment. The Cambrian Period had ushered in the Paleozoic Era--the first occurrence of abundant complex animal life on Earth. It was a time of explosive biological diversification, and numerous burgeoning plants and animals were vying for every available ecological niche. Perhaps the olenellids, generally recognized by paleontologists as the earliest family of trilobites to appear in the geological record, could not overcome the inevitable encroachment of other increasingly aggressive varieties of trilobites into their domain. As a group, though, trilobites made it past the Cambrian Period and went on to flourish for close to another 235 million years or so, until at last they became extinct at the conclusion of the Permian Period, around 252 million years ago.

Roughly 265 million years earlier, though, trilobites flourished and their remains have been found on practically every continent on Earth. In the western United States--in California and

Nevada, specifically--most well-known trilobite localities occur in Early Cambrian through Middle Ordovician-age rock deposits. And, of course, one of the most famous places in California to find Early Cambrian trilobites was at the prime fossil quarry in the Marble Mountains. There, the oldest geologic rock formation exposed is the lower Cambrian Zabriskie Quartzite. This is a massive, resistant accumulation of heat and pressure-altered sandstone, mostly unfossiliferous except for a stray olenellid or two, plus distinctive vertical tubes that paleontologists call *Skolithos*. These represent the feeding burrows and living chambers of some kind of ancient, extinct suspension feeder. Sitting directly atop the Zabriskie--in bold, dramatic stratigraphic contact--is the fabulous lower Cambrian Latham Shale, the specific rock deposit which contained a profusion of trilobite remains at the fossil quarry in the Marble Mountains; it's approximately 50 feet thick here, consisting of rusty-red to greenish-colored shale that typically weathers to recessive slopes, often masked by eroding debris from the overlying, younger rock formations in the local stratigraphic section.

All told, roughly 21 different species of fossils--from tracks and trails of soft-bodied organisms (who left no other evidence of their existence)--to a siliceous sponge have been identified from the Latham Shale of the Marble Mountains. In addition to trilobites, the fossil faunal list includes a coelenterate (possible jelly fish), three species of brachiopods, two kinds of mollusks, an annelid (worm), an echinoderm, *Anomalocaris* fragments (this was the largest predator of the Early Cambrian seas--olenellids likely ducked whenever they saw this monster lurking about...), and *Girvanella* nodules (precipitated by a species of cyanobacteria, blue-green algae).

But by far the most-common specimens found are trilobites, whose remains in the shales typically consist of a lone head shield called a cephalon (although thoracic and tail segments are sometimes encountered, as well). While this fragmental preservation might appear meager and non-diagnostic, a single isolated cephalon is quite enough to accurately identify the genus-species of the animal from which it originated. The seven most-abundant species of trilobites found in the Latham Shales are (in no particular order of dominance in the fauna): (1) *Bristolia bristolensis*; (2) *Bristolia insolens*; (3) *Olenellus nevadensis*; (4) *Olenellus mohavensis*; (5) *Olenellus fremonti*; (6) *Olenellus clarki*; and (7) *Olenellus gilberti*. Additional trilobites identified from the Latham Shale include Bristolia anteros, Peachella iddingsi and two new species--one an olenellid, the other a ptychopariid.

After the prolific trilobite remains, probably the second-most commonly found fossil specimen at the Latham Shale quarry was an unusual variety of brachiopod, referred to scientifically as *Paterina prospectensis*. This is one of the oldest species of brachiopods ever found, a significant find, indeed, but it was often overlooked by collectors in their single-minded eagerness to uncover trilobites. When spotted on the shales it closely resembles a

tiny phonograph record, a flattened, and circular to oval specimen slightly less than a half-inch in diameter.

Lying directly above the trilobite-rich Latham Shale is a gray to dark blue ledge-forming limestone approximately 140 feet thick. This is the slightly younger lower Cambrian Chambless Limestone, within whose dense, rather massive strata occur prolific remains of a fossil algae. Many collectors at the trilobite quarry often developed quite a fascination and fondness for these extinct remains, taking time out from their intense trilobite-searching to look for the dark oval structures, roughly a half-inch to two inches in diameter, embedded in the lighter-colored grayish-blue limestones. For decades, paleontologists have called these curious algal bodies *Girvanella*, a catchall genus used to describe any non-specified cyanobacterial remains present in rocks of Cambrian through Ordovician (began 485 million years ago) age in the Mojave Desert and neighboring Great Basin. Although very little is known about the possible life history of *Girvanella*, it is believed to have been a species of blue-green algae which, based on its exclusive occurrence in silt-free limestone, apparently preferred to propagate in warm, shallow, clear sea waters. In addition to *Girvanella* cyanobacteria bodies, the Chambless Limestone also yields two species of brachiopods, a mollusk, seven kinds of trilobites and an echinoderm.

For all intents and purposes, the Chambless Limestone marks the uppermost, or youngest exposed horizon of the lower Cambrian system in the vicinity of the trilobite quarry. Above it occur shales, sandstones, quartzites and limestones of the predominately middle Cambrian Cadiz Formation, a sparsely fossiliferous unit approximately 75 feet thick. Some five species of trilobites have been recovered from it, in addition to three kinds of brachiopods. And above the Cadiz Formation, capping the entire sequence of Cambrian formations in the Marble Mountains, is the upper Cambrian Bonanza King Dolomite, whose massive accumulations of magnesium carbonate yield occasional "bonanza" layers of trilobites, plus locally abundant *Girvanella* algal bodies.

It should be noted, of course, that the stratigraphic terminology used to describe Cambrian rock formations in the Mojave Desert and western Great Basin can be confusing. For example, throughout the northeastern Mojave Desert and southern Great Basin the three Lower to Middle Cambrian rock formations that outcrop in the Marble Mountains (Latham Shale, Chambless Limestone and Cadiz Formation) correlate stratigraphically with the lower (oldest) three members of the very widespread Carrara Formation; quite recently, by the way, one specific Carrara locality, many miles from the Marble Mountains, has generated a great deal of excitement among amateur fossil seekers, since it represents one of the few remaining places in all the Mojave and Great Basin deserts where unauthorized visitors can still legally collect Early to Middle Cambrian trilobites from the Carrara Formation.

Then, too, in western Nevada and the neighboring northern Death Valley district of California, the stratigraphic nomenclature changes once again. Here, the fossiliferous Latham Shale correlates with the upper portion of the Harkless Formation, or the locally recognized Saline Valley Formation, where it is present in the famous Waucoba Spring section of Death Valley National Park. Above the Harkless/Saline Valley complex, lies the Mule Spring Limestone, whose bluish-gray accumulations of *Girvanella*-bearing calcium carbonates correlate quite nicely with the Chambless Limestone in the Marble Mountains. And the lower to middle Cambrian Cadiz Formation is equivalent to the Monola Formation in northern Death Valley and the Emigrant Formation in adjacent western Nevada.

All of these numerous Cambrian rock formations can be dated pretty accurately at some 520 to 505 million years old. At that distant time, the Marble Mountain trilobite quarry was situated near the equator in warm, shallow tropical sea waters that encouraged a genuine proliferation of early marine plant and animals life. Today of course, thanks to the slow, sure inexorable power of Continental Drift--working its geologic magic through millions upon millions of years--the trilobite-rich deposit occurs well north of the equator in present-day North America, where in the midst of a vast arid desert an uplifted, lithified bed of primal ocean ooze holds the bodies of innumerable extinct arthropods, the trilobites, preserved for eons in a state of suspended animation, attaining a grand kind of immortality.

At the Marble Mountains fossil quarry, trilobite hunters classically fall into their own individual styles of enthusiastic fossil-finding. One major collecting method is to sit upon the talus slopes and sift through the shale debris discarded by previous visitors. The idea here is to try to locate specimens that may have been left behind by hunters who in their rush to quarry the larger, more dramatic head shields, overlooked the less-obvious, though often better-preserved trilobites. A second and arguably more efficient technique is to clear a small, localized area of the overlying loose shale and then, with a quality chisel, in combination with a geology rock hammer or sledge hammer (be sure to sear safety glasses at all times), work your way through the shales, layer by layer, splitting the rocks along their natural bedding planes. This obviously involves a lot of work, but it is definitely the most productive way to find fossils. Wrap the pieces of fossiliferous shale in heavy-duty paper towels or even newspaper, to ensure their safe transport back home. Very little cleaning of the specimens is usually required, perhaps just a careful scrubbing with water and an old toothbrush to remove any dirt or grime caking the surfaces of the shales.

Occasionally you may want to try to expose an inviting-looking, partially exposed head shield obscured by a layer of matrix on a large slab of fossiliferous shale. Proceed with caution, though, since the fossilized chiton carapaces are deceptively fragile; they tend to crack or crumble if subjected to an improper chiseling technique. Before attempting to work out a

potentially exceptional find, practice on less well-preserved specimens or those you wouldn't mind losing should you make an accidental and fatal slip of the hand.

There are of course loads of trilobites still remaining to be found in the Latham Shale, even after many decades of intensive collecting by both amateur paleontology enthusiasts and professional invertebrate paleontologists.

The history of fossil explorations in the Marble Mountains begins in the early 1900s when geologist N. H. Darton discovered the southwesternmost exposure of fossiliferous Cambrian rocks in the United States. Darton was thus the first scientist to collect trilobites in the Marble Mountains, but it's not clear whether his finds came from the exact area of the present-day trilobite quarry. For identification and age-assignment of the specimens, Darton submitted his collection to perhaps one of the most famous and knowledgeable Cambrian Period expert of all time Dr. Charles D. Walcott, who considered the fossils to be "undoubtedly of Cambrian age, probably Middle Cambrian." That would indeed be correct, if Walcott had identified trilobites collected exclusively from the Cadiz Formation--but nobody knows for certain where in the local stratigraphic column the fossils came from. If on the other hand he examined collections Darton secured from what today we call the Latham Shale, then Walcott was decidedly incorrect on the specific geologic age-assignment. At any rate, the question is probably moot, since the exact faunal succession of the Cambrian Period had not yet been definitively worked out in the early 1900s.

In 1907 Darton published a brief announcement of his find in the Journal Of Geology, volume 15, number 5--a paper entitled, *Discovery of Cambrian Rocks in Southeastern California*. At that time Darton referred to the area of discovery as the Iron Mountains, a name soon to be discarded interestingly enough by geologist Clifton W. Clark, who published the first detailed geological study of the region in 1921. In that paper, published in the University of California Publications Bulletin of the Department of Geological Sciences, volume 13, number 1, Clark wrote that he preferred the name "Bristol Mountain" to "Iron Mountain," because this was the name given on "the official map of San Bernardino County." While this would appear to be a sound and logical approach to deciding the name of an important geographic area, evidently that "official" map was far from the definitive source. Twelve years later, in 1933, John C. Hazzard and Colin H. Crickmay published their *Notes on the Cambrian Rocks of the Eastern Mohave Desert, California*, University of California Publications in Geologic Science, volume 23, number 2, in which we find the "common name" given to this area is now the "Marble Mountains;" and besides, report Hazzard and Crickmay, "this has likewise been used on the topographic maps made by the Los Angeles Water Bureau."

End of discussion. If the Los Angeles Water Bureau of 1933 could ignore the evidence of the "official" map of San Bernardino County and conclude that the region should be called the "Marble Mountains"--not the Iron Mountains or even Bristol Mountain--there can be little room for doubt regarding the authenticity of the name.

A great bulk of scientific writing has been published on the fossils of the Marble Mountains. Likely candidates for the best reference works available include-- *The Lower Cambrian Olenellidae of the Southern Marble Mountains, California*, by Joseph F. Riccio, Bulletin of the Southern California Academy of Sciences, volume 51, part 2, May-August, 1952; *Fauna of the Cambrian Cadiz Formation, Marble Mountains, California*, by John F. Mason, Bulletin of the Southern California Academy of Sciences, volume 34, number 2, 1935 (Even though Mason specifies that his studies focused on the fossils of the Cadiz Formation, his descriptions of specimens leaves little doubt that he was actually investigating the faunas of what was later understood to be the Latham Shale.); *Early Cambrian faunas from the Marble and Providence Mountains, San Bernardino County, California*, by J. D. Mount, Bulletin of the Southern California Paleontological Society, volume 6, number 1, 1974; *Characteristic of Early Cambrian Faunas from Eastern San Bernardino County, California*," by J. D. Mount, Paleontological Tour of the Mojave Desert, California-Nevada, Southern California Paleontological Society Special Publications, number. 2, 1980, pp. 19-29; and *Cambrian Fossils from the Mojave Desert*, by C. E. Resser, Smithsonian Miscellaneous Collections, volume 81, number 2, 1928, which bears a noted distinction: it's the very first systematic discussion of fossils from the trilobite quarry in the Marble Mountains.

The Marble Mountains trilobite quarry certainly used to be a great place to bring children and others who wished to experience the joys of fossil collecting for the first time. The trilobite specimens were easily spotted in the shales, and because they were so exceptionally abundant everyone was almost certain to take home a memorable find. Camping sites there tended to be dry, as most folks who wished to spend time collecting brought along their own food, water and wood, pitching tens or parking their cars along reasonably flat, level areas considerably downslope, well-removed from the actual fossil quarry.

The trilobite quarry in California's Marble Mountains holds a special place in my heart. I was taken there as a youngster on my very first fossil-hunting trip (long before the federally established Trilobite Wilderness, of course). We arrived in the dead of night, a winter wind howling from the north, the temperature hovering around freezing; and we pitched our tent on the rock-strewn ground near a prominent, convenient parking area amidst the rugged desert terrain. I found sleep difficult to come by that night, but it wasn't the cold that kept me alert. Nothing as "commonplace" in southern California as a wind chill factor in the teens could have prevented sleep. I was all revved up, ready to find those trilobites right then and

there, with a flashlight if necessary. I lay awake listening to the savage whipping of the walls of our canvas tent, envisioning numerous perfect trilobites specimens in my hot little hand, knowing that they represented some of Earth's oldest identifiable remains of an animal with hard parts--a creature who 518 million years ago had actually witnessed its primordial environment through crystal eyes of calcite, an amazing adaption in the progression of life on our planet.

That following morning we hiked up the footpath to the quarry, against the crazy frigid sting of a Mojave Desert wind. All along the trail I kept inspecting the exposed shales, trying to imagine what a real trilobite in the rocks would look like. I had often poured over their pictures in books--but, to genuinely hold one, to actually touch the once-living representative of such awesome prehistory was anticipation of the most electrifying kind.

At last we arrived, and the fossil quarry was before us. I started probing through the shales left behind by others. Trilobites began to show up almost everywhere I happened to look. This was indeed, a fossil-hunter's paradise. With each head shield that came to light, I inspected the sad stony eyes of a creature whose descendants survived for over 250 million years.

It didn't seem fair that the first of these great animals, the olenellids, should die out while their lucky relatives endured for eons to come. There was an injustice here I firmly decided, although the uncluttered mind of a child could not then have known of the Darwinian struggle for survival of the fittest and other such impressive explanations for the olenellids' disappearance.

I never did find that perfect, complete trilobite I had dreamed of during my first fossil hunt in the Marble Mountains. But it didn't matter. That single experience charged me with a life-long fascination with fossils and the stories they can tell us of distant, long-vanished ages.

Chapter 18

Late Triassic Ichthyosaurs And Invertebrate Fossils In Nevada

Introduction

Take field trips to two classic, world-famous Late Triassic (Late Carnian to Norian Stage age--roughly 218 to 210 million years old) fossil localities in Nevada. First off, observe in-situ at Berlin-Ichthyosaur State Park, in what geologists call the upper Triassic Luning Formation, the remains of several huge ichthyosaurs--an extinct marine reptile that ruled Mesozoic Era seas for many millions of years--exposed in a fossil quarry, similar in scientific conservation style to the Late Jurassic geologic age bone quarry at Dinosaur National Monument in Utah-Colorado; and then, drive outside the state park's boundaries to find pelecypods, gastropods, brachiopods and ammonites (Triassic Period types are also called ammonoids) in the very same rock strata that preserved the ichthyosaurs.

Next, head over to Coral Reef Canyon, several miles from Berlin-Ichthyosaur State Park, a place situated on America's public lands, where paleontology enthusiasts can collect many species of corals, sponges, echinoids (sea urchins), gastropods, pelecypods, belemnites (straight-shelled cephalopods related to modern squids) and ammonites (such Triassic forms are also called ammonoids) from the upper Triassic Luning Formation.

Part 1—Field Trip To Berlin-Ichthyosaur State Park, Nevada

Berlin-Ichthyosaur State Park in Nye County, Nevada, contains the greatest concentration of some of the largest ichthyosaurs ever found. Although it's true that a later discovery in Canada disclosed a species that actually grew somewhat bigger than the Nevada examples--recognized for many years as the largest ever recorded--the Nye County locality nevertheless remains unique in its abundant association of huge ichthyosaurs.

During Late Triassic geologic times, these were enormous predatory marine reptiles that grew to 60 or more feet in length and by many estimates could have weighed in excess of 50 tons. Two-hundred and eighteen million years ago they lived in a tropical sea that covered much of present-day west-central Nevada, plus portions of Oregon, Washington, California and British Columbia, as well. The now stone skeletons at Berlin-Ichthyosaur State Park have been exposed by paleontologists in a quarry in Union Canyon, roughly a mile and a half southeast of the old mining camp of Berlin, now a ghost town protected in what's colloquially called a state of "arrested decay." The fossil reptile bones of the great "fish-lizards" can be observed in-place in the sedimentary rocks of the Luning Formation--an ichthyosaur graveyard, the only one of its kind in the United States.

In addition to ichthyosaurs, many other kinds of aquatic life thrived in that ancient ocean some 218 million years ago. Pelecypods, gastropods, ammonites (such Triassic types are also called ammonoids) and brachiopods can also be found in the Late Triassic rocks present in Union Canyon. Most of the famed fossil-bearing section is currently included in the Nevada state park system, but happily for folks infused with paleontological enthusiasm there are not a few areas outside the Berlin-Ichthyosaur park where fossils can still be collected legally, without formal prior approval from the authorities.

The fossil-yielding region is easily reached. Take the well-posted turnoff to Berlin-Ichthyosaur State Park just north of Gabbs along State Route 361. This junction lies 29 miles south of Highway 50 and 34 miles north of Highway 95. Go east roughly 20 miles or so, through classic Great Basin territory, to the intersection with the dirt road to Ione (which is around seven miles to the north). Bear to the right here (south) in the direction of Berlin ghost town, which lies just south of the junction.

This is an interesting little ghost town, part of the Berlin-Ichthyosaur State Park. Many of the old wooden buildings have been mildly renovated (such as they are, as it were), and footpaths throughout the site lead to instructive plaques whose writings detail life and activity in a typical Nevada silver mining camp of the late 1800s, through the early 1900s.

The original silver ore locations at Berlin were made in 1895 by a state Senator Bell, who soon sold his property to John G. Stokes of New York. In 1898, the Nevada Company, with a notorious reputation for its aggressive acquiring of mineral rights, bought out the Stokes claims. In an attempt to consolidate its regional influence, the company quickly purchased the Pioneer and Knickerbocker mills in the vicinity of Ione, moving all of the machinery to the Berlin site. What the Nevada Company intended to do was construct a state of art, brand new thirty-stamp mill to begin a systematic and, with a fair amount of luck, profitable development of the reportedly extensive ore bodies.

During the boom years roughly 250 persons lived in Berlin. They had a general store, post office, and even a stage line to other mining towns in the immediate area. Although the silver ore reserves had initially appeared worthy of exploitation, the yields turned out to be rather disappointing. In 1909, the big mill originally financed by the Nevada Company shut down. But an article that year in a newspaper at Goldfield, Nevada, asserted that there was certainly enough silver ore remaining to fuel the mill for an additional three years. Nobody seemed to believe this optimistic evaluation, though. Berlin had apparently run its course.

Then, in 1911, some investors decided that it might be worthwhile to process the low grade, spent mining tailings at Berlin--the stuff left over from the original operations. A fancy new

and improved 50-stamp mill was constructed (the hulk of which towers above the road to the ichthyosaur bone bed) and the mounds of tailings went through a second pulvarization. The 50-stamper operated for three years, extracting a paltry two dollars and fifty cents to the ton of material processed. During World War II, all of the equipment in the mill was systematically hauled off, stripped, its metal evidently used in the allied effort.

Continue south along the dirt road through Berlin. To the west of the path spreads the awe-inspiring expanse of Ione Valley, a great sage-coated basin that hugs the base of the Shoshone Mountains. At a point approximately eight-tenths of a mile from the road back to Gabbs and State Route 361, the path turns east through pinyon pine and juniper-studded Union Canyon, which has been carved in the upper Triassic Luning Formation, deposited here in the vicinity of Berlin-Ichthyosaur State Park during the Late Carnian through Early to Middle portions of the Norian Stages, about 218 to 210 million years old. Elsewhere in Nevada, the Luning Formation includes strata solely of Early to Middle Norian Stage geologic age--that is, around 216 to 210 million years old. The limestones and shales exposed throughout Union Canyon not only contain the world-famous ichthyosaur bone graveyard, but in addition a wealth of excellently preserved mollusks--including ammonites, pelecypods and gastropods.

Almost immediately upon turning east to Union Canyon, you will spot to the right of the road, in the distance, the impressive A-frame construction which houses the ichthyosaur skeletal quarry. At last check, the fossils are on display here on weekends only throughout about half of the year, accessible to the public for a nominal fee, from around mid-March to mid-November. One would do well, though, to check with the ranger station in Berlin for specific times; in other words, don't rely completely on published time schedules provided on the internet. Paleontologically informed rangers give talks at the quarry site, where the individual skeletal remains of nine huge ichthyosaurs have been excavated and left in place--all in their original burial positions--in sedimentary rocks deposited roughly 218 million years ago during the youngest phases of what stratigraphers call the Carnian Stage of the Late Triassic. A typical tour usually lasts about 40 minutes and consists of a general geological, anatomical and behavioral overview of ichthyosaurs, plus a detailed explanation of all the specific kinds of skeletal elements preserved on the quarry floor--skulls, jaws, vertebrae, flippers and ribs, among others. It's a genuinely educational, inspiring and fun tour. At the quarry parking lot you can also view a 57-foot bas-relief, life-size reconstruction of a Union Canyon ichthyosaur, Nevada's state fossil, *Shonisaurus popularis*--a specimen that in actual life probably weighed in excess of 40 tons.

The first fossil ichthyosaur bones in Union Canyon were certainly observed by silver-gold prospectors in the 1890s. Perhaps the old-time miners really didn't fully appreciate the finds,

but as the often-told story goes, folks in Berlin regularly placed them as decorations in their fireplace hearths. Some of the more ingenious individuals even used the large disc-shaped vertebrae as dinner plates—although, it should be pointed out that several historians have dismissed out of hand this particular story, claiming that the genesis of it derives from famed professor Charles L. Camp, an ichthyosaur aficionado intimately involved in the early scientific investigations of the Union Canyon bone bonanza, who supposedly exclaimed with excitation that the creature's eyes were as large as dinner plates. Then again, nobody with definitive documentation has ever disproved the claim, either.

The pioneering scientific investigation of the ichthyosaur deposit came in 1929 when a geology professor at Stanford University, Siemon W. Muller, visited Union Canyon. He studied the exposed vertebrae specimens in the Late Triassic strata and determined that they belonged to an ichthyosaur. While the find was incredibly significant, Muller decided that there was no use in attempting to excavate the fossils, at that time. First off, he concluded, they were very large--way too bulky to transport safely back to civilization from such a remote region. And second, the ichthyosaur skeletons were buried far too deep in the hard sedimentary section; he could not be certain that a quarrying operation would be successful. Indeed, he speculated such digging might actually do more harm than good. In the end, Muller returned to Stanford University without really determining the full extent of the fabulous fossil occurrence. Perhaps he was convinced that he had obeyed that golden Shakespearean rule of conduct, that "discretion is the better part of valor." To Muller's credit, it must be emphasized of course that some reports disclose that when he finally returned to Stanford from his visit to Union Canyon, he tried to drum up interest in his ichthyosaur finds.

Fortunately, more actively persistent individuals would not let the fossils rest in peace in those remote reaches of the Great Basin. An acquaintance of Professor Muller, Margaret Wheat--an avid amateur fossil hunter--visited Union Canyon in the summer of 1952. What she saw immediately impressed her: nicely preserved ichthyosaur bones still partially articulated; that is, the skeletal elements were essentially aligned in their natural anatomical relationships. She then contacted Dr. Charles L. Camp, a noted paleontologist and director of the University California Museum of Paleontology in Berkeley, California. The pair returned to the locality in 1953. It didn't take Dr. Camp long to determine the grand importance of the exposed ichthyosaur skeletons--that here was perhaps the greatest accumulation of the largest ichthyosaur specimens ever encountered. A major paleontological dig was definitely in order.

The scientific excavations began in 1954 under the direction of Dr. Camp and his colleague, Samuel P. Wells. Along with a select group of paleontology and geology students, the scientists carefully removed the thick, indurated limestone overburden to expose the

mineralized remains. The digging was strenuous, tedious and exacting. In all, seven field seasons were required to get the job completed: from 1954 through 1957, then a second session from 1963 to 1965. When the "smoke had cleared," Dr. Camp had identified at least 37 adult ichthyosaurs from the upper Triassic Luning Formation of Union Canyon. These included three distinct species, each of which exceeded 37 feet in length. One species, *Shonisauris popularis* (named Nevada's state fossil, by way), was for many years the largest ichthyosaur ever discovered (a later find in Canada exceeds by somewhat the Union Canyon critter)--the ultimate predator of the Late Triassic seas, a frightening giant that grew to almost 60 feet in length and weighed 40 to 50 tons.

Ichthyosaurs were exclusively marine, sea-going reptiles. They first appear in the geologic record during the middle portion of the Triassic Period, about 240 million years ago. The earliest forms grew to an average length of about three to 30 feet, the latter roughly the size and weight of a modern-day killer whale. One mid-Triassic species discovered in the New Pass Range of north-central Nevada in 1868 was described scientifically by famous paleontologist Joseph Leidy as belonging to a new genus of ichthyosaur, *Cymbospondylus*. It had a three-foot long skull filled with sharp conical teeth, perfect adaptions for preying on a balanced diet of shellfish (ammonites, belemnites and various other cephalopods), small ichthyosaurs (such as *Mixosaurus cornalianus*, an undersized type that grew to only three feet), and any variety of fish around which it could clamp its vice-like jaws. Later, more advanced specimens of ichthyosaurs apparently continued these feeding patterns. In comparison with ichthyosaurs studied from the Late Triassic and Jurassic Period, the tail of the early species was rather primitive; there was no bend to it, which may indicate that it possessed a limited ability to propel itself through the water. It is also interesting to note that the eye socket of the 30-foot *Cymbospondylus* was actually smaller than its diminutive three-foot long relative *Mixosaurus cornalianus*.

Ichthyosaurs reached their zenith of adaptation in the Late Triassic through mid-Jurassic seas. For approximately 50 million years they were the so-called biggest fish in pond, at the very top of the marine biological food chain. While the species of the Jurassic Period were much smaller than their Triassic predecessors--they grew to a maximum length of only 12 feet--the later ichthyosaurs possessed stream-lined bodies built for speed and agility. By the close of the Jurassic, though, approximately 145 million years ago, the numbers of species had been greatly reduced. Ichthyosaurs indeed survived the Jurassic Period, but could only manage to hang on half-way through the succeeding Cretaceous Period of the Mesozoic Era, eventually going extinct by 90 million years ago, roughly 24 million years prior to the demise of the dinosaur.

Many explanations have been advanced to account for the ichthyosaur's disappearance. Some investigators suggest that the rise of plesiosaurs and monosaurs, reigning reptilian terrors of the Cretaceous seas, contributed to their inevitable decline. Another line of thought holds that the increase in numbers of sharks hastened their demise, that these large predatory fish began to feast on the once invincible ichthyosaur, reduced in Cretaceous times to a modest-sized creature less than 12 feet long. In the end, perhaps ichthyosaurs were just too specialized to last. During their doomed Cretaceous days they subsisted primarily on cephalopods such as ammonites, belemnites, nautiloids and perhaps giant squid (if true, then ichthyosaurs anticipated by many millions of years the feeding habits of modern sperm whales), as well--molluscan varieties, excepting the squid, that in a paleontologically provocative coincidence began their own sure decline to disappearance in the Middle Cretaceous--just as the ichthyosaurs went extinct.

It is not known for certain how the ichthyosaurs of Union Canyon came to be preserved, but investigators have developed three competing explanations of what happened here some 218 million years ago.

At present, many vertebrate paleontologists believe that all of the ichthyosaurs preserved in the upper Triassic Luning Formation at Union Canyon accumulated gradually as individual deaths--that is, not catastrophically as a group of animals--in rather deep, oxygen-poor waters--perhaps the result of natural deaths or a stray kill here and there from anoxic sea waters. The scientists base their conclusions primarily on how they choose to interpret the geologic meaning behind the lithology of the sedimentary rocks within which the ichthyosaurs have been preserved--a thick deposit of calcium carbonates called by many geologists a "shaly limestone"--a type of rock whose deposition, they say, probably occurred in deeper waters, not in relatively shallow areas of the Late Triassic sea. Other geologists interpret the evidence differently, of course, and see shallow water, even a beach deposit, where different eyes would observe an abyss.

A more recent avenue of speculation borders perhaps on the fanciful, if not outright fantastical. One imaginative, creative visitor to the fossil quarry at Union Canyon came away with the distinct impression that he could see a cephalopodic pattern in the way the ichthyosaur vertebrae were aligned in the rocks. That pattern reminded the visitor of the suction cups on the arms of an octopus. And that observation led, further, to the idea that perhaps the 37 to 60 foot-long Luning Formation ichthyosaurs were attacked by something even more terrifying in the Triassic--yes...a giant octopus (a Kraken of mythology, as it were), who grasped the passing ichthyosaurs with its monstrous tentacles: hauling the unlucky vertebrates back to his invertebrate's lair; consuming there the marine reptiles; and then curiously arranging the vertebrae in a quasi-self-portrait, reminiscent of its own suckers.

But, the original idea proposed by Dr. Charles L. Camp remains perhaps the most compelling explanation yet offered.

At that date, some 218 million years ago, present-day Union Canyon was located slightly north of the equator, near the shoreline of a warm water tropical embayment, whose original position has of course been transported by the slow, sure, inevitable laws of plate tectonics to its present place in an arid Great Basin terrain. Ichthyosaurs and other sea-going animals were able to swim in and out of this bay, returning to the open marine waters whenever they so desired.

But then something treacherous happened.

Rapidly falling tides stranded at least 37 fully grown ichthyosaurs on a lonely mudflat. No human eyes were there to witness the slow suffocation of these magnificent sea reptiles when they were unable to lift their massive 40 to 50 ton bodies off of the beach. Yet, it must have been a haunting sight. An ichthyosaur was perfectly adapted to a life exclusively in the ocean; it could not hope to operate once out of water. An identical phenomenon happens today when whales and porpoises are occasionally beached. When the tides returned, the ichthyosaur carcasses were aligned parallel with wave action near the shoreline. Scavengers plucked the reptilian flesh, helping to expose the bones to the elements. In time, only the skeletons of the great marine reptiles remained along the ooze-rich mudflat.

Over the course of geologic time, the bones were eventually covered by thousands of feet of sandstones, shales, limy muds and limestones belonging to the upper Triassic Luning and Gabbs Formations and the lower Jurassic Sunrise and Dunlap Formations. Minerals brought in by percolating lime-rich water slowly replaced the organic content in the skeletons. Given enough time, perhaps millions of years, the once living-breathing ichthyosaurs finally turned to stone.

The sediments that accumulated in the Late Triassic through Middle Jurassic seas were apparently unaffected by mountain-building processes until approximately 60 million years ago. This is when the western end of the continental plate carrying North America northward began to collide with what geologists call the Farallon Plate. Tectonic activity began on a dramatic, widespread scale. Great faults appeared across what's now west-central Nevada, thrusting the once flat-lying marine-originated muds, silts, sands and carbonates thousands of feet upward. The Late Triassic mudflat, with its mineralized ichthyosaur bones, became part of the Shoshone Mountains, uplifted some 7,000 feet higher than the level of the sea in which it was originally deposited. Erosion of the ichthyosaur-bearing Lining Formation began in earnest during the glacial stages of the Pleistocene Epoch two and a half million years ago.

Hundreds of feet of sedimentary rock were worn away until at last, some few thousand years ago, the ichthyosaurs came to their first light of day in 218 million years.

The fossil ichthyosaurs of Union Canyon were first officially protected in 1955 when the Nevada legislature created Ichthyosaur Paleontologic State Monument; many years later, with the inclusion of Berlin ghost town, the locality became known as Berlin-Ichthyosaur State Park. In 1966, the distinctive A-frame shelter over the main fossil quarry (called the Visitors' Quarry) was erected, an excellent and attractive means of protecting the 218 million year-old remains in the rocks. Ultimately, in 1975 Berlin-Ichthyosaur State Park became a Registered Natural Landmark--a designation reflecting a region of "exceptional value to the citizens of the United States."

Many fossils have been recovered from the upper Triassic Lining Formation of Union Canyon. At the Visitors' Quarry, display cases contain beautiful specimens of ammonites and pelecypods that date from the day of the ichthyosaur. Exceptionally fossiliferous rocks occur at the western end of Union Canyon, but those exposures lie within the park's boundaries; obviously, they are off-limits to unauthorized amateur paleontology enthusiasts.

As a matter of fact, the Union Canyon outcrops of the Luning Formation used to reign supreme as world-famous producers of several key genera of Late Triassic transitional Carnian-Norian Stage ammonites, plus three kinds of nautiloid cephalopods, as well. Unfortunately, repeated intensive professional paleontological expeditions, in addition to frequent amateur hobby collecting (prior to the area's status as a state park, of course) spanning 100-plus years has reduced surface cephalopodic occurrence to virtual nonexistence. There are still plenty of other kinds of invertebrates to observe there, one must note--pelecypods and brachiopods and gastropods, primarily. Stratigraphers allow, though, that should paleontologists conduct additional formal, structured fossil quarrying at Union Canyon, exposing more ichthyosaur skeletons in the rocks, abundant ammonites, preserved in their original layers of zonation--one key species stacked atop another in succession--could again be studied. Among the ammonites (such Triassic ceratites varieties are also referred to as ammonoids, by the way) described from the Luning Formation of Union Canyon were such important genera as *Klamathites*, *Mojsisovicsites*, *Tropites*, T*ropiceltites*, *Guembelites* and *Discophyllites*.

But do not despair. The fossiliferous Luning Formation is exposed over a rather sizable area in this part of Nevada's Great Basin terrain. While it's true that all of the principal mollusk-ichthyosaur-bearing horizons have been officially protected, representative outcroppings of fossil-yielding Luning Formation strata can still be explored outside the park's boundaries. The trick, of course, is to know precisely where those boundaries lie. And that means

obtaining the most recent up-to-date map one can find. Territory outside Berlin-Ichthyosaur Park lies within a United States National Forest, administered by the US Forest Service, where hobby collecting of reasonable amounts of common invertebrate fossil specimens has long been allowed--although that too could change without any manner of advance warning. Be sure to check with the local rangers in Berlin for the most recent fossil collecting regulations. Of course, all fossil vertebrate remains must be left where found, unless one has secured a special use permit, a permit given solely to individuals with a minimum B.S. degree from an accredited university, whose research projects can be verified as authentic by independent investigations. Taking photographs of fossil vertebrates, when found, is not yet illegal.

Ok--so now you've completed the necessary due diligence, your proverbial homework, and you're presently ready to head out into the hills surrounding Berlin-Ichthyosaur State Park to fossil prospect. Where to look? One would do well to watch for the so-called "shaly limestone member" of the upper Triassic Luning Formation, the very same stratigraphic unit that preserved the ichthyosaur bone bed, plus enormous quantities of mollusks (ammonites-pelecypods-gastropods) and to a lesser extent brachiopods back at the Visitors' Quarry. In natural outcrop, it's a thinly bedded dark brown to black limestone, sometimes visible along the hillsides as poorly to decently exposed "ribs" and ledges.

More often, though, junipers and pinyon pines have formed a dense "pygmy" forest atop the Late Triassic rocks, which have been so brutally eroded that they resemble little more than an alluvial soil cover. But in reducing the strata to rubble, the powers of erosion have also released numerous fossil mollusks and occasional brachiopods once embedded in the limy matrix. Simply hike away from the dirt roads, into the pleasing pitch-scented perfume of the pines and junipers, and watch carefully for the perfect pelecypods (*Septocardia* types with both valves intact) and gastropods, primarily (a few ammonites and brachiopods can also be located)--all weathered out whole and intact, ready to be collected.

And keep your eye out for rattlesnakes, too! During my last visit, I had one close encounter of the viperous variety--an angered anguiform animal buzzing its tail off at my intrusion into its domain. I did not contest his territorial demands. Although I have run into two rattlesnakes during my explorations here, rest assured that the snake population is likely no denser than anywhere else in the Great Basin. It's just that I have a special ability to locate the reptiles in the bush.

For those wishing to spend a few days at Union Canyon, a clean spacious campground can be found near the fossil quarry. It is well posted and easy to locate. If a visit is made during summer, be prepared for warm temperatures plus swarms of blood-sucking gnats. At least one of the species of insect is especially virulent, causing maddening allergic reactions that

typically do not flare up until a day or so after the bite. No one brand of insect repellent seems to provide a reliable safeguard against the onslaught. Expect maximum protection for a couple of hours, at most, then you're on your own.

Two-hundred and eighteen million years ago, Union Canyon was a tropical bay situated near the equator. The warm waters supported many species of ammonites, pelecypods, gastropods, brachiopods and ichthyosaurs. Today, the fossilized remains of these animals can be found the upper Triassic Luning Formation deposited in that Mesozoic sea--a vast ocean that was alive with the great fish-lizards, the ichthyosaurs, who were in their day just as graceful and as efficient predators as our modern-day killer whales.

Part 2—Field Trip To Coral Reef Canyon, Nevada

Numerous species of Late Triassic-age fossils (roughly 228 to 201 million years old) have been identified from extensive accumulations of marine-originated Mesozoic Era sedimentary rocks in Nevada. The area surrounding Union Canyon, at Berlin-Ichthyosaur State Park in Nye County, is certainly one of the more prolific producers--from strata geologists call the Luning Formation--a rock unit that also entombed throughout its widespread exposures in central to west-central Nevada abundant marine Triassic paleontological remains.

An additional remarkable and productive exposure of the fossil-bearing Luning Formation can be explored in a place called Coral Reef Canyon, situated several miles from the Union Canyon ichthyosaur bone bonanza. Here, the Luning reaches an estimated stratigraphic thickness of over 6,000 feet, and it's loaded with all kinds of plentiful invertebrate fossil remains--in addition to not uncommon ichthyosaur bones, to boot.

At Coral Reef Canyon, the most consistently fossiliferous sections of the Luning Formation are certainly better exposed than anywhere else in Nevada, yielding a prolific assortment of well-preserved invertebrate fossil specimens, including: foraminifers; five species of thalamid (chambered) sponges; five kinds of spongiomorphs (peculiar types that resemble both sponges and corals); brachiopods (the Luning Formation yields more species of brachiopods than any other Mesozoic Era locality in North America); gastropods; pelecypods; belemnites (straight-shelled cephalopods related to the modern squid); ammonites (the Triassic types are also called ammonoids); echinoids (sea urchins); crinoids; ostracods (a minute bivalved crustacean); and some 23 varieties of corals.

Indeed, one of the more significant scientific aspects of Coral Reef Canyon is the prominent presence of coral reefs preserved in the upper Triassic Luning Formation--massively bedded calcium carbonate accumulations which yield innumerable remains of corals, all tangled together in their original growth positions. While few of the coelenterates are perfectly

preserved, their sheer abundance in rocks of proved Triassic age--a geologic period that witnessed a precipitous decline in the numbers of coral species from the preceding Permian Period of the Paleozoic Era--commands a kind of paleontological awe. At the conclusion of the Permian Period, for example, all of the once-dominant rugose and tabulate corals went belly-up, extinct.

Based on the overwhelmingly abundant fossil material identified from Coral Reef Canyon, paleontologists have been able to date the Luning Formation exposed there with great accuracy. It was deposited during the lowermost and middle portions of the Norian Stage of the Late Triassic Period, or roughly 216 to 210 million years ago. Many early investigators believed the Luning in Coral Reef Canyon included strata representing the Carnian, the oldest stage of the Late Triassic. But more accurate determinations, based on suites of key species of ammonites, have pretty much constrained the age of the Luning Formation there to the younger Norian Stage.

In a bit of good fortune for geologists, paleontologists and amateur fossil seekers alike, the fossiliferous exposures at Coral Reef Canyon are accessible by conventional vehicle. This is not to suggest that the route to the site is paved--far from it. Collectors must still safely negotiate a system of well-graded dirt paths (kudos to the Nevada Department of Transportation for keeping thousands of miles of dirt roads throughout the Silver State in at least a modicum of decent shape most of the time) that are subject to periodic degradation due to washouts and windstorms that can at least temporarily deteriorate the quality of the driving surface. Too, one must not automatically assume that the Bureau of Land Management continues to allow hobby fossil collecting in Coral Reef Canyon. At last check, all was good to go--legally. Always remember to contact the local district BLM ranger to learn of any new regulations and/or restrictions.

At Coral Reef Canyon, representative fossiliferous outcrops of the Luning Formation are clearly obvious, even to casual inspection. The steep slopes throughout the area consist of interlayered reddish-brown shales and dark bluish-gray limestones, from which abundant invertebrate fossils can be secured. These sedimentary outcrops represent the oldest of three recognized members (subunits) of the upper Triassic Luning Formation, generally referred to as simply "member one" by field geologists and stratigraphers who’ve mapped the region.

Member one is on the order of 2,700 feet thick and is, happily for the student of paleontology, best exposed here in the neighborhood of Coral Reef Canyon. It also happens to be--by far--the most fossiliferous of the three known subunits in the Luning Formation.

Member two on the other hand is a monotonous sequence of barren shales, sandstones and conglomerates that can be observed in bold outcrop above the predominantly carbonate accumulations of the older member one. The youngest sequence in the Luning, member three, is roughly 1,600 feet of pure limestones and dolomites (magnesium carbonate) from whose oldest exposures (those lowest in the stratigraphic section) most of the ammonites identified from the Coral Reef Canyon complex have been collected.

Member one, within which almost all of the abundant fossil specimens occur throughout Coral Reef Canyon, is easily recognized from afar due to its distinctive mix of brownish shales (often containing abundant gypsum; occasional slabs of rock reminiscent of petrified wood are from time to time encountered in these shales, yet no such fossil plant material has been formally documented from Coral Reef Canyon) and thick "rib-like" protrusions of dark blue to gray limestone. Most collectors quickly discover that only those massive reefs of limestones yield significant concentrations of fossil material; the shales provide far fewer finds.

And what a cache of interred invertebrate remains the limestones have preserved. Almost two dozen species of corals are available, many in their original reef form of 215 million years ago. Also seen in the rocks here are: several interesting species of brachiopods, including *Spondylospira lewesensis*, *Plectoconcha aequiplicata* and *Zugmayerella uncinata*; thick-shelled oysters, plus other profuse and diverse pelecypods; belemnites; echinoids; sponges (often identified by their hollow central cavity when seen in cross-section); ammonites; and even disarticulated ichthyosaur skeletal elements (of course, without a special use permit issued by the Bureau of Land Management, one must leave the bones alone).

It should be noted of course that a majority of the fossil material observed in the rocks is fragmental. The corals, for example, while generally abundant at many Luning outcrops, are seldom if ever preserved as a complete colony; they are instead found weathered out the limestones as modest-sized chunks up to a few inches in diameter. When observed in situ the coral colonies often attain impressive dimensions, sometimes several feet across, though such stunningly attractive specimens are in practical experience impossible to remove from the densely solidified matrix without the use of hard-rock mining techniques--sledge hammer, crow-bar and Superman's back. The best preserved remains from member one of the Luning Formation include: many weathered-free, complete spiriferid and terebratulid brachiopods; *Septocardia*-type pelecypods with both valves preserved intact; large and small oyster-like pelecypods; echinoids (sea urchins--they are prized, but uncommon specimens); belemnites; sponge-chunks; coral chunks; and ammonites (also not overly plentiful, but usually pretty well preserved when found).

Coral Reef Canyon attracts many fossil specialists from all across America. It is truly one of the great marine Late Triassic fossil localities in North America--and for the astounding diversity of specimens available to study it indeed may have no equal. A serious collector could spend several consecutive field seasons in the Coral Reef Canyon district and still not run out of new outcrops to explore.

As a matter of fact--several professional paleontologists have done just that, conducted extended collecting expeditions to the area. One of the earliest investigators was a paleontologist with a major university on the US West coast. In his own words, the scientist later wrote that he had spent "several seasons' work on the Triassic rocks," focusing his attention on the profusion of corals in Coral Reef Canyon. He was the first to recognize in the canyon species of Triassic reef-building corals then known only from the Alpine region of Europe.

Back in his laboratory, the paleontologist eventually identified over a dozen species of corals from the upper Triassic Luning Formation (the list has since grown to some 23 species, and counting), including such diagnostic types as *Montivaultia noria*, *M. marmorea*, *Thecosomilia venstrata*, *T. delicatula*, *Isastra parval*, *I. profunda*, *Latimacandra norica*, *Confusatraea borealis*, *Thanmastraea recitalmellosa*, *T. norica*, *T. borealis*, *Stephanocoenia juvavica* and *Stroatomorpha california*. All are of course hexacorals (the colonial creature constructed its individual homes, called polyps, based on a six-fold symmetry), the kind of coelenterates that supplanted, replaced the rugose and tabulate corals, which went extinct at the close of Paleozoic Era.

As you travel farther up Coral Reef Canyon, the productive lower member one of the Luning Formation is well exposed--its distinctive rib-like coral-sponge and pelecypod reefs eventually grading into the younger barren member two, whose shaly-terrigenous constituents appear from a distance almost indistinguishable from the youngest phases of member one. Many a field geologist has been tricked by the lithologic mischief, but the absence of limestones in the exclusively clastic section of member two should prevent any long-term difficulties in distinguishing the two major rock units.

Once beyond a major branching of trails, the main road through Coral Reef Canyon begins to slice directly through the fossiliferous lower member of the Luning Formation. For the next mile and a half to two miles, productive limestone beds can be found along both side of the road, many of them yielding vast quantities of oyster-like pelecypods and tangled, reef-building corals and sponges. The more eroded rubble-strewn slopes of carbonates frequently contain weathered-free brachiopods, pelecypods, belemnites, echinoids, sponge chunks, coral chunks and occasional ichthyosaur bone fragments. Such easily recovered specimens

are not abundant, by any means, when compared with the profusion of fragmented remains in the bedrock matrix, but they often hide in small localized pockets amid the jagged debris brought down from the outcrops above.

Based on the remarkable faunal diversity displayed in the Luning Formation, there can be little doubt that deposition of the fossiliferous sections occurred in shallow tropical sea waters. The abundance of corals and sponges alone suggests this much. Today, such reef-building corals are found only in the tropical latitudes, in relatively shallow marine waters. That their Late Triassic relatives also preferred similar--if not identical--conditions seems reasonable enough to assume. The oyster-like pelecypods, which developed their own reef accumulations in the lower member of the Luning Formation, also testify to deposition in warm shallow waters; modern analogs of such mollusks regularly inhabit coastal waters close to the shoreline.

Coral Reef Canyon certainly deserves its exalted reputation among students of paleontology. It is a region rich in fossils from many of the major groups of invertebrate animals. Some collectors regard the locality so highly that with dedicated regularity they return time and again, eager to find out what the previous winter's erosive power has pried free from the rocks. Yet, the quantity and quality of the fossil remains never seems to diminish. Coral Reef Canyon continues to amaze and delight visitors with its 215 million year-old treasures in the rocks. Here lies preserved a coral reef community from the tropical waters of the Late Triassic age in the middle of the arid Great Basin Desert. There may not be a more curious contrast in environments imaginable.

Chapter 19

Field Trip To Pleistocene Lake Manix, Mojave Desert, California

Perhaps it is difficult to picture, but some 450,000 to 18,000 years ago a great fresh water lake covered roughly 83 square miles (236 square kilometers) of the present-day Mojave Desert in southern California. This was ancient Lake Manix, some 200 feet deep at its highest stand, created by a combination of flood waters from the ancestral Mojave River and an increase in precipitation during an interglacial period of the Pleistocene Epoch. Around the lake lived a fascinating variety of now extinct animals including Dire wolves, mammoths, La Brea storks, Oregon gulls, Shasta ground sloths, and scimitar cats.

Today, the remains of 21 species of mammals and 25 species of birds can be found in the sands, silts and clays deposited in that relatively long-lived body of water--in addition to abundant ostracods (a minute bivalve crustacean), freshwater mollusks, and skeletal elements from a fish--the extant Tui Mojave Chub.

Those fossiliferous Late Pleistocene sediments exposed in parts of San Bernardino County have been named the Manix Formation. It's an Ice Age lake bed which now yields an important diversity of nicely preserved vertebrate and invertebrate specimens that furnish invaluable paleontological data on the historical geology of the Mojave Desert district.

The fossil mammal bones from the Pleistocene exposures were discovered sometime in the early 1900s by John T. Reed of San Bernardino, California. Reed was an amateur fossil prospector who immediately understood the significance of his find. He showed the bones to a geology student from the University of California--H.S. Mourning--who in turn took the information to the noted paleontologist/geologist John P. Buwalda.

On January 22, 1914, Buwalda published a brief notice of the discovery of vertebrate fossils in the "Manix Beds" (his original name for the rock formation containing the fossils--a name derived from the Manix railroad siding situated near the most fossiliferous exposures of Pleistocene sediments) in the University of California Publications Bulletin of the Department of Geology, volume 7, number 24. This was a true pioneering work, as Buwalda observed in his report that "no reference to Pleistocene lake beds in this region has been found in the literature." Based on six species of mammals described from the lacustrine deposit, Buwalda dated the "Manix Beds" as Pleistocene, although he was unable to establish the exact stage of the epoch from which his vertebrate specimens were recovered. It is interesting to note, though, that professor Buwalda, in this initial reconnaissance investigation of the Pleistocene beds, correctly determined that the primary reason Lake Manix eventually disappeared was

due to a downcutting of its outlet in the Afton Canyon region 40 miles east of Barstow. The rush of water through this "breach in the beach" some 18,100 years ago actually created Afton Canyon, a popular scenic attraction on the Mojave Desert today.

In the years following Buwalda's original research, many Earth scientists have studied the fossil-bearing Late Pleistocene sediments that accumulated in Lake Manix. In 1934, Lawrence V. Compton wrote *Fossil Bird Remains From The Manix Lake Deposits Of California*, an article published in the avian scientific journal Condor, volume 36; perhaps unduly influenced by the presence of some small horse specimens in the fossil fauna, Compton originally thought that the Manix beds might be as old as Late Pliocene, but eventually concluded that they were more likely Early Pleistocene in geologic age--a rough estimate later contradicted by more reliable avian and mammalian fossil material from the Manix Formation; today, the Manix beds are universally regarded as Late Pleistocene in age. The third important paper on the subject was *Pleistocene Lake of the Afton Basin, California*, by E. Blackwelder and E.W. Ellsworth, 1936, American Journal of Science 5th Series, volume 31. Blackwelder and Ellsworth recognized two separate periods of lacustrine deposition. The older of the two lakes disappeared they concluded due to desiccation, while the younger body of water vanished--as Buwalda had claimed many years before--when the overflow channel at Afton Canyon was eventually downcut enough to allow the ancestral Mojave River to flow freely across the land, draining the lake.

More research followed. In 1954, H.H. Winters wrote an important scientific report that concentrated specifically on the fossils of the Manix Formation: *The Pleistocene fauna of the Manix beds in the Mojave Desert, California*, an unpublished Masters thesis for the California Institute of Technology. During his field work Winters collected 12 species of fossil birds which were later (1955) described in detail by Hildegarde Howard in United States Geological Survey Professional Paper 264-J, *Fossil Birds From Manix Lake California*. In 1968, George T. Jefferson completed an unpublished Masters thesis from the University of California, Riverside, *The Camp Cady local fauna from Pleistocene Lake Manix*. For several years Mr. Jefferson was associated with the George C. Page Museum, La Brea Discoveries, located at the world famous La Brea Tar Pits in Los Angeles, California--a site which contains the greatest accumulation of Late Pleistocene mammals and birds yet discovered on our planet. He has written exhaustively of the fossil fauna of Pleistocene Lake Manix, and in fact formally named and described the Manix Formation in his 1985 paper, *Stratigraphy and Geologic History of the Pleistocene Manix Formation*, Central Mojave Desert, California, Contributions to Science, number 352, Natural History Museum of Los Angeles County. Jefferson also co-authored the 1982 report, *Manix Lake and the Manix Fault Field Trip Guide*, Quarterly San Bernardino County Museum Association volume 29, with Jeffrey R. Keaton and P. Hamilton.

In the 1990s, Dr. Norman Meek contributed additional noteworthy scientific investigations of the Manix Basin. See his following references, for example: *Geomorphic and hydrologic implications of the rapid incision of Afton Canyon, Mojave Desert, California*, Geology Magazine, volume 17; unpublished doctoral dissertation for the University of California at Los Angeles, *Late Quaternary geochronology and geomorphology of the Manix basin, San Bernardino County, California*, 1990; and *New discoveries about the Late Wisconsinan history of the Mojave River*, San Bernardino County Museum Association Quarterly, 46(3), p. 113-117, 1999.

The upper Pleistocene Manix Formation is one of the most famous and paleontologically important fossil-yielding areas in all of the western United States. For this reason, the fossiliferous badlands carved in the Manix Formation were first set aside by the Bureau of Land Management as an Area of Critical Environmental Concern; numerous years later, the area became part of the federally protected Mojave Trails National Monument. This means that it is illegal to remove any fossil from the Manix Formation--vertebrate or invertebrate, for that matter--without a special permit issued by the administrative authorities.

But all interested persons are certainly welcome to visit the region, a classic desert land of harsh extremes and austere beauty. Any particularly well preserved bones or invertebrate remains should be brought to the attention of a professional paleontologist, who will be able to assess their scientific value: this is a paleontologically priceless region. Each fossil specimen secured from the Manix exposures could help write yet another page in the historical geology of the Mojave Desert. It is imperative that professional paleontologists have the opportunity to examine the finds made by those who visit the area; and who knows, you might even have found a species that is new to science.

Probably the best place to examine the upper Pleistocene Manix Formation is Bassett Point, which overlooks the area most-studied by paleontologists. Here, the gray to pale-greenish and brownish clays, silts and sands of the Manix Formation are well-exposed along the course of the Mojave River, a bed of parched sand most of the time, devoid of all moisture. Two-hundred thousand years ago, however, that very spot would have been completely submerged beneath the pristine waters of an Ice Age lake. At Bassett Point one stands atop the youngest sediments of the Late Pleistocene strata. Approximately 100 yards (90m) west, in deposits slightly higher in the section, a bed of fresh water mollusks has been dated by the Carbon 14 radiometric age method at 19.1 thousand years old. A fossil horse bone from near the base of the 127 foot-thick (38m) Manix section yielded a radiometric age of roughly 350,000 years (a date not established with the Carbon 14 method, of course, which is accurate only up to around 50 thousand years); this is certainly the oldest vertebrate fossil horizon in the Manix Formation.

Most of the fossil bones, though, have been collected from a narrow three-foot zone in the middle of the formation, vertebrate specimens dated by the Uranium-Thorium equilibrium method at 290 thousand years old. Two additional bone-bearing horizons occur in the Manix Formation, although they yield far fewer specimens than the older zone. One occurs a few feet above the main bone bed and has been dated by the Uranium-Thorium technique at 195 thousand years; the second is found throughout the uppermost 20 feet (6m) of the Manix Formation in strata approximately 60 to 19 thousand years old.

Two widespread beds of freshwater mollusks also occur throughout the Manix Formation. The older of them yielded a Carbon 14 dating of 49 thousand years, while the younger shell horizon, also dated by the famous Carbon 14 radiometric age method, was determined to be 19.1 thousand years ago.

The Manix Formation of San Bernardino County, California, has yielded one of the most significant fossil faunas of Late Pleistocene mammals and birds on the West Coast. Many of the species identified have also been recognized in the incredible tar traps of the famous Brea pits in Los Angeles and McKittrick.

In addition to the mammals and birds, several other varieties of animal life have also been recovered from the sediments of Ice Age Lake Manix. These include five species of ostracods (a minute bivalve crustacean), two species of fresh water pelecypods, nine species of fresh water gastropods, two species of fish (the Tui Mojave Chub and Three-spine stickleback), and one species of reptile (the Western pond turtle).

Among the 25 varieties of fossil birds identified from the Late Pleistocene section are such extinct forms as the Large-footed Cormorant, the Brea Stork, the Small Flamingo, Cope's Flamingo, Shufeldt's American Coot, and the Oregon Gull; living members of the avian fauna include the Arctic Loon, Eared Grebe, Western Grebe, American White Pelican, Double-crested Cormorant, Tundra Swan, Honker, Green-winged Teal, Mallard, Greater Scaup, Common Merganser, Ruddy Duck, Bald Eagle, Crane, sandpiper, a phalarope, a large gull, Golden Eagle, and the Great Horned Owl.

In analyzing the variety of bird fossils in the Manix Formation, it is germane to note that 96 percent of the specimens are considered waterfowl. Also, two-thirds of the living members of the fauna presently prefer to feed exclusively on small fish. From this line of evidence, it appears probable that the Tui Chub represented in the fossil record here provided a substantial diet for many of the birds at Lake Manix. The life habits of living members of the fossil bird assemblage show that the primary Late Pleistocene habitats included open water, sandy beaches and abundant reedy marshlands. Many extant representatives of the fossil

bird fauna range at present throughout southern California and can be found seasonally on the Salton Sea and other inland bodies of water; several living species prefer coastal marine conditions or inland areas in the San Joaquin Valley of California.

Among the 21 species of mammals identified from the Manix Formation, the following extinct types can be recognized: a medium-sized ground sloth; the Shasta Ground Sloth; a large ground sloth; a mammoth; the Dire Wolf; a short-faced bear; a scimitar cat; the Western Camel; the Minidoka Camel; a Large-headed llama; an Antique (Ancient) Bison; the small Mexican Horse; and a large Western Horse. Living members of the mammalian fauna include a jack rabbit, a mouse, Coyote, a bear, Puma, Pronghorn, and a Bighorn Sheep.

Plant remains in the Late Pleistocene beds are rare, but a few poorly preserved specimens have been encountered, mainly carbonized wood and leaf fragments that have not appreciably helped to determine the kind of vegetation that once existed here. Better evidence is supplied by fossil pollen found at the Calico Early Man archaeological excavation site near Yermo, California, about 15 miles west of Bassett Point, in alluvial material that correlates with strata in the Manix Formation some 100 to 75 thousand years old. Here scientist S. Peterson recovered pollen specimens from pine, oak, sagebrush, ragweed (woe to American aboriginal allergy sufferers!), goosefoot and juniper. Such plants were probably widely distributed in the moderate uplands bordering Lake Manix.

In an attempt to better understand the Ice Age vegetation of Lake Manix time, scientists have also analyzed the plant remains in packrat middens that date from the Late Pleistocene. Based on the fossil gatherings of such rodents in southern Nevada, Arizona and southeastern California, there is convincing evidence to suggest that modern-day woodlands now restricted by altitude were some 3,000 feet (910m) lower during deposition of the Manix Formation. This means that Pinyon pine and juniper, presently kept to a regional minimum elevation of 5,850 feet 1,780m), were in all likelihood thriving at 2,600 feet (790m) 200 thousand years ago in the neighboring Alvord, Cady, Calico and Newberry Mountains. Today these mountains are practically barren of any kind of vegetation.

From the available evidence, it appears that juniper, sagebrush and creosote brush covered the alluvial slopes surrounding Lake Manix. Slightly higher elevations supported a pinyon pine-juniper-evergreen live oak woodland, while white fir likely formed a dense forest in the Newberry and Ord Mountains at an altitude of 3,950 feet (1,200m); present-day conditions keep white fir a minimum elevation of 7,150 feet (2,180m). Bordering the lake were marshlands that probably supported reeds, rushes, pondweed, duckweed and cattails. Patches of grasslands apparently existed in the drier flats, much like they do in present-day regions characterized by a similar juniper-oak woodland.

Today, the luxuriant growth of Pleistocene plants has vanished. In their place is an extensive barren badlands of pastel sediments which yield a wealth of fossils. The most commonly encountered mammalian remains belong to the Western Camel (an impressive reconstruction of this creature can be viewed at the George C. Page Museum of La Brea Discoveries in Los Angeles), the Large-headed llama, the large Western horse, the Mexican Horse and the mammoth. Among the birds--whose hollow, delicate bones are miraculously well preserved in the Manix Formation-- the most frequently reported species include the Western Grebe, the Small Flamingo, The American White Pelican, and the Honker.

Specimens of the Tui Chub and Three-spine stickleback, while found scattered throughout the fine silts and sands of the upper half of the Manix Formation, are often concentrated in the middle of the sedimentary section in strata roughly 290 thousand years old. Curiously, the bones and scales from these species of fish are the most commonly encountered vertebrate fossils in the Late Pleistocene beds. The remains are often rather small, however, and even professional paleontologists get down on all fours, with nose to the ground, when prospecting a likely fish-bearing horizon in the Manix exposures.

Also living in ancient Lake Manix were numerous gastropods and pelecypods. Such mollusks are among the most abundant of forms found in the Late Pleistocene section. The two widespread beds crammed with well preserved snails and clams occur near the top of the formation in distinct zones about 18 feet (5m) apart. Their original shell material has been preserved intact, although it is extremely brittle. Both mollusk-bearing beds yield a bewildering mixture of forms that, individually, prefer different freshwater habitats--such as rivers, streams, ponds, lakes, bogs and swamps. Apparently this unusual assemblage of snails and clams resulted from deposition due to flooding. Mollusks from every local habitat were jumbled together by the rising waters of Ice Age storms, and then transported and dumped into the reaches of Lake Manix by the engorged streams.

Those streams also brought in loads of clays, silts and sands over a period of perhaps 430 thousand years--sediments that contributed to the 127 foot-thick (38m) section presently exposed on the Mojave Desert. Today, it is indeed fascinating and fun to hike amidst the badlands carved in those lake-deposited, loosely consolidated materials of the upper Pleistocene Manix Formation. The exposed strata have been preserved in an essentially horizontal bedding attitude, and there is a gradual and easily negotiated slope that leads downward from Bassett Point to the outcrops below. With each step taken, you move back thousands of years in geologic time to a lush late Pleistocene landscape of water and green and abundant animal life.

When you visit the 450 to 18 thousand-year-old Manix Formation, take some special time to enjoy the view afforded at Bassett Point. Below is stark desert, a blistered region of subdued hues, a harsh and unforgiving landscape where vegetation is scarce and visible animal life apparently nonexistent. That a great Ice Age lake once covered this land seems improbable, but the fossils in the sediments prove the case--that 290 thousand years ago you would have seen flamingos, pelicans, ducks, eared grebes, gulls, storks, cranes and loons swimming and wading in Pleistocene Lake Manix, a vast 83 square miles (236 square km) of pristine, clear glacier-fed waters that teemed with fish for the hungry birds. Above the lake would circle Bald Eagles and Golden Eagles and Great Horned Owls--large predatory birds, raptors, ready to seize the unwary in their powerful talons.

Amid the surrounding countryside a Shasta Ground Sloth might be seen leisurely browsing on the upper branches of a juniper tree; a pack of hungry Dire Wolves is cutting off a large Western Horse from the herd; and a scimitar cat has just brought down a baby mammoth on an open grassy plain. There is blood gushing from the punctured jugular and the vulturous condors soar high above.

In the distance, a violent storm is developing, a storm that will create a rushing flood of waters destined to sweep along the carcasses of both mammals and birds to the momentarily placid lake; there, the bones will be covered by fine clays, silts and sands, to remain hidden for some 290 thousand years until they are seen for the first time by human eyes in the middle of a great desert.

Chapter 20

Paleozoic Fossils At Mazourka Canyon, Inyo County, California

Among the more paleontologically important Earth Science localities in California is Inyo County--an astoundingly vast, often impressively rugged region of great elevation extremes situated in approximately the east-central area of the Golden State that boasts not only the lowest point in the Northern Hemisphere (Badwater Basin at 282 feet below sea level, in Death Valley National Park), but also the highest place in the contiguous United States (Mount Whitney, at an altitude of 14,505 feet).

Distributed across Inyo County are numerous justifiably famous fossil-bearing regions, including--but of course not limited to: Death Valley National Park (features world-class suites of Cambrian-through Permian Period invertebrate animal material, including the practically incomparable Early Cambrian Waucoba Spring Geologic Section; plus, many Cenozoic Era vertebrate skeletal preservations and associated ichnofossils--mammalian trackways); the Nopah Range, positioned within California's Mojave Desert Geomorphic Province, where the lower Cambrian Carrara Formation yields plentiful trilobites, an extinct arthropod; Westgard Pass in the White-Inyo Mountains' Early Paleozoic Era stratigraphic complex, a world-renowned geologic wonderland which remains one of the best places on earth to find Early Cambrian archaeocyathids--an enigmatic invertebrate animal, usually considered a variety of calcareous sponge--in addition to locally common trilobites, brachiopods, annelid and arthropod trails, and primitive echinoderms; Cerro Gordo Grade along the eastern flanks of the Inyo Mountains east of Keeler, adjacent to dry Owens Lake, where abundant ammonoids and pelecypods--plus, some shark teeth and terrestrial plants occur in the upper Mississippian Chainman Shale, roughly 325 million years old; Union Wash (another paleontologicly rewarding locality found within a major drainage tributary of the eastern slopes of the Inyo Mountains; lies in the vicinity of Lone Pine, directly east of Mount Whitney--a ne plus ultra place to find abundant cephalopod ammonoids in the lower Triassic Union Wash Formation, with the back-drop of the glacier-gouged Sierra Nevada skyline in dramatic view to the immediate west); and the Coso Range (at the southern end of California's Owens Valley, where vertebrate fossils some 4.8 to 3.0 million years old can be observed in the Pliocene-age Coso Formation: it's a paleontologically noteworthy place that yields many species of mammals, most particularly the remains of *Equus simplicidens*, the Hagerman Horse, named for its spectacular occurrences at Hagerman Fossil Beds National Monument in Idaho; *Equus simplicidens* is considered the earliest known member of the genus *Equus*, which encompasses the modern horse and all other equids).

Yet another Inyo County place of extraordinary paleontological productivity can be explored at Mazourka Canyon, a major defile that drains an appreciable area of the western flanks of the Inyo Mountains a number of miles east of Independence, the county seat of Inyo County. Here can be examined in full view of the prominent Sierra Nevada to the immediate west one the more reliably fossiliferous stratigraphic successions of Ordovician, Silurian, and Devonian Period rocks in the entire western reaches of the Great Basin Desert Geomorphic Province. Its often well preserved Early to Early-Middle Paleozoic Era fossil material, advantageously amenable to recovery by professional Earth Scientists and amateur paleontology enthusiasts alike within the presently accessible Mazourka Canyon corridor (always check with the local Bureau of Land Management, of course, to determine the most up-to-date status of fossil localities that occur on public lands), is in the western US ordinarily particular to correlative stratigraphic sections exposed several hundred miles east of the Inyo Mountains, throughout central and eastern Nevada to western Utah.

Representative fossil varieties present at Mazourka Canyon constitute a genuinely diverse assemblage of classic Early to Middle Paleozoic Era invertebrate and primitive vertebrate animal remains, in addition to interesting algal structures. Expect to encounter, for example: *Girvanella*, an extinct genus of blue-green algae; the usually rare *Verticillopora* dasycladacean algae (a large green algae--it's quite plentiful in the Silurian-age Mazourka Canyon section, actually); annelid (worm) trails; articulate brachiopods; bryozoans; conodonts (minute, roughly tooth-shaped calcium phosphate specimens, unrelated to modern vertebrate jaws, that served as a feeding apparatus for an extinct lamprey eel-like organism--recovered only from insoluble residues remaining from dissolution of carbonates and shales in a dilute organic acid solution--usually glacial acetic acid); rugose and tabulate corals; echinoderms (crinoid ossicles and columnals; and cystoid echinoderm segments and columnals); graptolites (an extinct hemichordate--a primitive vertebrate animal; Mazourka Canyon remains one of California's premiere producer of graptolites); and trilobites.

Throughout Mazourka Canyon's regional distribution of sedimentary deposition, all seven Periods of the Paleozoic Era are excellently represented--that is to say, one can expect to encounter in ascending order of relative age nicely exposed rocks from the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian geologic periods. Unfortunately, as one must ultimately come to recognize, individual Mazourka stratigraphic formational units of Cambrian, Mississippian, Pennsylvanian, and Permian age contain, in general, only relatively uncommon exceptional biological preservations; sedimentary accumulations of the Ordovician-Silurian-Devonian Paleozoic succession, on the other hand, provide locally abundant and for the most part wonderfully preserved fossil material. For example--except for a solitary anomalous example (the Lead Gulch Limestone)--among the

Cambrian stratigraphic rock units present within territory that is by common convention assigned to Mazourka Canyon, several specific renowned formations, so richly fossiliferous elsewhere in Inyo County (the Harkless Formation, Saline Valley Formation, Mule Spring Limestone, and Monola Formation, for example; indeed, in not a few instances paleontologists the world over visit such fantastic localities quite regularly), bear but sporadic occurrences of superior paleontologic evidence.

In Mazourka Canyon, the Cambrian Period (approximately 541 to 485 million years ago) is represented in ascending stratigraphic successional order by the following rock intervals (unless otherwise noted, they contain relatively sparse paleontology): lower Cambrian Harkless Formation (bears occasional fucoid markings preserved in curious configurations that suggest annelid trails); lower Cambrian Saline Valley Formation; lower Cambrian Mule Spring Limestone; middle Cambrian Monola Formation; middle to upper Cambrian Bonanza King Dolomite (contains locally obvious oval to circular bodies that represent an extinct variety of blue-green algae paleontologists call *Girvanella*; minor occurrences of presumed annelid fucoid markings present, as well); upper Cambrian Lead Gulch Formation (an exception to the usual Mazourka Cambrian rule of rare significant paleontological preservations: bears the agnostid trilobites *Homagnostus* sp., *Pseudagnostus* sp. and *Loganellus* sp., in addition to acrotretid brachiopods and various echinoderm parts--dissociated cystoid-type ossicles); and the Upper Cambrian Tamarack Canyon Dolomite.

Among rocks of Mississippian, Pennsylvanian, and Permian Period age in Mazourka Canyon (European stratigraphers consider the North American-designated Mississippian and Pennsylvanian Periods, combined, their equivalent of the Carboniferous, of course) both the upper Mississippian Perdido Formation and overlying Rest Spring Shale (roughly 335 to 325 million years old) actually do contain surprising localized concentrations of rather interesting invertebrate animal remains, in addition to a few botanic preservations. Within the Perdido, for example, identifiable specimens of Strophomenoid brachiopods, horn corals, bryozoans, trilobites, and pelmatozoans (crinoid ossicles and columnals) have been recovered; the geologically younger Rest Spring Shale also produces a pretty decent diversity of forms, including: *Cravenoceras* and *Cravenoceratoides* cephalopod ammonoids; gastropods; pelecypods; brachiopods; crinoid plates; and plant fragments (presumably from a nearby swamp paleoenvironment). The overlying Pennsylvanian Keeler Canyon Formation (about 290 million years old), despite its prolific paleontologic content elsewhere in Inyo County, yields at Mazourka Canyon only occasional, frustrating indications of poorly preserved fusulinids, an extinct single celled animal that secreted a distinctive wheat-shaped shell with a geometrically intricate internal structure. Above the Keeler Canyon lies the Permian Owens Valley Formation (298.9 to 252.17 million years old) that only a few miles removed from

Mazourka Canyon produces beaucoup brachiopods, bryozoans, corals, and fusulinids--yet, within the Mazourka corridor it is mysteriously lacking paleontology.

Fortunately for folks invigorated with fossil-finding enthusiasm, Mazourka Canyon provides numerous reliable opportunities to collect quality quantities of identifiable, fabulously preserved Paleozoic Era invertebrate animal specimens. The recommended geologic rock formations in which to concentrate one's exploratory investigations remain restricted to those deposited approximately 485 to 415 million years ago during the Ordovician, Silurian, and Devonian Periods. And within Mazourka Canyon, that specific stratigraphic interval would of course include the following rock units, in ascending order of geologic age (oldest to youngest): lower Ordovician Al Rose Formation; lower to middle Ordovician Badger Flat Limestone; middle Ordovician Barrel Spring Formation; late middle Ordovician Johnson Spring Formation; upper Ordovician to lower Silurian Ely Springs Dolomite; lower Silurian to lower Devonian Vaughn Gulch Limestone; and the lower to middle Devonian Sunday Canyon Formation.

Where to first concentrate fossil searches is an individual decision, naturally enough, possibly predicated on what particular varieties of paleontological forms one wishes to hunt with immediate urgency; suggested organismal exemplars to choose from include algae, brachiopods, bryozoans, conodonts, corals, echinoderms, gastropods, graptolites, and trilobites. Still and all, probably a rewarding initial fossil-oriented reconnaissance would be to the lower Ordovician Al Rose Formation (approximately 485 to 480 million years old).

The Al Rose enjoys a richly deserved, exalted reputation for yielding up some superior graptolites, trilobites, and brachiopods. Indeed, it's one of California's premiere producers of graptolites, an extinct variety of hemichordate (by definition, a primitive vertebrate) that shows some similarities to the modern pterobranch.

The Al Rose Formation is composed primarily of some 400 feet of clastic siltstones, mudstones, and shales that typically weather to shades of orange and red-brown, with subordinate carbonate-dominated intervals of arenaceous medium-gray to bluish gray limestones. Almost all of the paleontology derives from the colorful clastic unit. In some places the Al Rose is a genuine bonanza body, packed with showy, exquisitely detailed graptolites that exhibit an aesthetically pleasing "golden glow" of preservational contrast on a darker shale matrix--impregnated as they are by the mineral limonite, a hydrated iron oxide ($FeO(OH) \cdot nH_2O$).

Fossil goodies identified from the lower Ordovician Al Rose include the following: brachiopods--*Lingulella*, plus several additional species not yet formally described in the

scientific literature; the trilobites *Globampxy trinucleoides*, *Peraspis erugata*, *Shumardia*, *Trigonocerca*, *Anthrorhacus* sp., *Cryptolithus* sp., and *Hypermercaspis brevifrons*; the graptolites *Tetragraptus bigsby*, *Tetragraptus reclinatus*, *Tetragraptus serra*, *Phyllograptus anna*, *Phyllograptus ilicifolius*, *Didymograptus protobifidus bifidus*, *Didymograptus protoindentis*, *Didymograptus artus*, and *Didymograptus nitidus*; gastropods; two varieties of pelmatozoan echinoderms; Chondrites ichnofossils (a trace burrow); and Conulariids (an extinct type of scyphozoan cnidarian).

Lying directly above the lower Ordovician Al Rose Formation is the exceptionally fossiliferous middle Ordovician Badger Flat Limestone, which in part most certainly correlates stratigraphically with the world-famous Antelope Valley Limestone exposed in western to central Nevada. Blue-gray limestone is the dominant lithology, with irregular lenses and layers of light-gray, orange, and red-brown silty and marly sections. Most its 500 to 600 foot thickness is accurately described as limestone, but specimens studied in microscopic thin section reveal abundant clastic quartz grains, as well.

The Badger Flat Limestone is notably fossiliferous. In an interval roughly 100 to 200 feet below the top of the formation, *Palliseria robusta* gastropods up to three inches in diameter are so regularly abundant that they constitute a mappable horizon. Elsewhere, numerous additional kinds of invertebrate animals can be recovered from the well exposed Middle Ordovician carbonate accumulations. These include: the extinct blue green algae *Girvanella*, and an extinct green algae called *Recepticulites*; the brachiopods *Orthombonites mazourkaensis*, *Orthambonites patulus*, *Orthidiella* sp., *Rhysostrophia nevadensis*, and *Rhysostrophia occidentalis*; bryozoans (two genera); conodonts; a favositoid coral; the cephalopods *Rewdemannoceras* sp. and *Rossoceras* sp.; cystid echinoderms; gastropods of a kind different from the large *Palliseria*; sponges that can be assigned to *Calycocoelia* sp.; and trilobites identified as belonging to--a bathyurid, *Isotelus*, an *Asaphid*, *Achatella*, a pliomerid, *Pseudomera*, and a dalmanitid.

Next up in the Mazourka Canyon Ordovician-Silurian-Devonian stratigraphic sequence, right above the Badger Flat Limestone, is the middle Ordovician Barrel Spring Formation--an aggregate of 130 feet of predominantly light-colored limestone, impure quartzite, and siltstone (lower member) overlain by distinctive red-brown-weathering shale, mudstone, and siltstone (upper member). While Barrel Spring fossils are not reliably well preserved, readily identifiable remains are nevertheless rather common throughout the lower portions of the upper terrigenous member. Organisms described from the Barrel Spring include: the trilobites Remopleurides, *Isotelus spurius*, *Lonchodomas*, and *Ampyx;* the brachiopods *Valcourea* cf. *V. plana*, *Orthambonites decipiens*, *Hesperorthis*, *Hesperorthis* cf. *H. dubia*, *Plaesiomys*, and

***Rafinesguina*; bryozoans; graptolites, *Dicellograptus sextans*; and pelmatozoan echinoderm columnals.**

Overlying the middle Ordovician Barrel Spring Formation is the highly fossiliferous late middle Ordovician Johnson Spring Formation. It's approximately 400 feet thick, on average, consisting in most measured geologic sections of three white to gray orthoquartzite layers (a heat and pressure-altered sandstone, which here contains vertical phoronid worm borings called *Skolithos*) interbedded with five medium-gray to medium dark-gray carbonate beds (limestone and dolomite). The carbonate rocks of the Johnson Spring Formation contain a large and varied fossil fauna in which corals are predominant. Identified specimens include: the extinct green algae *Recepaculites*; vertical ichnofossil borings created by an extinct phoronid worm called *Skolithos*; a sponge, *Anthaspidella inyoensis*; the corals *Streptelasma tennysoni*, *Paleophyllum mazourkensis*, *Favistella* cf. *F. discreta*, *Grewingkia whitei*, *Brachyelasma bassleri*, *Lichenaria sisyphi*, and *Eofletcheria kearsargensis*; the brachiopods *Zygospira, Nicolella*, *Ptychopleurella arthuri*, *Sowerbyella merriami*, and *Desmorthis*; echinoderm columnals (crinoids); bryozoans; gastropods; pelecypods; and cephalopods.

What's additionally fascinating about the Johnson Spring Formation at Mazourka Canyon is that its stratigraphically correlative lateral rock equivalent is none other than the world famous, though uniformly unfossiliferous middle to lower upper Ordovician Eureka Quartzite--certainly one of the most widespread Early Paleozoic Era rock units in all the Great Basin Desert. Not only has it been recognized throughout Death Valley and Nevada, but it also shows up in geologic sections as far away as Millard County in western Utah.

Lying in stratigraphic positional contact directly above the Johnson Spring Formation is the upper Ordovician to lower Silurian Ely Springs Dolomite. This is some 590 feet of mostly medium gray to dark gray magnesium carbonate typically preserved in individual beds one to six inches thick, with interesting associated chert bodies that sometimes contain sponge spicules. While it's never really been universally appreciated as an especially rich receptacle for the retention of fossils at Mazourka Canyon (exposures of the Ely Springs Dolomite in eastern Nevada, though, frequently yield beaucoup paleontology), the Ely Springs nevertheless actually does indeed contain an important fauna of sponge spicules, *Streptelasma* corals, crinoidal debris, and a large selection of conodonts (minute structures that served as a unique feeding apparatus in an extinct lamprey eel-like organism).

Next youngest geologic rock formation exposed at Mazourka Canyon, resting atop the Ely Springs Dolomite, exhibits such extraordinary fossil content that most visitors would certainly categorize it as a genuine paleontological crown jewel of the entire area: the lower Silurian to lower Devovian Vaughn Gulch Limestone. Its diverse and well preserved fauna--invariably

silicified (that is, replaced by the mineral silicon dioxide) and imbued an aesthetically attractive reddish-brown on a dark blue-gray limestone matrix by the mineral limonite--has justifiably attained legendary proportions among fossil aficionados in the western United States. For purposes of propaedeutical pedagoguery, for instance--instructing their students in the foundational principles of Historical Geology--geology professors from community colleges and universities throughout the West regularly schedule field trips to the Vaughn Gulch exposures; consequently, opportunities obviously arise there for lots of folks to run off with loads of sample fossil material, although one must note that at last field check it's still a productive place to examine abundant showy, readily recognizable Paleozoic Era sea life.

The Vaughn Gulch Limestone classically consists of about 1,500 feet of dominantly medium to dark gray limestone that additionally incorporates subordinate shades of red, yellow, and orange; minor shale partings typically separate the most diagnostic rock variety present--a stunningly fossiliferous bioclastic limestone that tends to form ledges crowded with the following forms: algae--*Verticillopora annulata*; brachiopods--*Gypidula*, *Athyris*, *Trematospira*, *Schizophoria*, *Plectatrypa* sp., *Camarotoechia*, *Atrypa*, and *Eatonia bicostata*; such rugose and tabulate corals as *Australophyllum*, *Strombodes*, *Favosites*, *Chonophyllitm*, *Rhisophyllum*, *Heliolites*, *Alveolites*, *Cladopora*, large *cyathophyllids*, a small tryplasmid, a pycnostylid, *Aulacophyllum*, *Acinophyllum*, *Diplophyllum*, *Kyphophyllum nevadensis*, *Phacelophyllum*, *Camerotoechia*, *Syringopora*, and *Disphyllum*; sponges--stromatoporoids and *Hindia*; bryozoans; conodonts; and pelmatozoan and crinoidal echinoderms.

The youngest--and therefore final--significant fossil-bearing unit within Mazourka Canyon's Early to Middle Paleozoic Era successional complex is the lower to middle Devonian Sunday Canyon Formation (around 415 million years old), which stratigraphically speaking intertongues with and overlies the slightly younger uppermost Vaughn Gulch sedimentary deposits. In its traditionally familiar outcropping aspect, the Sunday Canyon weathers to form rather poorly exposed slopes composed of thin flaggy fragments of calcareous siltstone, calcareous shale, and argillaceous limestone in shades of light gray to yellow and orange.

And it bears lots of invertebrate fossils. The Sunday Canyon Formation faunal list, for example, includes at least six species of the highly prized *Monograptus* graptolites, which developed distinctive rhabdosomes that resemble tiny sawblades. This is the westernmost outcropping of *Mongraptus*-producing strata in the US, by the way. To find comparable, correlative lower Devonian graptolite-yielding rocks to investigate, you'd have to travel a few hundred miles east of Mazourka Canyon to the Roberts Mountains Formation in central Nevada. Sunday Canyon graptolite species present include: *Monograptus dubius; Monograptus tumescens*; *Monograptus vomerirnus*; *Monograptus vulgaris*; *Monograptus scanius*; *Monograptus uniformis*, and *Monograptus hercynious*. Also well represented in the

Sunday Canyon geologic sections are rynchonellid brachipods; ostracods; sponge spicules; tentaculites--*Tentaculites* cf. *T. bellulus* (taxonomic classification uncertain, but it could be related to the modern-day pteropods, the sea snails); conodonts; and corals--*Alveolites*, Favosites, Ceriod rugose corals, cylindrical rugose corals, horn corals, *Thamnop*ora sp., and *Cystiphyllum*.

While fossil prospecting at Mazourka Canyon, it is fitting to consider that before the great neighboring Sierra Nevada was uplifted to its present impressive elevations, before it was even a minor protuberance on the face of the earth, Mazourka Canyon's fossil organisms now situated within its shadow had already been covered over by countless primal ooze deposits at the bottoms of unknown numbers of successive Paleozoic Era seas some 541 to 252 million years ago. Eventually, through the ceaseless invisible activity of passing vanished time, geologic forces successfully thrust both the now lithified sedimentary beds of those long-lived oceans and the younger, once-buried solidified magma of the batholithic Sierra several thousands of feet above sea level.

Now the inevitable, the inexorable laws of erosion take their turn at the rocks. And yet, while standing atop Mazourka Canyon's fossil beds--inspecting an outcrop of 485 to 415 million year-old sedimentary rock, with the seemingly adamantine peaks of the Sierra in bold relief against the western skyline--it is perhaps difficult to believe that all mountain ranges, including the surely eternal Sierra, must someday be no more. They must be leveled to a plain, just as countless nameless ranges have been so reduced in the geologic past.

But perhaps another sea will have its day atop their former glory, and new creatures may stay alive in the rocks left behind, to rise with the mountains of a yet-distant age to the delight of future fossil hunters.

Chapter 21

Fossil Leaves And Seeds In West-Central Nevada

Perhaps the richest producer of Miocene-age (23-to-5.3-million-year-old) plants in the entire state of Nevada is a geologic rock deposit known as the Middlegate Formation. Its primary and most paleontologically productive exposures lie within a rather localized geographic area of west-central Nevada, where paleobotanists have identified some 64 species of fossil plants--including such diverse types as evergreen live oak, giant sequoia/Big Tree, willow, fir, maple, and spruce. The fossil specimens, which consist of leaves, winged seeds (called samaras in technical botanical terminology), acorn cups, seed pods and branchlets, occur as pale to dark brown carbonized impressions on a cream-white to pale-brownish matrix of opaline shale--many of them exhibiting such an exceptional degree of preservation that the original delicate venation on the leaves is clearly visible.

All of the remains are Middle Miocene in geologic age, dated by radiometric methods at some 16 million years old. They occur in the uppermost (the youngest layers of deposition) 30 feet of the Middlegate Formation, just below the overlying middle Miocene Monarch Mill Formation, whose basal sedimentary conglomerates have yielded to paleontologists a large vertebrate fauna, including the silicified bones of moles, rabbits, squirrels, beavers, mountain beavers, mice, weasels, martins, rhinocerotids, oreodonts, camels, llamas, and pronghorns.

Such scientifically invaluable fossil vertebrate material on public lands is of course off limits to all collectors who do not possess a special use permit issued by the Bureau of Land Management, a permit issued solely to individuals with a minimum B.S. degree from an accredited university whose research projects can be verified as authentic by the petitioned authorities--a formal collecting status that is likely well understood (and appreciated) by most amateurs and professional paleontologists alike. At present, though, there is no such legal restriction on the hobby gathering of leaves, winged seeds, petrified wood, and other paleobotanical remains from the Middlegate Formation--but that much-welcomed legally lenient status could of course change without advance warming.

The troubling circumstance is that commercial collecting interests have been known to concentrate on a select number of fossil leaf-yielding fields in Nevada--obviously those sites which happen to provide them with the greatest numbers of well-preserved specimens. Needless to report, this is patent illegal activity, since no fossil remains collected on public lands may be either sold or bartered (legal argot for the act of trading specimens). And while there is certainly nothing criminal about selling fossil specimens collected on private lands (with the land owner's unambiguous permission, of course), any desecration of a fossil

horizon on public lands in an attempt to secure as many saleable remains as possible is without question an offense punishable by law. Also, such behavior is with sure consequence horribly counterproductive, since it only invites federal officials with the Bureau of Land Management and the Forest Service to close down popular fossil areas, preventing conscientious amateurs from sampling places of significant paleontological interest.

The Middlegate Formation locality certainly fits that description. It's a remarkably productive fossil plant-yielding region situated in the middle of the Great Basin Desert, amid what botanists call a shadscale desert flora, or an association of low, rigid, spinescent shrubs no more than two feet high. But 16 million years ago the Middlegate Formation district was the site of a deep, cool, clear-water lake, a great body of water into which creeks and streams occasionally discharged loads of fine detritus, along with abundant plant debris from the surrounding countryside--a landscape rich with conifers, deciduous varieties and evergreen live oaks which now lie preserved along the bedding planes of fine-grained shales.

The most efficient way to locate fossil plants in the Middlegate Formation is to dig into the slab-like weathering siliceous shales, exposing fresh sedimentary strata below the surface. Fortunately, most of the shales within a few inches of the surface are severely fractured; hence, little splitting of them is necessary, since they tend to separate from the outcrops in thin sheet-like plates. Watch closely for the fossil plant compressions and impressions along the bedding planes of every shale fragment you remove from the hillside exposures. The deeper you dig, though, the more thickly bedded the opaline shales become, until at last it will become necessary to begin splitting the extremely dense concrete-like rocks. When doing this, always remember to wear safety goggles, or at least some kind of eye protection such as sunglasses. The denser, thick-bedded opaline strata crack apart only with the greatest of applied brute force, thus increasing the likelihood that sharp fragments might launch off the matrix into your eyes. Stand slabs of shale on end, then give them a sure whack with the blunt end of a geology hammer. If you're fortunate, the sedimentary layers will break apart along their original planes of deposition, revealing perfect carbonized leaf and seed impressions and compressions to their first light of day in approximately 16 million years.

By far, the most common specimens found in the Middlegate Formation are leaves and acorn cups belonging to an evergreen live oak, *Quercus pollardiana*, which is identical to the modern canyon live oak native to the western flanks of the Sierra Nevada and the coastal ranges of central California.

The 18 next most frequently encountered remains in the Middlegate shales include: interior live oak (leaves); Birchleaf mountain-mahogany (leaves); tanbark oak (leaves); common cattail (leaves); Bigleaf maple (leaves and samaras); Balsam poplar (leaves); willow (leaves);

Boxelder (samaras and leaflets); Brewer spruce (samaras); Tigertail spruce (samaras); silver maple (samaras and leaves); Arizona madrone (leaves); Catalina ironwood (leaves); Giant Sequoia (branchlets); New Mexican locust (leaflets and seed pods); California Red fir (samaras and needles); small-stemmed Horsetail (stems); and Ponderosa Pine (samaras and needles).

Twenty of the less common species reported from the Middlegate Formation include: Golden Chinkapin (a brush-sized variety--leaves); Paper birch (leaves); Hairy mountain-mahogany (leaves); quaking aspen (leaves); Utah juniper (branchlets); an extinct water oak (leaves); Narrowleaf cottonwood (leaves); a second species of willow (leaves); White ash (samaras); Oregon grape (leaves); Alaskan cedar (branchlets); water lily (leaves and rootstocks); Rocky Mountain hawthorn (leaves); Rocky Mountain maple (samaras and leaves); Douglas-fir (samaras); Mountain hemlock (samaras); Golden chinkapin (tree variety--leaves); East Asian maple (samaras and leaves); and *Cedrella* (samaras).

The Middlegate fossil flora was discovered in the spring of 1949 by Laura Mills, an avid amateur fossil collector from Fallon who at the time was searching for petrified wood. She brought the rich fossil deposit to the attention of paleobotanist Daniel I. Axelrod, who accompanied her to the locality in the early summer of 1949. Several weeks later Axelrod made his first substantial collection of plants from the Middlegate Formation--a fantastic array of Miocene species preserved in superior detail; here was certainly one of the most productive and important fossil plant localities in all the Great Basin.

Two years later, during the spring of 1951, Axelrod made yet another visit to Middlegate, this time accompanied by his long-time field assistant Robert E. Smith, who maintained accurate records of the various plant taxa recovered from the shales. They spent an entire week in the field, eventually amassing a truly exhaustive selection of Miocene fossil plant material. In all, Axelrod and Smith gathered some 3,458 specimens from the Middlegate Formation, 2,917 of which belonged to the evergreen live oak *Quercus hannibalii*.

Axelrod published his scientific examination of the Middlegate plant material in 1956 in a formal scientific paper. In it, he described 42 specimens of ancient plants, assigning them a transitional Miocene-Pliocene geologic age, or what was then understood to be roughly 12 to 10 million years old.

Axelrod later revised the Middlegate fossil plant association in another formal paleobotanical publication. He based this new scientific analysis on supplemental collections of fossil plants supplied by Axelrod's students in paleobotany at the University of California, Davis, during the 1970s. The student collecting expeditions not only increased the total number of

specimens known from the Middlegate Formation to 6,882, but also added some 22 new species of fossil plants to the ever-expanding paleobotanical record.

In addition to the larger plant collections, Axelrod also had at his disposal increasingly sophisticated and accurate radiometric methods of dating volcanic rocks interbedded in a sedimentary sequence. In the late 1960s, geologist Harold Bonham of the Nevada Bureau of Mines And Geology selected fresh samples from hornblende rhyolite tuffs present near the middle of the Middlegate Formation. When Bonham ran the volcanics through a series of radiometric-age analyses, paleobotanists were shocked to learn that the fossil plants could not be transitional Miocene-Pliocene as originally determined (12 to 10 million years old, prior to the recalibration of both the Miocene and Pliocene Epochs; for example, the Pliocene now begins at about 5.3 million years ago), but rather more in the range of 18.5 million years old, or Middle Miocene in geologic age. More recent radiometric determinations, though, prove that the Middlegate Formation is younger still--more in the range of 16 million years ancient.

In his monographs dealing with fossil plants from Nevada, paleobotanist Daniel I. Axelrod concluded that the Middlegate Flora most closely resembles a modern sclerophyll forest, which reaches its ultimate development in the western Sierra Nevada and the coastal ranges of central California. Such a forest is dominated by evergreen dicotyledons, principally madrone, Golden chinkapin, tanbark oak and several specimens of oak; typical evergreen shrubs include buckbrush, mountain mahogany, toyon, sumac, and manzanita--all of which contribute to a classical chaparral botanic association. In addition to the evergreen species, a typical sclerophyll forest can also include such deciduous types as maple, ash, black walnut, sycamore, cottonwood, currant, rose and willow, each of which prefers the moister sites around streams and seepages.

The association of sclerophyllous species found in the Middlegate Formation suggested to Axelrod that the fossil plants lived under environmental conditions quite similar to those present today in the Santa Cruz and Santa Lucia Mountains along the coast of central California. There are also obvious relationships to the modern groves of Giant Sequoia in both the northern and southern portions of the Sierra Nevada, particularly the North Grove (southeast of Auburn) in Placer County and the Tule River Grove near Belknap Creek in Tulare County.

Based on the available geological evidence, the fossil plants accumulated in waters of moderate depth roughly one-half mile from the southern margin of the Miocene lake, into which creeks and streams discharged detritus from south-facing slopes of volcanic origin during periods of intermittent storm runoff. Surrounding the basin of deposition and reaching

down to lake level was a dominantly sclerophyllous forest consisting of madrone, Golden chinkapin, tanbark oak, canyon live oak, interior live oak, and water oak. Drier sites in the ancestral Middlegate Basin supported such shrubs as buckbrush, mountain-mahogany, toyon, Lyontree, and locust. The stream banks were lined with species of maple, cottonwood and willow, while higher elevations along the distant slopes supported an impoverished conifer-hardwood forest of fir, spruce, pine, Alaska-cedar, Douglas-fir, and Giant Sequoia. Associated with the conifers were such deciduous varieties as alder, maple, hawthorn, willow, and mountain ash.

Summer rain indicators in the Middlegate Flora include types whose closest modern relatives live in the eastern United States, eastern Asia, and the southern Rocky Mountains--such deciduous species as birch, persimmon, hawthorn, hydrangea, Oregon grape, maple, and cottonwood. All of these varieties prove that throughout Middle Miocene times there must have been, at a minimum, some two to three inches of precipitation during each of the three summer months; this contrasts wildly with the extreme aridity of the Middlegate Formation territory today, which receive on average only 5 inches of rain per year.

Yet, 16 million years ago the Middlegate Basin received approximately 35 to 40 inches of rain on an annual basis, an estimate based on the known environmental requirements of living members of the fossil flora. The middle Miocene Middlegate climate can be categorized as mild-temperate, with an average temperature reading for the month of January of 40 degrees; today, temperatures there remain below freezing throughout January, averaging a chilly 30 degrees. Summertime weather conditions were also more moderate during Middle Miocene times, when typically an entire month of July averaged fully 10 degrees lower than that experienced in the area today--68 degrees for the Miocene, compared with 78 in the present-day. Elevations at the site of deposition were likely much higher than today's 5,000 to 5,300 feet--more in the neighborhood of 8,000 feet. This estimate is based on innovatively sophisticated geophysical and paleobotanical studies which demonstrate that 16 million years ago the ancestral Great Basin region stood appreciably higher than it does at present; by 13 million years ago, elevations had collapsed through extensional geologic stresses to roughly the same as what we see today in the Great Basin.

Here is certainly one of the premiere fossil localities in all of Nevada: the Middlegate Formation, a place where professional paleobotanists and amateur fossil enthusiasts alike have recovered through a period of several decades thousands upon thousands of well-preserved leaves, seeds, acorn cups, seed pods, conifer needles, and branchlets. Today, the site lies within the brutal aridity of a shadscale desert, a land of low spiny shrubs adapted to harsh alkaline soils, great extremes in temperatures, and scant rainfall--as low as 5 inches per year. It's a scene radically different from the one which existed throughout this portion of the

Great Basin some 16 million years ago, when vegetation identical to that now living near the Giant Sequoia groves in the western Sierra Nevada and in the coastal ranges of central California thrived in a moist land of ample rainfall--where a great pristine lake splashed the trunks of canyon live oak and Giant Sequoia.

Chapter 22

A Visit To The Sharktooth Hill Bone Bed, Southern California

Many fossil prospectors across America are familiar with the name Sharktooth Hill. This is an old and venerable locality, where innumerable shark teeth and marine mammal bones have been collected over the years. It is certainly one of the most famous vertebrate fossil sites in the world--a place where roughly 125 species of sharks, bony fishes, sea mammals, sea turtles, marine crocodiles, birds and even land mammals have been found.

The fossils are concentrated in a rather narrow one-to four-foot thick layer in the Round Mountain Silt Member of the middle Miocene Temblor Formation, which is exposed over several square miles in the erosion-dissected western foothills of California's southern Sierra Nevada. Although the diggings at Sharktooth Hill have historically yielded the most prolific occurrences of the 16 to 15 million-year-old vertebrate material in the Round Mountain Silt, the so-called Sharktooth Hill bone bed continues to provide collectors with nicely preserved fossils wherever it outcrops.

This is indeed fortunate for amateur paleontology students, since Sharktooth Hill presently lies on private property and is in fact a registered national landmark; unauthorized collecting is obviously forbidden at that most famous of sites, but several other fossil-bearing zones in the immediate vicinity can still be explored by interested amateurs--at least by direct permission from the many local landowners who presently own almost all of the Sharktooth Hill bone bed exposures not included in the Sharktooth Hill paleontological preserve.

And there is certainly no doubt about it--lots of folks over a lot of historical time have visited the Sharktooth Hill area to investigate its marine Middle Miocene vertebrate paleontological preeminence.

The history of fossil collecting at Sharktooth Hill goes all the way back to the middle portion of the 19th Century. In August of 1853 geologist William P. Blake reported the occurrence of well-preserved shark teeth and sea mammal bones from the general area of present-day Sharktooth Hill. At the time, Blake, employed by the United States Topographical Corps, was conducting a field survey for possible railroad routes from the Eastern Seaboard to the West Coast. His discovery is generally heralded as the first confirmed report of fossil shark teeth west of the Rocky Mountains. Blake's important collection was eventually studied in 1856 by the legendary Swiss geologist and paleontologist Louis Agassiz, who at the time was one of the leading authorities on vertebrate fossils.

Sometime after Blake's discovery, enthusiastic amateurs began to explore the Middle Miocene deposits in the dusty hills northeast of present-day Bakersfield. Nobody knows for sure who first coined the name "Sharktooth Hill" to describe the rich fossil occurrences, but there is little doubt that the term accurately identifies the most popular type of fossil found there. Even today, in the centuries after the original find by geologist Blake, well-preserved shark teeth continue to attract considerable attention.

As the populations of the southern San Joaquin Valley and of metropolitan Los Angeles (only 90 miles south of Bakersfield) began to increase during the latter half of the 1800s, so did the numbers of regular visitors to Sharktooth Hill. From the beginning of its popularity, the site became a mecca of sorts for fossil hunters. Shark teeth and sea mammal remains in the middle of an arid valley, over 100 miles from the Pacific Ocean, became irresistible attractions and have drawn innumerable individuals to this site over the decades.

Perhaps the most famous amateur collector to visit Sharktooth Hill was Charles Morrice, a clerk for the Pacific Oil Company. Morrice became ardently interested in collecting fossil specimens from the bone bed in 1909 during his off-work hours. Over the course of several years he single-handedly dug up hundreds of thousands of shark teeth weighing, literally, several tons. There is an historically valuable photograph of the legendary Morrice in the informative reference volume, *History of Research at Sharktooth Hill*, by Edward Mitchell (published by the Kern County Historical Society in 1965); Morrice is shown on-site at Sharktooth Hill, by one of his many digs, with a huge bucket filled to the brim with nicely preserved shark teeth of all kinds. At first, Morrice would simply give his finds away to friends, relatives and acquaintances. But he eventually became an indefatigable, scientifically motivated collector, donating his exhaustive collections to museums and universities throughout the world. In recognition of his contributions to science, two extinct animals from the Sharktooth Hill bone bed have been named in honor of Charles Morrice: a shark, *Carcharias morricei*, and a sperm whale, *Aulephyseter morricei*. In the later 20th and early 21st centuries, the two most important amateur collectors in the Sharktooth Hill bone bed were Bob Ernst (who before his passing collected upwards of 2 million vertebrate remains) and Russ Shoemaker, private land owners in the Sharktooth Hill district who donated exhaustive amounts of Middle Miocene vertebrate fossil material to any number of museums and scientific institutions throughout the world.

Although the prolific bone bed at Sharktooth Hill had been known to paleontologists since the 1850s, the first formal scientific investigation of the fossil-bearing layer was not conducted until 1924. That year the California Academy of Sciences initially decided to spend four months in the field analyzing the fossil deposit on-site. But the diggings proved so productive and challenging that the Academy continued to collect there, off and on, through

the 1930s. After the preliminary fieldwork was completed, paleontologists required several years to clean, catalog and identify the abundant material recovered. In all, some 18 new species of mammals, birds, sharks, rays and skates were named from the collections amassed.

From 1960 to 1963 a second major scientific study of the Sharktooth Hill bone bed was undertaken, this time by the Natural History Museum of Los Angeles County. To expose an undisturbed layer of the fossil-rich zone, researchers bulldozed away roughly 15 feet of the barren silty overburden. Using whisk brooms and awls, the scientific teams then carefully removed the essentially in-place bones and teeth from the 16 to 15-million-year-old sediments. This was the first time that paleontologists had actually been able to observe firsthand the relationships of the fossils as they lay preserved in the bone bed. Thus, not only were innumerable perfectly preserved bones and teeth recovered, but invaluable information was also gathered on how the remains of the preserved animals came to rest on the silty floor of a Miocene sea. A major highlight of the museum excavations was the discovery of an almost fully intact skeleton of the extinct sea lion, *Allodesmus*. Since articulated remains of marine mammals are uncommon in the primary bone-bearing zone, such a complete specimen ranks as one of the most significant finds in the history of explorations at Sharktooth Hill. Another mostly complete, articulated *Allodesmus* was discovered in deposits above the bone bed many years later by the dedicated amateur fossil hunter Bob Ernst, who donated the remains to science--a fine sea lion specimen now housed at the Buena Vista Museum in Bakersfield.

Perhaps the zenith of paleontological investigations at Sharktooth Hill happened during the 1960s and 1970s. Research crews from universities and museums throughout the United States visited the area, carting away tons of excellently preserved fossil material. Amateur interest in the bone bed also increased, and many a Southern Californian was likely first introduced to the rewards of fossil hunting at Sharktooth Hill.

But the steady stream of visitors appeared to be getting out of hand. Much of the precious bone-bearing horizon was rapidly disappearing. Scientists expressed justifiable concerns that, if left unprotected, the most fossiliferous sections of the bone-yielding horizon would soon be obliterated. The proper government officials agreed with this assessment and in May, 1976, Sharktooth Hill was added to the United States Landmark Registry, a designation which protects the locality from unauthorized collectors.

The Sharktooth Hill bone bed has provided paleontologists with the single largest assemblage of Middle Miocene marine vertebrate animal fossils in the world (the famous Miocene Calvert Formation of Maryland also produces many kinds of marine vertebrate remains). The

impressive list of marine mammal specimens alone from the Temblor Formation includes dolphins and dolphin-like creatures, porpoises, sea lions, whales, sea cows, walruses, seals and an extinct hippopotamus-like fellow called *Desmostylus*--a 10-foot-long animal related to the elephant that evidently walked around on the sea floor crushing shellfish with its massive, powerful jaws. Also identified have been extinct large turtles, a marine crocodile, many kinds of bony fishes, and some 20 species of birds--in addition to the astoundingly abundant sharks and rays.

In addition to the marine fauna, several skeletal elements from land mammals have also been taken from the fossil beds. These include a lower jaw of the mustelid (weasel-like) *Sthenictis lacota*; a lower jaw of the huge amphicyonid, or "beardog" *Pliocyon medius*; the dog *Tomarctus optatus*; the three-toed horses "*Merychippus*" *brevidontus* and *Anchitherium* sp.; the rhinoceroses *Aphelops megalodus* and *Teleoceras medicornutum*; the tapir *Miotapirus* sp.; the deer-like dromomercyids *Bouromeryx submilleri* and *Bouromeryx americanus*; the protoceratid (sort of a cross between a modern deer and a cow) *Prosynthetoceras* sp.; and the gomphothere *Miomastodon* sp. (an extinct proboscidean). Such remains are exceedingly rare, though, and are usually considered anomalies in the local Middle Miocene fossil record. Their presence in proved marine-deposited rocks points to preservation in shallow sea waters, since it is unlikely that the carcasses of land animals could have been transported far from the ancient shoreline before they settled to the ocean floor.

All of these remains lie waiting to be uncovered in the rolling brush-covered western foothills of the southern Sierra Nevada, several miles northeast of Bakersfield in Kern County, California.

One of the better extensions of the fabulous bone bed was for decades a genuinely fun and educational place to visit. Here, shark teeth and various fragmental skeletal elements from a variety of marine mammals constituted the available fossilized assemblage, a place that for many years amateur collectors were welcome to visit; on any given day of the week, for example, one could expect to find at least a handful of folks (on weekends, the numbers of visitors increased exponentially) exploring the prolific Middle Miocene fossil horizon, collecting loads of well-preserved shark teeth and generally enjoying their outdoor experience without having to worry about legal restrictions on their fossil-hunting activities. The local law enforcement and BLM authorities left the collectors alone, as long as the area remained free from litter and vandalism, of course. When I last visited the locality, enthusiastic visitors were still allowed to gather Middle Miocene shark teeth and miscellaneous sea mammal bones, but there is no guarantee that the area has remained accessible to unauthorized amateurs. If the site has been formally closed off, make certain that you obey all the rules and regulations: do not attempt to climb over a locked gate, or

with reckless disregard disobey No Trespassing signs which may have sprung up to warn visitors that their presence is no longer welcome.

Upon stepping out of one's vehicle to survey the territory, where to search for the fossilized specimens was quite obvious to all visitors. Along the steep to moderately inclined slopes above the parking area one could observe the unmistakable World War I-style infantry entrenchments that, dipping at a low angle of approximately four to six degrees to the southwest, marked the trend of the prospected bone bed. These excavations were made by armies of a different sort: fossil hunters who in their determination to recover shark teeth and marine mammal bones had created a single extended trench along the entire length of the exposed fossiliferous horizon in this immediate area.

The shark tooth-bearing layer averaged roughly one foot thick here, but was often difficult to spot due to the random digging of previous fossil prospectors. It helped to watch for the dark-brown fragmental bones of sea mammals embedded in the pale-gray matrix of the Round Mountain Silt; these were the most common finds in the Sharktooth Hill bone bed exposures, although the perfectly preserved shark teeth remained the prized items sought by the majority of visitors. The best way to locate fossils was to settle into your "battlefield" entrenchment and commence digging. Here, there was just no substitute for good old-fashioned manual labor. Most collectors simply dug into the fossil-bearing zone with a pick or shovel, carefully inspecting each chunk of Middle Miocene material removed from the exposure. Others brought along some kind of screening device--even a riddle (usually employed by gold seekers)--into which they dumped fossil-bearing dirt. After the sands and silts had passed through the fine mesh, any bones and teeth scooped up remained atop the screen, ready to be packed away for safekeeping.

Unfortunately, the fossil zone was not as prolific as at classic Sharktooth Hill, where almost any section of the bone-yielding horizon explored managed to yield abundant perfectly preserved material. Weathered-free fossils were sometimes found, too, especially after a heavy rainy season, before the hordes of eager collectors had descended on the hill for a new season of fossil-finding; at the once-accessible locality, though, freely eroded forms were conspicuously absent. This was best explained by the great numbers of collectors who visited the site each year. Any remains that had naturally washed out of the 16 to 15-million year-old sediments were in all likelihood immediately plucked up and stored away by the lucky few who happened upon them. As this specific locality remained for many years the primary spot where amateurs were still legally allowed to collect fossils from the Sharktooth Hill bone bed, it was not surprising that such easy pickings were nonexistent.

Other than keeping well-hydrated during hot summer days, the major hazard one faced at the fossil locality, and indeed wherever one happened to dig into the Sharktooth Hill bone bed, was exposure to Valley Fever, called scientifically Coccidioidmycosis—or "coccy" for short; it's a potentially serious illness caused by the inhalation of an infectious airborne fungus whose spores lie dormant in the uncultivated alkaline soils of California's southern San Joaquin Valley: And the region in which the Sharktooth Hill bone bed occurs is known to contain, in places, significant concentrations of the spores which cause this disease. Medical complications that can arise from Valley Fever include pneumonia, meningitis, and even death.

With regard to the direct risk of contracting Valley Fever while digging in areas where the Sharktooth Hill bone bed occurs, a year 2012 posting at the Facebook page of a major commercial, fee fossil dig operation situated on private property sheds at least a modicum of light on the subject:

"Question: How many people catch Valley Fever after digging at your quarries?

"Honestly, more participants have had encounters with rattlesnakes, than have contracted Valley Fever (VF). Nearly all of our participants DO NOT use dust masks while digging. We have had over 2000 diggers on the quarry in the last 18 months, and we only have 3 reported instances of participants contracting VF. That falls well belo...w the Kern County average, and may say something as to the prevalence of the spores in areas we are excavating. We have four quarries open currently, all located below the surface, in fossil beds aged between 14 and 18 million years. This 'soil time-line' predates the emergence of c. immitis by over 10 million years."

So, here's the bottom line, the proverbial upshot--Valley Fever spores definitely exist in California's southern San Joaquin Valley, and Valley Fever can indeed be contracted from digging in the area where the Sharktooth Hill bone bed occurs. The reported statistic that "only" three individuals in 18 months of supervised digging there have contracted Valley Fever may or may not assuage the justifiable concerns of potential visitors.

The Round Mountain Silt Member of the Tumbler Formation, which contains the Sharktooth Hill bone bed (and could harbor fungal spores of Valley Fever--a non-collectible item if there ever was one), apparently accumulated roughly 16 to 15 million years ago in a semi-tropical embayment. This great body of water covered all of the present-day San Joaquin Valley from the Salinas area southward to the Grapevine Grade, just north of Los Angeles. The incredible bone bed was evidently preserved along the southeastern edges of the sea in waters no deeper than about 200 feet--an estimate based on the presence of fossil rays and skates,

whose modern-day relatives prefer such relatively shallow depths. It is illuminating to note that all of the living members of the fossil fauna recovered from the bone layer can be found today in Todos Santos Bay off Ensenada, Baja California Norte; the extant marine mammals of the Sharktooth Hill fauna all migrate there during the winter months.

While scientists understand very well the variety of animals that formerly lived in the Middle Miocene Temblor-period sea, they are less certain of what caused restricted preservation in such a narrow bed in a locally unfossiliferous deposit. Although the Temblor Formation does yield moderately common fossil mollusks and echinoids elsewhere in its area of exposure (Reef Ridge in the Coalinga district, for example), the Sharktooth Hill bone bed occurs in sediments that are mysteriously barren of any other kinds of organic remains. In an interval several hundred feet both above and below the bone-bearing horizon there is absolutely no trace of past animal or plant life.

Typically, such a shallow marine environment as is suggested by the bone bed would be expected to include many sand dollars, gastropods, pelecypods and a wide variety of microscopic plants and animals such as diatoms and foraminifers. But such is not the case here. Even after decades of assiduous, dedicated scientific examination, vertebrate animal specimens remain the only diagnostic types of fossil specimens yet recovered in abundance from the Sharktooth Hill bone bed (a few internal casts of gastropod and pelecypod shells have also been reported from the bone bed, in addition to occasional coprolites, invertebrate burrows, and gypsum-coated pieces of petrified wood--none of which is particularly significant or diagnostic, except to say that such occurrences support the idea that the bone bed formed in relatively shallow waters).

Such an unusual abundance of diverse species of marine mammals, sharks, birds, rays, skates and even land mammals requires a unique mechanism of preservation. Clearly the curious mixing of both land and marine vertebrates in the same layer points to an as-yet incompletely understood set of circumstances. Needless to report, ever since the bone bed's discovery on that summer day way back in 1853, investigators have wondered just what events could have created such a remarkable concentration of vertebrate remains in a narrow horizon, to the exclusion of all other marine invertebrates normally associated with a shallow-water environment.

Several ideas have been advanced to explain the rare occurrence.

One of the earliest explanations was offered during the first quarter of the 20th century by paleontologist Frank M. Anderson of the California Academy of Sciences. Anderson suggested that violent volcanism in the region poisoned the Miocene waters with ash and noxious gasses, causing the sudden extinction of the fauna. While it is true that widespread volcanic activity occurred in the Middle Miocene of the present-day San Joaquin Valley, there is no direct evidence to suggest that the Sharktooth Hill fauna was adversely affected by it.

A second hypothesis states that during the Middle Miocene, the bay in which the Sharktooth Hill animals lived became landlocked. As the waters gradually evaporated the unlucky inhabitants were doomed to try to survive in an increasingly smaller area, until at last the creatures succumbed, thus creating a narrow zone in which their skeletal and tooth remains were concentrated.

Yet another explanation concerns the "red tide" phenomenon. Occasionally, a toxin-producing marine microbe multiplies so rapidly that it kills smaller fish by the millions. The organism contains a minute amount of a potent poison that can be easily concentrated in the food chain. Larger fish consume the smaller types that feed on the lethal organism until, eventually, all of the fish are killed.

An additional once-popular proposal was that the Middle Miocene Sharktooth Hill area was a great calving ground for marine mammals, an irresistible attraction for sharks who seasonally feasted on the animals gathered there to give birth. Unfortunately, there is a paucity of juvenile sea mammal bones in the deposit--not the amount one would reasonably expect to find preserved in the Round Mountain Silt Member of the Temblor Formation had the area witnessed for thousands upon thousands of seasons youngsters cavorting in the same warm waters that held their predators--the sharks.

Other possible mechanisms of deposition proposed for the famed bone bed are turbidity currents--which are masses of water and sediments that flow down the continental slope, often for very long distances. Presumably, the carcasses of sea and land animals were caught up in such underwater sediment flows, their bones transported for considerable distances before the remains dropped out of suspension in a submarine canyon, far removed from the Middle Miocene shoreline. Perhaps favoring this explanation is the fact that many of the vertebrate remains from the bone bed reveal obvious signs of wear and tear, suggesting some degree of transport and agitation prior to their eventual burial. As a matter of fact, this is the one specific scenario of bone deposition that most closely matches the evidence; indeed, its among the most widely accepted methods by which literally millions of sea mammal bones and shark teeth and ray teeth could have possibly been preserved in such a narrow internal, to the exclusion of virtually every other kind of marine life.

This is but a sampling of the ideas proposed to account for the Sharktooth Hill bone bed. Unfortunately (for the theorists who suggested them), all but one of the above proposals--the turbidity current idea, specifically--are quite simply put, flat-out wrong. They have been disproved. Over the years, there have probably been as many hypotheses advanced as there are theorists to invent them. Suffice it to say that no one single explanation, save perhaps the turbidity current proposal, has yet been delivered to answer all the questions posed by this famous bone bed of the Middle Miocene.

In early 2009, though, some researchers claimed that the problem had been solved once and for all. The "definitive" explanation--as published by The Geological Society Of America in a paper entitled, *Origin of a widespread marine bonebed deposited during the middle Miocene Climatic Optimum* by Nicholas D. Pyenson, Randall B. Irmis, Jere H. Lipps, Lawrence G. Barnes, Edward D. Mitchell, Jr., and Samuel A. McLeod--is that the Sharktooth Hill Bone Bed accumulated slowly above a local disconformity over a maximum of 700 thousand years due to sediment starvation timed to a major transgressive-regressive cycle during Middle Miocene times 15.9 to 15.2 million years ago. The conclusion here, according to the authors, is that the world-famous bone-bed is not the product of a mass dying, neither is it the inevitable result of red-tide poisoning, nor the remains of animals killed by volcanic eruptions, nor the preservations of vertebrates through the concentrating action of turbidity currents; not even the site of a long-term calving region where sea mammals birthed and sharks hunted can fully explain the fabulous bonanza bone layer. The Sharktooth Hill Bone Bed came about, the scientists claim, over thousands of years due to slow and steady bone accumulation during a period of geologic time when very little clastic sedimentation (sands and silts and muds) occurred.

Perhaps this new research has indeed finally resolved the mysteries surrounding the deposition of likely the greatest concentration and diversity of fossil marine vertebrates in the world. The turbidity current idea still holds water (pun intended) for many, though, and will likely remain a lasting viable explanation for many folks in the paleontological and geological communities.

Research on the Sharktooth Hill area has been exhaustive, to say the least. Reference materials on the subject abound. Probably the single best book to consult is the aforementioned *History of Research at Sharktooth Hill, Kern County, California*, by Edward Mitchell. Other worthwhile works include *Birds from the Miocene of Sharktooth Hill, California*, in Condor, Volume 63, number 5, 1961, by L.H. Miller; *Sharktooth Hill*, by W.T. Rintoul, 1960, California Crossroads, volume 2, number 5; and the July 1985 issue of California Geology, published by the California Division of Mines and Geology, in which an excellent article appears entitled, *Sharktooth Hill, Kern County, California*, by Don L. Dupras.

The once-accessible locality used to make a terrific substitute for Sharktooth Hill. While the fossil remains were obviously not as plentiful as at the more-famous site, amateur collectors and professional paleontologists alike continued to find many beautifully preserved shark teeth and marine mammal bones in the fabulous Sharktooth Hill bone bed. It is a world-class paleontological deposit which has yielded some 125 species of vertebrate animals from the Middle Miocene of 16 to 15 million years ago--a time when a tranquil semi-tropical sea similar to Todos Santos Bay off Ensenada covered the present San Joaquin Valley. It was a time when the ancestors of great white sharks lived where vast fruit orchards now grow in the agriculture-rich Great Central Valley of California.

Chapter 23

Dinosaur-Age Fossil Leaves At Del Puerto Canyon, California

The great debate rages on. What killed off the dinosaurs, that exceptionally spectacular and successful group of animals that ruled Earth for roughly 165 million years?

There has certainly been no lack of creative speculation to account for their disappearance. Not a few years ago, for example, a body of paleontology experts declared that the agent of doom was a devastating, mysterious disease epidemic peculiar to dinosaurian systems, a deadly plague that decimated the ranks, leaving the ecologic niches wide open for the immune mammals hiding underfoot, patiently awaiting their turn to dominate. Perhaps.

Soon thereafter a consensus developed among many students of paleontology that less exotic factors determined dinosaurian fate--such "mundane" geologic events as gradual changes in climate and geography brought about through the slow, sure drifting of continents over millions of years; an arguably more plausible explanation, one would assume, since such a scenario could have altered the once dino-salubrious environment, leaving it wholly unsuitable for the continuation of the dinosaur dynasty.

Then again, not to be outdone in the ongoing guessing game, one researcher once postulated with pretty convincing argumentation that a "glandular disorder" played a cruel trick on the massive metabolisms of the larger dinosaurs, causing their extinction through some sort of dietary malfunction.

Another fashionable hypothesis of current vogue posits that a tremendous meteorite impact in the neighborhood of the modern Yucatan Peninsula (AKA, the infamous Chicxulub crater) almost instantaneously ignited a world-wide inferno--after which great clouds of sulfur-laden dust (geochemists say that sulfur was readily available in the substantial quantities of gypsum preserved in strata penetrated by the massive bolide) blocked all vital sunlight, thus terminating terrestrial and oceanic photosynthesis, eventually plunging the delicately balanced average temperature of the atmosphere low enough to usher in a short but lethal ice age--exterminating dinosaurian existence.

Whatever the eventual answers to the puzzle might be, there is little argument among earth scientists that the last of the dinosaurs lived on Earth during the late Cretaceous Period of the Mesozoic Era, roughly 66 million years ago.

Rocks dating from this geologic age are of course widely distributed in the western United States. The thickest and most classically fossiliferous exposures occur in Montana, Wyoming, Utah, Colorado and New Mexico, where numerous prize dinosaur skeletons have been discovered--along with paleobotanically important associated fossil floras.

For the most part, though, these fossil remains have been quarried from terrestrial deposits, sedimentary beds that accumulated on land in rivers, lakes, ponds and swamps. Marine-originated Cretaceous strata in Texas, Colorado, Utah, South Dakota, and Kansas bear an abundant molluscan fauna of ammonites, pelecypods, gastropods, belemnites, and baculites (a variety of uncoiled ammonite).

In California, rocks of late Cretaceous age are restricted to the western half of the state. There, they often contribute to the dramatic contrasts in topography of several of the coastal mountain ranges. Excellent exposures of these almost exclusively marine sandstones, siltstones, and shales can be studied in the Santa Ana Mountains (which border the Los Angeles Basin); in the interconnected ranges that stretch northward from Santa Barbara to a few miles south of Point Sur; and in Humbolt County near Eureka, far up in the extreme northwest sector of the state.

One of the more promising California areas amenable to paleontological prospecting lies along the west side of the Great Central Valley: Here, starting just south of Coalinga, a rather thick belt of late Cretaceous detrital strata extends some 300 miles northward to the vicinity of Redding--an impressive Mesozoic Era accumulation within which there are but minor, localized interruptions in the generally conformable stratigraphic sequence.

And despite the undeniable fact that the rocks overwhelmingly represent marine-originated horizons--a lithologically monotonous interbedding of alternating shales, siltstones and sandstones--several sections nevertheless reveal near-shore paleoenvironments where the abundant remains of terrestrial plants and occasional hadrosaur duckbilled dinosaurs can be found in strata whose normally diagnostic fossils include ammonites, pelecypods, gastropods, foraminifers (microscopic shells secreted by a single-celled animal), tube worms, corals, giant sea turtles, and marine reptiles--plesiosaurs and mosasaurs. According to paleoherpetologists, the Moreno mosasaur *Plotosaurus bennisoni* achieved the highest degree of aquatic adaption of all mosasuars; it died out in Moreno times only 158,000 years before the meteorite strike that many investigators believe abruptly ended the reign of the dinosaur some 66 million years ago.

Within those rocks, a most productive district for hunting late Cretaceous fossil leaves happens to lie within western Stanislaus County, near the westernmost reaches of California's Great Central Valley--east of San Jose. Here, a near-shore interval in an otherwise deepwater deposit of marine mudstones, siltstones and sandstones yields up numerous species of preserved plants that thrived some 68 million years ago amid the very terrain where dinosaurs dwelled.

This especially rich locality occurs at Del Puerto Canyon, just south of Del Puerto Creek in Stanislaus County. It's approximately 40 miles east of San Jose, and while it's indeed possible to travel backroad to the fossiliferous exposures from that South Bay Area community a more accessible route to the general public is via Interstate 5 to County Road J17--the Patterson Exit. As a matter of fact, I independently ran across the fossil leaf site a number of years ago during a paleontological reconnaissance investigation of late Cretaceous sedimentary deposition along the western side of California's Great Central Valley. Much to my great surprise, several years later (earlier in the 21st century), I learned that the geocaching community had also discovered the Moreno plant-bearing locality in Del Puerto Canyon, when an individual in a geocache rockhounding sub-section posted online its GPS co-ordinates, inviting folks to visit and prove that they'd actually found the exact spot by submitting to his web page a photograph of a fossil leaf from the site.

County Road J17 is of course one of innumerable obscure side roads that connect Interstate 5 with a second major north-south thoroughfare through the wondrously endless flatlands of the Great Central Valley--Highway 99. Taken east, J17 slices through rural farmlands to Turlock, where it intersects Highway 99 at a point roughly 15 miles south of Modesto. The J17 turnoff lies 26 miles north of the Los Banos cutoff--State Route 152--and it's 30 miles south of Interstate 580, which heads over to the San Francisco Bay region.

The locality occurs in a roadcut on Del Puerto Canyon Road--a cut that exposes a 10 to 12-foot thick series of buff-brown, gray-brown, and reddish to purple-tinged silstones and sandstones. The roughly 68 million year-old leaves occur in these detrital rocks.

Approached from the east (that is, beginning at Interstate 5), the exposure extends generally northwestward for some 500 feet, but the majority of plants occur within the first half of the section, as explored from east to west. In addition, the better-preserved paleobotanical specimens seem confined to the pale purplish siltstones interbedded in the predominantly coarse-grained, crumbly, ferruginous sandstones.

These leaf-bearing beds represent the youngest Cretaceous-age depositional phases of the upper Cretaceous to lower Paleocene Moreno Formation--here, around 68 million years old. Indeed, the Moreno spans the world-famous K-T boundary. In geologic map terminology, K is the universal symbol for the Cretaceous Period; and T is used to represent the succeeding Tertiary Period, whose initial epoch is called the Paleocene. Beginning with the Paleocene Epoch some 66 million years ago, dinosaurs no longer lived on our planet.

At the Del Puerto Canyon roadcut exposure of the Moreno Formation, several sedimentary layers reveal abundant carbonaceous content. Numerous black specks, blobs, and slivers of macerated plant material, plus carbonized twigs up to two or three inches long constitute conspicuous components in a few of the blocky grayish sandstones. The best preserved leaves are generally found in several thin pale-purplish

silstone layers near the middle of the roadcut. Typical late Cretaceous plants one would expect to encounter include walnuts, oaks, figs, alders, laurels, and magnolias--a decidedly modern-appearing angiospermous association that had already begun to colonize with great success the once conifer/cycad/fern dominated Triassic, Jurassic and early to mid Cretaceous Mesozoic Era world.

Patience is the operative attitude to assume at fossil leaf localities. Often, much splitting of the rocks with a geologic rock hammer (or perhaps a wide-blade putty knife) is necessary to recover the better-quality specimens--that is to say, protracted repetitive physical activity that on occasion tasks endurance.

But this is all part of the thrill of potential discovery that accompanies a fossil-hunting excursion. You never know what that next chunk of material pried apart might reveal. And the ultimate rewards of such wonderful late Cretaceous paleobotany here are very much worth the wait.

In addition to the fascinating paleobotany, the fossil-rich strata at this site also reveal an unusual stratigraphic bedding trend. Stand back from the roadcut to note that the terrigenous sediments would appear to stand at "attention"--at a near vertical tilt. Geologists call this special style of outcropping a dip slope, as the surfaces of the bedding planes, or their dip, correspond to the exposed profile of the cut.

After exploring the primary fossiliferous Moreno Formation beds, one may wish to investigate two additional plant-yielding roadcuts along Del Puerto Canyon Road a short distance away. The first lies two-tenths of a mile west of the main paleobotanical place, where upon causual inspection there appears to be negligible variation in the fossil flora--and the leaves remain far less plentiful and not nearly as obvious in the sedimentary rocks. The third locality can be found one mile west of the second site, or 1.2 miles from the first roadcut discussed; here again the fossil plant diversity and associated specimen preservation is just not as rewarding, although some serious dedicated splitting will usually disclose a number of nice leaves.

Even though the upper Cretaceous to Paleocene Moreno Formation yields important terrestrial fossil material--including leaves, petrified wood, carbonized woody structures, and hadrosaur dinosaurs (unless you've obtained a special dispensational permit from Stanislaus County, by the way, one must not collect vertebrate specimens from the Moreno Formation)--the duckbilled fellow *Augustynolophus morrisi*, for example, is California's state dinosaur (it occurs only in the Moreno Formation), the world-famous geologic rock unit is nevertheless recognized as a marine-originated deposit; taphonomists suggest that on occasion bloated carcasses of Moreno-time dinosaurs floated far offshore before settling to the sea floor, where silts, sands and muds eventually covered the disarticulated skeletal elements, scattered by currents and

oceanic scavengers.

Regarding the herbiverous hadrosaur *Augustynolophus morrisi,* a fascinating paleontological side-story here is that sophisticated high resolution stratigraphic sampling of Moreno Formation foraminfera (tiny shells secreted by a microscopic single-celled organism)--exquisitely sensitive time indicators whose multitudinous species lived and died during specific, restricted moments in geologic time--proves that during deposition of the Moreno Formation, the hadrosaur dinosaurs went extinct a full 1.23 million years before the infamous meteorite impact of 66 million years ago that many investigators identify as the kill-shot which ended the dinosaurian dynasty on Earth.

In the vicinity of the fossil leaf locality at Del Puerto Canyon, such obvious marine specimens as ammonites, pelecypods (including Inoceramus prisms), foraminifera tests (secreted by a microscopic single celled organism), mosasaurs, plesiosaurs, and the bones, scales and teeth of sea going bony fish occur locally. The sensational Moreno Formation shell beds situated south of Del Puerto Canyon--which produce abundant, world-famous specimens of *Glycymerita banosensis* pelecypods--occur in sedimentary sections considerably more conglomeratic than the finer-grained strata in the Del Puerto Canyon district. This major change in lithologies and faunal content indicates a high energy near shore environment there during later Cretaceous times.

Of course, fossils of terrestrial plants in the Moreno Formation necessarily demonstrate that deposition of the plant-bearing sections occurred in rather shallow marine waters, perhaps in the vicinity of a delta where organic-rich sediments discharged with regularity into the Cretaceous sea.

And speaking of fossil plants--one unique locality (meaning, it's the only one of its kind in the world) in the Moreno yields apatitized wood--that is, petrified material replaced by phosphate minerals, in association with leucophosphite preserved in gypsum-encased nodules. As one might justifiably expect, paleobotanists have had a regular field day with this specific fossil plant occurrence; the apatized wood has been assigned to the modern genus *Chrysophyllum*, now native to tropical regions throughout the world, one species of which has managed to colonize southern Florida.

An especially informative scientific study that encompasses the Del Puerto Canyon area is Special Report 104, *Upper Cretaceous Stratigraphy on the West Side of the San Joaquin Valley, Stanislaus and San Joaquin Counties, California*, by Charles C. Bishop, published by the California Division of Mines and Geology in 1970. Included is a superior quality geologic map that fossil enthusiasts will find particularly useful. Not only does it detail the geographic extent of the Moreno and related Cretaceous formations exposed in the region, but it also pinpoints specific fossil localities--a genuine bonus for seekers of Cretaceous paleontology.

At Del Puerto Canyon, the leaf-bearing upper Cretaceous rocks of the Moreno Formation provide a wonderful window into our geologic past; they were deposited some 68 million years ago while dinosaurs still roamed the land. And the fossil plants now preserved in them witnessed the final struggle of dinosaurs to survive, to endure. The leaves you find here knew the thunder of the dying dinosaur.

Chapter 24

Early Triassic Ammonoids In Nevada

In the backcountry wilds of Nevada occur two truly classic Early Triassic ammonoid localities. Both sites yield innumerable beautifully preserved ammonoids--an extinct order of cephalopod--in what geologists, stratigraphers and fossil cephalopod researchers call the lower Triassic Thaynes Formation, roughly 248 million years old, deposited near the beginning of the Mesozoic Era only three or four million years after the close of the preceding Paleozoic Era. The Thaynes is exposed at several localities in the rugged mountain ranges of the Great Basin, yet only one lone specific place in Nevada produces abundant Early Triassic ammonoids of such extraordinarily exceptional preservation.

Of course, both Nevada Thaynes localities remain highly regarded among ammonoid specialists the world-over. Each experiences rather regular visitation from professional paleontologists, although admittedly that single unparalleled ammonoid locality is not only the finest Early Triassic ammonoid-bearing site in North America, but also one of the great Mesozoic Era cephalopod horizons in the world, in general--all of this, mind you, despite the fact that its overall aerial sedimentary outcrop is confined to a meager few square acres within an isolated canyon. The entire stratigraphic section lies within what ammonoid enthusiasts call the *Meekoceras* and *Anisibirites* Zones--units of cephalopod-bearing rocks in which the ammonoids *Meekoceras gracilitatus* and *Anasibirites kingianis* are the defining characteristic specimens encountered.

What makes that single ammonoid locality so significant in a paleontological context is that nowhere in North America are the world-famous *Meekoceras* beds exposed through anywhere near the thickness that they are at the fossil-rich section. Through roughly 175 feet of exposed strata, abundant ammonoids representing the *Meekoceras* Zone can be found. At the most fossiliferous and famous of the Early Triassic geologic sections, the extinct cephalopods occur in three of the seven limestone beds in the lowermost portions of the lower Triassic Thaynes Formation. Above that principally carbonate interval, the Thaynes consists of several hundred feet of thin-bedded grayish brown to tan shales in which organic remains of any kind are consipicuously absent.

Geological research completed in the late 20th Century, though, demonstrated pretty convincingly that the renowned fossiliferous section consists of several faulted, fractured and vertically displaced blocks, and at least one of the blocks is overturned. The upshot here is that contrary to conclusions conveyed by early geological investigations, there are only two ammonoid-bearing horizons at the locality, not several separate zones as previously

determined. Still and all, stratigraphers agree that the Nevada *Meekoceras* zone can be confidently correlated with several additional notable occurrences around the globe, places such as: the Olenek-Lena River Basin in Siberia; Okhostsk-Kolyma Land, Siberia; Japan; Kwangai, China; Timor; New Zealand; Himalayas, India; Salt Range, Pakistan; Barabanja, Madagascar; northern Caucasus Mountains; Arctic Canada; and former Yugoslavia.

It's a stratigraphic section that continues to receive considerable attention from successive waves of geology students, who've mapped its sedimentary intricacies with great detail many times over.

And so, the Thaynes ammonoid-bearing sequence is indeed now very well known. At that most-special of ammonoid-bearing localities at that isolated Nevada canyon, the Thaynes Formation is formally subdivided into seven distinct mappable lithologic units, called Members "a" through "g."

The uppermost, or youngest fossiliferous bed in the Thaynes is termed member "g." It's roughly 12 feet of gray calcium carbonate that tends to weather into shades of dark brown, a fine to medium-crystalline limestone characterized by thick to irregular bedding; fragmental and complete ammonoid conchs occur throughout. While the cephalopods are perhaps not as well preserved as their counterparts in the oldest member at the measured section, at least eight species of ammonoids have been described from the rich interval, including *Juvenites septentrionalis*, *Owenities koeneni*, *Owenoites stokesi*, *Parannanites mulleri*, *Pseudosageceras multilobatum*, *Meekoceras gracilitatus*, *Flemingites russeli*, and *Wyomingites arnoldi*.

Unit "f," just below the fossiliferous "g" member, is a barren interval of fine to medium-crystalline light gray limestone some 48 feet thick; it is frequently difficult to distinguish "f" and "g" from a distance, but the uniformly unfossiliferous nature of "f" suggests that if you come upon it in the field you should walk up section a short distance, through the barren carbonates to intersect the productive limestones of member "g" above it.

Next oldest unit in the Thaynes section is member "e," a rusty-brown weathering fine to medium crystalline limestone roughly 45 feet thick that produces abundant remains of a genuine "living fossil"--the inarticulate brachiopod called *Lingula*, which most paleontologists believe represents one of the great survivors of geologic time. It's a species that has persisted through the eons when many other perhaps more glamorous creatures such as the dinosaur, the trilobite and the ammonite vanished from earth many millions of years ago. Resembling a slender fingernail, *Lingula* first appears in the fossil record during the Early Cambrian Period,

approximately 520 million years ago. It has survived unchanged in physical appearance for all that time.

Immediately below the productive *Lingula* zone lies the second ammonoid-rich layer, unit "d." This is a fine to medium-crystalline light-gray limestone some 15 feet in thickness, massively bedded with slabby partings. And it is everywhere crammed with plentiful cephalopodic remains, mostly fragmental; but the coquinoid nature of member "d" keeps many collectors busy for hours at a time, gently cracking the organic-rich carbonates to free the prized ammonoids within. Paleontologists have identified eight species of ammonoids from the horizon: *Juvenites septentrionalis*, *Aspenites acutis*, *Owenites koeni*, *Inyoites stokesi*, *Paranannites mulleri*, *Meekoceras gracilitatus*, *Wyomingites aplanatus*, and *Preflorianites toulai*.

The successively older Thaynes stratigraphic units "c" and "b" are both poorly exposed--and unfossiliferous. They have a combined thickness of roughly 30 feet, consisting of pale gray limestone and occasional micaceous calcareous shales that tend to weather into platy slabs.

But the underlying unit "a," which reaches a maximum development of some 33 feet, is abundantly fossiliferous with both broken and complete cephalopods. As a matter of fact, approximately half or more of the light-gray to brown-weathering limestone, characterized by frequent limonitic flecks and partings, is composed of ammonoid remains. It is indeed a stunning deposit that innumerable fossil collectors have visited over a period of many decades. As a consequence, horizon "a" has suffered an appreciable ammonoid attrition; the perfect fossils have become increasingly difficult to find, especially the larger showy shells, several inches in diameter, for which commercial dealers pay top dollar.

Editorial time now, I reckon: There is obviously no way to prevent commercial fossil collectors from visiting the area, but one can only make the obvious observation that if the desecration trend continues there won't be much left to find there except unidentifiable fragments. For the benefit of all conscientious paleontology enthusiasts, commercial collectors must keep their distance, or the Bureau of Land Management (BLM) will surely close it all down, enacting severe restrictions on who can keep what they find there.

Member "a" of the Thaynes Formation is justifiably a world-famous ammonoid deposit; some 23 species have been described from it, including *Dieneroceras* (three species), *Xenocelities* (two species), *Juvenites* (two species), *Meekoceras gracilitatus*, *Hemiaspinites obtusus*, *Flemingites russeli*, *Anaflemingites silberlingi*, *Preflorianites toulai*, *Pseudospidites wheeleri*, *Owenites koeneni*, *Paranannites apenensis*, *Prophingites slossi*, *Parussuria compressa*,

***Lanceolites compactus*, *Aspenites acuts*, *Wyomingites whiteanus*, *Arctoceras tuberculum*, *Arctoprionites* sp. and *Pseudosageceras multilobatum*.**

A second major Early Triassic Thaynes ammonoid locality also occurs in Nevada. Even though it's certainly not nearly as well known to collectors as the primary locality, sporadic waves of avid fossil enthusiasts nonetheless continue to successfully find their way to the reliably productive ammonoid-bearing Thaynes Formation deposits, approximately 248 million years old.

An encouraging bit of news it that at last visit this second Nevada section could still be found in essentially pristine stratigraphic condition, despite the fact that the ammonoidiferous horizons have been known to fossil hunters since at least the late 1800s. For example, legendary Triassic ammonoid specialist James Perrin Smith first visited the locality in the early 1900s and took away loads of identifiable cephalopods.

The ammonoids occur, of course, in the lower Triassic Thaynes Formation, which is sporadically exposed throughout a specific geographic area of Nevada. In California, noteworthy outcrops of ammonoid-bearing Early Triassic strata can also be examined at Union Wash in the shadows of Mount Whitney (highest point in the contiguous United States); the paleontological material there resides in the Union Wash Formation. And Early Triassic ammonoids occur in western Utah, as well.

At the two ammonoid localities in Nevada's lower Triassic Thaynes Formation, it is intriguing to reflect that in the context of deep geologic time the roughly 248 million year-old animals you find there lived "only" three to four million years after the greatest mass extinction ever recorded in the rocks--the traumatic end time Permian Period of 252 million years ago, when fully 96 percent of all life on earth died out. An ammonoid you hold in your hand survived it all, and lived on to eventually weather out of the Thaynes limestones that gave it a kind of immortality.

Chapter 25

Fossil Plants At The Chalk Bluff Hydraulic Gold Mine, California

While conducting research on the many interesting fossil plant localities in Northern California, I happened to read about an especially promising site in the fabulous Gold Rush Country, western foothills of the Sierra Nevada--the Chalk Bluff area, a number of miles from Grass Valley/Nevada City (they are contiguous communities in Nevada County).

The Chalk Bluff region was the scene of extensive hydraulic gold recovery operations during the mid to late 1800s, an historic period when miners extracted millions of dollars' worth of gold (mostly at the old price of around 20 dollars per ounce) from the widely exposed auriferous gravels of the northern Mother Lode.

In California, hydraulic mining initially began on a small scale in 1852, but soon developed into a regionally ubiquitous, sophisticated method of working great volumes of gold-bearing gravels. The basic idea was to aim high-powered jets of water through huge nozzles at the auriferous gravels, washing away tons upon tons of debris, after which the gold-bearing debris/sludge traveled through a deep cut or tunnel that was lined with a series of sluices to capture the gold. During roughly a 30-year period, from 1855 to 1884, hydraulic miners washed away approximately 250 million cubic yards of material. This created repeated catastrophic flooding of farmlands and valuable property in the flatlands below the hydraulic operations. Eventually, a farmer in Marysville by the name of Woodruff decided to sue the North Bloomfield Gravel Mining Company to prevent further debris from being discharged into the Yuba River. That case was presided over by Judge Lorenzo Sawyer, who issued his famous "Sawyer Decision" in January of 1884--a 225-page document that with effective legal decree abolished large-scale hydraulic operations in California for all time.

During the decades of gold extraction, the hydraulickers at Chalk Bluff incidentally exposed a wonderful fossil plant-bearing horizon interbedded with the auriferous gravel deposited by the Tertiary Yuba River (sedimentary accumulations usually considered a proximal correlative stratigraphic manifestation of the distal Eocene Ione Formation, whose type locality lies in the vicinity of Ione, Amador County, western foothills of the Sierra Nevada, about 62 miles southwest), a relatively narrow zone of fine-grained clays, usually not more than 3 feet thick, situated within the roughly 400 feet of pebble-cobble gold-bearing gravels of early middle to middle Eocene geologic age, some 48 to 45 million years old. This fossilferous bed of claystone--typically referred to as "chocolate shales" for their memorable coloration upon fresh exposure--contains the remains of numerous species of ancient botanic specimens: leaves and seeds and pollens and flowering structures, whose preservation is often magnificent. Sometimes the leaves reveal beautiful examples of the original cuticle, which is that thin wax coating on the upper epidermis of leaves that helps protect against excessive water loss, mechanical injury, and fungal attack. In the middle Eocene chocolate shales, exposed by hydraulicking methods during gold recovery, the original cuticle is locally quite common, appearing as a thin wax paper-like material that easily peels off the matrix upon direct exposure to the air; for this reason, paleobotanists wrap it in tissue paper with urgent immediacy to prevent any loss of the invaluable substance--a genuine rarity in the fossil record. In addition to the fossil leaves, relatively common pieces of petrified wood can also be observed in the same general area, mainly from a gravelly channel a few feet below the leaf-bearing chocolate shales.

My personal research disclosed rather quickly that the Chalk Bluff region is frequently mentioned in the paleobotanical literature on the fossil floras of Northern California. It is in fact a renowned fossil-bearing district, among the first plant-yielding areas scientifically studied in California after hydraulic operations had exposed the leaf-petrified wood deposit in the mid 1800s.

Indeed, the history of paleobotanical and geological investigations pertaining to Chalk Bluff is quite extensive. A professor Josiah Dwight Whitney first mentioned the Chalk Bluff fossils in an article published in the first volume of Geology, early 1870s. They were later described in detail in a truly remarkable paper, *Report of the Fossil Plants of the Auriferous Gravel Deposits of the Sierra Nevada* by Leo Lesquereux, Memoirs of the Museum of Comparative Zoology at Harvard College, Volume 5, Number 2, 1878. Prior to the advent of cyber-technology (AKA, the Internet), where even the most obscure scientific papers can often be accessed online, I was fortunate to locate an original copy of Lesquereux's classic monograph at the library of the California Division of Mines and Geology in Pleasant Hill. Lesquereux includes numerous detailed line drawings of the fossil leaf specimens--a feature usually inferior to photographs, but in this example the scholarly drawings definitely enhance the quality of the finished product. In 1880, professor Whitney discusses the Chalk Bluff area once again in his monumental publication *The Auriferous Gravels of the Sierra Nevada, California*, Vol. 1, Memoirs of the Museum of Comparative Anatomy at Cambridge, Massechesetts.

In 1911, geologist Weldemar Lindgren published the definitive statement on the gold-bearing gravels of the northern Sierra Nevada: United States Geological Survey Professional Paper 73, *The Tertiary Gravels of the Sierra Nevada of California*. For a section of the volume entitled Tertiary Fossil Plants, Lindgren solicited a report from then leading paleobotanist F. H. Knowlton, who mentions the Chalk Bluff site, along with 12 additional plant-bearing localities in northern California, including: Washington Gravel Mine, Independence Hill near Iowa City in Placer County; Volcano Hill, Placer County; Monte Cristo Gravel Mine, "summit of Spanish Peak in Plumas County;" Mohawk Valley, Plumas County; Bowens Tunnel, along the North Fork of Oregon Creek near Forest City in Sierra County; "about seven and a half miles southwest of Susanville, Lassen County;" Table Mountain, Tuolumne County; the north end of Mountain Meadow, Lassen County; and "near Moolight," Lassen County.

In her 1935 report on a fossil leaf deposit in Plumas County, Northern California, Susan S. Potbury wrote that H. D. MacGinitie was, at that date, revising the Chalk Bluffs Flora, the results to appear in a forthcoming paleobotanical monograph. MacGinitie finally published his findings in 1941 in Carnegie Institute of Washington Publication 534, *A Middle Eocene Flora from the Central Sierra Nevada*. This is certainly the best study of the Chalk Bluffs Flora. "Mac" (an endearing moniker, given to him by contemporary professional paleobotany acquaintances) concluded that the Chalk Bluffs Flora could be assigned stratigraphically to the "Capay Stage" of the Eocene (named after the marine Capay Formation)--then understood as middle Eocene in geologic age--around 48 to 45 million years old--an interval that geologists currently correlate with the coal-bearing Domengine Formation exposed in the East San Francisco Bay area.

Of course, based on several independent lines of scientific evidence, Capay-age now refers to rocks of late early Eocene times. Still and all, "Mac" got it right. The refined stratigraphic calibration of the "Capay Stage" is presently established at 52 to 50 million years old, which is not the geologic age of the younger Chalk Bluffs Flora (48 to 45 million years) that "Mac" had in mind.

As can best be determined, the Chalk Bluff leaf-bearing site is far from under-reported. It has been quite well known to amateur paleobotany enthusiasts since the 1860s, and several scientists have also spent considerable time investigating the fossil occurrence. As a matter of fact, the Chalk Bluff leaves that Leo Lesquereux first examined in the 1870s had been collected in the late 1860s by Charles D. Voy, an acclaimed naturalist and indefatigable gatherer of South Sea Islands ethnological items.

So imagine my frustration when I could not find in any of the listed references a single explicit description of the exact geographic position of the Chalk Bluff region. The most promising lead came from a generalized map of the Northern Mother Lode contained in the volume, *Geologic History of the Feather River Country, California*, by Cordell Durrell, 1987. Durrell's map placed Chalk Bluff somewhere between Nevada City and Colfax in Nevada County--a decent start, I'll admit--but the map lacked important side-roads leading directly to the area.

Now, normally, I'm not inclined to head off on a paleontology excursion without a full complement of accurate field information. But in this instance I was pretty much forced to do just that. If I was going to find the reportedly magnificent Chalk Bluff fossil field, I would necessarily need to head in to the hills impoverished in supporting directions data.

My plan of attack was pretty straightforward. I'd simply follow Interstate 80 east out of the Sacramento area (at that date, I had fortuitously been visiting Northern California on personal business unrelated to matters paleontological), then turn north at the first major road in Colfax, about 46 miles distant in the direction of Reno, Nevada. Along the way toward Nevada City from Colfax, I'd decided to strike out east at approximately the "correct" distance north of Colfax--all of this itinerary, mind you, dictated to me by that generalized map included in Cordell Durell's publication.

The plan was admittedly a long shot. I couldn't be sure I'd be able to recognize the Chalk Bluff region even if I were actually right on top of it. Additionally complicating the situation was that, based on previous journeys into that portion of the Gold Rush Country, I already understood that innumerable side roads presented a bewildering maze of routes that led to isolated communities and recent real estate developments--all part of the burgeoning populations of Nevada and Placer counties.

So, which path to take to the fossils? My general idea, of course, was to watch for telltale evidence of hydraulic mining; the middle Eocene fossil plants were associated with auriferous gravels exploited by open pit hydraulic methods during the mid to late 1800s. But unless I could happily choose the correct route right off, I might travel far afield of my destination, losing precious time that could have been devoted to paleobotanical explorations.

For this reason--and, simply because I had the hankering for it--I had decided to tote along a gold pan I'd borrowed from an acquaintance, in addition to my usual store of paleontological equipment. If I couldn't locate the Chalk Bluff fossil plant horizons within a decent amount of time, I figured I'd spend the remainder of my allotted day's adventures panning for gold along the famous Bear River, a known gold-producer of the 1800s. As a matter of fact, the so-called Colfax Quadrangle (within which Chalk Bluff and Bear River reside) yielded many millions of dollars' worth of gold during the Gold Rush delirium days, albeit the vast majority came from the hydraulic operations at Chalk Bluff.

By the time I made Auburn (33 miles east of Sacramento) in the early morning hours of a potentially blistering summer's day down in the Great Central Valley, I was ready for some breakfast--a propitious decision as it turned out. Maybe it was the strong bracing coffee, or perhaps the energizing nourishment provided by the bacon and eggs and biscuits but suddenly I began to think more clearly on my day's adventures. While gazing out the window of that coffee shop on the striking mixed conifer/oak woodland scenery of the western Sierran foothills, I happily concluded that I was not necessarily compelled to report to luck in order to locate the Chalk Bluff fossil plant bonanza. What if I could obtain a map of Nevada County? And what if that map showed the exact location of Chalk Bluff? This idea was definitely worth a try, I decided.

At the grocery store across the street I found a road atlas of California. So far, so good, I thought. The publication I'd come across had a positive reputation for reliability. Immediately I turned to Nevada County and scanned the page for any kind of conceivable clue--and then, there it was right before my eyes--all the information I needed to find Chalk Bluff. I purchased that road atlas on the spot, and the rest as they say is history.

It's probably problematic whether I would have been able to locate Chalk Buff without the aid of that road atlas, but at least I'm comforted to realize that I intuitively had the correct idea: Head north out of Colfax along the first major road I came to.

Speaking of Colfax. Here's a geological aside to keep in mind: If you travel about 9 miles further on up the freeway from Colfax (roughly a mile past the Gold Run rest stop), you'll encounter along the north (left) side of I-80 one of the most accessible and extensive sections of unexploited middle Eocene auriferous gravels yet remaining in all of Northern California; it's the spectacular roadcut that extends roughly a half mile along I-80, a cut that gives travelers a wonderful opportunity to view up close and personal, from a moving vehicle, the excellently preserved fossil thalwegs of a river that dropped unimaginable fortunes in gold.

A few miles north of Colfax, by the way, one crosses the Bear River. It was here that I decided to try my hand at a little gold panning during that initial visit to Chalk Bluff. On my return from the fossil plant horizon, I must have spent the better part of a couple of hours with bare feet in the Bear, rear on the bank and nose to the water, peering intently into the swirling material in my pan--all to no avail, ultimately.

That golden gleam eluded my sight, although I'm not in the least surprised. My gold panning technique is far from efficient. Perhaps this has to do with a woeful lack of practice, because it's not that I haven't tried to improve my gold recovery method. I once had a certified gold panning expert try to improve my ways. He repetitively dropped two or three pieces of lead shot into my successive pans of experimental gravel, then instructed me to recover those pieces by slowly and surely concentrating the "fines' of my dirt with waters supplied by a mountain stream. After I'd cost him a small fortune in lead, he concluded with high confidence that I'd likely become prolifically rich someday, as he was certain that I would have no trouble finding gold nuggets no smaller than a cannonball.

During that first visit to the Chalks Bluffs Flora deposit, I continued to follow the road atlas with faithful fidelity, managing to arrive at the great abandoned hydraulic pit in good order, with plenty of time available not only for fossil prospecting, but general geologizing, as well. As I quickly ascertained through reconnaissance, getting up to paleontological speed as it were, the fossil leaves and petrified wood occur to the immediate north and south of the primary dirt path through the middle Eocene auriferous gravels exposed by hydraulic gold miners during the mid to late 1800s.

I also noted, upon subsequent visits undertaken not a few years later, that one needs to watch carefully for No Trespassing signs here. Most of this area remains in private ownership, where explicit advance permission from the property owners must be secured prior to fossil hunting. And even if you don't observe obvious posted documentation of private property--never assume that one is allowed to step anywhere off the main road within the Chalk Bluff hydraulic mining region without advance approval. Always conduct preliminary due diligence: Contact officials with the local United States Forest Service office to determine the most up-to-date rules and regulations regarding fossil collecting at Chalk Bluff.

As you look to the north at the main Chalk Bluff fossiliferous sector, you will observe a broad ravine directly before you. Fossil leaves, seeds, flowering structures, and pollens occur in the pale brown-weathering shales near the base of the south side of that steep ravine--in other words, directly below your feet. When freshly exposed by hand excavation, the drab fossil-yielding shales instantly transform into a rich chocolate brown coloration--hence, their popular informal name "chocolate shales."

But before you begin to hunt for fossils along that northern side, step across the road and take in the vista that spreads to the south. Here you will observe great chasms sliced through the gold-bearing gravels--acre after acre of water-blasted land that yielded unfathomable fortunes in gold.

And now, only if unambiguous permission is still granted to collect here, proceed to find your way to the bottom of that ravine along the north side of the dirt road.

From that top-side vantage point, though, there appears to be no easy route to reach the fossil-bearing area. Most of this north-facing wall is way too steep to try to descend safely. It was exposed by the gold seeking hydraulickers of the mid to late 1800s when they laid bare mile after mile of the auriferous gravel throughout the northern Mother Lode Country. During my first visit to Chalk Bluff, I was so exhilarated about having reached the right area that I impatiently scrambled down the south side of that ravine, dangerously sliding most of the way. Subsequent visits proved that this method was not only unesthetic, but needlessly reckless as well. A much safer path to the bottom exists a short way west of a convenient parking area, where the slopes remain far less precipitous and treacherous.

Once at the base of the hydraulic cut, watch carefully for the fine-grained fossiliferous layer of chocolate-colored material, the so-called chocolate shales. Although this horizon is relatively narrow within the exposed sedimentary section--it is only three feet thick at most (and often partially masked by eroding overburden)--the leaf-bearing rocks are so different in lithology from the reddish brown pebble-cobble saturated auriferous gravel that you should have little difficulty identifying it in the field. If in doubt, give any potential fossil-bearing strata a whack or two with a geology hammer, exposing fresh rock. The leaf-yielding claystone is so fossiliferous that almost any chunk exposed will reveal at least a few 48 to 45 million year-old plant remains on the surface.

The lithology of the fine-grained claystone, in combination with the abundance of fossil plants preserved within, provides persuasive evidence that the fossiliferous zone accumulated in stagnant oxbow lakes along the floodplains of Eocene-age aggrading rivers (watercourses that built up sediments, instead of downcutting their channels) that dropped great quantities of gold derived from now long-eroded lode veins in igneous rocks.

And make no mistake about it. This claystone horizon in the middle Eocene auriferous gravel is often amazingly fossiliferous; the carbonized leaf impressions frequently lie plastered across the bedding planes, crisscrossing in a fascinating design of exceptional preservation (so-called "leaf litter"). The fossil-bearing layer of "chocolate shales" occurs in the coarse gravels that lie stratigraphically above the older "inner channel," a relatively narrow zone only about 40 feet deep (on average) and tens of feet wide, situated near bedrock, within which the vast majority of the abundant gold recovered by hydraulic methods was concentrated. Above the inner channel, or "blue ground" as the miners referred to this unbelievably rich zone, the younger gravels accumulated to a thickness of approximately 400 feet. These "bench gravels" contained much lower concentrations of gold, although a few reported localities in the younger auriferous gravels did indeed yield prolific quantities of the precious metal.

Of course, the popular term "auriferous gravel" is not a formally accepted geologic formation name. It has no strict nomenclatural significance because there are other gold-bearing gravels in California of different ages. But, through long usage and tacit acceptance by local California geologists, the phrase has come to connote a very specific rock deposit. The auriferous gravels accumulated approximately 48 to 38 million years ago during the Eocene Epoch of the Cenozoic Era, an epoch technically calibrated at 56 to 33.9 million years ago. Based on the traditional interpretation of the geologic evidence, the gravels were deposited along the flood plains of aggrading rivers (most famously, the Tertiary Yuba River)--that is, water courses which were building up sediments instead of eroding their channels.

One of the great mysteries confronting geologists who've studied the auriferous gravel is why rivers that for millions of years were eroding their channels would suddenly begin to aggrade, or build up sediments. Several explanations have been considered to account for this occurrence, but only two competing plausible models appear to offer possibilities to fulfill the equation, answer all the questions.

In his classic work *Geologic History of the Feather River Country,* geologist Cordell Durrell suggested that a prolonged change of climate from one of regular wet-and-dry seasons to one of irregular wet-and-wetter cycles may have triggered repeated episodes of catastrophic flooding, much like that which occurs in the vicinity of Rio De Janeiro, Brazil, a region with a climate and vegetation similar to that inferred for the Sierra Nevada area some 48 to 45 million years ago; such floods are very local, of course, but Durrell pointed out that no single flood need cover a large area to account for the accumulation of auriferous gravel. All that was needed was to have a sufficient number of flooding episodes within every part of the region where auriferous gravels now occur--in other words, the 10 northern counties of the Sierra Nevada, or an area of roughly 12,000 square miles.

At first, this might seem to represent a prohibitively extensive area for floods to affect. But consider Durrel's calculations. Deposition of the auriferous gravel probably lasted for as long as 10 million years, or all of the middle Eocene. Therefore, there was ample time for periodic flooding to account for the gold-bearing gravels. Durrell suggested that if only one consequential flood occurred every 50 years, there could have been as many as 200,000 floods. If the rain gods were more generous and the figure was closer to one flood every 20 years, then the total climbs to a possible 500,000 floods.

Now, Durrell introduces us to some basic arithmetic. Suppose each flood deposited an average of only two feet of sediment affecting an area of 10 square miles (a conservative figure completely within reason). That would mean that it would require 250,000 floods to bury the 10 northern counties of the Sierra Nevada to a depth of 400 feet, the actual measured thickness of the auriferous gravels we see today in California.

An alternate, second, explanation was championed by the late paleobotanist/geologist Howard Schorn, former Collections Manager of Fossil Plants at the University California Museum of Paleontology. Schorn and others postulated that about 52 million years ago (early Eocene), the marine waters that had covered what's now California's Great Central Valley for several million years began to regress, or retreat. That drop in sea level caused streams flowing westward from the ancestral Sierra Nevada to begin to incise their channels. At around 48 million years ago (early middle Eocene), sea levels began to rise once again when the Domenguine-Ione Seaway re-flooded (transgressed) the proto-Great Central Valley, returning marine conditions to a terrestrial area previously left high and dry.

That rise in sea level began to block, or dam, the mouths of the ancient northern Sierra Nevada rivers, among them the Tertiary Yuba River, initially causing gold-rich sediments to accumulate in the moderately downcut inner channels (areas later known to hydraulickers as the fabulous "blue ground"). Continuing incremental sea level increases contributed to the deposition of progressively greater volumes of sedimentary material in the older eroded river courses, completely filling them, until at last the Tertiary Yuba River spread out over the floodplains in wide meandering curves, thus creating by aggradation the bench gravels and chocolate shales--within which the middle Eocene Chalk Bluffs Flora occurs.

Some 70 species of ancient plants have been identified from the Chalk Bluffs Flora (which refers collectively to the total aggregate of plants obtained from every locality in the middle Eocene auriferous gravels of California's Northern Mother Lode district), including such varieties as: American climbing fern; cinnamon fern; flowering fern (solely from pollen evidence); Mexican cycad; broadleaf lady palm; sarsaparilla vine; crack willow; swamp hickory; an extinct genus of *Engelhardia*, a tree whose modern types are native to northern India east to Taiwan, Indonesia and the Philippines; Formosan alder; a species of chinquapin now endemic to Vietnam and China; three extinct oaks similar to the living interior live oak, Sierra oak, and Japanese blue oak; Mexican elm; Breadfruit; Pea fig; an extinct fig; Yellow lotus (also called Yellow pond lily); Katsuna tree; a species of *Hyperbaena* resembling a variety now native to Central America; umbrella magnolia; two species of extinct *Cinnamomum* (Cinnamon trees); six species of evergreen laurels, including swampbay; Chinese hydrangea; American witch-hazel; American sweetgum (also called Liquidamber, now native to the southeastern United States, Mexico, and Central America); five species of extinct sycamores (one resembles the modern American sycamore), including the magnificent *Magnititiea whitneyi* (leaves can spread to 13 inches wide; it resembles the living sycamore *Platanus lindeniana* of east-central Mexico to Guatemala); Cocoplum; Slimleaf rosewood; a species of rosewood that resembles a kind now native to China; a species of Tick clover that is similar to a type now endemic to East Asia; a legume whose closest modern counterpart lives in the Amazon flooplains; Chinese olive; Tree of heaven; Cuban cedar; a spurge (Euphorbia) now endemic to southern Mexico and Central America; East Asian mallotus (also called the "food wrapper plant"); staff vine; a species of *Phytocrene* now native to Myanmar, Sumatra, Java, and the Philippines; Smooth sumac; an extinct maple that resembles the living Red maple and trident maple (now native to China); mallows (obtained only from pollens); a *Cupania* tree presently endemic to the South American countries--Argentina, Uruguay, Paraguay, Brazil, and Bolivia; a species of *Thouinidium*, a shrub to small tree now common in southern Mexico; a variety of *Meliosma*, a large brush to small tree, presently native to China; a species of *Bridelia*, a large shrub or small tree native to southeast Asia; walnut (only from pollens); two species of buckthorne now endemic to southeastern Asia and China; princess vine; Franklin tree; spicewood; black gum (also known as Black tupelo); Tropical almond; Pacific dogwood; Pongame oiltree; American persimmon; black ash; oleander; milkwood; dog-strangling vine; a species of viburnum presently common to Mexico; a species in the genus *Mikania,* often called hempvine--it's native to Mexico, Central and South America, the West Indies, and the southeastern US; a species that most closely resembles the genus *Tylophora*, a vine native to tropical and subtropical Asia, Africa, and Australia; a type that most closely matches the genus *Premna* (mint family), a small tree or shrub common in tropical and subtropical regions of Africa, southern Asia, northern Australia, and several islands in the Pacific and Indian Oceans; a specimen that is quite similar to the extant nettlespurge; forms that most closely match the genus *Croton*, currently native to Indonesia, Malaysia, Australia, and the western Pacific Ocean islands; a mysterious extinct plant that shows characteristics typical of both Blackjack oak and a sycamore; and the following conifers, all obtained only from palynological specimens blown in from great distances--pine, spruce, and fir.

All specimens are middle Eocene in geologic age, roughly 48 to 45 million years old--an awe-inspiring fossil flora whose overall composition resembles a modern subtropical Mexican Elm-Liquidamber forest at the foot of Mount Orizaba in Vera Cruz, Mexico, where rainfall averages 60 to 80 inches a year, and the usual year-round temperature is close to 65 degrees, with no frost. There are also similarities to such modern subtropical forests as those found along the Rio Moctezuma at Tomazunchale, Mexico; to the Liquidamber-Oak and Mexican Elm forests near Coban, Guatemala; and to the Liquidamber forests in the state of Morelos and the eastern Sierra Madre west of Tomazunchale, Mexico.

Today, the Chalk Bluffs Flora lies at elevations between 2,500 and and 4,000 feet amid what botanists variously categorize as the Transition Life zone, the Sierra Transition life zone, or the Sierran Lower Montane vegetation zone--an area within California's western Sierra Nevada foothills now dominated by a decidedly Mediterranean-style meteorology; that is to say, summers typified by rather high daytime temperatures (often exceeding 100 degrees), low humidity, and scant rainfall (usually as little as one inch for the entire three month period). Virtually all the effective precipitation occurs during wintertime--when temperatures can drop to 5 degrees Fahrenheit--as frequent heavy rains and occasional snow. It's a land

characteristically populated by the following common plants: Azalea (*Rhodendron occidentals*); Big-leaf maple (*Acer macrophyllum*); Black cottonwood (*Populus trilocarpa*); Black oak; (*Quercus kelloggii*); Canyon live oak (*Quercus chrysolepis*); Chinquapin (*Castanopis sempervirens*); Chokecherry (*Prunus demissa*); Coffeeberry (*Rhamnus rubra*); Creambush (*Holodiscus discolor*); Deer brush (*Ceanothus integerrimus*); Dogwood (*Cornus nuttallii*); Douglas-fir (*Pseudotsuga texifolia*); Elk clover (*Aralia californica*); Gooseberry (*Ribes roezlii*); Hazelnut (*Corylus rostrata*); Incense cedar (*Libocedrus decurrens*); Knobcone pine (*Pinus attenuata*); Labrador tea (*Ledum glandulosum*); Madrone (*Arbutus menzsiesii*); Mahala nut (*Ceanothus prostratus*); Manzanita (*Arctostaphylos patula*); Mountain mahogany (*Cercocarpus betuloides)*; Mountain misery (*Chamaebatia foliosa*); Pigeonberry (*Rhamnus californica*); Poison oak (*Rhus Taxicodendron diveriloba*); Red alder (*Alnus rubra*); Serviceberry (*Amelanchier alnifolia*); Sugar pine (*Pinus lambertiana*); Sumac (*Rhus trilobata*); Tan oak (*Lithocarpus densiflora*); Thimbleberry (*Rubus parviflorus*); Tobacco brush (*Ceanothus velutinus*); White fir (*Abies concolor*); Wild grape (*Vitis californica*); Wild rose (*Rosa* spp.); Willow (*Salix* spp.); and Yellow pine (*Pinus ponderosa*).

A major collecting convenience at Chalk Bluff is that the claystone is quite soft. This means that the fossilferous material is easily split with a geology hammer (chisels, optional), or perhaps a brick layer's wide blade tool--as advocated by not a few paleobotanists for all leafiferous localities, even though the tool obviously lacks the necessary punch/mass required to split the more indurated, hardened, leaf-bearing rocks; the upshot: a good old regular geology hammer is best for splitting virtually all leaf-bearing shales. The plants preserved in the chocolate shales have remained most life-like in preservational detail, despite the undeniable fact they've been buried for approximately 48 to 45 million years. For example, several specimens I've uncovered reveal actual original cuticle, a thin wax coating on the upper layer of leaves that helps protect against damage that could interfere with photosynthetic activity.

In addition to the paleontologically rewarding leaf-bearing chocolate shales, the Chalk Bluff district also yields locally obvious examples of petrified wood. It's of similar geologic age as the fossil leaves, middle Eocene, but the permineralized wood occurs primarily within auriferous bench gravel beds slightly older than the chocolate shales. Most of the sporadic concentrations of petrified woods lie north of the shale beds just explored for fossil leaves, where it erodes free of the brownish auriferous gravels as hand-sized specimens, mainly. Even though the wood is excellently silicified, replaced by the mineral silicon dioxide, the material is far from gem quality. It has not been agatized or replaced by the kinds of colorful minerals that might justify great lapidary value. Preservation of the woody structure is usually superb, though, so folks with slabbing saws just might want to try sectioning specimens to expose the growth lines.

In an historical perspective, petrified wood used to be quite abundant in the coarser auriferous gravel lenses during hydraulic mining days--including occasional spectacular occurrences of standing stone stumps and lengthy fallen logs. The old-time gold seekers

removed great quantities of it while they blasted away entire mountainsides with their powerful jets of water, stacking the permineralized organic remains in sizable piles so that they would not interfere with gold extraction activities. Sometimes they used the larger rock logs to line their long flumes, employing with practical ingenuity a plentiful natural resource to help transport water to the operations. Today, petrified wood is only common to locally abundant in the many massive, abandoned surface mines scattered throughout the northern Mother Lode country--notably Buckeye Flat, Sailor Flat, Dutch Flat, North Columbia, Iowa Hill, and Malakoff Diggins--most of it having been carted away decades ago as curiosity pieces.

The petrified wood, leaves, seeds, flowering structures, and pollens preserved in the Chalk Bluffs Flora have figured quite prominently in a great geophysical and geomorphological debate: Just how high was the ancestral Sierra Nevada during the geologic past? The traditional view, famously championed by the late paleobotanist Daniel I. Axelrod (and numerous other scientists, of course), is that the Sierra Nevada, as we know it today, is a relatively recent topographic expression, uplifted to its present dramatic elevations mainly during the past five million years--with most of that uplift occurring over the last three million years. Yet, studies based on sophisticated geophysical evaluations of many mountain ranges, combined with paleobotanical leaf character analysis (study of leaf size, shape, venation, and percentage of entire to serrated margins, among other parameters, to help determine the paleoclimate and paleoelevation of a given fossil site), preliminarily suggested quite strongly that the Sierra Nevada, along with the neighboring ancestral Great Basin region, stood just as high if not higher during middle Eocene Chalk Bluff times than at present.

Finally, though, after analyzing multitudinous information amassed from disparate disciplines of scientific research, investigators seem to be gradually approaching a consensus--namely, that the ancestral central to southern Sierra Nevada existed during Eocene times as a relatively low-lying, gradual-gradient western slope to a high plateau region, the so-called Nevadaplano, that stretched eastward across present-day Nevada, an Eocene upland area that rose as high, if not higher, than the peak elevations seen there today. At around 16 million years ago, the Nevadaplano began to collapse, drop, through extensional geophysical strains associated with incipient formation of the Great Basin, eventually falling to roughly present-day elevations by about 13 million years ago.

Which would mean, ultimately, that the central to southern Sierra has indeed been dramatically uplifted during the past five million years or so. On the other hand, today's northern Sierran areas would have remained at around the same elevations as those that existed during deposition of the Eocene auriferous gravels some 48 to 38 million years ago. If that indeed turns out to be the case, everyone involved in the Sierran elevation studies can claim a partial victory: the grand solution to the Sierra Nevada Eocene elevation problem would involve a major compromise--around two-thirds of the Sierran length would have been greatly uplifted during the past five million years.

Today, at an elevation of roughly 3,000 feet, the Chalk Bluff fossil field is theoretically accessible to year-round exploration. Realistically, though, you'll probably wish to consider skipping a wintertime visit, due to the usual heavy rains and occasional snowstorms that effectively prohibit efficient and comfortable explorations. Also, if one calculates that one could possibly beat the invariable extreme summertime heat in California's Great Central Valley by fleeing to Chalk Bluff--forget it. The altitude there is just not sufficient to influence an appreciable daytime temperature reduction from "down below." The evenings and nights tend to range somewhat cooler, though, so that would constitute a positive meteorological condition. All in all, late spring (after the rainy season) and early to mid fall (before seasonal precipitation patterns) usually offer the most reliably comfortable conditions for hiking, for efficient paleobotanical investigations.

Access to the Chalk Bluff district is via a system of excellent asphalted surface streets and well-graded dirt roads. Most conventional vehicles in reliable operating condition should have no trouble reaching the fossiliferous area. The main dirt road in can turn treacherous during the rainy season, of course, especially if humungous logging rigs have rumbled through, transforming the route into a hazardous quagmire. Too, throughout the Sierra freezing season, be extra alert for "black ice" along the roads--patchy frozen invisible films that can send unsuspecting drivers into a panicked slide.

Today, the Chalk Bluff fossil locality lies amidst what botanists often call the Sierran Lower Montane vegetation zone, characterized by ponderosa pine, sugar pine, knobcone pine, willow, Black cottonwood, alder, manzanita, and madrone. Yet, during middle Eocene times some 48 to 45 million years ago, this very area would have held a stagnant oxbow lake within the vast floodplains of a meandering Amazon-like river, where countless leaves, seeds, flowering structures, and pollens from a subtropical forest fell into the gradually accumulating clays of oxygen-poor waters, preserving such plant life as palm, magnolia, swampbay, sarsaparilla vine, breadfruit, tupelo, fig, persimmon, cinnamon, sycamore, and liquidamber in amazing detail.

Chapter 26

In Search Of Fossils In The Tin Mountain Limestone, California

One of the most persistently fossiliferous geologic rock formations in all the western Great Basin Desert wilds of Inyo County, California, is the lower Mississippian Tin Mountain Limestone, a classic carbonate accumulation that has yielded an abundance of well-preserved invertebrate animal remains 358.9 to 350 million years old--including such major groups as brachiopods, bryozoans, conodonts (minute phosphatic tooth-like structures, unrelated to modern jaws and teeth, that served as a unique feeding apparatus in an extinct lamprey eel-like organism), corals, mollusks (gastropods, pelecypods, and ammonoid cephalopods), ostracods (diminutive bivalved crustaceans), and trilobites. It was first named in the scientific literature, appropriately enough, for its prominent exposures on Tin Mountain in then Death Valley National Monument (now of course it's situated within the confines of Death Valley National Park, as of 1994), the northernmost peak in the Cottonwood Mountains around 12 miles southwest of Scotty's Castle (as the crow flies).

While the outcrops there are obviously off-limits to unauthorized amateur collecting, other amazingly fossiliferous exposures of the mid Paleozoic Era formation that occur outside the park's boundaries on Bureau of Land Management (BLM)-administered public lands remain wide open for hobby gathering of reasonable amounts of common invertebrate fossils.

But here is where the proverbial fun begins. Despite the fact that the Tin Mountain Limestone is a widely distributed and distinctive rock unit exposed throughout the mountains bordering Death Valley, easily accessible outcrops remain tantalizingly few and far between. And even if collecting were allowed within the national park, one problem would still remain to be solved: how to reach the fossiliferous strata without incurring injury, since many of the especially promising outcrops that I've observed occur along the skylines of steep ridges where access to the potential paleontology present there would probably demand sophisticated mountain-climbing techniques--boo, hiss. This circumstance is definitely most discouraging, in the main.

Yet all is not lost. Happily, through persistent geological and paleontological due diligence (consulting geologic maps and old United States Geological Survey reports, primarily), Tin Mountain aficionados--a rather loose-knit association of interested invertebrate animal enthusiasts, as it were--have identified for inspection three easily accessible, representative exposures of the Lower Mississippian Tin Mountain Limestone, where visitors can sample innumerable photogenic fossil specimens stained an aesthetically attractive reddish-brown on a dark blue limestone matrix. Even though two of the prime fossil localities admittedly lie

within the borders of Death Valley National Park--a third site happens to reside on public lands and is wide open for hobby fossil acquisition--seekers of exceptional Tin Mountain paleontology nevertheless continue to frequent with considerable consistency those places still under jurisdiction of the National Park System. The reasons for this behavior are not difficult to identify, of course: Combining a Death Valley scenic adventure with an opportunity to take photographs of some special Paleozoic Era fossils is an irresistible attraction, indeed.

A first Tin Mountain Limestone site occurs in the vicinity of Towne Pass, which used to lie just outside the western boundary of Death Valley National Monument; it's now well within territory that is federally mandated as a national park. Prior to 1994, though, when the Desert Protection Act became law--assimilating in one fell swoop zillions of acres of adjacent wilderness lands into a newly created Death Valley National Park system, the legendary Towne Pass locality could be found with happy convenience but a literal stone's throw outside Death Valley National Monument. As a consequence, it was a very well-known and productive fossil locality, one that furnished generations of amateur paleontology enthusiasts and professional Earth Scientists alike with myriads of beautiful Early Mississippian fossil forms.

Towne Pass used to lie two-tenths of a mile southwest of the entrance to Death Valley National Monument, but it presently resides wholly within the confines of Death Valley National Park along California State Route 190, 60.3 miles east of its junction with US 395 in Olancha (Owens Valley). Elevation is 4,956 feet here--it's indeed the final major grade one encounters before the plunge into Death Valley, proper, on the eastern slopes of the Panamint Range. A faint dirt trail which connects with RS 190 but a few feet downgrade from Towne Pass provides a convenient place to park off the main road.

The fossiliferous lower Mississippian Tin Mountain Limestone beds occur about three-quarters of a mile almost due east of Towne Pass. A relatively non-strenuous hike across a gradually ascending alluvial fan is necessary to reach them. To gain a general overview of the fossil-bearing area, stand next to the signpost at Towne Pass and look to the southeast, to the right side of the state route as it head toward Death Valley. Navigationally speaking, the Tin Mountain outcrops occur 4,200 feet south, 65 degrees east of Towne Pass. But you don't need to drag out the sextant or the trusty Brunton compass to find out where to hike.

As you look southeast from Towne Pass to the moderately steep ridge nearest route 190, you will note three distinct types of rocks exposed. At the northermost end of the ridge is a poorly stratified reddish-brown material banked against a thick wedge of cliff-forming dark blue limestone which in turn overlies a narrow band of light gray dolomite situated farthest south

in the sequence. The reddish-brown sediments lying to the immediate north of the dark blue limestone and light gray dolomite are what geologists call a fanglomerate, a kind of fossilized alluvial fan deposited three to six million years ago during Late Miocene through Upper Pliocene times. It was derived from eroding Paleozoic Era sedimentary material exposed during the rather "recent" geologic uplift of the Panamint Range. It's a consolidated, cemented accumulation of pebbles, cobbles, and boulders weathered out of every Panamint Mountains Paleozoic rock formation present--a stratigraphically significant "layer cake" that faithfully records a mostly uninterrupted, conformable sequence of continuous sedimentary deposition dating from the earliest Cambrian Period, some 541 million years ago, all the way up to the conclusion of the Paleozoic Era, around 252 million years ago.

That fanglomerate is truly fascinating in a strict geologic context, but it's obviously unfossiliferous (except for weathered chunks of organic-bearing sedimentary rock out of their normal stratigraphic position). Two-tenths of a mile south of the later-Cenozoic fanglomerates lies the relatively narrow interval of pale gray dolomites--rocks belonging to the middle to upper Devonian Lost Burro Formation, 393 to 359 million years old, which is one of the most immediately recognizable rock formations in all of Inyo County. Locally it yields abundant reef-like accumulations of tangled stromatopoids, an extinct variety of calcareous sponge that experienced its greatest adaptive success during the Devonian Period. Additional Lost Burro fossil material includes spirifer-style brachiopods, corals, and Orecopia genus gastropods. Typical stromatoporoid types encountered in the Lost Burro include what Porifera specialists call scientifically genus *Amphipora*--though it's more often referred to colloquially as the "spaghetti stromatoporoid" because it usually resembles strands of pasta when spotted in the rocks--and a "bulbous" to conically configured variety with distinctive concentric laminations.

Sandwiched between the grayish dolomite of the Devonian Lost Burro Formation to the south and the reddish-brown upper Miocene to upper Pliocene fanglomerate to the north is the material you want to explore for fossils--the bluish cliff-forming carbonates of the lower Mississippian Tin Mountain Limestone.

From the parking area at Towne Pass, hike the roughly three-quarters of a mile to the base of the limestone slopes, where several obvious mound-like accumulations of talus--eroded chunks of limestone brought down from the steep outcrops above--provide the most effective and efficient opportunities for productive fossil-finding. Remember, of course, that this spot lies within Death Valley National Park. Keep all that you find only in a camera. Search carefully through the limestone rubble outwash, watching in particular for brachiopods and corals--two of the more abundant invertebrate kinds present here. *Spirifer*-type brachiopods are very conspicuous, as are numerous specimens of such extinct corals as

the colonial *Lithostrostrotionella* (a hexacoral), *Zaphrentites* (rugose horn coral), *Caninia* (a second type of rugose horn coral), and the colonial *Syringopora* (a tabulate coral--often referred to as the "spaghetti coral").

All of the specimens here are rather easily spotted on the surfaces of the Tin Mountain carbonates; typically they stand out in bold brownish relief against the dark blue limestones. Many of the corals reveal exquisite external preservation, appearing almost lifelike in their internment in the rocks. The fossil-bearing horizons in the Tin Mountain Limestone accumulated some 358.9 to 350 million years ago along a shallow marine shelf then situated astride the equator, where optimal equable environmental conditions favored a genuine proliferation of invertebrate animal life. Based on the regional distribution of Paleozoic Era paleontology throughout Inyo County, paleo-geographers calculate that the Early Mississippian shoreline existed many miles southeast of present-day Death Valley. Probably there were several Madagascar-like large island masses scattered in the general vicinity of where the Tin Mountain Limestone accumulated in a warm, relatively shallow tropical sea setting through Early Mississippian geologic times.

After exploring the prolific paleontology at Towne Pass, it's time to visit probably the most accessible exposure of lower Mississippian Tin Mountain Limestone in all of Death Valley National Park--incomparable Lost Burro Gap in the Cottonwood Mountains, several miles north of world-famous Racetrack Playa (site of those mysterious sailing stones), where you can actually drive right up to it in the field and then hop out of your vehicle and literally stand right next to Tin Mountain's geologic contact with the underlying dolomites and quartzitic sandstones of the middle to upper Devonian Lost Burro Formation.

Lost Burro Gap, as a matter of fact, is the very place that reinvigorated my enthusiasm for Paleozoic Era fossils--my first paleontological interest; a visit with my parents, as a youngster, to California's Marble Mountains trilobite quarry in the lower Cambrian Latham Shale started my life-long fascination with paleontology. After not a few years of concentrating primarily on Cenozoic Era terrestrial fossil deposits (paleobotanical, paleoentomological, paleomalacological, and vertebrate-bearing localities), a chance spur-of-the-moment decision to take a drive through Lost Burro Gap while heading south to the Racetrack Playa provided a serendipitous opportunity to rekindle my Paleozoic passions.

Lost Burro Gap is indeed special. It preserves a remarkably representative geologic example of the same patterns of mid Paleozoic Era strata one finds exposed throughout the western United States; rocks of roughly similar lithologies and of identical age can be traced all the way across the Great Basin, from the Inyo Mountains, California (west of Death Valley), clear through Nevada to western Utah, then north to Idaho and Montana (where the Lower

Mississippian Lodgepole Limestone of the Madison Group is in part a correlative geologic time equivalent of the Tin Mountain Limestone). Here's a great opportunity, then, to examine fossiliferous rocks of Silurian, Devonian, and Early Mississippian age that record approximately 93 million years of passing geologic time. Not only is the lower Mississippian Tin Mountain Limestone easily prospected there for its abundant paleontology (remembering of course to take only pictures of the specimens), but the underlying middle to upper Devonian Lost Burro Formation and lower Silurian to lower Devonian Hidden Valley Dolomite also contain bountiful silicified preservations of invertebrate animals (that is, replaced by the mineral silicon dioxide)

The way to Lost Burro Gap is pretty straightforward, of course. A preliminary necessity for staging purposes is travel to the northernmost terminus of State Route 190 in Death Valley National Park. Take the route to Ubehebe Crater and Racetrack Playa. You will need a sturdy and reliable vehicle to negotiate safely the occasionally rough road up ahead. From the junction with SR 190, proceed 28 miles to Teakettle Junction. Here, Racetrack Playa with its world-famous sailing stones lies only seven miles farther south. Save that visit for another time, please. Proceed left on the branching dirt trail that leads to Hunter Mountain.

Lost Burro Gap, proper, begins roughly one and a quarter miles from the intersection with Teakettle Junction. For approximately three-quarters to one mile the dirt path slices through spectacular exposures of the pale gray dolomites and brownish quartzitic sandstones of the middle to upper Devonian Lost Burro Formation, capped by medium to dark blue carbonates of the lower Mississippian Tin Mountain Limestone. At the southernmost reaches of Lost Burro Gap, extending onward into the hills surrounding Hidden Valley, easily accessible and representative outcrops of the lower Silurian through lower Devonian Hidden Valley Dolomite occur.

All the geologic rock formations at Lost Burro Gap offer ample chances to examine nicely accessible mid Paleozoic Era paleontology (that is to say--fossils of Silurian, Devonian, and Mississippian age). Just about any gully there, for example, leads you to within reach of the Tin Mountain Limestone, while the Lost Burro Formation and Hidden Valley Dolomite are for the most part exposed within immediate reach on both sides of the road. At the southern end of Lost Burro Gap, the Tin Mountain Limestone dips down to road level in direct geologic contact with the older underlying Lost Burro Formation, and you can get out of your vehicle, right on the spot, and stand at the precise moment in geologic time when the Devonian changed to the Mississippian Period 358.9 million years ago.

In the Lost Burro Gap district, the lower Mississippian Tin Mountain Limestone is quite fossiliferous. It's roughly 475 thick here, divisible into two main members based on a general

aspect of outcropping, variations in limestone bedding, and relative prevalence of interstratified shales. The lower unit, for example, is a bench to mild slope-forming unit roughly 275 feet thick--a medium gray limestone preserved in beds two to six inches thick, separated by thinner layers of calcareous shale in shades of light brownish-gray to pale red; dark gray chert nodules are occasionally encountered. Above that is member two's 200 feet of cliff-forming, erosion-resistant medium gray limestone in beds a few inches to two feet that bear a few dark-gray chert nodules; pale-red shale parting are faint, few and far between. Fossils occur throughout the full 475 feet, but the best material can be observed in the lower bench-forming unit, where limestone beds composed almost entirely of crinoid stems (technically termed an encrinite) lie positioned stratigraphically with carbonates crammed with tabulate "spaghetti" *Syingopora* corals, rugose horn corals, and wildly branching favositoid corals. Brachiopods are common, and diverse. Expect to encounter such genera as *Shumardella*, *Spirifer*, *Brachythyris*, *Composita*, *Productella*, *Schizophoria*, and *Punctospirifer*.

Lying in conformable stratigraphic position below the lower Mississippian Tin Mountain Limestone is the middle Devonian to upper Devonian Lost Burro Formation, originally named in the scientific literature as a matter of fact for its occurrence here at Lost Burro Gap. It forms virtually all of the eye-catching sculpted walls of Lost Burro Gap closest to the main road. With minor lithologic variations, the Lost Burro is a great accumulation of some 1,500 feet of dolomite (magnesium carbonate), sandy dolomite, quartzitic dolomite, and limestone characterized by dramatic banded bedding in alternating shades of pale gray to dark blue and almost black. In a roughly 530 foot thick interval of dark gray to almost black limestones and dolomites near the middle of the Lost Burro, myriads of interesting stromatoporoids--an extinct variety of calcareous sponge that often dominated Devonian marine ecosystems--occur as tangled masses of "spaghetti”-style "strands" of *Amphipora* and associated concentrically laminated hemispherical to conical examples; all quite photogenic, indeed. Near its contact with the overlying Tin Mountain Limestone, the upper 35 feet of the Lost Burro Formation consists of a brown and pinkish-brown weathering shaly quartzitic dolomite which produces stunning specimens of the spirifer-type brachiopods *Cyrtospirifer* and *Eleutherokomma*. Additional Late Devonian brachiopods from the uppermost Lost Burro beds include *Tylothyris* cf *T. raymondi* Haynes, "*Camarotoechia*" aff. "*C*" *doplicata* (Hall), *Cleiothyridina* cf *C. devonica* Raymond, and *Productella*.

Resting in geologic contact directly beneath the Lost Burro Formation is the lower Silurian to lower Devonian Hidden Valley Dolomite, named in the technical literature for its typical exposures in Hidden Valley just south of Lost Burro Gap. That's where it reaches its ultimate development, its thickest and most representative style of outcropping--some 1,300 feet of a

medium gray and light gray magnesium carbonate. At the southernmost reaches of Lost Burro Gap, lying along the west side of the road in particular, a conveniently accessible exposure of the fossiliferous Hidden Valley can be examined. Here one may observe in situ many nice examples of Silurian corals from the lower section of the Hidden Valley Dolomite, including--globular *Favosites*; solitary tetracorals; "spaghetti" *Syringopora* tabulate corals; and the important Index Fossil *Halysites*, more commonly called a tabulate chain coral. *Halysites* is classically diagnostic of Ordovician and Silurian-age rocks worldwide, though it's most especially characteristic of Silurian deposits. In strata nearly transitional with the overlying Lost Burro Formation, from a 65-foot thick section of medium gray dolomite that tends to weather light olive gray, the Hidden Valley yields several quality Early Devonian fossil varieties--including cup corals; a rugose coral called *Papiliophyllum elegantulum*; two species of tetracoral--*Amplexus lonensis* and *A. invaginatus*; *Cladopora* favositid corals; *Heliolites* tabulate corals; *Platyceras* gastropods; and the brachiopod *Acrospirifer kobehana*. Of particular interest to coral specialists is the reported occurrence in the Hidden Valley Dolomite of beautifully preserved rugose "button corals" called scientifically *Porpites porpita*. Also described--from Hidden Valley carbonate samples dissolved in a diluted solution of acetic acid (by technicians who've secured a collecting permit from the National Park Service)--are abundant conodonts, minute tooth-like structures (unrelated to modern jaws or teeth) that acted as a unique feeding apparatus in an extinct lamprey eel-like organism.

After fossil-prospecting Lost Burro Gap (with a camera in hand, of course--no need to recapitulate NPS rules and regulations, I reckon), it's time to head on over to a third accessible Tin Mountain fossil-bearing area. It lies on public lands administered by the Bureau of Land Management (BLM) and is therefore open to the hobby fossil collecting of reasonable amounts of common invertebrate animals. This third locality lies in the Funeral Mountains outside Death Valley National Park.

Here in the Funeral Range, geologists and paleontologists have probably conducted their most exhaustive scientific investigations of the lower Mississippian Tin Mountain Limestone. Most authors mention in their formal reports that the Tin Mountain here is exceptionally fossiliferous with corals and brachiopods and crinoids and conodonts and foraminifers and ostracods in particular from a measured section some 315 feet thick. In the Funeral Mountains fossil area, the Tin Mountain is divisible into five mappable lithologic subunits, or members, which rest in conformable relations on the underlying middle to upper Devonian Lost Burro Formation--a predominantly dolomitic deposit (composed of magnesium carbonate) that contains locally abundant *Amphipor*a "spaghetti" and concentrically laminated hemispherical stromatoporoids, an extinct calcareous sponge--in addition to brachiopods, corals, crinoidal debris, and the remarkable gastropod *Orecopia*.

At the Funeral Range site, the Tin Mountain Limestone rests with dramatic lithologic and color contrast directly above the massive pale gray dolomites of the Devonian Lost Burro Formation. The lowest of the five Tin Mountain units (usually referred to as t1 through t5), is about 25 feet of interstratified medium dark gray limestone, shale, and argillaceous limestone that produces many corals, brachiopods, foraminifers, and conodonts.

Above that lies about 75 feet of member 2 (t2), a medium dark gray limestone that weathers to shades of medium gray; brachiopods are common near the base of t2, while corals become more abundant toward the top, with microfossils--foraminifers and conodonts--associated with both the brachiopods and coelenterates. Relative prevalence of corals in unit t2 is best judged by the fact that all five of the following forms show up in most collections secured from it: *Rylstonia*, *Homalophyllites*, *Syringopora*, *Vesiculophyllum*, and *Caninia*.

Next youngest Tin Mountain Limestone member is unit t3--usually described by field geologists as roughly 75 feet of coarsely bioclastic crinoidal limestone, crammed with large crinoid columnals and impressively robust disarticulated segments, that weathers to a distinctive light gray band along the mountainsides, in contrast with the darker blue carbonates immediately above and below it. Indeed, the unit produces some stunning crinoidal echinoderms that make attractive showcase specimens. Corals and brachiopods occur more commonly near the base and top of t3, in the dark to medium gray to limestones more characteristic of the formation.

Unit t4 generally forms a 50 foot thick rubble-strewn bench below the steeper slope or cliff of the youngest Tin Mountain Limestone unit t5. T4 is a medium gray or darker limestone that contains distinctive pale-red and pinkish gray silty partings in its lower sections, while reddish argillaceous intervals tend to characterize the upper horizons. Numerous elongated chert nodules that almost coalesce with one another typify the upper limestone layers. Conspicuous unbroken fossils occur throughout the member. Obvious silicified organic constituents (replaced by the mineral silicon dioxide) include gorgeous coral heads, fantastic lattice-style bryozoans, and numerous species of beautiful brachiopods. Microfossil collections (recovered from a diluted acid solution) disclose abundant conodonts and ostracods. *Goniatites* ammonoids have also been reported here.

Above the fabulously fossiliferous (t4) lies the steep slope or often cliff-forming limestones of member 5 (t5). Compared with the extraordinary prolific diversity and richness of well-preserved paleontology exhibited by t4, member t5 could at first blush be considered a disappointing experience. This is fully expectable, in the main, one must admit. For one, t5's brachiopods and corals are usually less plentiful and not nearly as well preserved as their counterparts in the older underlying Tin Mountain unit. Still, some dedicated searching

eventually discloses a satisfying assortment of fossil goodies from t5. Of course, by this time one really needs to watch one's footing, as the terrain becomes increasingly treacherous to try to explore. The steeper slopes reliably inhibit enthusiastic examinations of member 5, and probably this dramatic incline increase contributes to its under-reported fossil content.

Because of its fortuitous accessibility in such proximity to the world-class geology and paleontology of Death Valley National Park, the Tin Mountain Limestone locality in the Funeral Range remains a seasonally popular destination for any number of university Earth Science field classes--primarily during the traditional field trip months of early spring and mid fall when meteorological conditions in this part of the Northern Hemisphere most reliably favor a comfortable outdoor experience.

Probably not all of Tin Mountain's potential paleontological treasures will be spotted at the three sites visited here, but it is certainly stimulating to consider for future paleo-prospecting reference that even a partial listing of Early Mississippian invertebrate forms documented from its regional Death Valley area of outcropping includes the following:

Foraminifers--*Latiendothyra* of the group *L. parakosvensis*, *Palaeospiroplectammina* aff. *P. parva* (Chernysheva), *Septaglomospiranella primaeva*; Corals--*Amplexus* sp., *Aulopora* sp., *Beaumontial* sp*., Caninia* sp., *Cyathaxonia* sp., *Enygmophyllum* sp., *Homalophyllites* sp., *Lithostrotionella* sp., *Menophyllum* sp., *Rylstonia* sp., *Syringopora surcularia* Girty, *Syringopora* aff. *surcularia* Girty, and *Vesiculophyllum* sp.; Bryozoans--branching bryozoans, indet., *Cystodictya* sp., Fenestella sp.; Brachiopods--*Buxtonia* sp., *Camarotoechia* sp., *Chonetes* sp., *Cleiothyridina* cf. (*C. obmaxima* (McChesney), *Cleiothyridina* sp. *Composita*, sp. *Cyrtina* sp. *Dielasma* sp., orthotetid brachiopod, genus indet., *Productella* sp., *Punctospirifer* sp., *Rhipidomella* sp. aff. *R. michelini* (Leveille), *Rhynchopora* sp., *Scizotfhoria* sp., *Spirifer* sp., (centronatus-type), terebratuloid brachiopod, genus indet., *Torynspirifer* sp.; Pelecypods--*Allorismal* sp., *Parallelodonl* sp.; Gastropods--cf. *Anomphalus* sp., *Baylea* sp., *Bellerophon* sp., *Lanthinopsis* sp., cf. *Loxonema* sp., Mourlonia, sp., *Murchisonia* sp., *Naticopsis* sp., *Platyceras* (*Platyceras*) sp. *pleurotomarian* gastropod, genus indet., *Rhineoderma* sp., *Straparollus* (*Euomphalus*) *utahcnsis*, (Hall), *Straparollus* (*Euomphalus*) *subplanus* (Hall and Whitefield), *Straparollus* (*Euomphalus*) sp., indet. *subulitid* gastropod, genus indet.; Cephalopods--goniatite cephalopod, undet. orthoceroid cephalopod, undet.; Trilobite--phillipsid trilobite, genus indet.; Worms (phylum Annelida)--cf. *Spirorbis* sp.; Conodonts--*Siphonodella cooperi* Hass, *S. obsoleta* Hass, *Polygnathus symmetricus* E. R. Branson, *P. inornatus* E. R. Branson; Ostracods--*Tetrasacculus* sp. aff. *T. stewartae* Benson and Collinson, Amphissites n. sp. aff., *A. similaris* Morey, *Roundyella*, n. sp. aff. *Scrobicula crestiformis, Kummerowia*, n. sp. aff. *Kirkbya fernglennensis, Kirkbya keiferi*, *Kirkbyella* (*Berdanella*) n. sp. aff. *Kirkbyella annensis* Benson and Collinson, K. B., n. sp. aff. *K. recticulata* Green, *Psilokirkbyella ozarkensis* (Morey),

Rectobairdia **sp. cf.** ***R. confragosa*** **Green,** ***Acratia*** **(*****Cooperuna*****), n. sp. aff.** ***A. similaris*** **Morey Green, Bohlenatia, n. sp. aff.** ***Acanthoscapha banffensis*** **Green, Monoceratina, n. sp. aff.** ***M. virgata*** **Green,** ***Monoceratina*** **n. sp. aff.,** ***M. elongata*** **Benson and Collinson,** ***Graphiadactylloides*****, n. sp. aff.** ***Graphiadactyllis moridgei*** **Benson.**

Theoretically, at least, all three Tin Mountain Limestone localities can be visited in reconnaissance style in a single day. That would of course entail quick flitting from place to place, spending but a perfunctory period at each paleo-treasure area. A more leisurely adventure scenario of relaxed exploration is obviously advocated here.

Finding a place to spend a few days in this Great Basin Desert region is certainly not a difficult proposition. The primary campgrounds within Death Valley National Park are situated at Mesquite Spring, Stovepipe Wells, Furnace Creek Ranch (Sunset and Texas Spring campgrounds), and Panamint Springs Resort (about 13 miles west of the Towne Pass Tin Mountain fossil site). Cabins can also be rented at Panamint Springs, and motel rooms are available at Furnace Creek Ranch. Once outside the boundaries of Death Valley National Park on public land, you are permitted to choose just about any camping place that strikes the fancy. If all else fails, excellent accommodations can be found at Beatty, Nevada, or even Lone Pine, California.

Here's an opportunity to journey back in deep geologic time to a tropical Tin Mountain Limestone sea teaming with Early Mississippian life. That reefs of corals and other creatures flourished at the equator here some 358 million years ago in a warm-water ocean in what is today a supremely dry Death Valley area desert seems incalculably improbable.

Yet, in the Great Basin Desert of eastern California--at Lost Burro Gap, the Funeral Range, and a site within view of Towne Pass--you can stand at the equator of gone time, of 358 million years ago, and witness the vanished animals living on in stone all around you.

Chapter 27

High Sierra Nevada Fossil Plants, Alpine County, California

Those who would like to combine a trip to California's High Sierra Nevada wilderness with a visit to a fossil plant locality just might want to try the Mount Reba area of Alpine County. Here is a leaf-bearing site that dates from the late Miocene epoch, approximately 7 million years old. Some 14 species of ancient plants have been identified from the sedimentary-volcanic stratigraphic section of the Disaster Peak Formation, including specimens of cypress, Douglas-fir, evergreen live oak, tanbark oak, willow, and giant sequoia.

Today, the fossiliferous rocks lie at an elevation of 8,640 feet, but the plants preserved in them prove that 7 million years ago the site of deposition in that specific sector of the Sierra Nevada could not have been any higher than about 2,500 feet. This so-called Mount Reba Flora thus demonstrates that at least a lengthy segment of the central to southern Sierra Nevada has been uplifted thousands of feet by geologic forces during the past 7 million years, although sophisticated geophysical studies of regional rates of erosion and plate tectonics suggest that most of that mountain building has happened over the past three million years.

While the fossil locality is not difficult to find, be forewarned that a reliable four-wheel drive vehicle is required to reach the late Miocene botanic association. The "final assault" to the site is made along a rocky, rutty, and at times incredibly steep dirt path impassable in conventional vehicles. But the ultimate reward of such breathtaking High Sierran country, in addition to the opportunity to find some paleobotanically significant fossil leaves and petrified wood, is definitely worth the effort. Of course, prior to any excursion to the Mount Reba locality, always check with the local United States Forest Service officials to determine changes in collecting status.

A convenient place to begin a journey to the fossil-bearing site is Angels Camp in Calaveras County, along historic State Route 49. This is justifiably one of the more famous of the old gold mining communities in the Mother Lode, western Sierra foothills. In addition to sightseeing and souvenir hunting, a main attraction at Angels Camp is the yearly encounter with frogs.

The humorous Mark Twain short story "The Celebrated Jumping Frog of Calaveras County" (1865)--inspired by a story Mr. Clemens had heard in Angels Camp while spending 88 days in California's Gold Country during the winter of 1864-'65 (most of that time in a cabin at Jackass Hill, about 6 miles southeast of Angels Camp; from January 22 to February 23, 1865, Twain resided in Angels Camp)--is commemorated each year here with a jumping-frog contest, a traditional event that has had its share of unusual turns.

A number of years ago, for example, an ambitious individual keen on competition imported several two-and-a-half-foot-long carnivorous frogs from Africa and decided to enter them in the contest. Straight away, though, a regular shouting match broke out among the organizers over whether the monstrous amphibians should be permitted to compete. It was generally feared the African type would escape captivity and proceed to devour its smaller and less-aggressive cousins. Apparently siding with the alarmists, the California Department of Fish and Game initially would not even allow the man to bring his frog-whoppers into the Golden State.

But regulations were eventually relaxed. Not only did the amazing amphibians find their way into California (the owner gleefully showed them off to the media at every conceivable opportunity), but Calaveras County officials ruled amid escalating controversy that the animals could indeed complete.

Perhaps it was a foregone conclusion, but all this publicity brought in record crowds to the celebrated doings. Everybody wanted to see the fierce frogs in action. After all, how far could such a powerful creature leap? Rumor had it that the frogs regularly hopped across wide streams in their native land.

Well, when all was said and done, the results were rather disappointing for the highly touted amphibians. It turned out that the winner was an unassuming small-fry, some youngster's favorite regulation-sized frog. The African carnivores barely got off the launching pad. It was conjectured by the more conspiracy-minded that somebody had fed them too many bull frogs for breakfast.

Historic Angels Camp, which yielded vast fortunes in gold from Mother Lode veins during the mid to late 1800s, lies in the western foothills of the Sierra Nevada--the Snowy Range. Much of this Gold Rush country area is underlain by three famous Tertiary Period geologic rock formations: the middle Eocene Ione Formation (roughly 48 to 45 million years old), the late Oligocene to early Miocene Valley Springs Formation (dated by radiometric means at about 29 to 20 million years old in the Sierra foothills Mother Lode district) and the late middle Miocene to late Pliocene Mehrten Formation, dated through radiometric methodology at 11.6 to 2.59 million years old.

The older Ione Formation accumulated in floodplains, estuaries, lagoons, deltas, mashes-swamps, and shallow marine waters (based on extraordinarily rare occurrences of unquestioned marine mollusks) along the eastern shores of a vast inland sea during regionally sub-tropical middle Eocene times--a sea that had flooded, transgressed, what is now California's Great Central Valley during the earlier portions of the Eocene, approximately 53 million years ago.

In the vicinity of Ione (38 miles north of Angels Camp), that Ione sea left behind world-renowned commercial deposits of extraordinarily pure silica sand and high-grade

kaolinite clays--in addition to extensive accumulations of the rare and valuable Montan Wax-rich lignite, which is mined commercially at only two places in the world--the other Montan Wax site is in Germany; lignite of course is classified as a type of low-grade coal whose alteration of original vegetation has proceeded further than in peat, but obviously not as great as anthracite coal. Montan Wax occurs quite rarely in the geologic record when the waxy substance which once protected the original plant leaves from extremes of climate did not deteriorate, but instead enriched the coal. Commercial applications for Montan Wax include polish, carbon paper, road construction, building, rubber, lubricating greases, fruit coating, water proofing and leather finishing. All of these mineral commodities--silica sands, kaolinite clays and Montan Wax-yielding liginites--have been mined in the Ione area by open-pit methods for many decades. As a matter of fact, today the Ione lignites remain California's only actively mined coal resources.

Not far from the community of Ione, on private property, lies an especially rich fossil leaf-bearing section of the middle Eocene Ione Formation that paleobotany aficionados affectionately call "Lygodium Gulch"--a site informally named in honor of the common well preserved specimens of a climbing fern encountered there--*Lygodium kaulfussi* (probably best known from its spectacularly abundant occurrences in the late early Eocene Green River Formation and the lower middle Eocene Bridger Formation of Utah, Wyoming, and Colorado), which most closely resembles the living American climbing fern *Lygodium palmatum*, now endemic to the US southeastern states (roughly the Appalachian territories down through the South).

It is an as-yet completely undescribed fossil flora, characterized by an absence of leaves with serrated edges; all Ione Flora botanic specimens encountered possess entire margins; that is to say, the leaf edges are uniformly smooth, lacking notches. Such a prevalence of smooth-margin fossil leaves is in botanical analyses traditionally indicative of unusually wet and warm paleoenvironments--decidedly subtropical, in the main. Even though abundant leaf material from Lygododum Gulch and several additional productive Ione Formation localities in the vicinity of Ione is presently stored in the archival paleobotany catacombs of the University California Museum of Paleontology in Berkeley--the cumulative culmination of multiple collecting expeditions by various folks over a period of 12 years (1991 to 2003)--to the best of my knowledge (as of 2018) no formal peer-reviewed scientific examination of the middle Eocene Ione Flora exists.

Directly above the Eocene Ione Formation, in nonconformable stratigraphic relations (denoting a lengthy hiatus in regional terrestrial deposition), lies the late Oligocene to early Miocene Valley Springs Formation--a mid Cenozoic Era interval characterized by rhyolitic pyroclastic flows and airfall ash layers that accumulated within an ancestral Sierra Nevada foothill district punctuated by ephemeral lakes and localized vegetation-lush watercourses. While productive paleobotanical evidence is only sporadically encountered in the Valley Springs Formation, one specific locality on private property near San Andreas (12 miles northwest of Angels Camp), the County Seat of Calaveras

County, does indeed yield numerous undescribed (in the professional paleobotanical literature) early Miocene leaves of oaks, willows, and an extinct fig, all accurately dated by radiometric methods at 22.9 million years old. The specimens occur as excellently preserved impressions set within a whitish-weathering rhyolite tuff that gold seekers of the early 1900s expelled from a now abandoned drift mine excavation.

Supplemental Valley Springs Formation fossil leaves from a few additional sites in California's Gold Country, western foothills of the Sierra Nevada--mainly in the vicinity of State Route 49 between Ione and Angels Camp--provide tantalizing paleoenvironmental indications of an early Miocene scene approximately 23 million years ago. The Valley Springs Flora is not large, yet it sheds invaluable light on an important period in mid Tertiary geologic history. Plants secured from all Valley Springs Formation localities include: undescribed pine; Nutmeg yew; Chinese maple; Boxelder maple; Oregon grape; an extinct alder; Pasadena oak; Canyon live oak; Chinese evergreen oak; swampbay; California bay; an extinct fig similar to the extant Moreton Bay fig; Western sycamore; Monterey ceanothus; Catalina ironwood (now grows in the wild only on the Channel Islands off the coast of southern California); Serpentine willow; and Western soapberry.

The geologically younger late Miocene to late Pliocene Mehrten Formation developed as andesitic sedimentary detritus within flood plains of rivers that had their source in the nascent Sierra Nevada to the immediate east. Some portions of the Mehrten contain thick beds of auriferous gravels, similar in richness to the older (Eocene-age) and more famous accumulations farther northeast in the western foothills of the Sierra Nevada. Many Gold Rush-era drift mines and shafts penetrate these gold-bearing gravels throughout the Mother Lode belt, and more recent explorations have demonstrated conclusively that productive horizons can still be discovered.

Abundant fossil plants have also been collected from at least two places in the late Miocene portions of the Mehrten Formation. One specific site near Columbia State Park, 26 miles south of Angels Camp--the fossil-bearing bed lies on private property, so I am not at liberty to divulge its exact location--has yielded abundant fossil leaves, a botanic association that provides vital information about the paleoenvironment of the California Gold Country approximately 10 million years ago. Side bar: during my first visit to the locality, I contracted a devastating case of poison oak dermatitis, which ultimately prompted a late night trip to an emergency room to acquire a physician's prescribed two-week regimen of steroids--the proscribed medical treatment for such an extreme reaction to urushiol.

Some 28 species of Miocene plants have been identified from the Columbia site, including Chinese maple, laurel sumac, American holly, Mexican grapeholly, Oregon grape, Pagoda dogwood, Black tupelo, Pacific madrone, Chinese rhododedron, extinct Asiatic oak (first specimen discovered at the Pliocene-age Petrified Forest in Sonoma County, California), Engelmann oak, coastal sage scrub oak, Bitternut hickory, swampbay, California bay, Eastern redbud, New Mexico locust, Southern magnolia, Desert olive, Western sycamore, Alabama supplejack, Mountain mahogany, Chinese hawthorn, Brewer's willow, Lewis' mock-orange, western hackberry, American elm, and Knobcone pine.

The specimens suggest that a mixture of four distinct floral communities existed here 10 million yeas ago: A border-redwood element, with modern relatives now living in the central Sierra Nevada, south Coast Ranges, and southern California; an oak woodland-chaparral association, presently distributed throughout the Southwest; an eastern American element, whose modern-day representatives now live in the southeastern United States (elm and magnolia, in particular); and an East Asian element, with now living species native to China and the Philippines.

Based on the known needs of living members of the fossil flora, precipitation patterns were quite different some 10 million years ago in the ancestral Gold Country. Rainfall was roughly 25 to 30 inches per year, distributed throughout the winter and summer months. Today summers are characteristically dry; a continental, Mediterranean climate has eliminated from the modern flora all members of the East Asian and eastern American botanic communities.

It is estimated that the fossils near Columbia accumulated at an elevation no higher than 500 feet. Presently, the locality lies at an altitude of 2,000 feet. Topographic relief in the region was apparently rather low. The late Miocene Sierra foothill belt was essentially a broad flood plain with interspersed undulating hills in which rivers and streams wandered their way to the Pacific Ocean to the west.

According to climatic preferences of modern-day relatives of the fossil plants, both summer and winter months were considerably more moderate some 10 million years ago. Winter weather was probably quite comfortable since frosts were rare if not nonexistent in the lowlands. And while summer temperatures likely exceeded 90 degrees at times, there is no indication that they often topped 100. The moderating influence of sea breezes from the nearby Pacific, which had periodically flooded the Great Central Valley through the Tertiary Period, probably contributed to an almost perfect climate. Today, summertime temperatures in the Sierra foothills regularly surpass 100 degrees, and pollution from the Great Central Valley to the west surges against the base of the mountains with increasing frequency.

A second exceptional Mehrten Formation paleobotanical locality occurs several miles east of Nevada City/Grass Valley (about 85 miles north of Angels Camp). It's absolute geologic age is established through radiometric analyses at 9.5 million years old, or late Miocene on the geologic time scale. Although the leaf-rich andesitic shales of fluviatile origin had been exposed by hydraulic gold miners during the mid 1850s to 1870s (a gold nugget taken from the diggings in 1855 weighed in at 11.6 pounds--the 22nd-heaviest gold nugget ever discovered in California), nobody bothered to study the remarkable paleobotany preserved there until the early 1940s.

32 species of late Miocene plants have been identified from the Mehrten locality east of Nevada City/Grass Valley (they are contiguous communities in California's northern Mother Lode country), including: Port orford cedar (not really a cedar, of course, but rather a cypress); Coast redwood; Boxelder maple; an extinct species of *Mahonia* (barberry); oval-leaved viburnum; Pacific madrone; manzanita; Sierra laurel; Blue oak; Valley oak; California black oak; Oracle oak; an extinct oak similar to the extant Chinese evergreen oak; Oriental white oak; Interior live oak; American sweetgum; Ohio buckeye; Eastern black walnut; Red bay; California bay; roundleaf greenbrier; Western sycamore; Alabama supplejack; Buckbrush; mountain hawthorn; Hollyleaf cherry; Black cottonwood; Quaking aspen; Fremont cottonwood; Shining willow; Mexican buckeye; American elm; an extinct species of grapevine.

Today, the Mehrten Flora east of Nevada City/Grass Valley resides at an altitude slightly over 4,000 feet within a mixed-conifer Sierran forest association of Ponderosa pine, Incense cedar, White fir, and California Black oak. But some 9.5 million years ago, the fossil flora likely accumulated at elevations no higher than 2,000. The paleoenvironmental setting probably resembled areas in California that host the southernmost occurrences of Coast Redwood--notably Big Sur and the south side of Carmel Valley (northwest of Big Sur), approximately 7.5 miles inland from the Pacific Ocean. Precipitation was in the neighborhood of 35 to 40 inches per year, and that distributed liberally during both the summer and winter months--a weather pattern that contrasts radically with modern Mediterranean-style meteorology, where all effective rain falls during the winter months. Temperatures were much more moderate than those at the fossil site today, with cooler summers and little to no frost during the colder months (even at 4,000 feet, Sierran summer readings surpass 90 degrees).

In addition to the rich paleobotanical record, the Mehrten Formation also yields locally plentiful vertebrate fossil material approximately 7 to to 4 million years old, including: ground sloths (*Megalonyx mathisi*, *Pliometanastes protistus*); dogs (*Borophagus parvus*, *Osteoborus*, *Vulpes* sp.); cats (*Felis* sp., *Machairodus coloradensis*, *Pseudaelurus* sp.); a badger (*Pliotaxidea garberi)*; racoon *(Procyon* sp.); beavers (*Castor* sp. and *Dipoides williamsi)*; a vole (*Copemys* sp.); pocket gopher *Cupidinimus* sp.); Kangaroo rat (*Dipodomys* sp.); North american rock squirrel (*Otospermophilus argonotus*); hares (*Hypolagus* sp.); horses (*Dinohippus coalingensis*, *Hipparion mohavense*, *Nannippus tehonensis*, *Neohipparion molle*, *Pliohippus coalingensis*, *P. interpolatus*); rhinos (*Aphelops* sp., *Teleoceras* sp.); gompotheres (*Gomphotherium* sp., *Platybelodon* sp.); mastodons (*Mammut americanum*); camels (*Altomeryx* sp., *Paracamelus* sp., *Pliauchenia edensis*, *Procamelus* sp.); peccary (*Prosthennops* sp.); pronghorns (*Garberoceras* sp., *Merycodus* sp., *Sphenophalos* sp., *Tetrameryx* sp.); deer (*Pediomeryx* sp.); Pacific newt (*Taricha*); Pacific giant salamander (*Dicamptodon)*; Slender salamanders (*Butrachoseps)*;

Climbing salamanders (*Aneides*); an extinct giant tortoise (*Hesperotestudo)*; Spotted turtle (*Clemmys*); Gopher tortoises (*Gopherus*); Star tortoises (*Geochelone*); an extinct sabertooth salmon (*Smilodonichthys*); and Sacramento blackfish (*Orthodon*).

Most of the Mehrten mineralized skeletal material derives from several classic and long-established fossil localities, but one newer discovery described in a 2018 scientific document yielded something rather extra-extraordinary, as it were--canid coprolites--AKA, petrified poop from *Borophagus parvus*, an extinct bone cracking dog, probably analogous in behavior to the modern striped and brown hyenas. The Mehrten Formation fossil feces, collected some 55 miles south of Angels Camp in a transition zone situated between the Great Central Valley and the western foothills of the Sierra Nevada, provided the first unambiguous evidence that *Borophagus* canids (obligate large-prey hunters) consumed large amounts of bone, an idea that vertebrate paleontologists had long suspected but could never directly prove until now.

In addition to the "Big Three" Tertiary Period leaf-bearing geologic rock units exposed in California's Gold Rush district (Ione Formation, Valley Springs Formation, and Mehrten Formation), a second major fossil plant-bearing area can be explored in the vicinity of Carson Pass, Sierra Nevada proper, at elevations from 8,000 to 9,200 feet; the turnoff is at Jackson, the County Seat of Amador County, about 11 miles east of Ione (28 miles north of Angels Camp). Not far from the famed summit, for example, named after intrepid Mountain Man and Army scout Kit Carson, locally abundant petrified woods--including at least one stump--occur within an unnamed middle Miocene formation, dated by radiometric methods (radioactive isotope analyses) at 14.7 million years old--a rock unti technically categorized as a volcanic debris flow/braided stream deposit, with common inclusion clasts that might represent repeated avalanches.

Fossil leaves can also be found near Carson Pass--from a specific site the late paleobotanist Daniel I. Axelrod (July 16, 1910 – June 2, 1998) had under formal scientific investigations for at least four decades; as a matter of fact--family, friends, and colleagues of Dr. Axelrod scattered his ashes in the vicinity of Frog Lake, not far from Carson Pass, on what would been his 88th birthday, July 16, 1998. The fossils occur at an elevation of approximately 9,200 feet in the andesitic sandstones and shales of an unnamed middle Miocene geologic rock unit calculated at around 16 million years old (preliminary geologic evaluations had placed the fossil flora in the Relief Peak Formation); the paleobanically significant sedimentary matrix represents stream and hyperconcentrated flood deposits, yielding a chiefly riparian association of plants whose modern day counterparts, in general, live at elevations no higher than 2,500 feet. Taxa dominants include the leaves of maple (*Acer*), tupelo (*Nyssa*), sycamore (*Platanus*), avocado (*Persea*), poplar (*Populus*), lingnut (*Pterocarya*), Catalina Ironwood (*Lyonothamnus*--a tree that presently grows in the wild only on the Channel Islands off the coast of southern California), oak (*Quercus*), elm (*Ulmus*), and willow (*Salix*); interestingly, no conifers occur in the so-called Carson Pass Flora. Today, the fossil site

lies in the arctic-alpine zone of fell-fields and meadowland, above a subalpine forest of whitebark pine and mountain hemlock.

After reflecting on the rich regional Cenozoic Era paleontology of California's Carson Pass/Gold Rush areas--and visiting Angels Camp--it's time for the ride to the High Sierra fossil plants.

To reach the Mount Reba fossil-bearing area, first take State Route 4 northeast out of Angels Camp toward Ebbetts Pass. At a point 23 miles from Angles Camp, you will arrive at the turnoff to Calaveras Big Trees State Park. I most definitely recommend a side visit. Here you will find two of the finest groves of giant sequoia in existence. The North Grove receives most of the visitor attention, but if you really wish to experience the overwhelming wonder of an essentially pristine giant sequoia floral community, then head over to the less-frequented South Grove a few miles from the entrance gate.

A two-mile hike is required to reach the South Grove, but the going is easy (no serious elevations to ascend) and, once amidst the big trees, you will likely marvel at the undisturbed nature of the spectacle. The associated understory of plants which contribute to an ancient giant sequoia forest have not been trampled into submission as, unfortunately, they have been in Sequoia National Park, where millions of visitors each year wander among the trees, preventing the natural vegetation from reestablishing itself. This South Grove shows off the same unique grouping of big trees, pines, shrubs, and deciduous trees--all unchanged--that once covered all of west-central Nevada and most of east-to-central California some 16 to 5 million years ago.

Once you've explored Calaveras Big Trees State Park, it's time to proceed onward to the turnoff to the Mount Reba fossil plant locality in the general vicinity of an ultra-popular ski resort. From late fall to early spring thousands of enthusiasts pack up their equipment and head this way--the quality of the snow pack is according to experts quite extraordinary, conducive to a sensational skiing experience.

But prior to the ascent to the fossiliferous locality--assuming that the United States Forest Service (USFS) continues to allow vehicular access, mind you--take a moment to dispassionately evaluate your own ability to negotiate off-road a four-wheel drive vehicle over a steep, rocky, unimproved path in the mountains. I am not trying to scare anybody off here--far from it. In a seance, I am appealing to a sense of adventure. At the same time, I am providing a gentle warning to novice off-road drivers that, while the route is far from expert-only, it does require a modicum of technical proficiency in two or three places. Most of the trail is easily and safely negotiated.

If authorities no longer permit motorized access, you'll just have to hike the remaining distance to the Disaster Peak Formation paleobotanical area--the very same way I did upon my first visit; even though officials allowed vehicular travel at that date, I

nevertheless voluntarily chose to walk to the site, not confidently anticipating that first time around that I'd be able to safely negotiate the unknown incline in my four-wheel drive mechanism.

Once at the convenient parking area near the fossil-bearing site at an elevation of almost 9,000 feet--and contingent of course on permission from the USFS to continue to collect fossil plants here, walk downslope from the parking spot along the narrow dirt trail. The first outcrops you encounter, in the roadcut along the left side of the path, contain the 7 million-year-old leaves. The fossil plants occur in the yellow-to-buff, moderately compacted andesitic sandstones of the upper Miocene Disaster Peak Formation. Widely scattered pieces of unidentified petrified wood also occur along the steep slopes to the right of the trail. But watch your footing here, as trying to hike over the weathered sandy mudstones and volcanic rocks is hazardous.

The Disaster Peak Formation exposed along the trail is approximately 29 feet thick. It's primarily a mudstone-sandstone andesite breccia--the hardened material remaining from a mudflow that moved with inexorable inevitability down a moist hillslope some 7 million years ago, a massive mudflow event probably triggered by a volcanic eruption in the neighborhood. Two rather thin sandstone beds in the section--2 feet, and 1.5 feet thick, respectively--yield all of the moderately common fossil leaves; the remainder of the deposit is unfossiliferous. A distinctive feature of the fossils in the sandstone is that they are curled and twisted, a telltale style of preservation that indicates that the mudflow contorted the leafy structures as it slid downslope.

Altogether, 14 species of fossil plants have been secured from the Disaster Peak Formation. The four most abundant forms in the sandstones are leafy branchlets from a cypress, *Cupressus mokelumnensis* (an extinct cypress that is similar to the living Chinese weeping cypress--now native to China); leafy twigs from a Douglas-fir, *Pseudotsuga sonomensis*; entire leaves from an evergreen live oak, *Quercus pollardiana* (Canyon live oak); and leaves from a species of tanbark oak, *Lithocarpus klamathensis*. In decreasing order of relative prevalence, the flora also contains a cattail, *Typha lesquereuxii*; a willow, *Salix wildcatensis* (arroyo willow); a white fir, *Abies concoloroidea*; a giant sequoia, *Sequoiadendron cheneyii*; a second species of willow, *Salix hesperia* (Pacific willow); an elm, *Ulmus affinis* (an extinct species most similar to the extant American elm); a species of sugar pine, *Pinus prelambertiana*; a pine, *Pinus sturgisii* (western yellow pine); a juniper, *Juniperus* sp.; and a third species of willow, *Salix boisiensis* (Scouler's willow).

In general, the fossil floral association resembles a modern-day Douglas-fir forest in the western foothills of the central to northern Sierra Nevada, at elevations of 2,000 to 3,000 feet; today, the fossiliferous section rests at an altitude of 8,650 feet, above the local timberline in the upper subalpine belt. During the upper Miocene, rainfall was likely as high as 40 inches per year, with storms distributed in both winter and summer months.

This is in dramatic contrast with present-day weather patterns, which release virtually all of the effective precipitation as snow during the winter. But 7 million years ago summertime rain was a necessary occurrence, in order to account for the presence of cypress and elm in the local fossil record.

The species of cypress, Douglas-fir, evergreen live oak, and tanbark oak--which comprise 97.8 percent of the fossil specimens recovered from the flora--clearly lived nearest the actual site of deposition, probably along the cool shady north-facing slopes of a southwesterly draining valley. Farther upstream, white fir, sugar pine, yellow pine, and giant sequoia contributed to a mixed conifer forest. The drier slopes in this area supported specimens of juniper. The three species of willow thrived along the watercourses, no doubt forming dense thickets. The lone species of elm in the fossil record could have lived in the mixed conifer forest, where greater rates of precipitation would favor its survival. An interesting observation is that the most abundant member of the Disaster Peak Formation flora, the specific species of cypress, no longer lives anywhere in the United States; its closest modern-day relative is now native to China.

After analyzing the fossil leaf, twig, and branchlet material secured from the upper Miocene Disaster Peak Formation, paleobotanists have arrived at a fascinating line of thought. Perhaps it is possible to determine the time of year when the mudflow engulfed the plants. Numerous specimens of cypress, Douglas-fir, and oak, for example, appear to represent immature leafy structures---signifying that before they became buried by the mudflow the plants had just begun their first spurts of growth during the new season. It is a tentative conclusion, but the overall size and shape of the preserved plant structures suggests that the event which preserved them occurred during either spring or early summer.

Here is a fossil plant locality worth visiting: But only during the "dead of summer" through early fall, of course, when the roads at higher Sierra elevations remain "reliably" passable. Not only are excellent leaf and twig specimens from 14 species of upper Miocene plants available, but the scenery up there is absolutely stunning--a wide vista that takes in mile after mile of the pristine High Sierra Nevada back country, a true wilderness, one of the great natural treasures in America. As you stand there at an elevation of 8,650 feet, above local timberline, the Disaster Peak Formation fossils prove that 7 million years ago Douglas-fir, cypress, and giant sequoia thrived where today no trees exist.

Chapter 28

Ordovician Fossils In The Toquima Range, Nevada

Scattered across the pristine Great Basin isolation of Nevada are many productive Ordovician-age fossil localities roughly 485 to 444 million years old, and two of the more significant sites can be visited in the rugged Toquima Range.

At what many fossil seekers call Ordovician Canyon, for example, paleontology enthusiasts can find a plethora of well-preserved invertebrate animal remains from the middle Ordovician Antelope Valley Limestone, including silicified brachiopods, bryozoans, sponges, cystoid echinoderms, conodonts, trilobites, gastropods, pelecypods, cephalopods, and ostracods.

And a second site that lots of paleontology buffs refer to as Graptolite Summit provides visitors with a fossil type many hobbyists rarely see outside of a textbook or popular guide to paleontology--the intricately designed graptolite, a colonial organism most often referred to as an extinct variety of hemichordate (or primitive chordate). The specimens at Graptolite Summit occur in a rock deposit called the Vinini Formation, which has been dated by geologists as Early to Late Ordovician. The Vinini is an incredibly widespread unit throughout Nevada, a dominantly siliceous assemblage of shales, siltstones, cherts and quartzites that bear sporadic occurrences of abundant graptolites. With the possible exception of the type locality (where a geologic rock formation was first named and described in the scientific literature), this particular area surrounding Graptolite Summit is probably the most intensively investigated graptolite-yielding section in all of the Vinini Formation. Over the decades it has provided both professional paleontologists and amateur fossil seekers with myriads of identifiable graptolites, in addition to common inarticulate brachiopods and carapaces belonging to a peculiar species of extinct crustacean called *Caryocaris*, whose oval- to D-shaped exoskeletons up to an inch across appear to be confined throughout the world to shales in which graptolites are the dominant fossil specimens preserved.

Both fossil areas are easily and safely reached. Still, collectors must not be lulled into dangerous complacency. The important thing to remember is that this part of Nevada remains one of the most remote sectors in all the Great Basin. Should a genuine emergency emerge while in the deep backcountry, medical and mechanical assistance will certainly be a long time in arriving, even if your situation has been communicated to the authorities by satellite. For this reason, it is recommended that visitors travel to the fossiliferous regions in the Toquima Range only in a reliable four-wheel drive vehicle, obeying all of the necessary rules that apply to back country travel; carry plenty of water (enough to provide one gallon

per person per day), emergency provisions, cold-weather clothing, spare fan belts, and medical supplies. And by all means notify the authorities in the nearest community of your whereabouts, remembering to check back in with them upon leaving the area.

The Graptolite Summit locality rests directly atop the lower to upper Ordovician Vinini Formation, which is locally loaded with all kinds of interesting graptolite remains. Here in the Toquima Range the Vinini Formation has been measured by geologists at some 6,000 feet thick. It is predominantly a siliceous accumulation of thin-bedded black chert, quartzite, red to black siltstone and shale, minor dark limestone, and even some interbeds of pillow lavas, presumably formed on the ancient Ordovician ocean floor when hot magmatic extrusions came in contact with obviously much colder marine waters; identical kinds of lavas develop today in ocean waters near sites of sea-floor-spreading, where the so-called Mid-Atlantic Ridge produces new earth crust through the upwelling of superheated magmas.

Most of the graptolites occur in pastel-colored shaly siltstones of the Vinini Formation. Numerous scientific crews have worked these fossiliferous siltstones in the vicinity of Graptolite Summit over the decades, periodically entrenching the thin-bedded, moderately well exposed sedimentary layers to a depth of several feet in search of productive graptolite layers. Depending on the degree of erosion inflicted by wintertime's snow drifts in the Toquima Range, remnants of their abandoned excavations may be visible just up slope from a prominent bed of whitish-brown quartzite interbedded in the section. The quartzite layer is called a key marker bed by stratigraphers, because it conveniently separates the lower member of the Vinini Formation from the upper member. All of the rich graptolite horizons in the vicinity of Graptolite Summit occur within a rather restricted interval of shaly siltstones and shales some 400 to 600 feet thick, a productive section that happens to straddle that massive, distinctive bed of quartzite. In general, rocks to the southeast of the quartzite marker bed are younger than those to the northwest, but the fact remains that most of the shales and siltstones that sandwich the quartzite horizon yield rare to locally abundant graptolite specimens.

The most efficient way to find graptolites here is to remove sizable chunks of the varicolored to black shaly siltstones, then carefully split the rocks along their natural bedding planes (remember to wear protective eye gear). In doing this, most collectors soon realize the despite such a prominent presence of graptolites in the rocks, the fossils are sometimes difficult to spot on the fine-grained matrix, a number of them appearing as small silvery sheens on the surface of the shales. Do not become discouraged. What you have discovered is what graptolite specialists have known for ages--that the vast majority of specimens project to the unaided eye what has become known as a "traditional graptolitic aspect of preservation." That silvery sheen found glinting out at you when the sunlight strikes the

surface of the rocks at just the right angle represents a 470-million-year-old graptolite colony whose original skeleton has been compressed through geologic time. Most specimens range anywhere from a quarter to an inch and a half in length and, depending of course on the particular genera of graptolites unearthed, can present a fascinating variety of distinctive shapes and sizes to study. *Phyllograptus* graptolites, for example, one of the more obvious types found near Graptolite Summit, grew oval to roughly football-shaped colonies a little over a half inch long. Also present are the blade-like *Orthograptus* and *Climacograptus*, plus wishbone-shaped *Didymograptus* and slingshot-like *Dicranograptus*. Other genera available in the Graptolite Summit rocks include *Clonograptus*, *Tetragraptus*, *Isograptus*, *Glyptograptus*, *Dicellograptus*, *Paraglossograptus*, *Pterograptus*, *Amplexograptus*, *Durangograptus*, *Callograptus*, and *Cardiograptus*.

In addition to the graptolite remains in the Vinini Formation near Graptolite Summit, two other fossil types can be encountered in the shales and siltstones--inarticulate brachiopods and *Caryocaris* crustaceans. Such remains are far less abundant than the graptolites, though. Collectors interested in finding them would be advised to explore as many of the shale deposits as possible, splitting heaps of the easily separated layers wherever you go. And don't be shy about exploring the little gullies and ravines in the Graptolite Summit district--many graptolites, for example, can be found in the poorly exposed shales and siltstones that seem to hide in the most improbable-appearing areas.

Graptolites first appear in the geologic record during the middle stages of the Cambrian Period, some 505 million years ago. Even though they persisted all the way up to the Late Mississippian age, or roughly 325 million years ago, most species of graptolites had already become extinct by the latest Devonian Period 35 million years earlier. Graptolites achieved their highest degree of success during the Ordovician Period, when they attained worldwide distribution by adapting with ingenuity to three distinct modes of life. One order of graptolite, for example--the fan to leaf-shaped dendroids--led a sessile life attached to the sea floor, apparently straining the marine waters for microscopic organisms. Another type developed a special flotation device which allowed the graptolite colony, termed a rhabdosome, to drift in the open ocean; and a third kind solved its own planktonic challenge by attaching itself to floating strands of seaweed to hitch a free ride through the open ocean in search of better feeding grounds--presumably it too strained the sea waters for microscopic particles of food.

In all three examples of graptolitic adaption, the actual colonial animal lived inside the minute rows of cups called thecae that developed along each individual segment of the rhabdosome; technically, these segments are called a stipe. The tiny saw-tooth compartments that housed the graptolite animals along the stipe show to best advantage

under magnifications of ten or more power. Thus, a good-quality hand lens is indispensable in order to gain a detailed and aesthetic appreciation of your finds.

The exact zoological classification of graptolites has presented a serious challenge to paleontologists. Early investigators referred graptolites to such disparate groups as coelenterates or bryozoans; yet, there certainly was no unanimity of opinion among fossil specialists throughout the 19th century. The breakthrough came when some perfect, three dimensional specimens were etched out of cherts using powerful brews of acids around 1948. Paleontologists then realized that the graptolite colony most closely resembled the modern pterobranch, a tiny marine hemichordate, which by definition is a primitive chordate whose notochord (a spine-like notch) is restricted to the basal part of the head.

That explanation seemed to satisfy most paleontologists. Even the basic idea that the graptolite was an extinct colonial organism went completely unchallenged until 1992 when Noel Dilly, a marine biologist in London, suggested that the graptolite had not died out, that a single species had survived the Paleozoic Era and was alive and well on Earth today.

What Dilly had identified was a dime-sized colony dredged up by a French team from 800 feet off of New Caledonia in the South Pacific. Dilly called it *Cephalodiscus graptiloides*--the sole surviving member of the graptolitic race, he claimed. Dilly, who published his ideas in the Journal of Zoology in the early 1990s, also reported that while on vacation he actually witnessed his "living graptolites" cavorting in the warm, shallow waters off the coast of Bermuda. He speculates that his living fossils are "survivors of the main group who hung on in places where there hasn't been massive change in the environment in over 300 million years."

The suggestion was a novelty, at best. By Dilly's own admission the chemical structure of the graptolite rhabdosome and that of his living fossil was only "similar," not identical. What generated most of the early enthusiasm for the theory was that his *Cephalodiscus* apparently possessed an extended spine-like protrusion from the main colony, a structure similar to what paleontologists call a nema on fossil graptolites. Modern pterobranchs, with which the graptolite is most often compared, do not develop such a needle-like projection, or nema, so the identification of a colonial hemichordate that seemed to bear a nema created quite a short-lived stir among paleontologists. One of the main problems with the entire concept was that Dilly's *Cephalodiscus graptiloides* is not the only species in its genus, and it's the only one to produce a nema--a structure which may not be directly analogous to the structures graptolites developed.

After collecting graptolites near Graptolite Summit, visitors will want to visit the spectacular fossil exposures of the Antelope Valley Limestone at Ordovician Canyon in the Toquima Range. Here, the middle Ordovician Antelope Valley Limestone is roughly 950 feet thick, yielding prodigious numbers of fossilized shelly creatures. The productive limestone layers near the mouth of the canyon (referred to as the Mill Canyon Sequence by geologists; two miles from the mouth, geologists call the strata the June Canyon Sequence) consist principally of silty to finely crystalline limestones that weather into shades of dark gray, medium gray, grayish orange, grayish yellow, yellow gray, brownish orange and yellowish orange. The most fossiliferous exposures occur northeast of the mouth of Ordovician Canyon, but productive horizons can be discovered through the canyon corridor up to two to two and a half miles west of the mouth.

Many collectors like to concentrate their attention along the moderate talus slopes immediately north of the mouth. Here can be found infrequent to relatively common brachiopods and gastropods, in addition to abundant cystoid echinoderm debris, or small crinoid-like ossicles whose precise identification to species level is impossible owing to the fragmentary nature of the material. Since these easily accessible exposures have been probed by eager collectors for decades, the richest limestone layers, those yielding the greatest diversity and abundance of specimens, can now be found only in the rugged terrain farther north of the road. In this area the Antelope Valley Limestone is more reliably fossiliferous, yielding a genuinely remarkable assemblage of nicely preserved remains--all of them thoroughly silicified, by the way, replaced by silicon dioxide. Such a style of preservation means that collectors can immerse the fossiliferous calcium carbonate matrix in a diluted acid bath, dissolving away the limestones to leave intact, perfect specimens in the residues.

In addition to brachiopods, gastropods and cystoid echinoderms, other specimens identified from the Antelope Valley Limestone include ostracods, trilobites, conodonts (acetic acid must be used to dissolve out the phosphatic conodont elements), cephalopods, sponges, pelecypods and bryozoans. Many of the fossil groups tend to occur within their own individual rock layers, to the exclusion of other types of organisms. Not a few of the protruding limestone ledges for example yield profuse ostracods, while others bear plentiful trilobite remains, brachiopods, sponges, gastropods, or cephalopods. Conodonts, on the other hand, may show up in the residues of limestones collected throughout the entire thickness of the formation, appearing as minute (only one to three millimeters in length, or less than an eighth of an inch) tooth-like specimens--unrelated to modern jaws--that originally served as a unique feeding apparatus of an early, primitive lamprey eel-like animal.

The Toquima Range localities offer collectors a superlative selection of well-preserved middle Ordovician fossil specimens some 470 million years old. Along with several correlative time-

equivalent localities in Utah and eastern Nevada, Ordovician Canyon may well be one of the most fossiliferous Middle Ordovician sections in all the Great Basin. Add to that the profusion of fascinating graptolites near Graptolite Summit and you have an extensive fossil field that begs to be explored--preferably during mid spring through early fall when the weather conditions most reliably favor a comfortable experience.

Both Toquima Range fossil areas lie within a designated United States national forest. This means that they are administered by the United States Forest Service, not the Bureau of Land Management, even though the sites occur on public lands. In the past, hobby fossil collecting has been allowed to go on here without the need of a special use permit. Just to be on the safe side, though, you might want to contact the local Forest Service office before any visit is made to the Toquima Range.

Chapter 29

Late Miocene Fossil Leaves At Verdi, Washoe County, Nevada

Yosemite, Kings Canyon, Mount Whitney--each is an awesome example of nature's handiwork amidst the grandeur of California's central to southern Sierra Nevada. Yet, some six to five million years ago that mighty mountain range revealed far less precipitous extremes, and the great alpine altitudes so spectacular today there were in their youthful stages of development. At that early period of Sierran geomorphological creation, sluggish rivers wandered through extensive floodplains in a region of only moderate topographic relief; lakes and stagnant ponds lay scattered in the basins, and thickets of riparian vegetation associated with elevations dramatically lower than present grew along the watercourses.

Proof of this radically different scene can be found in rocks exposed near Verdi, Washoe County, Nevada, on the eastern slopes of the Sierra. Here occurs a wonderful fossil leaf locality in a sequence of sedimentary beds dated by sophisticated geophysical radiometric techniques at 5.8 million years old, a site where the numerous species of plants preserved provide a direct link with the climate and geography of the geologic past.

Verdi is a small gaming community that lies along Interstate 80 approximately 10 miles west of Reno, Nevada. The leaf-bearing beds occur in the vicinity of town along a railroad cut in what stratigraphers have assigned to the uppermost (youngest) layers of the upper Miocene Hunter Creek Sandstone.

This railroad cut exposes a 28-foot thick section of the Hunter Creek Sandstone, presently considered 5.8 million years old through accurate radioactive isotope analyses. The exposure extends in an east-west direction for a minimum of 125 feet and fossil leaves can be found throughout it--primarily in the bluish to gray andesitic sandstones that were derived during late Miocene times from an older volcanic formation, the Kate Peak Andesite. Interbedded with the sandstones are minor lenses of tan to white diatomaceous shales (composed mainly of diatoms, a microscopic photosynthesizing single-celled aquatic plant), within which occur nicely preserved leaves of a species of pond weed, referred to scientifically as *Potamogeton verdiana*--named specifically for its special occurrence here in the Hunter Creek Sandstone near Verdi.

The history of fossil plant collecting at Verdi goes back to the 19th Century. In his 1878 report regarding the famous Fortieth Parallel Survey--an exporatory expedition mandated by the US Congress, conducted from northeastern California through Nevada to eastern Wyoming during 1867 to 1872--geologist Clarence King (first Director of the United States Geological Survey) first mentions the occurrence of fossil plants near Verdi, Nevada. In 1909, in a report about oil and gas potential in the Reno region, R. A.

Anderson provides a brief but detailed examination of leaf-bearing beds in the vicinity of Verdi, from what Clarence King had previously called the Truckee Formation (a geologic rock unit whose paleobotanical preservations are now understood to occur in the newly named Hunter Creek Sandstone). On page 483 of that same paper, Anderson also describes a "near Reno" fossil leaf collection secured from probable Truckee Formation beds by a professor J. P. Smith, who kept the specimens at Stanford University; taxa preliminarily identified included birch, serviceberry, manzanita, willow, and a pine cone. Some five years later, around 1914, an H. S. Gale submitted a small collection of Verdi area leaves to the US National Museum, but apparently published no formal documentation of the occurrence; sad, that--because, as later paleobotanists have noted, Gale found several species that have never since been observed from what's now called the Hunter Creek Sandstone. In 1916, vertebrate paleontologist J. C. Merriam used information supplied by paleobotanist F. H. Knowlton to help establish what Merriam believed, at that date, was a geologic correlation between Clarence King's Truckee Formation and the bone-bearing Esmeralda Formation in Nevada--a paleontologically rich deposit presently known to contain middle to early late Miocene faunas approximately 16 to 10 million years old; Knowlton compared a collection of Verdi vicinity leaves with plants already sampled from the Esmeralda Formation and concluded (quite erroneously, of course) that the two floras could be considered contemporaneous. Not until the early 1920s did a professional paleobotanist--that would be R. W. Chaney--finally amass the first large collections of fossil leaves from the Verdi locality. Supplemental collecting expeditions to Verdi by the late paleobotanist Daniel I. Axelrod in 1939, 1947, 1953, 1954, and 1956 increased the number of fossil specimens exponentially. In 1977, David A. Orson, a graduate student at the University Nevada, Reno, extracted pollen grains from lignite beds exposed in the upper half of what's now called the upper Miocene Creek Sandstone, Verdi Basin, Washoe County, Nevada, but his palynological specimens, recovered through maticulous dissolution of the low grade coal matrix with potently hazardous acids (among them, hydrofluoric acid--one of the most powerful acids known to exist--which is frequently used to break down rocks suspected to contain microscopic pollens) did not come from the Verdi fossil leaf locality.

All told, seekers of fossil leaves have recovered 18 species of plants from the Verdi exposures of upper Miocene Hunter Creek Sandstone. The most abundant leaves found belong to a Miocene variety of black cottonwood, *Populus alexanderi*--called affectionately by paleobotanists the "common Pliocene cottonwood." Also present are the leaves of Miocene analogs of Scouler's willow (*Salix boisiensis*), Goodding's black willow (*Salix truckeana*), quaking aspen (*Populus pliotremuloides*), Korean aspen (*Populus subwashoensis*), pinemat manzanita (*Arctostaphylos verdiana*), valley oak (*Quercus prelobata*), Engelmann oak (*Quercus renoana*), interior live oak (*Quercus wislizenoides*), sierra gooseberry (*Ribes galeana*), buckbrush (*Ceanothus precuneatus*); and a bitter cherry (*Prunus moragensis*). All of these leaf specimens occur exclusively in the sandstone strata, along with the needles, cones, and cone scales of such conifers as

white fir (*Abies concoloroides*), ponderosa pine (*Pinus florrisanti*), sugar pine (*Pinus prelambertiana*), and Knobcone pine (*Pinus pretubercula*). In addition to yielding the slender leaves of pond weeds (*Potamogeton verdiana)*, the lenticular seams of whitish diatomaceous shales also contain the remains of water lilies (*Nymphaeites nevadensis*) and stonewarts (*Chara verdiana*).

Supplemental palynological material, secured in 1977 by University Nevada, Reno, graduate student David A. Orson from two separate lignite horizons in the upper half of the Hunter Creek Sandstone, Verdi Basin, Washoe County, Nevada, included--from the older level--pollen grains of red fir (*Abies magnifica*), white fir (*Abies concolor*), Grand fir (*Abies grandis*), knobcone pine (*Pinus attenuata*), Western white pine (*Pinus monticola*), Jeffrey pine (*Pinus jeffreyi*), Douglas-fir (*Pseudotsuga menziesii*), willow (*Salix* sp.), mountain whitethorn (*Ceanothus cordulatus*), maple (*Acer* sp.), and golden chinquapin (*Chrysolepis chrysophylla*). The younger low grade coal layer produced pollens of Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), cottonwood (*Populus* sp.), Mountain mahogany (*Cercocarpus betuloides*), mountain whitethorn (*Ceanothus cordulatus*), maple (*Acer* sp.), walnut (*Juglans* sp.), Pacific dogwood (*Cornus nuttallii*), and questionably (contamination with recent pollen grains is highly suspected) Mormon Tea (*Ephedra nevadensis*). The older plant association resembles a modern pine forest community on both sides of the Sierra Nevada, with obvious similarities to lower elevation yellow pine habitats in southern California, as well. Plants in the younger lignite bed have modern analogs now living in the woodland communities on the west side of the Sierra Nevada--primarily in low altitude Sierran yellow pine associations and the Sierra foothill chaparral areas of central California.

At the Verdi fossil site, the fossil leaves are predominantly preserved as black to brownish carbonized impressions throughout the bluish to grayish, dense to poorly compacted fluviatile sandstones; several intervals in the sequence reveal leaves matted together in an almost coal-like tangle of preserved vegetable debris. Specimens of pond weeds, water lilies and stonewarts recovered from the diatomaceous shales appear lighter colored than their counterparts in the sandstones, but they too are the impressions of original leaf material--organic remains compressed through geologic time by forces of heat and pressure. This process has driven out all the volatile constituents from the leaves, except the irreducible carbon residues, which now outline the original shapes and forms of once-living plants.

Although footing at the fossil site tends to be somewhat treacherous in places, owing to the extreme steepness of much of the railroad cut, most of the plant-bearing beds can be comfortably scouted. The most accessible collecting is available along the lower talus slopes, where natural erosion, combined with periodic pickings by other fossil hunters, has produced an abundant source of sandstone blocks.

And, happily for collectors, the fossil leaves tend to lie along distinct bedding planes, fossiliferous layers that when not in plain view on an already exposed surface can be reliably spotted as thin black strips parallel to the bedding of the unweathered sandstones. Where such an occurrence is suspected, take a rock hammer and chisel (wear eye protection at all times while cracking rocks) and strike the probable fossil-bearing layer forcefully. If the strike has been true, the sandstone will invariably split with a clean break, revealing leaf imprints to their first light in nearly six million years. They tend to pop out at you in dramatic display--a cottonwood, a willow, an aspen--plants never before seen by human eyes until you investigated this tangible link with the geologic past.

A time-honored observation is that many of the the better-preserved paleobotanical specimens occur in the finer-grained rocks at the western end of the railway cut. Which virtually guarantees that innumerable folks over a period of several decades have already explored the most promising leaf-bearing areas. Still and all, even though the westernmost area has obviously been heavily fossil-prospected over the years, be sure to investigate as much of that specific geologic rock exposure as possible; excellent paleontological material still awaits discovery by dedicated paleobotany enthusiasts, in both the fine and coarser-grained sandstones.

What the rocks and their 18 species of fossil plants inform us of the ancestral late Miocene Verdi Basin is most illuminating. First off, the sandstones in the Hunter Creek Sandstone prove that a wide floodplain existed within this portion of the eastern Sierra Nevada area 5.8 million years ago, through which sluggish streams wandered. This helps corroborate the geological conclusion, based on a synthesis of successive scientific investigations, that no significant elevation barrier existed at present-day Donner Pass (altitude 7,057 feet, 30.3 miles west of Verdi) in the proto-Sierra Nevada region prior to approximately 2.6 million years ago, suggesting substantial uplift of this portion of the Sierra Nevada during Pliocene times. Nevertheless, analysis of sedimentary depositional patters indicates that watercourses in the ancestral Verdi Basin never flowed westward across the nascent Donner "divide;" neither did streams carry detritus beyond the localized basin. Thus, present evidence inescapably supports the postulation that the late Miocene Verdi Basin was one of many widely scattered endorheic (internally drained) centers of sedimentary accumulation that came into existence during a period of later Tertiary Period extensional forces, which beginning about 16 million years ago had already begun to create today's Great Basin physiographic province.

Within the late Miocene Verdi area some 5.8 million years ago, watercourses supported thick woodlands composed of cottonwoods and willows. Ponds, lakes and swamps in the basin--where layers of diatomaceous shale accumulated--held colonies of water lilies, stonewarts, and pond weeds. Dominating the higher elevations was a forest community of aspens, ponderosa pine, Knobcone pine, Sugar pine, and White fir. In addition to the trees, such brushes as manzanita, bitter cherry, and gooseberry were confined to moister

valleys and slopes bordering the basin.

From the available geological evidence it appears that most members of the preserved Verdi Basin plant communities were transported into the floodplain during episodes of periodic flooding, although the aspens and willows could have extended down to the lowlands in moderate numbers. The well-drained drier slopes and flats supported a chaparral-style woodland of valley oaks, evergreen live oak, and buckbrush; a species of closed cone pine occupied the rocky, exposed slopes throughout the woodland.

Climatic conditions were much more moderate than those observed in the Verdi area today. Rainfall was in the neighborhood of 18 to 20 inches per year, but that figure could have increased to as much as 25 inches in the higher hills. Verdi today lies within a semi-arid region of sparse rainfall, receiving most of its 13 inches of effective annual precipitation as snow during wintertime. It seems that late Miocene summers were warm to hot, as the plants indicate that the average July highs stayed around 85 degrees. January low averages probably ranged near 45 degrees, which contrasts dramatically with the present January Verdi low normal of 21 degrees. Additionally, today, wintertime temperatures at Verdi can sometimes plummet to numerous degrees below zero, with windchill factors reminiscent of Antarctica meteorological conditions.

Within such a temperate late Miocene climate, the growing season was likely as long as 210 days; today in the Verdi district it is barely 114 days. Elevations at the site of deposition could not have much higher than 2,500 feet, an estimate based on the known habitats of living members of the plant groups identified in the fossil beds. Verdi today lies at an elevation of 4,905 feet.

Probably the closest modern-day comparison with the specific association of plants displayed in the late Miocene Hunter Creek Sandstone is the California Gold Country, western Sierra Nevada foothills, from Placerville south to Jackson. Here the lush Sierran forest of pine, aspen, white fir, and cottonwood interfingers with a vigorous chaparral community of Valley oak, evergreen live oak, and manzanita.

Today, by contrast, the Verdi fossil locality lies within a botanic transition zone from pinon-juniper woodlands to a classic Sierra Nevada conifer forest. Within proximity of the late Miocene leaf-bearing site, for example, occur such typical transition plants as pinon pine (*Pinus monophylla*), juniper (*Juniperus utahensis*), Basin sage (*Artemisia tridentata*), curl leaf mahogany (*Cercocarpus ledifolius*), rabbit brush (*Chrysothamnus nauseosus*), desert peach (*Primus andcrsonii*), antelope brush (*Purshia tridentata*), plateau gooseberry (*Ribes velutinum*), and horsebrush (*Tetradymia glabrata*). Only a slight increase in elevation here brings on a dominant Sierran forest community, characterized by three defined botanic associations as one gains altitude. The lowest zone contains Jeffrey pine (*Pinus jeffreyi*), white fir (*Abies concolor*), incense cedar (*Libocedrus decurrens*), sugar pine (*Pinus lambertiana*). yellow pine (*Pinus ponderosa*),

green manzanita (*Arctostaphylos patida*), chinquipin (*Castanopsis sempervirens*), deer brush (*Ceanotlius integerrimus*), white thorn (*C. cordidatus*), bitter cherry (*Prunus emarginata*), alder (*Alnus tenuifolia*), serviceberry(*Amelanchier alnifolia*), dogwood (*Cornus californica*), aspen (*Populus tremidoides*), black cottonwood (*Populus trichocarpa*), chokecherry (*Prunus demissa*), rose (*Rosa gymnocarpa*), and several kinds of willow (*Salix* spp.). From 7,500 feet to about 8,500 feet, a middle forest is dominated by white fir (A*bies concolor*), red fir (*A. magnifica*), Jeffrey pine (*Pinus jeffreyi*), pine-mat manzanita (*Arctostaphylos nevadensis*), chinquipin (*Castanopsis sempervirens*), huckleberry oak (*Quercus vaccinifolia*), alder (*Ainus tenuifolia*), bitter cherry (*Prunus emarginata*), lodgepole pine (*Pinus contorta*) and aspen (*Populus tremuloide*s). At about 8,500 feet elevation occurs a subalpine forest association with white-bark pine (*Pinus albicaulis*), white pine (*Pinus monticola*), and mountain hemlock (*Tsuga mertensiana*). Regionally, not far above 8,500 feet lies the Sierran timberline of barren arctic-alpine inclines and high summits.

A genuine field day can be experienced finding fossil leaves at Verdi. Not only are the paleobotanic preservations plentiful and easy to locate, but they're also scientifically valuable--exquisite carbonized evidence of an important geologic age, the latest Miocene of roughly 6 to 5.3 million years ago. And because fossil leaves remain relatively infrequent occurrences throughout the Sierra Nevada district, the Verdi locality assumes even greater paleontological significance. Hence, specimens that reveal especial excellence of preservation should be brought to the attention of a professional paleobotanist. Who knows, you might have discovered a species that is new to science.

Naturally speaking, some special words of caution are obviously in order here. The fossiliferous beds lie in close proximity to an occasionally busy railway line (read: you're practically right on top of the tracks). Fortunately for paleobotany adventurers here, approaching trains can be heard--and seen--from a distance, so you have ample opportunity to get completely clear of the tracks.

Of course, always conduct due diligence before visiting the area; check with the railroad folks to determine the most current collecting guidelines. If permission is still granted, be careful not to scatter rock debris on the tracks. Use good judgment at all times and this site will potentially remain a safe and accessible place to visit.

Chapter 30

A Visit To The Fossil Beds At Union Wash, California

Numerous 248 million year-old ammonoids can be found in the shadows of Mount Whitney--at 14,495 feet the highest point in the contiguous United States--near Lone Pine, California. The extinct cephalopods occur at Union Wash along the western flanks of the Inyo Mountains, directly east of the mighty Sierra Nevada, whose impressive ice-sculpted peaks dominate the skyline. At Union Wash, which happens to be one of the major drainage courses for the western slopes of the Inyos, geologists have identified more than 2,300 feet of Early Triassic strata belonging to the appropriately named Union Wash Formation. Within this thick and relatively undeformed sequence of marine-originated siltstones, mudstones, shales and limestones, ammonoids are common to locally abundant at two separate horizons.

What's more, both fossil-bearing layers are currently accessible to interested amateur collectors, though the most famous and ammonoid-rich area does happen to lie within the designated Southern Inyo Wilderness, established in December 1978.

Visitors to Union Wash may of course continue to explore that celebrated wilderness cephalopod horizon--called by ammonoid enthusiasts worldwide the *Meekoceras* beds (named for the most characteristic species present in the bed)--but those who choose to investigate the extensive fossil deposit (hiking is required to reach it, since motor vehicles are not allowed to enter a designated federal wilderness area) must not remove specimens from the bedrock deposits; only freely weathered ammonoids and chunks of fossiliferous rock already eroded off the exposed strata may be collected by unauthorized amateurs. Always check with the local rangers, though, before collecting even surface paleontological specimens within a formally established wilderness region: most places that have been placed into that kind of federal protection program are completely off-limits to any manner of fossil gathering. In order to conduct a formal paleontological dig at Union Wash--removing ammonoid-bearing material from the bedrock for scientific study--one must secure a special-use permit issued by the Bureau of Land Management. Without exception, the permit is granted only to personnel representing either a museum or a fully accredited university.

Even though it not as widely exposed, or nearly as fossiliferous as the justifiably famous *Meekoceras* ammonoid beds, a second ammonoid horizon at Union Wash also continues to provide amateurs fossil enthusiasts and professional paleontologists with loads of identifiable fossil specimens—from the so-called *Parapopanoceras* zone.

The most abundant ammonoid encountered in the *Parapopanoceras* zone is the species for which the layer was named, *Parapopanoceras haugi*. Somewhat resembling a tiny coiled gastropod, *Parapopanoceras* ammonoids measure but a few millimeters in diameter and are most efficiently examined under powers of 10X or greater magnification. Larger, more readily identifiable ammonoids described from the interval include *Hungarites vatesi*, *Parananites oviformis*, *Trilolites pacifica*, *Keyserlingites* (sp.), *Acrochorduceras inyoense*, *Xenodiscus bittneri* and *Xenodiscus multicamaratus*. In addition to the ammonoids, a few other fossil varieties have also been described from the *Parapopanoceras* horizon. These include an orthocone nautiloid cephalopod related to *Orthoceras* sp., pelecypods, and several species of conodonts--minute tooth-like structures, unrelated to modern jaws, that served as a feeding apparatus in an extinct lamprey eel-like organim (seen only in the insoluble residues of Union Wash limestones treated with dilute acetic acid).

The first paleontologist to study the *Parapopanoceras* zone at Union Wash was Triassic ammonoid specialist James Perrin Smith, who published his findings in 1914 in the classic monograph *Middle Triassic Marine Invertebrate Faunas Of North America*, United States Geological Survey Professional Paper 83. Smith concluded that the ammonoid fauna, while similar to forms recognized from the Mediterranean region, most closely resembled species already described from localities in the Arctic and India. Smith believed that the beds were lowermost Middle Triassic in geologic age, but more recent paleontological studies indicate that this is not the case, that the *Parapopanoceras* zone actually lies at the very top of the Early Triassic, approximately 248 million years old--specimens that in the context of geologic time chronology lived "only" three or four million years after the greatest mass extinction in history, the traumatic end time Permian Period, when fully 96 percent of all life on Earth died out.

After exploring the *Parapopanoceras* zone, it’s time to travel on down section to the geologically older Early Triassic *Meekoceras* beds. Most of the fossils there are preserved as fragmentary and complete calcium carbonate steinkerns of the original invertebrate animals. But be sure to collect only the fossil material that has already weathered out of the limestones. Unless you've secure the necessary BLM collection permit, don't conduct any digging into bedrock within the federally designated Southern Inyo Wilderness area.

The *Meekoceras* beds at Union Wash were discovered in 1896 by pioneering paleontologist Charles Doolittle Walcott during one of his epic expeditions to the Western states in search of fossiliferous Early Cambrian exposures. He eventually donated his collection from Union Wash to James Perrin Smith, who determined that the ammonoids were of Early Triassic geologic age, or roughly 248 million years old. Based on the presence of *Meekoceras gracilitatus* in the fossil collections from Union Wash, Smith assigned the entire fauna to the

formally recognized *Meekoceras* Zone, a major cephalopod horizon recognized from several localities around the globe, such as the Arctic Circle, Siberia, Japan, China, Timor, New Zealand, India, Pakistan, Madagascar, the northern Caucasus Mountains and the former Yugoslavia. The *Meekoceras* beds have also been identified at a handful of correlative sites in the United States, including Nevada, southeastern Idaho and northern Utah. As a matter of fact, it's the oldest Mesozoic ammonoid horizon yet described from North America, and is the third-oldest recognized in the world. Only the *Otoceras* and *Genodiscus* ammonoid zones precede it in the worldwide stratigraphic record of the Triassic Period, the oldest division of the Mesozoic Era.

Smith published his findings on the ammonoid fauna at Union Wash in 1932 in USGS Professional Paper 167, *Lower Triassic Ammonoids of North America*. He noted that the most distinctive variety recovered from the Union Wash limestone layers was *Meekoceras gracilitatus*, the species for which the zone was originally named in the first place. Other genera described from Smith's *Meekoceras* bed at Union Wash include *Ophiceras* (four species); *Owenites* (four species); *Xenodiscus* (four species); *Anasibirites* (three species); *Sturia* (two species); *Lanceolites* (two species); *Clypeoceras* (two species); *Lecanites* (two species); *Inyoites*; *Proptychites*; *Aspenites*; *Flemingites*; *Pseudosageceras*; *Prophingites*; *Danubites*; *Juvenites*; and six additional species of *Meekoceras*. Smith concluded that most of the ammonoid species at Union Wash showed close affinities to similar types recovered from localities in India and Timor; hence, he concluded they are Asiatic varieties, while the younger *Parapopanoceras* zone yields species that are more closely related to types discovered in the Arctic and Asia, with only a general similarity to the well-known Early Triassic faunas of the Mediterranean region. A more recent discussion of the Union Wash Formation can be found in USGS Bulletin *1928, Stratigraphy of the Lower and Middle(?) Triassic Union Wash Formation, East-Central California* by Paul Stone, Calvin H. Stevens, and Michael J. Orchard, issued in 1991.

Union Wash remains one of the great Early Triassic localities in North America. It's a place where at least two distinct fossiliferous horizons yield a rich association of 248 million year-old cephalopods. Even though the incredibly productive *Meekoceras* beds presently lie within a federally protected wilderness area, both amateur paleontology explorers and professional paleontologists may still hike to it and find plenty of ammonoids to take home--remembering of course to keep only loose, freely eroded specimens; don't dig into the strata within a wilderness zone without a BLM collecting permit.

While collecting ammonoids at Union Wash, it is inspiring to gaze back westward to the Sierran skyline across the Owens Valley, watching the glacier-incised canyons take on crevasse-like shadowing as the sun dips below snowy peaks whose elevations average over

14,000 feet--a great mountain range born from Jurassic-age batholithic magmatic intrusions of liquid rock, some 100 million years younger than the ammonoids you hold in your hand.

Chapter 31

Ice Age Fossils At Santa Barbara, California

Santa Barbara is an internationally renowned attraction located along the coast of Southern California approximately 100 miles north of Los Angeles. For decades the community has served as an ideal environment for assorted celebrities and other folks looking for a pleasurable get-away. Its climate has been liberally praised by those who ought to know, the jet-setters, as one of the very best in the world, and it's jewel-like setting along a fertile plain between a breathtaking expanse of the Pacific Ocean and a rugged backdrop of the chaparral-coated Santa Ynez Mountains contributes to the impressive scenic reputation of the area.

Santa Barbara obviously has no need of "hype." It is a rare and special paradise. But, what makes it even more attractive to many is the abundance of well-preserved fossils that can be found throughout the region.

For example, among its many undeniable paleontological charms, the Santa Barbara area is especially rich in Ice Age fossils. The appropriately named middle Pleistocene Santa Barbara Formation (first described and then named in the technical scientific literature for its most typical exposures in Santa Barbara) just happens to yield one of the largest and best preserved marine Pleistocene invertebrate faunas on the US West Coast. It's a really huge fauna, indeed, with approximately 400 taxa thus far identified: 91 bivalve molluscan forms (AKA, the pelecypods--or, the Lamillebranchia of older taxonomical terminology) such as pectens, clams, cockles, oysters, and mussels; 173 gastropods (the snails); 6 chitons; 3 scaphopods; pteropods; brachiopods; bryozoans; corals; ostracods (minute bivalve crustaceans); worm tubes; and around 102 species of foraminifers (minute shells with geometrically intricate internal structures, secreted by a single-celled organism--usually considered microfossils). Current geochronological considerations place the Santa Barbara Formation at approximately 1.2 million to 400,000 years old--although most of the world-class fossil occurrences lie between 1,000,000 to 750,000 years old (middle Pleistocene in geologic age).

Within the city limits of Santa Barbara, surface exposures of the Santa Barbara Formation rarely exceed 500 feet thick; yet, subsurface analyses demonstrate that, cumulatively, sedimentary deposition amassed an aggregate of well over 2,000 feet of marine-originated sands, silts, muds, and marls that, above-ground, contain locally abundant and often extraordinarily well-preserved invertebrate animals whose modern-day representatives, as a general rule, reside in marine environments significantly cooler than those off the coast of southern California today.

The most classically fossiliferous outcrops of the middle Pleistocene Santa Barbara Formation can be observed at a number of sensational sites--namely: (1) The type locality, positioned amidst the community of Santa Barbara--where of course geologists first named and

described the Santa Barbara Formation in a peer-reviewed scientific document (yields beaucoup pectens, clams, gastropods, and bryozoans); (2) "Foram Avenue" (a colloquial name)--a roadcut along a residential street in Santa Barbara, where paleontologists have not only identified some 102 species of foraminifera, but also loads of quality, identifiable pelecypods and gastropods; (3) The County Road--an informal title given to a specific street in Santa Barbara that yields astounding quantities of bryozoan "twigs," pecten shells, gastropods, and brachiopods; and (4)--The paleontological crown jewel of the Santa Barbara Formation, a place often referred to as Ice Age Fossil Hill, in the vicinity of Santa Barbara, within Santa Barbara County--a world-famous site that in addition to yielding 59 species of pelecypodal bivalves and 120 kinds of gastropods from some 25 separate fossiliferous beds, also produces numerous bryozoans, corals, brachiopods, worm tubes, ostracods (a diminutive bivalve crustacean), foraminifers, and algal developments from a roughly 300 foot-thick section of muddy to silty sedimentary detrital constituents deposited primarily in a shallow subtidal paleo-marine environment some one million years ago during the middle Pleistocene epoch; the vast majority of extant mollusks recovered from Ice Age Fossil Hill lived in waters from 20 to 40 m (65 to 98 feet) deep.

A number of years ago, while I lived in Santa Barbara, California, I happened to independently discover the spectacular fossil locality that not a few folks now call Ice Age Fossil Hill. As a matter of fact, that was such a powerfully exhilarating and rewarding paleontological experience that happily, to commemorate the event, I actually wrote a contemporaneous account of it in one of my field notebooks that I fortuitously rediscovered not too long ago (I thought I'd long-lost it, interestingly enough). I've transcribed that entry herein, in quotes:

"January 30: This afternoon, I discovered the best Pleistocene fossil locality I have ever seen, and quite possibly the best fossil locality period--in terms, that is, of abundance, variety and preservation of specimens; for here, sketching along the road and opposite side of the hill, occur several mollusk horizons in weakly consolidated brown to yellow-gray sand and silt. Successive strata contain a wide variety of specimens well preserved, and in an hour and a half's time I collected no less than 15 different species without the aid of paleontology equipment. I merely plucked fossils from the soft sandy Pleistocene formation (it's either the Ventura Sand or Santa Barbara formation, lower Pleistocene in geologic age). The lowermost fossiliferous stratum that I saw contained abundant pecten specimens; (thin-shelled *Pecten bellus*?) that might mark the Pleistocene-Pliocene boundary. This entire assemblage is similar in variety to the famed Palos Verdes Sand and the related formation, the San Pedro Sand, because I've found in all three such excellently preserved fossils as *Conus californicus*, *Olivia*, *Pecten*, etc.--typical Pleistocene forms that inhabited an ocean slightly colder than our present Pacific.

"I'd like to return well-prepared for paleontology: to have with me a back pack, rock hammer (geology pick), plastic bags, tissue paper (for wrapping delicate specimens), notebook, pencil, and my formal biology kit which contains sharp dissecting needles (good for probing in soft sand, for picking dirt away from easily fractured forms), and probes (these possess sturdier

needles that remove compacted sands and silt better than the dissecting variety). When next I visit the unbelievable exposure, I'll bring these valuable tools and conduct more scientific explorations. Armed with beneficial paleontological tools, I should be able to free some of the more fragile specimens embedded in hard sand.

"I can't help but compare this locality with one of the most famous fossil localities in the United States--a street-level exposure of Palos Verdes Sand in San Pedro, where thousands of perfectly preserved mollusks erode from a narrow strip of ancient ocean sand. The fossiliferous seam is covered by a thin veneer of younger reddish alluvium, in which the bones of Pleistocene mammals and birds have occasionally been found. At my new locality, there is not one rich horizon, but several outstanding ones and their specimens are just as unusually well preserved. It's almost as if you were holding a shell that only yesterday had been buried on the beach.

"One could spend much time there collecting specimens from the ascending fossil strata--making a scientific study of them, determining the ages of each horizon and the fauna they contain. It would make a fine project, I think. And the hill's thickness is easily determined--its dip and strike of strata, also. They dip generally northward, though for true accuracy I'd need a Brunton compass, a remarkable geological tool.

"I don't know exactly why I decided to stop off there. For a long while I had wanted to examine some of the sedimentary formations exposed along that route, but had never put my desires into action--until today. Sort of on the spur-of-the-moment I left my main route and discovered the abundance of Pleistocene fossils weathering free. To collect them was easy and fun and I could at this moment --12:20 am--return."

And so began my long-term paleontological infatuation with Ice Age Fossil Hill. Throughout my stay in Santa Barbara, I occasionally visited the locality and eventually amassed quite a representative selection of molluscan, byrozoan, coraline, foraminiferal, and even brachiopodal material from the middle Pleistocene Santa Barbara Formation.

In addition to the justifiably famous Ice Age fossil occurrences in the Santa Barbara Formation, a number of other Pleistocene geologic deposits in the vicinity of Santa Barbara also yield diagnostic fossil assemblages. One accessible and notably fossiliferous section can be examined at an emergent marine terrace, roughly 47,000 years old (late Pleistocene in geologic age), which yields an open-coast invertebrate fauna consisting of approximately 125 taxa, including 102 mollusks (bivalve pelecypods and gastropods), 18 foraminifers, and a solitary coral--*Balanophyllia elegans*.

Several such fossiliferous Pleistocene emergent marine terraces can be examined along the coast of Southern California (the Palos Verdes-San Pedro district of Los Angeles for one, of course, yields a world-class assemblage of late Pleistocene invertebrate paleontology). They're created when, first-off, an interglacial period of world-wide atmospheric cooling locks

up great quantities of oceanic water as polar ice. That causes the sea level to drop along the coast, exposing land and whatever invertebrate animal life happened to live in the intertidal zone. After that, if the environmental conditions are just right, detritus carried by rivers and streams and alluvial processes eventually buries the area now left high and dry, preserving in often exquisite detail the many evidences of marine Pleistocene animal life within. Once the interglacial period is over--the Santa Barbara marine terrace, by the way, was created during what stratigraphers call the Wisconsinan Glaciation Episode about 47,000 years ago--when polar ice melts and sea levels concomitantly begin to rise, you then need geophysical tectonic activity to gradually elevate the block/ledge of marine invertebrates now submerged beneath the very sea waters in which they originally lived. When the old sea bed finally reemerges from the ocean, a marine terrace is born and is once again subjected to erosion and, possibly, additional processes of terrestrial sedimentary deposition.

A second site of exceptional Ice Age paleontology occurs on Santa Rosa Island, Channel Islands National Park, off the coast of Santa Barbara, where the remains of a dwarf mammoth occur in late Pleistocene terrestrial detritus (recommendation: when in Santa Barbara, visit the Santa Barbara Museum of Natural History, where several skeletal elements from "Rosy" the dwarf mammoth are on display). A number of the Channel Islands also reveal evidence of Pleistocene marine terraces, loaded with abundant significant Ice Age invertebrate remains.

A third Ice Age spot of note lies several miles south of Santa Barbara, proper, in the vicinity of Carpentaria, Santa Barbara County--the renowned Carpenteria Tar Pits, which yielded a faunal assemblage similar to the La Brea Tar Pits in Los Angeles; mostly, the Carpenteria brea deposit produced a paucity of rather poorly preserved mammals (a horse and a camel, for example) and some 79 species of birds, including a bald eagle, golden eagle, cooper hawk, sharp-shinned hawk, barn owl, California condor, Merrium's Teratorn, pelicans, rails, ducks, king birds, western meadow larks, crows, scrub jays, finches, turkeys, road runners, wood peckers, and band-tailed pigeons. Plant remains recovered belong to Monterey pine (cones), Cypress (cones), oak, manzanita, juniper, and fir--all of which suggest that Ice Age Carpenteria probably resembled today's Monterey Peninsula, much farther north along California's coast. The primary scientific conservational problem with the Carperteria Tar Pits is that for decades they were used as a refuse dump--a long-term land status that obliterated the paleontological integrity of the original late Pleistocene deposit.

Not only is Santa Barbara famous for its Ice Age fossil remains, but geologically older Cenozoic Era rock deposits within the general vicinity of the community also contain locally common to abundant paleontolocal preservations.

A good place to start would be the south-facing front of the Santa Ynez Mountains, which form the dramatic backdrop to Santa Barbara immediately north of town (one must note that this is indeed California's "South Coast" area, where with peculiar improbability one must actually travel south--not the assumed traditional direction west--in order to reach the Pacific Ocean). It's comprised primarily of four quite famous marine Eocene-age geologic rock

formations that in ascending order of geologic age (oldest to youngest) include: the Juncal Formation; the Matilija Sandstone; the Cozy Dell Shale; and the Coldwater Sandstone, which in turn is overlain by a younger entirely terrestrial geologic rock accumulation called the upper Eocene to Oligocene Sespe Formation.

Although unfossiliferous throughout the Santa Barbara region (save for reworked fragments of oysters derived from the older underlying middle Eocene Coldwater Sandstone), the Sespe Formation exposed in Ventura County, several miles southwest of Ventura (which lies some 35 to 40 miles south of Santa Barbara), yielded one of the largest assemblages of late Eocene to Oligocene mammals west of the Rocky Mountains. The majority of vertebrate remains came from three separate sites: in the general neighborhood of a modern landfill operation; and the noted Pearson Ranch and Kew quarries, both situated on private property in the Las Posas Hills northwest of Thousand Oaks. Vertebrate paleontologists Chester Stock and R.W. Wilson conducted most of the scientific collecting from the Pearson Ranch and Kew quarries during the 1930s and '40s. Among their numerous important finds were large cats, early saber-toothed cats, dogs, a squirrel-like rodent, a squirrel, field mice, rabbits, a small "deerlet," primitive opossums, early insectivores, primitive rodents, an early rhinoceros, a brontothere, a rhinoceros-like animal, a primitive hedgehog, and an early lemur monkey.

Among the marine Eocene units exposed in Santa Barbara's Santa Ynez Range district, the middle Eocene Coldwater Sandstone is probably the best of the bunch for satisfying paleontological explorations; of course, all four formations yield fossil remains in varying degrees of abundance and excellence of preservation. In the Ojai district of neighboring Ventura County, for instance, the Cozy Dell Shale produces spectacular Brittle stars, while the Matilija Sandstone provides paleomalacologists with a large and varied Eocene molluscan fauna.

Through the high resolution methodology of magnetostratigraphy (a reliable technique that allows precise geologic correlations based on the timing of past magnetic reversals in the Earth's poles), the Coldwater Sandstone has been dated with great accuracy at 42.5 to 39.5 million years old. Its upper 1,000 feet of stratigraphic exposure, particularly near the geologic contact with the upper Eocene to Oligocene Sespe Formation, produces prodigious numbers of *Ostrea idriaensis* and *Ostrea tayloriana* oysters, plus locally common pelecypodal clams and turritella-type gastropods. While I lived in Santa Barbara several years ago, one of my favorite Coldwater Sandstone fossil haunts was what many local paleontology enthusiasts called the "Coldwater Clam Quarry;" that's where numerous carbonized valves of pelecypods, common turritella gastropods, and even a shark tooth or two could be collected.

Petrologically speaking, sands in the Coldwater Sandstone were deposited into a shallow gradually regressing middle Eocene sea by westward-flowing rivers that drained a granitic terrain--probably the ancestral Sierra Nevada. Too, a rather fascinating geological aside here is that as an integral lithologic member of the Santa Ynez Mountains (which belong to what geographers call the Transverse Ranges of Southern California), the Coldwater Sandstone

went along for quite a wild geophysical ride. From roughly mid Miocene to early-late Miocene times--15.2 million to around 10 million years ago--tectonic forces rather rapidly (in a geological sense) rotated the original declination of the ancestral Santa Ynez Range some 56 degrees clockwise; after that, more gradual clockwise rotational movements, until about two million years ago, helped establish the present-day east-west geographic orientation of the Santa Ynez Mountains.

After exploring the middle Eocene Coldwater Sandstone in the southern foothills of the Santa Ynez Mountains, fossil seekers might also want to investigate a representative sampling of Santa Barbara's many late Oligocene-Miocene-and Pliocene paleo-treasures. Oldest to youngest, some of the more notable examples include: the upper Oligocene to lower Miocene Vaqueros Formation (produces huge pectens, oysters, and turritella-style gastropods that flourished in warm tropical waters; furnishes many species of shark teeth, too); the middle Miocene Temblor Formation (the same geologic rock unit that preserves the fabulous Sharktooth Hill Bone Bed northeast of Bakersfield, California; in the Santa Barbara region, the Temblor contains large tropical-type gastropods and pelecypods, locally abundant sand dollars, brachiopods, and occasional marine mammal skeletal elements); the middle to late Miocene Monterey Formation (yields an astounding variety of fossil remains: a plethora of microfossils--foraminifers, diatoms, and radiolaria--seaweeds; whales; sea lions; walruses, bony and cartilaginous fishes; and birds); the middle Miocene Branch Canyon Formation (its so-called "echinoid optimum" zone provides plentiful sand dollars from a pure sandstone paleo-beach interval stratigraphers correlate with diatomaceous shales of the coastal Monterey Formation); the upper Miocene to lower Pliocene Sisquoc Formation (it's an especially rich paleontological zone, preserving the remains of diatoms, radiolarians, arenaceous foraminifers, sponges, and occasional marine mammal bones); the upper Miocene to lower Pliocene Santa Margarita Formation (yields prodigious quantities of barnacles, sizable pectens, clams, echinoids, and a monstrous oyster called appropriately enough, *Ostrea titan*); and the upper Pliocene Careaga Formation (produces myriads of fantastically well preserved mollusks (bivalve pelecypodal examples, and gastropods), in addition to locally prodigious quantities of exceptional echinoids (sand dollars).

That would constitute but a sampling of paleontological opportunities one could seriously consider exploring in Santa Barbara County. Please note, of course, that all the usual collecting admonitions apply here: Among them--You need explicit written permission from land owners to fossil prospect on private property; you must contact the local United States Forest Service folks to learn their latest official directives regarding unauthorized fossil collecting in the Los Padres National Forest; and, finally, before hiking along trails in the Los Padres National Forest above Santa Barbara, you just might need to purchase an Adventure Pass--it's a wholly local pass often required when exploring by non-mechanized means the Angeles, Cleveland, Los Padres, and San Bernardino National Forests of Southern California.

With collecting bona fides properly established through due diligence, one naturally begins to wonder whether specific seasonal meteorological conditions impinge on paleontological exploration activities.

The abbreviated answer is: not a chance. Temperatures remain consistently moderate year-round. And while the region does indeed experience a definite winter-early spring rainy season, fossil hunting in Santa Barbara can be comfortably conducted any time of the year. The community officially averages some 19.41 inches of precipitation per year, and the highest elevations in the neighboring Santa Ynez Mountains (3,800 to 3,900 feet) receive approximately 35 inches of rain annually--including on occasion a dusting of snow.

Of course, when the fossil hunting is finished for the time being--it's certainly time to participate in different forms of entertainment.

Because, obviously, there is much more to experience in Santa Barbara than paleontological investigations, alone. It's a community famously geared toward tourism. A few of the more-popular attractions include: the Botanical Gardens; the Mission (generally considered by a majority of architectural historians as the most aesthetically striking of all the old missions in California); the Museum of Natural History (which boasts an excellent geology section with an educational display of gems and minerals and local fossils); the Santa Barbara courthouse--from whose tower is obtained an outrageously inspiring 360 degree panorama of the city, Santa Ynez Mountains, and Pacific Ocean; and, naturally, the clean gorgeous beaches. There are innumerable eateries, from the inevitable fast food establishments to world-class restaurants--in addition to any number of hotel and motel accommodations.

While all of Santa Barbara's Ice Age fossil localities could theoretically be visited in reconnaissance style in a single afternoon, you'll likely want to spend a few extra days in Santa Barbara to check out the sights. Camping places along the beach--all within 20 to 30 miles of Santa Barbara--include Gaviota, Refugio Beach, El Capitan Beach, and Carpenteria Beach. For camping in the Santa Ynez Mountains, try the Santa Ynez River tract area a few miles south of Lake Cachuma, east of State Route 154, along Paradise Road about 15 miles northwest of Santa Barbara. Here can be found several quality campgrounds, including Fremont, Los Prietos, Lower Oso, Santa Ynez and Redrock.

My favorite time of year in Santa Barbara is fall, when the days are sunny, warm and clear--no dismal chilly fog to speak of--and the nights dazzling with stars, with a moderate crisp coolness to the air. The sunsets over the Pacific are extraordinary in autumn, and while I resided in Santa Barbara a number of years ago I'd sometimes hike to the Coldwater Clam Quarry in late afternoons, timing my fossil hunting to coincide with the glowing spectacle out over the ocean; then when it was too late to find fossils, I'd sit along the edge of the trail, reverent in the presence of the glorious colors of the sinking sun.

In the afterglow of twilight I'd head back down the mountain slope clutching the remains of clams that some 40 million years ago lived in a different ocean--a sea now long-vanished but one which also felt the setting of that same sun.

Chapter 32

Plant Fossils At The La Porte Hydraulic Gold Mine, California

Between the years 1848 and 1932, an estimated $1 billion worth of gold was taken from California at the old historical price of 18 to 20 dollars per troy ounce. Most of the early gold came from the incredibly rich and justifiably famous placer deposits in the foothills of the western slopes of the Sierra Nevada. During the first five years of California's Gold Rush, for example--1848 to 1853--the 49ers removed some 12 million ounces of the precious "yellow stuff." Another significant percentage of the total is credited to intensive dredging operations conducted on several major stream courses in Northern California, particularly along the American and Yuba Rivers; from the 1890s to 1932, the dredgers likely accounted for at least 10 million ounces of gold. In addition to the placer/dredge mines, rich lode ore deposits in the vicinity of Coloma, Nevada City/Grass Valley (they are contiguous communities), Jackson, San Andreas, Angels Camp, Columbia, Sonoroa, and Mariposa also produced millions upon millions in gold.

But perhaps the least-appreciated means of recovering the abundant gold of the Gold Rush era was by hydraulic mining. Hydraulicking began only a few years after the gold discovery at Coloma, California, on January 24, 1848, when prospectors, searching farther east up the stream courses, found gold in gravel deposits unrelated geologically to the placer accumulations farther down stream. This gold was locked away in the auriferous or gold-bearing gravel, a stratigraphic interval consisting of interbedded c1ay, silt, sand, pebbles, cobbles, and boulders whose origin was obviously related to long-vanished river channels many millions of years old. In the mid to late 1800s, most geologists and paleobotanists initially believed that all auriferous gravels deposited by the ancestral Tertiary Yuba River and its related Cenozoic tributaries were Miocene in geologic age, roughly 23 to 10 million years old, but later geologic analyses established them entirely of Eocene age, probably 48 to 38 million years old.

To get at the coveted metal, the miners employed hydraulic mining--that is, they directed high-pressured jets of water at the auriferous gravel to wash out the gold-rich concentrations hidden within the gravel beds. In the process, they often blasted away entire mountainsides to force massive volumes of potentially gold-rich sludge through a system of sluices, eventually capturing the locally prolific flakes and nuggets of aurum. A conservative estimate suggests that hydraulickers washed away more material than the total removed during excavations of the Panama Canal. Nobody knows for certain just how much gold the hydraulic method recovered--no reliable records were ever kept--but the general consensus among mining historians is that from 1855 to 1884, somewhat under a quarter of the $1 billion in gold can be accounted for by hydraulic mining (approximately 11 million ounces of gold), calculated of course at the antiquated price of about 20 dollars per troy ounce.

In 1884, the legally binding landmark Sawyer Decision effectively abolished all major California hydraulicking operations: United States Circuit Judge Lorenzo B. Sawyer issued an injunction which prohibited uncontrolled disposal of hydraulic debris into the Sacramento and San Joaquin Rivers. This alone probably would not have been enough to stop the practice, but the Sawyer ruling additionally stated that the tributaries of those rivers must also remain free of hydraulic tailings.

Today, probably the most accessible place to view a thick sequence of undisturbed auriferous gravel lies in the roadcut on the north side of Interstate 80 just east of the rest stop at Gold Run, between Auburn and Reno. Locally extensive deposits of auriferous gravels can also be investigated at many of the long-abandoned hydraulic mines--specifically at such sites as Howland Flat, St. Louis, Port Wine, Chalk Bluff, ScaIes, Malakoff Diggins, North San Juan, Iowa City, Cherokee, Quaker Flat, Dutch Flat, Buckeye Flat, Sailor Flat, and La Porte.

In addition to exposing extensive deposits of auriferous gravel at La Porte, northern Sierra Nevada territory, the hydraulic miners also brought to light a remarkable and paleontologically significant fossiliferous horizon associated with the gold-bearing rocks: a regionally limited exposure of reworked and re-deposited rhyodacite volcanic tuff which yields some 43 species of ancient plants, mainly beautiful carbonized leaves, dated radiometrically (through radioactive isotope analyses) at around 34.2 million years old. The fossils are thus latest Eocene in geologic age, younger by several million years than the gold-bearing gravels upon which they discomformably rest. Appropriately enough, geologists have named this leaf-bearing deposit of hardened volcanic ash the La Porte Tuff, and the plants that occur in it faithfully record a key interval of botanic life on our planet.

La Porte lies in the extreme southern sector of P1umas County, California. But before a visit to the fossil 1oca1ity, consider conducting some preliminary adventures: sightseeing in La Porte, a truly scenic mountain community situated amidst the rich mixed conifer forest of the northern Sierra Nevada. La Porte rests an an elevation of approximately 5,000 feet (when the furnace-fire heat of summer begins to flare in the Great Central Valley to the west, this area certainly provides a most refreshing and cooling refuge)--probably close to the same altitude that existed during deposition of the La Porte Tuff 34.2 million years ago; that's because, in a geomorphological sense, the northern Sierra Nevada has remained at approximately today's height since at least 50 million years ago while, conversely, the central to southern Sierra Nevada has been greatly uplifted since about five million years ago.

The history of La Porte begins in 1850 when prospectors discovered placer gold on Rabbit Creek at the head of Little Grass Va1ley. Early arrivals christened the site Rabbit Diggings, a name which stuck for several years. Major hydraulicking did not begin in the region until 1855, but by then the town was already bustling with its own hotel, stores, post office, and saloons. Hydraulic mining kept the community in "bacon and beans" for the next 16 years, as the auriferous gravels exploited there reportedly provided some of the richest gold-bearing concentrations ever discovered in California's Sierra Nevada district. From 1855 to 1871, for example, residents shipped some 60 million dollars' worth in gold from La Porte--a figure calculated at the historical price of roughly $20 per troy ounce.

By 1857, Rabbit Diggings folks began to experience dissatisfaction with their original town name; sophistication had set in. It was time for a change, they decided. A leading citizen by the name of Frank Everts suggested La Porte as an alternative--never mind that Everts hailed from La Porte, Indiana--and La Porte was quickly agreed upon. For the next five years, through 1862, La Porte experienced classic boomtown commerce activity; loads of gold came pouring out of the hydraulic operations, and the auriferous gravels seemed practically inexhaustible.

Unfortunately for La Porte's residents, the flush times couldn't last. Following the peak year of 1862, a gradual decline began, although as late as 1866 we find the citizens of La Porte embroiled in a spirited fight to secure the county seat of a proposed brand new California county called Alturus. Neither idea came to pass, though, and governmental officials eventually annexed La Porte to Plumas County, where it has remained ever since.

In addition to its mind-boggling lucrative gold-bearing gravels, La Porte boasts yet another important historical distinction in the, at first blush, improbable area of skiing. As the story goes, deep winter snows in the region regularly blocked the trails, so miners, exercising creative ingenuity, began to fasten "Norwegian snowshoes" to their feet, permitting travel over frozen crusts. These hand-fashioned snow runners became de facto skis, and inevitably a rivalry developed to determine which "snowshoer" could ski the fastest. This in turn led to the formation of the Alturus Ski Club, an organization that scheduled downhill races for cash prizes. Perhaps it is bombastic braggadocio, but today La Porte, California, claims the title of being the "birthplace of competitive skiing."

After exploring historic La Porte, it's of course time to get down to paleontological business. Once at the fossil locality in the vicinity of town--setting foot there with an intent to secure specimens only if the United States Forest Service continues to permit unauthorized fossil collecting (always check with local USFS rangers to determine the most recent rules and regulations)--you will observe a prominently precipitous cliff composed predominantly of brownish mudstones and shales, underlain by white to rust-tinged gold-bearing gravels. As observed from a distance, the relatively inconspicuous layer of greenish leaf-bearing upper Eocene La Porte Tuff occurs near the rim of this cliff which along with the auriferous gravel near the base was exposed by mid to late 1800s hydraulicking operations. At last field check, only a roughly 16 by 6 foot thick section of that once extensive, laterally continuous horizon of plant-yielding rhyodacite La Porte Tuff remains in its original stratigraphic position.

Within the immediate confines of the abandoned hydraulic pit, obvious strewn accumulations of spent rocky rubble will be observed--the dramatic evidence of copious outwash derived from untold cubic yards of auriferous gravels washed away during decades of hydraulicking. Sometimes splinters and chunks of petrified wood can be spotted among the gravel debris below the cliff, fragmental remains of permineralized trees dislodged from the middle Eocene auriferous gravels by the great hydraulic monitors. Fortunately for seekers of paleobotanical adventure, those high-powered streams of water also undercut the fossil-bearing upper Eocene Porte Tuff layer near the rim of the cliff, causing rather common blocks of talus material to accumulate at the base. These blocks provide easy collecting.

To reach the fossiliferous talus blocks, hike along the narrow erosion gully nearest the cliff. Be prepared, though, because this is sometimes a frustrating path; dense pockets of brush have claimed portions of the channel, creating natural obstacles to your progress. It's probably better to simply follow the erosion course from a safe distance, finally crossing the channel when you at last spot the large blocks of greenish fossil-bearing La Porte Tuff strewn along the base of the cliff for several hundred feet.

This leaf-bearing volcanic ash is easily distinguished from the brownish mudstones and whitish quartz pebble-rich beds of auriferous gravel that comprise most of the cliff. Watch for the pale

greenish, faintly stratified blocks lying against the lower slopes and at the foot of the cliff. The fossil leaves are locally quite abundant here, and are for the most part very well preserved. Evidently, the volcanic ash provided an excellent medium for the preservation of delicate organic vegetable tissues.

Many fragmental fossils will likely be observed exposed on naturally eroded surfaces of the greenish tuff, and numerous chunks of material fractured off by previous collectors sometimes reveal profuse, albeit mainly imperfect plants. The best fossil leaves can be secured by patient and persistent cracking of the tuff with the blunt end of a traditional geology rock hammer; wear adequate eye protection at all times while doing so, of course--and don't use a wide blade roofer's implement, as advocated by any number of paleobotanists: It lacks the necessary mass, heft, to cleave with repeated precision such hard rock.

Many, but certainly not all fossil leaves here lie at varying angles within the tuff, so it is difficult to prevent damaging superior specimens. Be sure to bring along a fast-drying glue, in order to mend breaks on the spot. The highly indurated tuff is easily glued back together, a blessing since in practical experience it is virtually impossible to collect here without fracturing several nice fossil leaves no matter how meticulous the method used. Wrap your specimens in tissue paper or paper towels; store the smaller samples in plastic sandwich bags for safe transporting back home.

While exploring the paleobotanically productive abandoned hydraulic pit near La Porte, one notes that typical trees growing in the vicinity of the fossil site today constitute a dominantly coniferous association of Ponderosa pine (*Pinus ponderosa*), Sugar pine (*Pinus lambertiana*), Lodgepole pine (*Pinus contorta*), Jeffrey pine (Pinus jeffreyi), California red fir (*Abies magnifica*), Douglas-fir (P*seudotsuga menziesii*), and Incense cedar (*Calocedrus descurrens*).

But approximately 34.2 million years ago, that botanically pervasive gymnospermous component so famously identified with a modern montane Sierra Nevada environment did not exist. Paleobotanical material identified from the upper Eocene La Porte Tuff cumulatively includes a predominance of excellently preserved dicotyledonous leaves that bear a close botanic affinity to modern-day equivalents now indigenous to southern Mexico, Central America, parts of South America, southeastern China, and the Philippines. Climate during deposition of the La Porte Tuff was probably semi-tropical, with approximately 65 inches of rainfall per year and an average annual temperature of 75 degrees.

All told, some 43 species of fossil plants have been secured from the long-abandoned hydraulic gold mine in the neighborhood of La Porte, Plumas County, northern Sierra Nevada, California. All specimens first studied by paleobotanist Susan S. Potbury in the 1930s occur in the fossiliferous volcanic ash bed--the upper Eocene La Porte Tuff--which has been dated through sophisticated radiometric methods at 34.2 nnillion years o1d.

Fossil specimens identified by paleobotanist Susan S. Potbury in her monumental paleobotanical treatise *The La Porte Flora Of Plumas County, California*, originally issued November 25, 1935, include:

1) A fern of uncertain taxonomic affinity, referred to the form genus *Polypolites* (incertae sedis), first erected by Goppert in 1836; lots of fossil ferns have been placed into this catchall genus, usually because they resemble examples in the family Polypodiaceae, which contains about 50 genera and an estimated 550 mostly tropical species.

2) A cycad that Susan S. Potbury originally identified as *Zamia mississippiensis*; re-assigned (in 2012) to *Dioonopsis macrophylla*, a species probably similar to the living evergreen cycad *Dioon edule*--common name Chamal--that can grow to 13 feet. Ranges in natural habitat through Central America to Mexico (gulf area and northeast), preferring deciduous and oak forests at elevations from sea level to roughly 4,900 feet.

3) *Cephalotaxus californica*, a new species of yew (family Taxaceae) that Potbury in 1935 compared to the living *Cephalotaxus argotaenia*, the Chinese flowering yew, now known taxonomically as *Amentotaxus argotaenia*, a small tree or shrub that grows from six and a half to 23 feet high in China (Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan) and southeast Tibet.

4) Leaf rays from a new species of fossil palm Potbury named *Sabalites rhapifolius*; resembles a living Asiatic palm that Potubury called *Rhapis flabilliformis*, which is now know as *Rhapis excelsa*. Common names for it include: Large Lady Palm; Ground Rattan Cane; Broadleaf Lady Palm; Slender lady palm; Bamboo palm; Broad-leaved slender lady palm; Fern rhapis; Ground Rattan Palm; and Miniature fan palm. Native to southern China and Taiwan. It's a thicket forming fan palm, producing 13 by 13 foot-wide clumps that eventually become very dense.

5) *Smilax goshenensis*--the Eocene equivalent of the extant *Smilax mexicana,* synonym of *Smilax spinosa*. Common name greenbriar or Sarsparilla vine. In much of Mexico it's called Zarzaparrilla, though in Yuctan Maya it's referred to as Koke. Grows from sea level to elevations as high as 8,000 feet. Native to Belize, Bolivia, Brazil Northeast, Colombia, Costa Rica, Ecuador, El Salvador, French Guiana, Guatemala, Guyana, Honduras, Mexico Central, Mexico Gulf, Mexico, Nicaragua, Panamá, Peru, Southwest Caribbean, Suriname, Trinidad-Tobago, and Venezuela.

6) *Chrysophyllum conforme*--The Eocene analog of the living satinleaf *Chrysophyllum mexicanum*, an evergreen shrub or a tree with a spreading crown that grows up to 75 feet. It's indigenous to Panama, Nicaragua, El Salvador, Belize, Guatemala, and Mexico, preferring a moist to wet mixed forest; most commonly found at low elevations, though it can ascend to 5,600 feet.

7) *Cinnamonum acrodromum*--The Eocene counterpart of today's Kalingag, *Cinnamonum mercadoi*. Usually a small evergreen tree that grows from 20 to 33 feet high. It's native to the Philippines, where it grows best in forests at low and occasionally medium elevations to 6,600 feet.

8) *Cinnamonum dilleri*--The Eocene genus-species of the extant Japanese cinnamon *Cinnamonum penduculatum*, an evergreen tree that grows to roughly 32 to 49 feet; presently native to Japan, Korea, Taiwan, and eastern China (Anhui, Fujian, Sichuan, Jiangsu, Jiangxi, and Zhejiang).

9) *Euphorbiaphyllum multiforum*--A fossil species that most closely resembles the modern *Drypetes alba* (common name, cafeillo), an evergreen tree indigenous to Cuba, Puerto Rico,

Domincan Republic, southern Florida, US Virgin Islands, Haiti, Jamaica, Leeward Is., and Windward Is.

10) *Ficus goshenensis*--An Eocene analog for the modern *Ficus bonpandiana,* synonymous with *F. obtusifolia*, an evergree tree that grows from sea level to 3,280 feet in Bolivia and Brazil, north through Central America to Mexico. Tolerates a wide range of environmental conditions, from very wet habitats to seasonally very dry areas; can grow to 148 feet tall.

11) *Laurophyllum intermedium*. A member of the laurel family that Susan S. Potbury equated with the modern evergreen *Misanteca capitata* (synonymous with *Licaria capitata*) whose common names include misateco, palo misateco, laurel of the sierra, black laurel, laurel canelillo de (Veracruz), hymnio moko, and xolimte. It's distributed from sea level to an elevation of around 1,968 in Mexico (Chiapas, Oaxaca, Puebla, San Luis Potosí, Tabasco, and Veracruz), Guatemala, Belize, and Honduras.

12) *Laurophyllum ramiferivum*: This is what paleobotanist Susan S. Potbury called the Eocene equivalent of an unspecified member of the genus *Ocotea,* a member of the laurel family; today the 300-some species of *Ocotea* are native to the Caribbean, West Indies, and tropical and subtropical areas of Africa, Madagascar, and the Mascarene Islands.

13) Leaf specimens that Susan S. Potbury called *Cornus kelloggi*, a presumably extinct species that has no known exact living counterpart. A dogwood, possibly akin to an extant species in southeast Asia. Early paleobotanists thought it resembled the living Pacific dogwood *Cornus nuttalli*.

14) Fossil leaves that paleobotanist Susan S. Potbury called *Hyperbaena diforma*, the Eocene analog of the living *Hyperbaena smilacina*, a member of the Moonseed family, several members of which contain the toxic alkaloid tubocurarine, used to prepare various forms of curare. Usually a twining woody vine, more rarely an upright shrub. Now native to Colombia, Costa Rica, and Nicaragua.

15) Paleobotanical material that Susan S. Potbury described as *Styrax curatus*, the Eocene variety of today's *Styrax arengteus*, sometimnes called Snowball. It's an evergreen tree usually topping out at around 65 feet, with occasional specimens to 98 feet. Harvested in the wild for an aromatic resin that is used locally. Ranges today from Panama to Mexico at elevations from roughly 300 to 5,577 feet.

16) *Phyllites alchorneopsis*--A form genus-species of uncertain botanic affinity (incertae sedis). It shows closest affinity to two modern members of the genus *Alchornea*--*Alchornea trewiodes* of southern China (notably in Guangxi) and north Vietnam and *Alchornea davidii* of southern China.

17) *Tabernaemontana intermedia*--The Eocene equivalent of the living *Tabernaemontana lanceolata*--common name Grape jasmine. An evergreen shrub or small tree that grows to one and half to 16 feet tall. Present native range is southern China, India, Myanmar, and Thailand. Grows at elevations from 330 to 5,250 feet in southern China.

18) *Cissampelos rotundifolia*--The Eocene analog of the living *Cissampelos pareira*, whose common name is Velvet-leaf (also known as Velvetleaf or Abuta), a climbing vine native to Aldabra, Andaman Is., Argentina, Aruba, Assam, Bahamas, Bangladesh, Belize, Bolivia, Borneo, Brazil North, Brazil, Cayman Is., China, Colombia, Comoros, Costa Rica, Cuba, Dominican Republic, East Himalaya, Ecuador, El Salvador, Ethiopia, Florida, French Guiana, Galápagos, Guatemala, Guyana, Haiti, Honduras, India, Jamaica, Kenya, Laos, Leeward Is., Lesser Sunda Is., Madagascar, Maluku, Mauritius, Mexico, Mozambique, Myanmar, Netherlands Antilles, New Guinea, Nicaragua, Nicobar Is., Panamá, Paraguay, Peru, Philippines, Puerto Rico, Rwanda, Réunion, Somalia, Southwest Caribbean, Sri Lanka, Sulawesi, Suriname, Taiwan, Tanzania, Thailand, Trinidad-Tobago, Uganda, Uruguay, Venezuela, Venezuelan Antilles, West Himalaya, Windward Is., and Zimbabwe.

19 *Leguminosites falcatum*: The Eocene counterpart of the living *Prioria copaifera*, an evergreen tree that can grow to 164 feet. It ranges from Nicaragua to Colombia (also occurs in Jamaica), preferring tidal estuaries in the vicinity of the mangrove fringe.

20) *Acalypha serrulata*--The Eocene genus-species of the extant *Acalypha schlechtendaliana*. A member of the Euphorbia family; a shrub whose modern range is Madagascar, Reunion Island, and various Islands in the Indian Ocean (excluding the Seychelles). In Madagascar, it grows from sea level to 6,500 feet.

21) *Persea pseudo-carolinensis*--The Eocene equivalent of the modern *Persea podandenia* (synonymous with *Persea liebmannii*), an evergreen tree (member of the laurel family) now native to parts of Mexico (Chiapas, Chihuahua, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, Nuevo León, Oaxaca, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, and Veracruz). Grows best in tropical deciduous and humid pine-oak forests at elevations between 1,900 and 5,900 feet.

***22) Persea praelingue*--The Eocene variety of *Persea lingue*, a member of the laurel family, native to Argentina and Chile. In Chile, it grows best in humid areas that receive almost constant rainfall; tolerates short dry periods of no longer than a month. In interior valleys and coastal mountains it grows at elevations from 1,600 to 6,000 feet.**

23) Leaves that Susan S. Potbury assigned to *Stercula ovata*, the Eocene analog of the modern *Sterculia lanceifolia*, an evergreen small tree indigenous to southern China, Bangladesh, and northeast India. In China, it grows at elevations from 2,600 to 6,500 feet on forested slopes.

24) Specimens of *Davilla rugosa*, which is the Eocene genus-species of the living *Davilla kunthii*, a woody vine or small tree native to Belize, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico (central, gulf area, southeast, and southwest), Nicaragua, Panamá, Peru, southwest Caribbean, Suriname, Trinidad-Tobago, and Venezuela. Prefers a moist to wet hilly pine forest habitat at elevations of 1,150 to 1,500 feet.

25) *Ilex oregona*--The Eocene variety of *Ilex paraguensis*. Common name is Yerba mate. It's in the holly genus. A small evergreen tree that typically grows from 13 to 26 feet high. Presently found in Argentina, Uruguay, Paraguay, and Brazil. Can grow at elevations up to 4,900 feet.

26) A species that Susan S. Potberry assigned to *Sophora respandifolia*, a presumably extinct form whose leaves correspond to no known specific living plant; extant members of genus *Sophoria* (pea family) are native to southeast Europe, east Asia, tropical regions in Australia and the Pacific, western South America (Chile, Argentina and Juan Fernandez Is.), coastal Kenya south to South Africa and Madagascar, and coastal east Brazil.

27) *Alangiophyllum petiocaulum*: An extinct Eocene species that shows closest relationships to the modern *Alangium chinese*, a shrub or small tree that grows to about 11 and a half feet in forest margins and exposed areas below 8,200 feet in China (Anhui, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Shanxi, Sichuan, Yunnan, and Zhejiang), Taiwan, south Tibet, Bhutan, India, Nepal, east Africa, and southeast Asia.

28) *Phyllites laportiana*--A form genus-species of uncertain taxonomic relationship (incertae sedis). Likely an extinct species. In studying the upper Eocene La Porte Flora, paleobotanist Susan S. Potbury concluded rather succinctly: "Thus far, no clues regarding its taxonomic affinities have been discovered."

29) *Quercus nevadensis*--The Eocene equivalent of the extant *Lithocarpus corneus var. hainanensis,* native to China (southern Fujian, Guangdong, Guangxi, southern Guizhou, Hainan, southern Hunan and eastern Yunnan), Vietnam (northeast), and Taiwan; prefers elevations below 3.200 feet along sunny mountain slopes and drier areas in evergreen forests.

30) *Petrea rotunda*--The Eocene variety of *Petrea volubilis*, a vine in the Verbenaceae family; common names include purple wreath, queen's wreath, sandpaper vine, and nilmani. Native to Belize, Bolivia, Brazil (North, Northeast, South, Southeast, and West-Central), Cayman Is., Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Florida, French Guiana, Guatemala, Guyana, Haiti, Honduras, Jamaica, Leeward Is., Mexico (Central, Gulf, Northeast, Southeast, and Southwest), Nicaragua, Panamá, Paraguay, Peru, Puerto Rico, Suriname, Trinidad-Tobago, Venezuela, and Windward Is.

31) Leaf specimens that paleobotanist Susan S. Potbury described as *Liquidamber californicum*, the fossil variety of *Liquidambar styraciflua*--American sweetgum. Also known as American storax, hazel pine, bilsted, redgum, satin-walnut, star-leaved gum, alligatorwood, or sweetgum; a deciduous tree indigenous to Central America, north through Mexico to the southeastern United States. Natural habitats include swampy woods that are often inundated annually and moist to wet areas of mixed forest, mostly on mountain sides or along streams. In Guatamala, it's often associated with oak or pine at elevations from 2,900 to 6,900 feet.

32) *Ocotea eocernus*--This is what Susan S. Potbury called the Eocene genus-species of today's *Ocotea cernua*, also commonly referred to as Cayenne Rosewood, an evergreen tree that typically grows 16 to 32 feet tall, with occasional specimens pushing 64 feet. It's regularly harvested in the wild for its essential oil. Native to Brazil, Bolivia, the Caribbean, Central America, and Mexico. In Guatamala, it lives at or a little above sea level in a wet mixed forest. Costa Rica specimens prefer a lowland evergreen forest. In general, it's a plant of tropical areas at elevations from near sea level to over 4,900 feet.

33) *Persea pseudo-carolinensis*--Paleobotanist Susan S. Potbury believed that this fossil species, while obviously similar to the common living swampbay of the southeastern United States, was closer to the modern Mexican redbay (*Persea podadenia*--synonymous with *Persea liebmannii*), an evergreen tree (grows to 50 feet) in the laurel family endemic to Mexico (Chiapas, Chihuahua, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, Nuevo León, Oaxaca, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, and Veracruz). It regularly grows in tropical decicuous and humid pine-oak forests at elevations from 1,900 to 2,600 feet.

34) *Sturculia ovata*--The Eocene equivalent of the living *Stercolia lanceifolia*, an evergreen shrub or small tree whose seed is sometimes harvested from the wild as a local food source. It's endemic to southern China, Bangladesh, and northeast India.

35) *Quercus suborbicularia*--A fossil species whose leaves match no living plant, though Susan S. Potbury found its closest contemporary counterpart in the white oak *Quercus durangensis* (synonymous with *Quercus rugosa*), endemic to Mexico (Aguascalientes, Baja California, Chihuahua, Coahuila, Durango, Guanajuato, Hidalgo, Jalisco, Michoacan, Oaxaca, Sinaloa, Puebla, San Luis Potosi, Sonora, Tamaulipas, Tlaxcala, Veracruz, and Zacatecas), southern Arizona, and Guatemala at elevations of 3,900 to 10,500 feet.

36) *Ulmus pseudo-fulva*--The Eocene analog for the living Mexican elm *Ulmus mexicana* (also called Membrillo) a deciduous tree that normally grows 32 to 82 feet tall (though some specimens can reach over 250 feet). It's sometimes harvested in the wild for medicinal use and a source of wood. Indigenous to Panama north to Mexico at elevations of 2,950 to 8,850 feet.

37 *Aleurites americana*--The Eocene variety of the modern Candlenut (also called Kuku Nut) *Aleurites triloba,* synonymous with *Aleurites moluccanus*, an evergreen tree that grows up to 98 feet. Endemic to China, India, Sri Lanka, Myanmar, Thailand, Cambodia, Vietnam, Malaysia, Indonesia, Philippines, New Guinea, Australia, and Pacific Islands in rain or monsoon forests at altitudes below 3,900 feet where mean annual temperatures range from 64 to 82 degrees Fahrenheit and the average annual rainfall is 26 to 170 inches.

38) *Columbia occidentalis*--The Eocene counterpart for the extant *Columbia longipetiolata* (a synonym of *Colona longipetiolata*), a member of the mallow family (subfamily Grewioideae). Indigenous to the Philippines.

39) *Lonchocarpus coriaceus*--This is what paleobotanist Susan S. Potbury called the Eocene genus-species of the living *Lonchocarpus hondurensis*, an evergreen tree that usually grows 19 to 26 feet tall, though occasional specimens can reach 38 feet. Develops a deciduous habit when growing in areas that experience a long dry season. Endemic from Honduras to Mexico at elevations up to 1,300 feet.

40) *Meliosma goshenensis*--The Eocene variety of the modern *Meliosma panamensis* (synonymous with *Meliosma glabrata*), an evergreen tree native to Bolivia, Colombia, Costa Rica, Ecuador, Honduras, Mexico Gulf, Mexico Southwest, Nicaragua, Panamá, and Peru. A member of the family Sabiaceae.

41) *Microdesmis occidentalis*--Susan S. Potbury matched fossil leaves from this species to the extant *Microdesmis casearifolia*, an evergreen tree that typically grows from 49 to 98 feet high It's native to China, Myanmar, Thailand, Cambodia, Laos, Vietnam, Malaysia, Indonesia and the Philippines, where it prefers rainforests and mixed deciduous forests at elevations from 32 to 2,600 feet.

42) *Mimosites acutifolius*--An Eocene species analogous to the present-day *Pithecellobium corymbosum* (a synonym of *Hydrochorea corymbosa*), often called a blackbead, a member of the legume family that is indigenous to Bolivia, Brazil North, Brazil Northeast, Brazil West-Central, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela. In Bolivia, it prefers the rainforest vegetation zone and savannas of southern Beni and Yungus to elevations of 4,900 feet.

43) *Rhamnidium chaneyi*--Paleobotanist Susan S. Potbury assigned leaves from this Eocene species to the living Saguaraji, *Rhamnidium elaeocarpum*, a deciduous tree that can grow 26 to 62 feet high in its native lands of Argentina, Paraguay, Brazil, Bolivia, Peru, and Ecuador. Prefers a tropical rainforest habitat or a savanna at altitudes between 492 and 3,940 feet.

Within the paleobotanically significant upper Eocene La Porte Tuff, those 43 species of fossil plants probably accumulated in reworked volcanic material re-deposited in a sluggish stream. This conclusion is based partly on the observation that the tuff frequently displays consistent evidence of well-defined bedding, and while some of the locally abundant leaves embedded in the rhyodacite tuff lie at random angles (ostensibly suggesting rapid entombment), a majority of specimens do not; they reside along distinct, cleavable bedding planes, signifying a more gradual mode of sedimentary accumulation, where eroding volcanic detritus eventually became re-deposited (re-purposed, as it were) in the river channel that had incised the older middle Eocene shales and auriferous gravels that lie with disconformable relations below the La Porte Tuff. In other words, for example, the upper Eocene La Porte Tuff does not represent a lahar deposit.

Part of the entire "La Porte problem," in a broader scientific context, is that nobody can actually correlate the upper Eocene La Porte Tuff with any known late Eocene to lower Oligocene volcanic tuff or ignimbrite deposit presently exposed in either neighboring Nevada or the Sierra Nevada; videlicet, it just doesn't fit mineralogically with any other known volcanic event. Some geologists speculate that it could be related to documented late Eocene extrusives in the Cascade physiographic region. At any rate, the geologic evidence suggests that the La Porte Tuff accumulated in a stream, mainly as re-deposited water-laid rhyodacitic ash reworked from volcanic exposures--now long eroded away--that postdate incision of the 45 million year-old middle Eocene shales that lie below the La Porte Tuff. Probably an initial pyroclastic impulse choked the ancient stream channel, instantaneously entombing many leaf specimens at varying angles within the volcanic fallout; eventually, though, the brief explosive activity ceased, after which rather rapid erosion processes continued to supply the channel with profuse quantities of poorly consolidated ash piled high in the immediate vicinity of the watercourse. The re-deposited volcanic detritus now settled out in the stream bed, along with minor muddy constituents, ultimately capturing within several feet of regularly bedded layers innumerable leaves and other botanic structures, now preserved in exquisite detail.

In addition to late Eocene leaves in the blocks of La Porte Tuff along the foot of the cliff, the brownish shales which comprise most of the cliff face itself are also fossiliferous. Nicely preserved plant impressions of semi-tropical vegetation are locally common, as are chunks of carbonized wood--not petrified, or permineralized, but rather more like a substance well on its way to becoming coal. The plant-bearing shales represent a middle Eocene age, approximately 45 million years old, correlated stratigraphically with the paleobotanically remarkable Chalk Bluffs Flora (contains 70 species of plants) found at numerous abandoned hydraulic gold mines distributed throughout California's northern Mother Lode Country. The shales conformably overlie the middle Eocene auriferous gravels and were no doubt laid down in stagnant bodies of water and oxbow lakes which came into existence along the extensive floodplains of rivers that only a few millions of years earlier had deposited vast fortunes in gold.

Not only is the fossiliferous La Porte Tuff and shale sequence worthy of exploration, but the underlying auriferous gravel is obviously a very interesting subject, too. Of course, the term "auriferous gravel" is not a formally accepted geologic formation name. It has no strict nomenclatural significance because there are other gold-bearing gravels in California's Mother Lode country of different age. But, through long usage and tacit acceptance by local California geologists, the term has come to connote a very specific rock deposit.

The auriferous gravels of the northern Sierra Nevada likely accumulated approximately 48 to 38 million years ago during the Eocene Epoch of the Cenozoic Era. Based on the available geologic evidence, the gravels were deposited along the floodplains of aggrading streams--that is, watercourses which were building up sediments instead of eroding their channels. Most of the gold recovered by hydraulic methods came from the so-called "inner channel" of the auriferous gravel, a relatively narrow zone only several feet deep and tens of feet wide situated at the base of the gravels, near bedrock. Above the inner channel, or "blue ground"--as the miners referred to this unbelievably rich zone--younger gravels accumulated to a thickness of 400 feet. These "bench gravels" were usually impoverished in gold, although there were a few localities of record where it was abundant. As the bench gravels slowly accumulated in the valleys, giant floodplains developed and the rivers began to create great anastomosing patterns. The surrounding countryside was covered with a lush semi-tropical vegetation similar to that of present-day southern Mexico, Central America, and parts of South America.

One of the more enduring mysteries confronting geologists who have studied the auriferous gravel is why would rivers, after having eroded their channels for millions of years, suddenly begin to aggrade, or build up sediments? Among several possible explanations proposed by not a few investigators, a model developed by the late geologist Cordell Durrell provided the first eminently reasonable working hypothesis. Durrell suggested that a change of climate from one of regular wet and dry seasons to one of irregular wet and wetter seasons could have triggered catastrophic flooding, much like that which occurs today in the vicinity of Rio De Janeiro, Brazil, a region with vegetation and a climate similar to that inferred for the Sierra Nevada some 45 million years ago.

Such floods are very local, of course, but Durrell pointed out that no single flood need cover a large area to account for the accumulation of auriferous gravel. All that was needed was to have a sufficient number of floods cover every part of the region where auriferous gravels now occur--in other words, the 10 northern counties of the Sierra Nevada or an area of roughly 12,000 square miles. At first, this night seem to represent a prohibitively extensive area for floods to affect.

But consider Durrell's calculations. Deposition of the auriferous gravel probably lasted for as long as 10 million years. or most of the middle Eocene. Therefore, there was ample time for periodic flooding to account for the gold-bearing gravels. Durrell suggested that if only one catastrophic flood occurred every 50 years, there could have been as many as 200,000 floods. If the rain gods were more generous and the figure was more like one flood every 20 years, then the total climbs to a possible 500,000 floods.

Now, Durrell introduces us to some basic arithmetic. Suppose each flood deposited an average of only two feet of sediment affecting an area of 10 square miles (an extremely conservative estimate, to be certain). That would mean that it would require 250,000 floods to bury the 10 northern counties of the Sierra Nevada to a depth of 400 feet, the actual measured thickness of the auriferous gravel we see today in northern California.

A second intriguing idea, championed by the late paleobotanist Howard Schorn (former collections manager of fossil plants at the University California Museum of Paleontology) and others, proposes that roughly 48 to 45 million years ago a major eastward marine transgression into the proto-Great Central Valley area backed up westward-draining watercourses in the ancestral western Sierra Nevada, creating hydrological conditions conducive to an aggrading depositional environment that introduced gold enrichment to the sedimentary system.

Yet a third explanation--advocated by a number of geologists---postulates that several highly resistant Paleozoic and Mesozoic metamorphic ridges (so-called "greenstone and greenschist barriers") acted as impedimentary obstacles to most westward draining Eocene rivers, creating natural geographic constriction points behind which waters began to "dam," initiating a vast system of braided streams that eventually began to aggrade.

Of course, as fascinating as the geological mechanics of aggrading rivers is, an inevitable question comes to mind: Just how much gold remains within the auriferous gravel? Nobody's really certain, but there is justifiable cause for pessimism. Very little of the gold-rich inner channel was left unexploited during the reign of hydraulic mining. Also, those portions of that fabulous bonanza deposit not amenable to profitable hydraulicking were cleverly gleaned of gold by traditional tunneling methods (where for instance the inner channel was buried too deeply). The inevitable conclusion is that prospective prospectors are likely to be disappointed when they find that the inner channel has been all but exhausted of its supply of gold. And while extensive exposures of overlying bench gravels remain undisturbed, left in place when the last hydraulickers walked away from their diggings in the mid 1880s, uniformly inferior gold content in strata above the once unimaginably rich inner channel certainly precludes a profitable mining enterprise--even if one could theoretically secure the necessary environmental permits.

Still, some questions remain concerning the gold contained in the auriferous gravel. For one, where did it come from? A general consensus is that most of the aurum that accumulated in the inner channel came from gold-bearing quartz veins in metamorphic rocks that outcropped within the regional hydrologic cachment of the ancestral northern Sierra Nevada. The gold was likely released from the veins by an extended period of weathering which preceded deposition of the auriferous gravel. Although locally significant amounts of gold occurred in the overlying bench gravel, the overall concentrations were far inferior to those of the inner channel. Yet, the fact that it did contain quantities of gold is important to note, because up to twenty percent of the bench gravel definitely came from sources well east of the Eocene Sierra Nevada area. This suggests that at least some of the auriferous gravel gold was delivered by watercourses whose headwaters existed in what's now present-day Nevada.

And that leads to the rather fascinating paleogeographical observation that some 45 million years ago, during deposition of the auriferous gravels, Nevada was roughly half as wide as it is today--in other words instead of 322 miles, only about 161 across. Then too, at that moment in middle Eocene geologic time, the regional geographic divide, presently situated in the Sierra Nevada at Echo Summit (west of which watercourses run toward the Pacific Ocean), likely resided in the vicinity of Austin, central Nevada.

Why Nevada experienced a geophysical inflation is due to extensional processes associated with creation of the Basin And Range physiographic province. Approximately 20 million years ago, potent Earth forces associated with upwelling magmas and crustal thinning began to stretch and pry apart the Miocene Nevadaplano--a ramp-like plateau of gradually increasing elevation that reached eastward from the ancestral Sierra Nevada--forcing nascent Nevada to expand to twice its previous width while, simultaneously, causing numerous parallel north-south trending block faulted mountain ranges (horsts), bounded by valleys (grabens), to develop perpendicular to the direction of crustal thinning precipitated by a subduction zone that had passed beneath the pre-Basin And Range territory. By 6.8 million years ago, Basin And Range elevations had dropped to approximate those observed today.

Today, La Porte is a scenic little vacation/resort community in the northern Sierra Nevada. But during the Gold Rush days of the mid 1800s it was a rollicking hydraulicking town whose citizens extracted millions of dollars worth in gold from the auriferous gravels. At a locality in the vicinity of La Porte, the hydraulickers also uncovered another kind of treasure--fossil plants, which tell of a time when the present-day gymnospermous conifer-rich Sierra Nevada scene resembled a subtropical forest in Mexico, Central America, South America, southern China, and the Philippines; a time when a violent volcanic eruption devastated the land, when skyward-flung searing ash fell back to Earth to accumulate in a stream that had incised a channel into underlying 45 million year-old plant-bearing shales.

Not long after, additional rhyodacitic ash gradually began to erode into the watercourse, where constant currents substantially reworked the volcanic constituents to form a re-deposited water-laid tuff, the La Porte Tuff, whose original slushy layers, lithified over several million years by geologic forces of heat and pressure, preserved in extraordinary detail the kinds of plant life which once thrived here some 34.2 million years ago--great quantities of leaves and associated botanic structures shed from shrubs, trees, and vines that bordered the late Eocene stream.

Yet, had it not been for hydraulic mining during the gold rush days of the 1800s, the fossils might have had to wait millions of additional years for the powers of natural erosion to expose them to the light of day. Now, at the rim of a crumbling water-blasted cliff, lies a bed of hardened ashy sludge, within which occurs direct evidence of a great subtropical forest that contrasts dramatically with today's dominant conifer association of Ponderosa pine and Incense cedar and

Douglas-fir--a late Eocene scene of Chinese Broadleaf Lady palm, ferns, Mexican cycads, Chinese flowering yew, liquidamber/sweetgum, Moonseed, Sarsparilla vine, satinleaf, cinnamon trees, fig trees, laurel trees, cafeillo, dogwood, Snowball, grape jasmine, Velvet-leaf, Yerba mate hollies, Asian stone oak, purple wreath, Cayenne Rosewood, Mexican redbay, Mexican white oak, Mexican elm, Candlenut, blackbead trees and Saguaraji, among others.

Fossil plants and gold--both are products of a distant geologic age, and both treasures lie side by side at La Porte in Plumas County, northern Sierra Nevada.

Chapter 33

Fossil Plants, Insects, and Frogs in the Vicinity of Virginia City, Nevada

When visiting Virginia City, western Nevada--the "Queen of the Comstock"--take a special look around you at the glorious Basin and Range scenery. It seems to sweep forever to the east, beyond the horizon, in the heart of a great pinyon pine-juniper woodland. The dominant shrub here is Basin sage, with such regular subordinate associates as rabbitbrush, desert peach, bitterbrush, and hairy horsebrush.

Now try to imagine what this land would have looked like some 12 to 13 million years ago: The pinyon pine-juniper-sagebrush botanic component is gone, no mountains, only hilly topography. In place of thirsty dry washes, many crystalline lakes and sluggish streams lie scattered eastward in the distance. To the immediate west, the central to southern sector of the ancestral Sierra Nevada is but a relatively low ridge approximately 3,000 feet high and gives no apparent indication that its summits will continue to rise, on average, many thousands of feet with the passing of geologic time (the northern Sierra Nevada has of course stood at roughly its present-day height since around 50 to 40 million years ago). All around you, enveloping you, is a dense mixed conifer forest of Douglas-fir, western white pine, ponderosa pine, white fir, and magnificent giant sequoia. The overall scene, in fact, is strikingly similar to the modern-day moist western slopes of the Sierra Nevada in the vicinity of Calaveras Big Trees State Park, some 23 miles northeast of Angels Camp, California--an area that supports an inspiring giant sequoia forest community.

If such a vastly different character of the land seems downright shocking---patently unbelievable in the main--the verifiable proof its existence in the geologic past can be examined only a moderate distance from the exciting Old West atmosphere of Virginia City in western Nevada, where the internationally renowned Comstock Lode yielded incalculable fortunes in silver and gold, mainly from 1859 to the 1880s (when miners discovered at least six individual, major bonanza bodies), with sporadic rich mineralization encountered underground through the 1920s. Within a reasonable driving distance of the famed silver mining camp lies a regional badlands district where paleontologically productive exposures of sedimentary rock yield the remains of numerous species of fossil plants, insects, and even frogs--all dating from the late middle Miocene, some 12.7 million years old.

This Virginia City-vicinity fossil site is an especially rich one. In addition to the remains of insects, occasional frog skeletons, and prolific microscopic diatoms, some 30 additional species of macrofossil plants have also been identified from the Virginia City/Comstock Lode area, including giant sequoia and such dicotyledonous deciduous varieties as willow, birch, alder and cottonwood, for example. Most of the fossil beds occur in an often economically lucrative sedimentary material called diatomite, a rock type composed almost entirely of diatoms, a microscopic photosynthesizing single-celled algae that periodically proliferated in ancestral west to central Nevada during middle to late Miocene times, contributing myriads of their intricately designed frustules to the accumulating geologic record. Indeed, in the early 1900s, a commercial mining operation extracted high grade diatomite from the vicinity of the fossil locality near Virginia City, and shipped the processed product to New York for use in the manufacture of a silver polish; and that leads to the rather curious consideration that perhaps numerous

individuals, in possession of silver ornaments and utensils created from Comtock Lode mineral extraction, might have polished their valuable metallic objects with a product originally mined near Virginia City, as well.

In addition to its value as an abrasive in polishes, diatomite also finds use in several other commercial applications, including: filters (in swimming pools, for exzample; also helps clarify beer and wine); insulation material; as a whitener in paints; toothpaste; as an absorbent for pet litter and industrial spills; a silica additive to cement and numerous other compounds; and a well-known natural insecticide (AKA, Diatomaceous Earth).

Geologist Vincent P. Gianella discovered the Virginia City-vicinity fossil flora in 1935 during his detailed investigation of the Comstock Lode in the neighboring Silver City region (a small community situated approximately four miles south of Virginia City). For a preliminary estimate of its geologic age, Gianella turned his collection over to then noted paleobotanist Ralph Chaney, who determined that the ancient botanic specimens were most likely of early Pliocene age--a rather raw initial relative geologic age evaluation that eventually proved inaccurate, but it was a close paleobotanical call due to a few exotic old-world deciduous plant species in the Comstock Lode-area flora. More recent, definitive, radiometric age-dating techniques (radioactive isotope analyses) on volcanic constituents within the local stratigraphic section constrain the flora to around 12.7 million years old--or late middle Miocene in geologic age.

For a more detailed analysis of the fossil flora, Chaney gave the specimens to a colleague, Mary S. Leitch, who concluded rather incisively that in order to accomplish the task much more fossil material needed to be collected; unable to undertake the necessary collecting expedition, Chaney and Leitch eventually directed 29 year-old paleobotanist Daniel I. Axelrod to head out into the field. In 1939, Axelrod spent several days gathering additional fossil plants at the Comstock Lode/Virginia City locality.

Axelrod's larger fossil sampling so altered the overall paleobotanical aspect of the collection originally studied that a whole new approach to its scientific interpretation was now in order. When Dr. Leitch informed Dr. Chaney that she could not complete the project due to a conflict in professional priorities, Axelrod happily took over the study, and over the next numerous years, interspersed among other scientific research projects, cumulatively amassed decades in assiduous elucubrations before eventually publishing a superior paleobotanical monograph on the Virginia City-vicinity fossil plant locality.

In preparation for his technical paleobotanical treatise, Axelrod employed especially efficient excavating expertise in the field to secure some 3,639 fossil plant specimens from the Comstock Lode/Virginia City flora. He then determined through methodical statistical analyses that the most common plants encountered were leaves belonging to (1) *Populus eotremuloides*, the Miocene analog of the living Black cottonwood (*Populus trichocarpa*)--followed by, in decreasing order of relative abundance: (2) *Betula thor* (leaves)--Paper birch, *Betula papyrifera*; (3) *Salix knowltoni* (leaves), Lemmon's willow--*Salix lemmonii*; (4) *Populus washoensis* (leaves), Bigtooth aspen--*Populus grandidentata*; (5) *Chamaecyparis linguaefolia* (leafy twigs and cones)--Lawson cypress, *Chamaecyparis lawsoniana*; (6) *Amelanchier alvordensis* (leaves)--western serviceberry, *Amelanchier alnifolia*; (7) *Sequoiadendron chaneyi* (leafy twigs)--Giant sequoia, *Sequoiadendron giganteum*; (8) *Pinus wheeleri* (fascicles and seeds)--Western white pine *Pinus monticola*; (9)

Abies concoloroides **(cone scales, *(*needles, seeds and leafy twigs)--white fir, *Abies concolor*; (10) *Populus pliotremuloides* (leaves)--quaking aspen, *Populus tremuloides*; (11) *Salix owyheeana* (leaves)--coastal willow, *Salix hookeriana*; (12) *Ceanothus chaneyi* (leaves)--Deer brush, *Ceanothus integerrimus*; (13) *Ceanothus leitchii* (leaves)--Tobacco brush, *Ceanothus velutinus*; (14) *Rhododendron gianellana* (leaves)--Western azalea, *Rhododendron occidentale*; (15) *Ribes stanfordianum* (leaves)--Flowering currant, *Ribes sanguineum*; (16) *Pseudotsuga sonomensis* (leafy twigs, needles and seeds)--Douglas fir, *Pseudotsuga menziesii*; (17) *Pinus florissanti* (cones and needles)--Ponderosa pine, *Pinus ponderosa*; (18) *Alnus smithiana* (cones)--Mountain alder, *Alnus tenufolia*; (19) C*astanopsis sonomensis* (leaves)--Golden chinquapin, *Castanopsis chrysophylla*; (20) *Salix laevigatoides* (leaves)--Red willow, *Salix laevigata*; (21) *Carya bendirei* (leaves)--Shagbark hickory, *Carya ovata*; (22) *Quercus simulata* (leaves)--Chinese evergreen oak, *Quercus myrsinaefolia*; (23) *Mahonia reticulata* (leaves)--Cascades oregon grape, *Mahonia nervosa*; (24) *Holodiscus idahoensis* (leaves)--oceanspray, *Holodiscus microphyllus*; (25) *Prunus moragensis* (leaves)--Bitter cherry, *Prunus emarginata*; (26) *Rhamnus precalifornica* (leaves)--California coffeeberry, *Rhamnus californica*; (27) *Arbutus matthesii* (leaves)--Pacific madrone, *Arbutus menziesii*; (28) *Cupressus* sp. (leafy twigs)--a second species of cypress; (29) *Tusga mertensiana* (seeds)--mountain hemlock; and (30) *Pinus balfouroides* (cones)--Foxtail pine, *Pinus balfouriana*.**

The fossil plant, insect, and amphibian (AKA, frog) material is found exclusively in the sedimentary strata of a geologic rock deposit called the Coal Valley Formation, dated at late middle Miocene on the geologic time scale, approximately 12.7 million years old. Axelrod, for example, collected all of his paleobotanic specimens from Member 3 of the Coal Valley Formation, some 330 feet of pure white to creamy white well bedded diatomite, often laminated, with occasional layers of yellow to brown andestic tuffs and breccias roughly six inches to four feet thick.

Once at the specific site within a reasonable driving distance of Virginia City and the fabulous Comstock Lode, hike into the hills, looking especially for the brilliant white stratified rocks--the diatomites (composed of diatoms, a microscopic photosynthesizing single-celled algae) and associated fine-grained siliceous shales which regionally underlie the diatom-rich deposits.

Axelrod's original primary fossil plant locality occurs in a prominent exposure of diatomite roughly 15 feet thick and about 30 feet long--obviously not an overly extensive area of fossiliferous sediments, yet infrequent to moderately common remains of deciduous and evergreen leaves occur here, in addition to gymnospermous conifer seeds, leafy twigs, needles, fascicles, cones, and cone scales. Use a geology pick/rock hammer to whack out--read: carefully remove--the potential leaf-yielding rocks. Should no evidence of a fossil appear on the exposed surface, gently rap the diatomites along their bedding planes with the blunt end of that same standard geology hammer. This procedure will provide a greater opportunity to locate something extraordinary; and please note, by way of a recommendation based on personal experience--disabuse oneself entirely of utilizing one of those wide blade roofer-type hammers, typically advocated by any number of paleobonists for all plant-bearing sedimentary rocks. Maybe such a roofer's "weapon" works well with classically soft fissile shales, but the implement lacks punch, heft, the necessary compact mass to efficiently cleave diatomites with a single sure strike, a method that improves exponentially the probability of discovering excellent paleontobotanical specimens.

Sometimes the fossil leaves remain difficult to spot due to the sun's glare on the bleached bone-white diatomite, so try getting into the shade of a nearby juniper or pinyon pine for a more comfortable examination of the specimens. The 12.7 million year-old leaf impressions typically appear in shades of reddish orange to pale brown. And while deciduous and evergreen leaves might at first blush appear most conspicuously represented, watch carefully for conifer seeds, needles, fascicles, leafy twigs, cones and cone scales--other botanic specimens commonly observed here.

Approximately two-tenths of a mile northeast of the main fossil locality first investigated by Daniel I. Axelrod lies an abandoned open pit diatomite mine. Excellent representative samples of high grade, quality diatomite can be collected here. The most common diatom specimens from the Virginia City-vicinity locality consist of *Actincyclus cedrus* and *Melosira granulata*; under powers of moderate magnification (through the implementation of microscopy), the diatom species fascinatingly resemble miniature discs and boxcars linked together in short chains, respectively. Paleoecologically speaking, a prevalence of *Actinocyclus cedrus* and *Melosira granulata* diatoms from the late middle Miocene Coal Valley Formation here signifies that the lacustrine hydrologic system within which they propagated probably displayed the following characteristics: moderate eutrophy; a relatively shallow depth; warm monomictic, with regularly cyclic circulatory mixing during winter; slight alkalinity, with a pH level that would have registered close to 8.0; a high silica content; and winter temperatures that never dropped below 39.2 degrees Fahrenheit.

Geochemical conditions required to stimulate a proliferation of diatoms necessary to produce economically valuable deposits of diatomite include: significant concentrations of silica, usually supplied by volcanic activity; a pH that generally ranges from 6 to 8; high potassium and magnesium content, in relative relatonship to low ratios of sodium and calcium; loads of the element boron; and high proportions of phosphate and nitrate, generally provided by upwelling waters in the lacustrine system.

While at the diatomite mine, examine the strata exposed there for additional fossil leaves, needles, seeds and twigs--plus, rare excellently preserved frog skeletons. Although not as plentiful here, the macro-paleobotanical remains are sometimes present within several layers of the less-pure, lower-grade diatomites, the sediments with an off-white to brownish tone. The specific species of fossil frog found in the late middle Miocene Coal Valley Formation is called *Rana johnsoni*, an amphibian that shows morphological relationships to two modern frogs. One is *Rana pipiens*, the Northern leopard frog, now native to parts of Canada southward through Kentucky and westward to New Mexico (southernmost occurrence is in Panama, Central America, though this is possibly an undescribed species); it prefers grasslands, lakeshores, and marshes. The other resemblance is to the California Red-legged frog *Rana draytoni* (historically endemic to California's western Sierra Nevada foothills and coastal areas, southward to the northern Baja peninsula, though for all intents and purposes it's been extirpated from Los Angeles south to the Baja border); in optimal natural habitat, the California Red-legged frog likes ponds, streams, marshes, and springs, preferably with deep pools that contain abundant overhanging willows and a fringe of cattails.

Of course, it is well to remember that one must not collect vertebrate fossils on public lands without first securing a special use permit from the BLM (Bureau of Land Management), a permit

issued solely to individuals with a minimum B.S. degree from an accredited university who either represent an officially recognized museum, or seek to undertake scientific research projects that can be fully verified as authentic by the petitioned authorities.

Another fossil type represented in the local late middle Miocene Coal Valley Formation near Virginia City, Nevada, is the arthropod--specifically, insects. They occur in detrital, non-diatomaceous strata slightly older than the fossil plants, but they're still in the neighborhood of approximately 12.7 million years old. The matrix upon which they're preserved is quite reminiscent of the classic paper shale deposits at world-famous Fossil Valley, Great Basin Desert, Nevada (now a federally protected region, completely off limits to unauthorized collectors). Here, though, the brownish to tan shale beds that exhibit cleavable planes of deposition no thicker than a proverbial sheet of paper are nowhere near as extensively exposed as those featured at Fossil Valley, and the insect preservations, while sometimes superbly striking, remain far less commonly encountered, as well. Unfortunate, that--most obviously--but due to the wholly natural vagaries of variable fossil abundance in the geologic record, that's exactly what one expects to experience in the field from time to time. Paleoentomologic specimens thus far identified from the Comstock Lode/Virginia City fossil district disclose dominantly diminutive dipteran varieties--that is to say, a paleo-fauna comprised of flies, gnats and midges, mainly, with a few hymenoptera also present. Examples of paleobotanical preservations also occur in the insect-bearing shales--on occasion, for example, one comes across excellently carbonized remains of winged conifer seeds and needles.

Based on the geological and paleobotanical evidence, the present-day Comestock Lode/Virginia City-area paleontologic locality indeed appeared dramatically different some 12.7 million years ago. For example, the diatomites within which the fossil leaves occur were laid down in a small lake basin at an altitude probably no higher than 2,500 feet (though regional summits would have ranged higher, of course), near the western terminus of the so-called Miocene-age Nevadaplano that gradually increased in elevation eastward toward the Rocky Mountains. By about 17 million years ago, extensional tectonic forces had already begun to pry apart portions of the nascent Great Basin, creating an emergent landscape that adumbrated modern Nevada geography; based on geophysical studies in Nevada's Pine Nut Range, westernmost ancestral Nevada (including the Virginia City area), still part of the once vast Nevadaplano, began to develop Great Basin-style geography through extensional strains at roughly 6.8 million years ago. Bordering the lake was a dominantly deciduous woodland consisting of Black cottonwood, Paper birch, Bigtooth aspen, and three kinds of willows (Lemmon's willow, Red willow, and coastal willow). A mixed conifer/Big tree forest reached the shoreline along well-drained gravelly stream banks that penetrated the riparian association. In addition to Lawson cypress and giant sequoia, the primary forest species present, there were also numerous examples of Douglas-fir, western western white pine, ponderosa pine, white fir, mountain hemlock, Foxtail pine, a second species of cypress, Golden chinquapin, Shagbark hickory, Pacific madrone, and Chinese evergreen oak. Included in the forest community were such understory shrubs as bitter cherry, serviceberry, Deer brush, Flowering currant, Western azalea, Cascades oregon grape, oceanspray, and Mountain alder. Modern-day botanic associations that most closely resemble the plant types preserved in the late middle Miocene Coal Valley Formation near Virginia City can be explored in such California areas as: Calaveras Big Trees State Park; Giant Forest in Sequoia National Park; General Grant Grove, Kings Canyon National Park; Sequoia Lake in Fresno County; and the south fork of the Sacramento River, southwest of Mount Shasta.

Not only did the landscape support a greater variety of vegetation than the present-day Great Basin terrain, but the climate of those ancient late middle Miocene times was also corresondingly more temperate. Today, rainfall in the region is about 15 inches yearly; yet, the known requirements of living members of the fossil flora show that at least 20 inches more rain fell approximately 12 to 13 million years ago, or roughly 35 inches annually. The Miocene rains were distributed as both winter and summer showers--in other words, pretty much year-round--whereas today's Mediterranean-style meteorological patterns, in areas of California's western Sierra Nevada foothills that support giant sequoias and other plants either identical or at least very similar to those observed in the fossil flora, produce effective rain and snow only from winter through spring; summers there typically provide but a paucity of precipitation, creating a somewhat less mesic environment than what existed in the vicinity of Virginia City during late middle Miocene times. That difference in seasonal rainfall eliminated from modern Sierran sequoia habitats all botanic species in the fossil flora that require regular, substantial summer showers: paper birch; Chinese evergreen oak; Lawson Cypress; a second species of cypress (*Cupressus* sp.); mountain hemlock; and Shagbark hickory. At the fossil site today, virtually every ounce of effective precipitation arrives as snow during the winter. Probably the Miocene frost-free season was as long as seven months--while today it's closer to four. In general, it appears that late middle Miocene winters were much warmer and summertimes cooler than those observed during recent times.

Today, Virginia City lies on the western edge of the arid Great Basin. As a physiographic province, this mountainous land dominates all of Nevada, in addition to portions of eastern California, southeastern Oregon, southern Idaho, and western Utah. It is a region characterized by three archetypical botanic types--sagebrush, juniper, and pinyon pine. Yet, the Comstock Lode-vicinity fossil plants prove that 12.7 million years ago a diverse deciduous and evergreen dicotyledon community mingled with a rich mixed conifer forest amid a moist environment quite similar to a giant sequoia/Big tree grove in present-day California.

At that distant Miocene time, the southern to central Sierra Nevada district was but a relatively minor ridge, perhaps 3,000 feet high, and nourishing rainstorms from the Pacific had free run across ancestral west-central Nevada. Vegetation was lush, the climate temperate--a rain-saturated humid scene reminiscent of today's western foothills of the Sierra Nevada and a tributary of the Sacramento River near Mount Shasta.

Eventually, about three million years ago, the central to southern Sierra began to rise in earnest, reaching skyward, thrust upwards thousands of feet by potent tectonic forces, until the now exposed western slopes captured most of the eastward-driven precipitation. In ancient Nevada, the once extensive forests of Big trees died back, shrinking, finding their final refuge in isolated, environmentally favorable localities in the western Sierran foothills. Aridity reigned. The numerous lakes and streams dried up, vanished, leaving behind within secret sedimentary layers their wonderful evidence of a prehistoric age, the fossil plants, insects and frogs waiting in the rocks, waiting for us to learn of what once existed in this part of western Nevada so many millions of years ago.

Chapter 34

Field Trip To The Alexander Hills Fossil District, Mojave Desert, California

One of the more important geological areas on California's vast Mojave Desert can be explored near the southern end of Death Valley National Park in the Alexander Hills, roughly 20 miles southeast of Shoshone. Here Precambrian rocks have yielded incontrovertible evidence of early cellular life that constructed a shell, mineralized skeletal elements secreted by animate soft-bodied eukaryotic organisms over three-quarters of a billion years ago in a shallow marine environment then situated near the equator. Even though the extraordinary specimens are obviously minute, microscopic, recovered by invertebrate paleontologists from chert layers in a thick accumulation of dolomites, magnesium carbonate, their significance is regionally inestimable: some of the oldest examples of increasingly complex life on the Mojave Desert.

In addition to fossil cells admittedly inaccessible to many amateur paleontology enthusiasts--isolating the miraculously preserved specimens requires special technical laboratory expertise in the practiced use of several potent acids, combined with access to mechanized equipment capable of slicing extremely hard samples of quartz chert into thin sections amenable for examination under a microscope--the Alexander Hills also offers visitors a different fossil type that is easily observed in the primordial Precambrian rock exposures: the fascinating stromatolites, distinctively laminated calcium carbonate structures created by photosynthesizing cyanobacterial blue-green algae approximately 1.2 billion years ago. These are quite probably the oldest fossil remains recognized from the meteorologically tortured Mojave Desert district--surprisingly well preserved specimens that occur in a readily accessible limestone reef.

Of course, productive Precambrian paleontology is not the only adventure attraction available in the Alexander Hills. The district also offers many mineralogical delights: among them, high grade talc specimens from numerous workings left behind at the currently idle Western Talc Mine, one of the more prolific producer of talc in San Bernardino County, California, and certainly one of the most significant mining districts in all the Mojave Desert.

But that's not all. There's more. Only a few miles from the Alexander Hills is fabulous Sperry Wash, where gem-quality agate and excellently preserved petrified wood can be observed. Although the well-known wood deposit has been heavily visited since its discovery in the late 1950s, exceptional material can still be discovered there.

Also, along the route to the Alexander Hills, you will have an opportunity to observe along both sides of the road the drab brown sediments and occasional ledges of whitish volcanic tuffs that accumulated in ancient Lake Tecopa. The Tecopa rocks have been dated through geological determinations at two hundred thousand to three million years old, or upper Pliocene to midd1e Pleistocene on the geologic time scale. Roughly 225 feet of mudstones, conglomerates, volcanic ash, and shoreline tufas were deposited in Lake Tecopa, only one of many large bodies of fresh water that came into existence during interglacial periods of the Pleistocene Epoch.

Tuff/tephra beds in the Lake Tecopa sediments have provided a stratigraphically fortuitous opportunity to trace the ancient air-fall pattern of distant volcanic eruptions. Two prominent layers of tuff, for example, were actually derived from volcanic ash ejected from the Yellowstone

caldera in present-day northwestern Wyoming; the ash beds have been dated by radiometric techniques at 2.02 million and 620 thousands years old, respectively. A third tuff interval came from the well-known Long Valley caldera in the Owens Valley region of California, several hundred miles north of Tecopa--hot ash blown out of the ground 720 thousand years ago that eventually came back to Earth to settle out in a placid Pleistocene lake. More tephra intervals drifted into Lake Tecopa from the Glass Mountain eruptions near present-day Mono Lake, California, 2.1 to 2.08 million years ago. At its high stand around 200,000 to 150,000 years ago, Lake Tecopa suddenly breached its "dam" and violently carved 16 miles of present-day Amargosa Canyon before spilling into Pleistocene Lake Manly in Death Valley.

In addition to documenting radiometrically dated volcanic tuff beds, earth scientists have also recovered a significant vertebrate and invertebrate fossil fauna from the ancient Lake Tecopa Basin. The late Pliocene-Pleistocene animals include mammoths, a mastodon, large and small horses, a llama, camels, a large antelope, abundant microtine rodents (the voles, lemmings, and muskrats), and a flamingo. Also identified have been ostracods (a diminutive bivalved crustacean), gastropods, 42 species of diatoms (microscopic photosynthesizing single celled algae), and chara (a green algae), all of which confirm a lacustrine environment.

Amateur collectors beware, though. Under current regulations, it is illegal to collect any vertebrate fossil without a special use permit, a document issued solely to individuals with a minimum B.S. degree from an accredited university (or museum representatives with appropriate credentials) who seek to undertake formal scientific research projects that can be fully verified as authentic by the petitioned authorities. Qualified folks wishing to apply for such a permit must contact the State Director of the Bureau of Land Management in Sacramento, California. An excellent reference to consult concerning the geology of the Tecopa area is United States Geological Survey Miscellaneous Investigations Map I-728 by John W. Hillhouse, *Late Tertiary and Quaternary Geology of the Tecopa Basin, Southeastern California*.

The Alexander Hills geologic district hosts a world renoumed geologic sequence of mostly conformable Late Precambrian through Early Cambrian strata--that is to say, geologists have identified up to 14,800 feet of very well exposed sedimentary, metamorphic, and igneous material approximately 1.3 billion to 520 million years old, in which relatively few recognizable breaks in geologic time interrupt the exceedingly ancient geochronogogical stratigraphic succession.

Rock formations present in the Alexander Hills include some of the most iconic geologic units in all the US southwest. Oldest is the Precambrian/Mezoproterozoic Crystal Spring Formation some 1.3 to 1.08 billion years old (side bar: Precambrian supercontinent Rodinia began to assemble 1.26 billion to 900 million years ago). Although many geologists assign the upper member of the Crystal Spring Formation to a distinct, separate geologic rock unit called the Horse Thief Spring Formation (approximately760 to 802 million year old), an excellent technical paper issued in 2019 convincingly demonstrated that the Horse Thief Spring interval is older than 1.08 billion years old, and so by inference it must surely remain a continuation of the Crystal Spring Formation. Not only that, but the author of a 2015 Ph.D. dissertation on Precambrian units in the Death Valley region could not corroborate the findings of the person who had erected the new Horse Thief Spring Formation in the first place, only a year earlier in 2014. The 2015 researcher found no detrital zircon grains from the Horse Thief Spring Formation that matched the geologic

age of those that the year 2014 person had apparently recovered to help prove his case; that 2014 rsearcher had supposedly foumd zirons dated at 780 million years, which would support a great disconformity in the Crystal Spring Formation. Yet, after examining 540 zircon grains from five different geologic sections (zircons amenable to age-dating are mighty difficult to locate and isolate, in the first place), the 2015 investigator determined that all his zircons from the Horse Thief Spring samples were over one billion years old, thus falsifying the 2014 person's claim of a younger age. Funny thing is, though: That 2015 individual continued to accept the Horse Thief Spring Formation as valid throughout his dissertation.

Next up is the overlying Beck Spring Dolomite, around 787 to 732 million years old. The dominantly magnesium carbonate sequence contains stromatolites and numerous kinds of eukaryotic cells, including vase-shaped microfossils produced by a testate shell-secreting amoeba; a chert layer near the base of the Beck Spring Dolomite yielded one of the oldest shells in the fossil record, a skeletal element from one of those testate amoeba dated at roughly 780 million years old--called scientifically, *Cycliocyrillium*. For geochronological perspective, the oldest known evidence of a shell-bearing organism comes from the 809 million year old Fifteenmile Group in Yukon, Canada. Note of course that there is a significant unconformity between deposition of the Crystal Spring Formation and the Beck Spring Dolomite. And something else was happening at about this time. From 750 to 633 million years ago, the Precambrian supercontinent Rodinia broke apart, when several great interlocked landmasses that would later form North America, South America, Antarctica, Australia, Siberia, China, and India began to drift away.

Lying directly above the Beck Spring Dolomite is the Kingston Peak Formation--roughly 732 to 700 million years old. Originally deposited in marine waters near the equator, it's a regionally remarkable rock unit that bears at least three distinct horizons comprised of diamictites and tills, distinctively diagnostic accumulations that indicate deposition by glacial activity--direct evidence of a so-called Snowball Earth, when ice sheets extended all the way to low tropical latitudes. The Kingston Peak also yields stromatolites and microscopic eukaryotic cells, some of which have been identified as testate amoebae of vase-shaped morphological configuration.

Stratigraphically speaking, the Crystal Spring Formation, Beck Spring Dolomite and Kingston Peak Formation are conveniently lumped together in the widespread Pahrump Group. Directly above the Pahrump sedimentary assemblage is the Noonday Dolomite (about 680 to 630 million years old--famously yields quite sizable stromatolitc structures); note once again that there is an unconformity between the Kingston Peak Formation and the Noonday Dolomite, afterwhich deposition of the overlying Johnnie Formation (630 to 580 million years old) coincides with the assembly of another Precambrian supercontinent called Pannotia 633 to 573 million years ago; Pannotia was rather short-lived geologically speaking, though, as it began to break up approximately 560 million years ago.

The youngest Alexander Hills stratigraphic units are the Stirling Quartzite, some 580 to 544 million years old, which bears an important Ediacaran age fauna within its youngest phases of deposition, and the late Neoproterozoic to lower Cambrian Wood Canyon Formation, 544 to 520 million years old; a Neoproterozoic horizon in the lower Wood Canyon strata also yields Ediacaran fossils, while early Cambrian sections produce the first trilobite remains in the local stratigraphic section.

Although the early Cambrian strata that outcrop here are admittedly not as fossiliferous as those of correlative stratigraphic age at classic Waucoba Spring, Inyo County, California (as of 1994, assimilated into Death Valley National Park, so that unauthorized fossil collecting there is now strictly verboten), the Alexander Hills reference section still provides exceptional opportunies for geologists, geophysists, stratigraphers, and invertebrate paleontologists to study the important Precambrian-Cambrian transition boundary. Of the several geologic rock units exposed in the Alexander Hills, only the Wood Canyon Formation contains remains of animals with hard parts recognizable with the unaided eye, principally trilobite fragments, occasional archaeocyathids (extinct calcareous sponge), and poorly preserved but paleontologically invaluable disarticulated echinodern plates, specimens that could very well be the oldest echinoderm evidence yet identified. Ichnofossils identified from the Alexander Hills paleontological district include excellently preserved tracks and trails of annelids and arthropods (some of which probably represent trilobitic activity on the ancient sea floor over a half billion years ago).

Not far from the primary locality in the Alexander Hills, you will observe excellent outcrops of the Neoproterozoic Beck Spring Dolomite, a massively bedded magnesium carbonate that accumulated in an intertidal region of a vast, shallow sea some 787 to 732 million years ago. From a casual distance the Beck Spring hillside perhaps appears to project just another monotonous rock deposit in the middle of the desert; but within those drab gray to bluish dolomites occur some of the oldest known eucaryotic cells in the southwestern US--in other words, cells with a well organized encapsulated nucleus, a feature which distinguishes them from primitive prokaryotic bacteria and the archaea. Animals, plants, fungi, algae, and protists, for example, all possess eukaryotic cells.

The Beck Spring fossil cells were discovered under the microscope in thin sections of chert interbedded in the dominantly dolomitic section; they are of course not the oldest eukaryotes ever discovered. Such unambiguous eukaryotic cells go back about 1.8 billion years in the geologic record (controversial evidence of their presence begins at about 2.1 million years), but when first reported in a scientific paper in 1969 they were considered for a short spell at least to represent the oldest eukaryotes ever found. In North America, earliest eukaryotic existence occurs in the roughly 1.4 billion year old Mesoproterozoic Greyson Formation of northern Montana and southern British Columbia, Canada. The Beck Spring fossil association is dominated by filamentous cyanophycean algae (the blue-green algae), with at least five genera that resemble modern chlorophytes (green algae) and chrysophtes (golden-brown algae). Their presence here constitutes a truly miraculous preservational occurrence, since soft-bodied organisms have been identified from but a minimal number of localities around the globe; ergo, the discovery of such fragile microscopic cells roughly three-quarter of a billion years old certainly rates as a phenomenal event.

The Beck Spring Dolomite also figures prominently in a most intriguing idea, indeed. Namely, that land life already existed on Earth over a billion years ago. Not too long ago, geotechnical explorations in the Death Valley National Park region produced tantalizing evidence to help support the hypothesis that abundant photosynthetic microbial communities had already colonized terrestrial habitats some 1.2 to 750 million years ago. Too, supplemental geochemical and paleontological documentation from different terrestrial deposits approximately 2.2 billion years old (not present in the Death Valley area) suggests that land-living photosynthesizing

organisms could have contributed substantially to the great oxygenation event that began approximately 2.3 billion years ago.

Of course, just to provide that proverbial "truth in advertising" qualifier, while many investigators with reluctant resignation now appreciate that significant microbial terrestrial life existed in the Neoproterozoic, not a few earth scientists continue to express a natural skeptical dubiety, unwilling to agree that land-life older than around 600 million years is incontrovertible fact.

But, that dramatically distant terrestrial microbial existence is difficult to disprove with definitive convincingness, because leading proponent Paul Knauth, geochemist-geologist with Arizona State University, not only believes he has the significant carbon isotope signatures from such primordial Precambrian deposits to help support the idea, but also loads of fossil, microscopic photosynthetic organisms secured from thin-sectioned rocks of proved karstic, terrestrial origin, roughly 1.2 billion to 750 million years ancient, including important collections from the world-famous 750 million-year old Beck Spring Dolomite (Death Valley National Park region), a magnesium carbonate accumultion that of course overlies the cyanobacterial stromatolitic developments present in calcium carbonate exposures of the 1.2 billion year-old Crystal Spring Formation.

But that's not the conclusion of the story. Not at all. Not only does Paul Knauth adduce abundant evidence to support pre-600 million-year old microbial land colonization, he also firmly advocates the potentially provocative postulation that animal life on Earth originated not in the sea, but within terrestrial environs; subjectively compelling evidence supports the existence of land-living multi-cellular animals devouring peacefully co-existing 750 million year-old photosynthetic microbial communities, just minding their own business, pumping important quantities of oxygen into Earth's ancient atmosphere.

After stopping for a look-see at the Neoproterozoic Beck Spring Dolomite in the Alexander Hills, continue onward toward the main fossil site, which in addition to stromatolite beds in the Mesoproterozoic Crystal Spring Formation also contains deposits of high grade commercial talc exposed by the Western Talc mining operations. The Precambrian fossil material occurs in that impressive reef-like ridge/peak before you, a prominent paleontological protuberance some 5,000 feet long that preserves locally comman stromatolites through some 300 feet of pure calcium carbonate, limestone, in the 1.2 billion year old Crystal Spring Formation.

Just up ahead from where you will park is a huge "hole in the ground" adjacent to an intrusive diabase sill dated at 1.08 billion years old, dramatic evidence of extensive open pit mining operations that obviously removed tons of talc over a period of numerous years. It is but one of many large-scale excavations found throughout the Alexander Hills, all part of the much famous Western Talc Mine, an aggregation of 11 separate claims that have operated off and on since the early 1900s. All the mines are silently idle at present, although most remain under patent subject to potentially productive redevelopment when commercial exploitation of mineral commodites becomes more reliably profitable.

The earliest workings in the Alexander Hills were made in 1912 by the Independent Sewer Pipe Company, an outfit that went out of business in 1914. In the following eight years, several different companies tried their hand at the rich talc bodies, including successively: the Tropico Tile and Terra Cotta Company; the Pacific Talc and Terra Cotta Company; the Pacific Minerals and Chemical Company; and the Tropico Potteries Company. All of these ventures belonged to a single organization headed by one A, Lindsay, who also owned the active claims and directed the first major operation, originally known as the Acme or Lindsay mine.

Lindsay's mining speculation failed in 1923, but a former business associate named Martin decided to lease the property and continue exploration. Martin organized the Master Minerals Corporation, which eventually became the Martin Minerals Company, and in 1923 the newly formed Western Talc and Magnesite Company struck glory-hole magnitude talc in the Snow Goose claims in a previously undeveloped portion of the deposit.

By the mid 1920s talc production was well under way in the Alexander Hills. In 1928, Fred Savell, president of the Western Talc and Magnesite Company, bought out the Martin Minerals Cermpany and consolidated all the active claims of both businesses under one name--the Western TaIc Mine, which continued to produce talc through 1959; up to that time 310,000 tons had been taken from the Alexander Hills.

An excellent reference work on the talc bodies of southeastern California, in general, is California Division of Mines and Geology Special Report number 95, 1968, by Lauren A. Wright, *TaIc Deposits of the Southern Death Valley-Kingston Range Region, California*. Professor Wright discusses all of the major talc mines in this part of the Mojave Desert, presenting the geology and history of exploration of each deposit in readily readable fashion. It is indeed a classic of mineralogical literature.

The fossil-bearing exposures of the Crystal Spring Formation occur along the moderately steep slopes of the massive limestone "reef" immediately east of the open pit talc mines. Here can be found rather common and surprisingly well preserved stromatolites (considering the considerable geologic stress they've experienced since their burial 1.2 billion years old), distinctively laminated calcium carbonate structures formed through successive layering by photosynthetic cyanobacterial blue-green algae. And while they are certainly not the oldest stromatolites identified in the fossil record--a suggestive indication of stromatolitic presence approximately 3.5 billion years ago does indeed exist in western Australia--the Alexander Hills examples nevertheless promote sober contemplation and inspirational awe--direct evidence of life some 1.2 billion years old, more than a full quarter the age of the Earth itself (which formed 4.5 billion years ago), microscopic life that first helped oxygenate our atmosphere, providing the crucial elemental gas that allowed us to exist. Today, similar kinds of stromatolites grow in Sharks Bay off the coast of Australia, where low tides expose distinctive dome-like bodies whose internal structure is identical to the fossil varieties.

The stomatolites in the Crystal Spring Formation do not represent the actual mineralized remnants of the once living gelatinous cyanobacteria, but rather they resulted from sediment trapped by the algae approximately 1.2 billion years ago. As each fragile layer of algae regularly disappeared beneath a veneer of calcareous sediment, a new algal surface would eventually develop atop the older one just buried, until successive concentrlc laminations developed over perhaps hundreds of years; in modern stomatolite growth cycles, when covered by sediment, the cyanobacteria instinctively migrate to the surface to find sunlight and continue their

photosynthetic ways. After the Crystal Spring sediments became lithified during the course of geologic time, the unusual layering created by successive cyanobacterial colonies became preserved in the rocks. Today, roughly one billion two-hundred-million years later, stromatolies preserved in the Precambrian Crystal Spring Formation probably remain quite similar to what they would have looked like in actual life all those eons ago.

Important side bar: Biologically speaking, stromatolites do not develop from algal activity. They are not algae, though colloquial convention perpetuates the technically incorrect use of the word "algae" to describe them; still and all, calling them algae is certainly not a taxonomical "criminal offense." It's just what most folks most often call them. And so it's all good.

The fossil stromatolites are not hard to spot at this Alexander Hills reef locality. They appear as circular to oval concentrically laminated structures a few inches to a foot in diameter. Erosion has frequently exposed them in bold, eye-catching relief against the pale gray limestones, and numerous chunks of quality cyanobacteria-bearing materal lie scattered about, fractured off the bedrock. When found in situ, a few of the stromatolitic algae heads reveal an elliptical profile, a feature which suggests that they grew in ocean waters strongly influenced by currents. Most of the stromatolite species, though, indicate a rather placid shallow intertidal or subtidal paleoenvironment. Two prevalent stromatolite varieties in the Crystal Spring Formation have been identified by paleontologists as *Baicalia* and *Conophyton*, genera previously identified in Precambrian rocks 1.35 billion to 900 million years old in other parts of the world.

In a historical perspective, establishing a precise geologic age for the Alexander Hills stromatolites has certainly presented a serious challenge. First off, it is happily well and good that over the years every Crystal Spring investigator could at least agree, could so stipulate as it were, that the cyanobacterial developments occur within a sedimentary section cut by an intrusive diabase sill of igneous origin. But that general consensus inevitably led to an obvious question: Just how old is that diabase sill? For decades, disagreements abounded, until sophisticated radiometric methodology finally established a definitive geologic age of 1.08 billion yeas for the diabase sill; that meant of course that the Crystal Spring Formation stromatolies must be older than 1.08 billion years, since the cyanobacterial creations were obviously already in place when the diabase sill intruded the sedimentary section within which they occur. Then too, because basement crystalline rocks that underlie the Crystal Spring Formation in the southern Death Valley area can be correlated with similar regional lithologies that yield radiometric dates of 1.7 to 1.4 billion years, the ultimate upshot is that after additionally factoring in the relative stratigraphic position of the stromatolites within the Crystal Spring Formation, well above the basement complex, most earth scientists now agree that the geologic age of the Crystal Spring Formation stromatolites is 1.2 billion years old.

One of the influential Alexander Hills stromatolite investigators was David G. Howell, formerly of the University of California at Santa Barbara. Howell took a series of thin sections of stromatolites from the Crystal Spring Formation and produced amazing three dimensional reconstructions of what the original cyanobacterial homes must have looked like. In 1971, he reported his findings in the important paper, *A Stromatolite from the Proterozoic Pahrump Group, Eastern California*, Journal of Paleontology, volume 45, number one, pages 48 to 51.

Another excellent reference paper concerning stromatolites is *Columnar Stromatolites and Late Precambrian Stratigraphy* by M.E. Raaben, American Journal of science, volume 267, January 1969. For several years, Raaben was associated with the Geological Institute, Academy of Sciences in Moscow. His report details a wide assortment of stromatolites present in Precambrian rocks in the defunct Soviet Union, specimens Raaben had hoped would help establish a systematized intercontinental stratigraphic model to correlate stromatolite-bearing strata around the world.

One of the better technical reports available regarding stromatolites in the Crystal Spring Formation is *Stratigraphy and Depositional Environment of the Crystal Spring Formation, southern Death valley Region, California* by Michael T. Roberts, an article contained in California Division of Mines and Geology special Report 106, 1976, *Geologic Features, Death Valley, California*. An accurate detailed geologic map of the area is Map Sheet number 77, *Geology of the Alexander Hills Area, Inyo and San Bernardino Counties, California*, by Lauren A. Wright, found in the California Division of Mines and Geology Bulletin 170, *Geology of Death Valley, California*.

After examining one billion two hundred million year old stromatolites, it's time for a trip to nearby Sperry Wash, one of the most famous petrified palm wood localities on the Mojave Desert. It's a region that also yields many well preserved tracks of extinct camels and horses, plus the relatively rare (in the geologic record) remains of silicified grasses. Along the way, you will pass large-scale mining operations that produce obvious concentrations of commercial grade talc, and it is indeed tempting to wander off the main route to explore the impressiuve abandoned pits left behind when the mining \venture fell flat. But heed the No Trespassing signs where applicable. Much of this area remains under claim, sitting idle, anticipating further exploitation of mineral commodities.

By general agreement among gem seekers, Sperry Wash is a fascinating area to explore. The wash slices through sandstones, mudstones, and conglomerates of the late middle Miocene China Ranch Formation, dated at 10.3 to 8.4 million years old. Petrified palm and dicotlyedon wood (birch and poplar have been identified), grasses replaced by silicon dioxide (assigned to *Tomlinsonia stichkania*m, whose closest modern analogs belong to the bahiagrasses, genus *Paspalum*, which utilize the C4 carbon fixation photosynthetic process--only three percent of modern terrestrial plants use the C4 pathway), horse and camel tracks (from an extinct species called *Lamaichnum macropodum*--at last check, the excellent museum in Shoshone has on display several tracks from China Ranch camels and horses), and attractive agates occur within silicified fine-grained sediments that happily preserve in fine detail the majority of Miocene permineralized plants present here.

According to Mary Frances Strong in the November 1975 issue of *Desert Magazine* (long out of business--July 1985 was their last month of publication), Aileen Mckinney discovered the Sperry Wash wood bonanza in 1956; Strong wrote the first article to describe the site for the January 1958 edition of *Gems and Minerals Magazine*, a publication that went belly-up not a few years ago. Since that time Sperry Wash has taken on an almost mythical reputation among rockhounds; many collectors rate the variety of petrified palm wood found at other localities on a standard set by the high quality they've encountered in Sperry Wash. Other folks are content to wax nostalgic for the wonderful wood formerly collected there. While it's true that the once

unbelievable quantity of wood and gem-grade agate is a matter of fond recollection in the minds of many who were there in the "early days," rest assured that excellent material remains to be discovered. It just takes a little longer to find the better quality petrified wood now that the years of frequent visitation have caught up with Sperry Wash.

Traditionally speaking, the Alexander Hills are most comfortably visited in early to mid spring and mid to late fall; sometimes early winter can be fun, too, although sudden ferocious winds with concomitant plunging wind chill factors often ruin an otherwise perfect outing, especially if you are "braving the elements" in a tent or simply sleeping outdoors under the stars.

One of my favorite trips, though, actually came in the midst of winter, when I spent a full week camped at the base of the Precambrian stromatolite-bearing reef. I was all alone with the desert--not one other individual appeared along the Western Talc Road during that memorable seven day period. I spent most of my time hiking about, exploring the great limestone reef and the numerous talc mines that penetrate the Alexander Hills. Once, I recall, I finally managed to climb to the very top of that massive mound of ancient algae, and I sat there with chunks of weather-sculpted stromatolitic rock all around me. From this position, I vividly remember watching a lone bird soar on a thermal far above me as a warm rush of wind whipped eroded limestone grains against the stromatolite exposure.

I wondered if a similar breeze had brushed the waters of a shallow sea over a billion years ago where I now rested, nudging gentle waves over gelatinous algal bodies anchored in the deep distance of vanished time when our sun shone some eight percent dimmer than at present, thinking too that if those humble microscopic life forms had not pumped out oxygen with unceasing cyanobacterial photosynthetic productivity, silently venting through the eons an elemental waste gas initially inimical to the cellular metabolism of Earth's early emergent complex animacules--until, finally, persistent natural adaptation fatally allowed more advanced organisms to utilize oxygen, to multiply and abound and ultimately conquer--stromatolites might have remained the dominate form of life on Earth.

Chapter 35

Plant Fossils In The Neighborhood Of Reno, Nevada

Not a few years ago, while driving through the pastoral oak woodlands of California's Gold Rush country en route to a couple of sensational fossil plant-bearing districts not far from The Biggest Little City In The world--Reno, Nevada--I knew that I needed to start the expedition off right by first visiting the very place where it had all begun, where I had initially learned of the superior localities I wanted to spend a few days examining from the undeniable doyen of Nevada paleobotany himself, the late paleobotanist Howard Schorn (passed in 2013), former collections manager of fossil plants at the University California Museum of Paleontology, he who had been among the first scientists to sytematically collect leaves, seeds, needles, fascicles, and cones from the places I intended to explore: the middle Miocene Pyramid and Chloropagus Formations of western Nevada, which produce 41 and 68 species of fossil plants, respectively.

Once I'd finally found my way back to a long abandoned but once fantastically productive leaf-bearing quarry, having bushwhacked through thick tangled stands of manzanita and tight copses of overgrown scrub oak, I began to recollect back several years earlier to an early August field trip with Howard to this very spot in the western foothills of California's Sierra Nevada, Ione Basin, in the vicinity of Ione, Amador County, to help recover leaf impressions from an especially rich locality I had informally named Lygodium Gulch--an appropriate reference to the rather common remains of an extinct species of climbing fern found there--*Lydodium kaulfusi*, specifically, which is also known from locally spectacular occurrences in the early to middle Eocene Green River and middle Eocene Bridger Formations of Wyoming, Utah and Colorado, plentiful Polypodiopsida specimens whose closest modern-day counterpart is *Lygodium palmatum*, endemic to southern New England southward through the Appalachians into the southern states. It was a site I had discovered around 1994 during exploratory reconnaissance in the paleobotanically and geologically remarkable middle Eocene Ione Formation, approximately 48 million years old, an early Cenozoic sedimentary sequence consisting primarily of fluviatile, estuarine, deltaic, marine, and marsh deposits that not only contain locally prodigious quantities of often well preserved semi-tropical vegetation, mainly bountiful leaves (numerous palm fronds found, as well) stained an aesthetically pleasing reddish brown on a brilliant white shale matrix partially composed of detrital feldspathic constituents, but also world-class horizons of high value ceramic clays, pure silica sands, and lignites that bear--in a global perspective--extraordinarily rare commercial-grade quantities of montan wax, used in such diverse applications as fruit coating to phonograph records; along with the Ione Formation example, Amsdorf Germany is the only other place on Earth that mines commercial quality montan wax-yielding coal.

Howard and I were there as an advance guard, as it were, to collect fossil specimens intended for a National Science Foundation project, secured by Howard, paleobotanist Jack A. Wolfe, and several other scientists to help determine the paleoelevation and paleoenvinment of the ancestral Eocene Sierra Nevada area. Along with supplemental leaf material collected from the middle Eocene auriferous gravels higher up the western slopes of the Sierra Nevada (fluviatile and lacustrine accumulations usually considered a proximal

paleohydrologic manifestation of the same watercourses that supplied detritus to the distal Ione Formation), exposed at several abandoned hydraulic gold mines that date from roughly 1855 to 1889, Dr. Wolfe wanted to run the Ione Formation fossils through his vaunted CLAMP system--that is to say, the Climate Leaf Analysis Multivariate Program, an accurate methodology that analyzes 31 different physiognomic parameters of fossil leaves (among them, lobing, margin characteristics, size, apex, and base) to help determine the past elevation and environment of a given fossil plant locality.

In order to efficiently secure at Lygodium Gulch the necessary quantity of paleobotanical material within our lone week of allotted field activity (Wolfe required at least 20 different leaf morphologies to analyze with confident precision a given paleo-flora), Howard eventually made a decisive command decision--one firmly settled upon, I might add, after we'd spent an arduously exhausting first full day whacking repeatedly into the unyielding ground in search of fossil leaves; we'd uncovered several excellent specimens amenable to Dr. Wolf's CLAMP analysis, but the going was brutally tedious, working as we were with repetitive backbreaking technique, pick and shovel brute force paleontology under a sizzling Sierran foothill summer sun that had topped 100 degrees before noon: Howard chose to hire a local backhoe operator to come on out to our fossil locality and entrench the lithified, highly compacted leaf-bearing sedimentary rocks, so that in the pleasant aftermath of the bobcat's excavations all we then had to do was sit around on the spoils piles of that trench and happily crack apart the fluviatile shales and sandstones at our leisure in the early and mid hours of successive mornings, eventually amassing numerous boxes brimmed with finely detailed middle Eocene leaves that Howard took back to the archival paleobotany collections at the University California Museum of Paleontology.

Today, of course, the roughly 48 million year old semi-tropical leaves of Lygodium Gulch lie within what botanists call the Ione Chaparral, a unique association of plants that inhabits Ione Basin, western Amador and extreme northern Calaveras Counties, western foothills of California's Sierra Nevada. It's a botanical province found nowhere else on Earth, restricted solely to oxisoils that erode from the harshly acidic and highly mineralized middle Eocene Ione Formation.

Typical botanic components of an Ione Chaparral include the following specimens: Ione manzanita--*Arctostaphylos myrtifolia,* the most characteristic member of the Ione Chaparral, a rare and endangered low shrub, wholly captivating with its striking diminutive dark green leaves and minute bell-like flowers (they typically bloom from December through February), which grows nowhere else in the wild except in scattered disjunct populations atop the acidic, toxically mineralized oxisoils of the middle Eocene Ione Formation within a narrow 19.5 mile north-south trending geographic corridor of California's Ione Basin; white leaf manzanita--*Arctostaphylos viscida*; common manzanita--*Arctostaphylos manzanita*; Hellers's manzanita (a natural hybrid between Ione manzanita and white leaf manzanita)--*Arctostaphylos helleri*; Ione buckwheat--*Eriogonum apricum* (a rare and federally protected botanic specimen that grows nowhere in the wild, except in California's Ione Basin); Irish Hill buckwheat--*Eriogonum apricum* var. *prostratum* (another rare and endangered buckwheat found only in the wild at Ione Basin, California); coyote brush--*Baccharis pilularis*; chamise--*Adenostoma fasiculatum*; yerba santa (sacred herb--here's one to ruminate on, to put in your proverbial pipe and smoke: the native Chumash

Indians of California used yerba santa in steam baths to treat hemorrhoids, and its flavinoid sterubin might eventually help alleviate Alzheimer's symtomatology)--*Eriodycton californicum*; interior live oak--*Quercus wislizenii*; California scrub oak--*Quercus berberidifolia*; and California foothill pine (an older, now seldom-used designation is the Digger pine)--*Pinus sabiniana*, in addition to various native grasses, and the cryptogam mosses and lichens--*Cladonia cervicornis* ssp. *verticillata*, primarily, a lichen restricted to mineral-rich subsurface areas where Ione manzanita dominates (the lichen is not present in adjacent regions where abundance organic litter accumulates).

Why Ione manzanita is confined to such a restricted geographic district in California remains a mystery. Even though the Ione Formation can be traced for some 200 miles throughout the western foothills of the Sierra Nevada, from roughly Oroville south to Friant, east of Fresno, the Ione manzanita grows atop Ione exposures only along that narrow 19.5 mile swath of the Ione Basin; perhaps maritime breezes that rush through the Carquinez Strait, San Francisco Bay region, situated 90 miles southwest of the Ione Basin (as the crow flies), help moderate summer temperatures enough to maintain viable stands of Ione manzanita within such a geographically restricted habitat.

A companion idea centers around those abundant lichens present in Ione Formation soils. As advanced by a researcher in 1995, a working hypothesis postulates that after periodic episodes of fire--a necessary requirement for Ione manzanita seeds to germinate--the lichen thallus releases substantial quantities of aluminum, an element the lichens efficiently assimilate from the highly mineralized middle Eocene Ione Formation; that critical increase in aluminum concentration inhibits most other chaparral plants from establishing early footholds in the Ione Basin, because seedlings of Ione manzanita preferentially tolerate such usually toxic levels of aluminum while other young chaparral plants do not. To bolster his idea, the specialist adduced evidence that as mature specimens, Ione manzanita and the common white leaf manzanita both flourish atop low pH (acidic) Ione Formation oxisoils with equally high concentrations of aluminum in their plant cells, demonstrating to his own satisfaction at least that based on levels of aluminum uptake alone, no special edaphic differentiation exists between the two manzanita species; he then concluded that any natural adaptive advantage conferred upon Ione manzanita probably stems from an ability to better survive the seedling stage in an extraordinarily challenging environment exponentially enriched in toxic aluminum released by lichens after fires.

Along with studying the Ione manzanita and associated Ione chaparral, collecting paleobotanical remains in the middle Eocene Ione Formation certainly gave me an increased appreciation of changing environments over the course of deep geologic time. Originally deposited in floodplains near the eastern shores of a vast inland Eocene sea that had once covered most of California's Great Central Valley 48 million year ago, the Lygodium Gulch locality contains abundant semi-tropical vegetation comprised entirely of leaves with smooth margins, lacking serrations or lobes, whose numerous species could undoubtedly thrive today alongside their modern analogs in proximity to southern Florida's mangrove swamps, where annual precipitation regularly approaches 45 inches, including substantial showers delivered during the summer months. Today, the Ione Formation fossils occur in the lower western foothills of the Sierra Nevada, in the neighborhood of Ione, California, within a Mediterranean meteorological regime characterized by hot dry summers lacking

effective rainfall, where showers usually relegated to winter through spring drop about 21 inches of precipitation per year, a dramatic alteration of prevailing weather patterns, rainfall totals, and geography that directly influences the differences in vegetational representation so obvious between that which lived here 48 million years ago and the modern chaparral community dominated by manzanita and chamise and scrub oak and interior live oak, and California foothill pine.

While we split shales that had been dumped around the perimeter of the trench created by our bobcat operator, Howard likely identified rather quickly my insatiable interest in such paleoenvironmental considerations. And so by and by he suggested that I should get out to western Nevada, around Reno, to investigate two additional fantastic paleobotanical localities that provide important information on drastically different environments over the course of millions of years: With meticulous attention to detail, he described the middle Miocene Pyramid and Chloropagus Formations, 15.6 and 14.8 to 13.3 million years old, respectively, where nicely preserved leaves, seeds, needles, fascicles, cones and cone scales prove that today's botanically depauperate Great Basin Desert scene around Reno not only once held lush deciduous hardwood trees similar to types now found in southeastern Tennessee, but also--a couple of million years later--a giant sequoia forest community reminiscent of Calaveras Big Trees State Park, western slopes of California's Sierra Nevada, not far from Gold Rush Country. Seems that Howard had actually accompanied legendary paleobotanist Daniel I. Axelod to the sites, helping to secure some of the earliest scientific collections from the Pyramid and Chloropagus Formations, fabulous fossil material now housed at the University California Museum of Paleontology.

That was how it all started. Howard had graciously provided me with invaluable paleobotanical information on a couple of Nevada Neogene sites--floristically fascinating fossil places that had instantly captured my imagination. And so it came to pass that almost a year after that Ione Basin expedition with Howard, after I'd attended to all that which needed attention in the interim (a lot of mundane particulars happily interspersed with periodic spurts of paleontological inquisitiveness), I finally got around to getting out into the field once again; I loaded up my trusty four wheel drive mechanism with needed supplies and important scientific references pertaining to paleobotany, botany, and geology and lit out for the territory.

First up on my paleobotany itinerary was a visit to the middle Miocene Pyramid Formation in the neighborhood of Reno, Nevada.

Today, the 15.6 million year old middle Miocene Pyramid Formation fossil locality (older of the two sites I explored) lies near Reno at roughly 4,800 feet elevation in an arid to semi-arid ecotone situated between Great Basin Desert and Basin Sage botanic communities, where it receives a sparse five to eight inches of effective precipitation per year, with more than fifty percent of it falling as snow. At the fossil site today, mean temperatures for each month of the year are (in Fahrenheit): January--30 degrees; February--33 degrees; March--40 degrees; April--50 degrees; May--60 degrees; June--70 degrees; July--74 degrees; August--72 degrees; September--63 degrees; October--50 degrees; November--38 degrees; and December--34 degrees. The effective growing season lasts on average some 133 days.

By contrast, based on the known environmental preferences of modern-day counterparts of plants preserved in the fossil flora, elevations during deposition of the middle Miocene Pyramid Formation 15.6 million years ago could not have been any higher than 1,800 to 2,000 feet. To support the vegetational varieties identified from the Pyramid site, the ancestral Reno region necessarily received at minimum 35 inches of annual precipitation, and 35 percent of that total needed to fall during May through August (in order to account for several exotic deciduous hardwoods in the fossil flora). In general, winter months were much milder and summers cooler than conditions experienced at the fossil locality today. Growing season lasted an expected 177 days, a figure calculated from approximated average monthly temperature conditions for middle Miocene Pyramid times (all degrees in Fahrenheit): January--43 degrees; February--47 degrees; March--52 degrees; April--58 degrees; May--64 degrees; June--69 degrees; July--70 degrees; August--70 degrees; September--67 degrees; October--57 degrees; November-- 48 degrees; and December--45 degrees.

In the immediate proximity of the Pyramid Formation paleobotanical bonanza, plant life is typical of a Great Basin Desert-Basin Sage transition zone: Sparse shadscale-type vegetation occupies low-lying areas, while increasing elevations above 5,000 feet support juniper (*Juniperus utahensis*), mountain mahogany (*Cercocarpus ledifolius*), basin sage (*Artemisia tridentata*), rabbit bush (*Chrysothamnus rauseosus*), desert peach (*Prunus andersonii*), plateau gooseberry (*Ribes velutinum*), and bitterbrush (*Purshia tridentata*). Rare moist areas reveal wild rose (*Rosa gymnocarpa*), cottonwood (*Populus fremontii*), several species of willows (*Salix* sp.), chokecherry (*Prunus cemissa*), dogwood (*Ccrnus californica*), and hairy horsebrush (*Tetradymia glabrata*). Higher mountain slopes underlain by geologically altered igneous rocks contain occasional specimens of Jeffrey pine (*Pinus jeffreyi*).

Now go back some 15.6 million years to that same geographic area and you'd observe quite a different botanic scene: A dominantly deciduous hardwood community of maple (*Acer*), alder (*Alnus*), birch (*Betula*), Kentucky yellowood (*Cladastris*), ash (*Fraxinus*), American hophornbean (*Ostrya*), sycamore (*Platanus*), willow (*Salix*), Chinese scholar tree (*Pterocarya),* and poplar (*Populus*) contribute to lush forested lakeshores, floodplains, and riparian places, while bald cypress (*Taxodium*) and a now extinct species of willow oak (*Quercus simulata*) grow in swampy areas. Along drier well-drained volcanic slopes above the basin of deposition, you'd take in a mixed conifer-deciduous association of fir (*Abies*), incense cedar (*Calocedrus*), spruce (*Picea*), pine (*Pinus*), mountain hemlock (*Tsuga*), chokecherry (*Prunus*), mountain ash (*Sorbus*), and wild rose (*Rosa*), with such broadleafed evergreen sclerophylls as madrone (*Arbutus*), mountain mahogany (*Cercocarpus*), giant chiquapin (*Chrysolepis*), and tanbark oak (*Lithocarpus*) also well represented.

The middle Miocene Pyramid Formation fossil plants were discovered in 1951 by entomologist Ira La Rivers of the University Nevada Reno during field investigations not far from Reno; he expeditiously relayed the information to paleobotanist Daniel I. Axelrod, who initially collected a modest supply of specimens there in 1952 with funds from the Carnegie Institute of Washington. In 1957, Geologist George S. McJannet first mapped the fossil-producing area and masterfully pinpointed a type locality for what he named the Pyramid Formation. Later on down the line, in the early 1960s, Axelrod secured a National Science Foundation Grant to continue scientific studies of the fossil flora, and that's the general

time period when paleobotanist Howard Schorn, collections manager of fossil plants at the University California Museum of Paleontology, assisted with the Pyramid plant project, helping Axelrod collect additional leaf, seed, and needle specimens from a single spot in the proximity of Reno, Nevada. In order to more efficiently collect enough fossil specimens from the poorly exposed sedimentary beds to accommodate a scientific analysis, Axelrod and Schorn soon opened up the locality with a caterpillar. In all, they amassed some 1,414 plant remains from McJannet's middle Miocene Pyramid Formation, more than enough fossil material to help Axelrod complete a monographic study of the Pyramid Formation plants.

Axelrod's paleobotanical locality lies in middle member C of McJannet's Pyramid Formation (for ease of stratigraphic evaluation, conveniently divided into three mappable units), a 250 foot-thick section that includes: bone-white leaf-bearing diatomite, a sedimentary rock type composed primarily of diatoms, miscroscopic single-celled photosynthesizing kinds of algae that constructed intricately designed frustules composed of silica; subordinate, organically barren shales and sandstones derived from local volcanic plugs; and unfossiliferous reworked swirls of rhyolitic and dacite sands produced by turbidity currents. Youngest member A, overlying the plant-yielding horizon, is 220 feet of scoriaceous dark-gray to black basalt with minor tuff and breccia, and the oldest unit C consists of yellow-brown basalt, tuff, breccia, with a conglomerate of rhyolite and dacite clasts at the base (770 feet thick).

The middle Miocene Pyramid Formation is but one of several igneous-metamorphic-sedimentary sequences exposed in the general area, and the stratigraphy on display there is quite fascinating. Oldest rocks that outcrop around the fossil locality constitute a roughly 80 million year old late Cretaceous basement complex comprised of: granitic aplite and pegmatite dikes; hornblende biotite quartz diorite; a roof pendant of andalusite-feldspar-biotite schist; quartz plagioclase amphibolite; greenish gray hornblende; and plagioclase cataclasite--all of undetermined thickness.

Above the Mesozoic material lies a significant unconformity in the local geologic record, a mysterious 55 million year old interval of depositional quiescence when prolonged erosive processes ultimately erased all local traces of the succeeding Paleocene and Eocene Epochs; probably at least part of this geologic time frame coincides with fluvial generation of the world-famous fossil plant-bearing middle to upper Eocene auriferous gravels and the stratigraphically equivalent Ione Formation, western foothills of the Sierra Nevada, by rivers that transected the ancient paleodivide, situated in Eocene times between present-day Battle Mountain and Austin, Nevada.

Lying directly atop the unconformity is the Tule Peak Formation, a 25 to 23 million year old upper Oligocene to lower Miocene volcanic accumulation approximately 3,740 feet thick, consisting of, in descending order of geologic age: welded rhyolite; white pumiceos crystal tuff; massive white pumice lapilli; reddish-brown welded vitric crystal rhyolite tuff with local basalt flows; light to dark welded rhyolite tuff that outcrops with a blocky fracture; collapsed pumice lapilli (lenticulite); and roughly 10 to 20 feet of arkose and breccia at the base.

Next youngest local geologic rock unit is the 23 million year old lower Miocene Sutcliff Formation, another exclusively igneous unit some 1,140 feet thick that includes, from top to

bottom (youngest to oldest): hard, massive to platy welded rhyolite breccias with associated lenticulites (collapsed pumice lapilli); lavender to gray welded biotite rhyolite tuff, usually massive; and resistant well-indurated rhyolite tuffs that outcrop in distinctive massive fashion.

Protruding above the Sutcliff Formation in unconformable geologic relations are several geomorphological features earth scientist call stocks, or volcanic plugs composed of massive reddish-brown quartz dacite that solidified from magmas inside volcanoes around 20 to 21 million years ago; they now form picturesque peakes and slopes, against which the 15.6 million year old leaf-bearing diatomites of the middle Miocene Pyramid Formation lap unconformably, signifying that several million years of erosion occurred between the last active volcano and lacustrine deposition of the overlying Pyramid Formation diatomite.

Another unconformity separates the 15.6 million year old Pyramid Formation from the overlying 1,920 foot thick middle Miocene Chloropagus Formation, roughly 13.3 to 14.8 million years old. Although not exposed in the immediate vicinity of the Pyramid Formation leaf locality, elsewhere near Reno the unit indeed provide paleobotany adventurers with leaves, seeds, needles, fascicles, cones, and cone scales from some 68 species of plants. Typical Chloropagus outcrops possess a dominant igneous component, chiefly green, black, dark-brown and reddish vesicular basalt and andestie flows, interbedded with occasional volcanic tuff breccias and agglomerates; intercalcating sedimentary constituents include water-laid tuff, tuffaceous sandstone, and locally fossiliferous siliceous fissile shales roughly three and a quarter to six and a half feet thick.

Next youngest member of the local straigraphic column, positioned unconformably above the middle Miocene Chloropagus Formation, is a mainly igneous middle Miocene section approximately 420 feet thick, dated by ratiometric methods at 12.7 million years old. Its three unnamed mappable subunits, members, include from youngest to oldest: flow-banded dacite vitrophyre with columnar jointed, collapsed pumice altered to perlite; buff coarse-grained poorly indurated dacite tuff, tuffaceous sandstones, and conglomerate; and dark-gray to black latite associated with tuff breccia and black collapsed pumice.

Resting unconformably atop the Tertiary Period exposures is a 515 foot thick aggregate of Quaternary Pleistocene-age sedimentary-volcanic material approximately 100,000 years old, probably representing at least four different Ice Age depositional events: (1)--an upper (youngest) sequence consists of playa silts, sands, and gravels that grade into lake clays; (2)--a distinctive unit of relatively well exposed clay, sand and gravel that correlates stratigraphically with distant sedimentary evidences of ancient Lake Lahontan--one of the largest bodies of fresh water ever to exist in Pleistocene age inorthwestern Nevada; (3)--a dark green to black olivine basalt flow; and (4)--a basal (oldest) unit of poorly sorted, weakly consolidated sands.

The Pyramid Formation fossils accumulated through current transport in a relatively small basin bordered by extinct volcanic plugs and active volcanism. Along with macroscopic vegetation, microscopic diatom species accumulated in a shallow cool clear lake saturated for prolonged periods with dissolved silica, stimulating repeated prodigious algal

reproduction cycles that eventually deposited a diatomite bed about 200 feet thick.

88 percent of the 1,414 Pyramid specimens belong to deciduous hardwoods. Geographic distribution analyses demonstrate that eleven of the 41 fossil plants are allied with kinds that now grow in the eastern US; 24 Pyramid species presently reside in the western US; and five others show close affinity with endemics in China, Mexico, and East Asia. In a generalized correlative trend, the Pyramid remains also reveal a greater relationship with Miocene fossil floras from the Columbia Plateau district of Oregon, Washington, and Idaho than they do with identical-age Miocene Nevadan paleobotanical sites.

Modern areas that support vegetation similar to associations that grew in western Nevada during deposition of the middle Miocene Pyramid Formation include the Yuba River drainage, western foothills of California's Sierra Nevada, in the transitional ecotone situated between a mixed conifer forest and a broadleaf sclerophyll community (chaparral), where several varieties closely allied to fossil types found in the 15.6 million year old middle Miocene Pyramid Formation now grow, among them--Ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), incense cedar (*Calocedrus masonii*), Pacific madrone (*Arbutus menziesii*), chinquapin (*Chyrsolepis*), tanbark oak (*Lithocarpus*), Western sycamore (*Platanus racemosa*), box elder (*Acer negundo*), bigleaf maple (*Acer macrophyllum*), Oregon ash (*Fraxinus oregona*) dusky willow (*Salix melanopsis*), sandbar willow (*Salix exigua*), and wild rose (*Rosa*); and around Metcalf Bottoms, southeast of Townsend, Tennessee, a floodplain region that hosts a mesic deciduous hardwood forest of plant species similar to kinds recovered from the middle Miocene Pyramid Formation, including species of maple (*Acer*), buckeye (*Aesculus*), alder (*Alnus*), birch (*Betula*), Kentucky yellowtree (*Cladastris*), ash (*Fraxinus*), American hophornbean (*Ostrya*), and chokecherry (*Prunus*).

Most common 21 fossil species found in the middle Miocene Pyramid Formation include, in decreasing order of relative abundance: (1) leaves and acorns from a presumably extinct oak called *Quercus simulata* (possibly related to the living willow oak *Quercus phellos*, southeastern United States, or even the silver oak *Quercus hypoleucoides* of southeastern Arizona, southwestern New Mexico, and northern Mexico); (2) leaves of *Betula thor* (fossil counterpart to the living paper birch *Betula papyrifera*); (3) leaves and cones from an alder *Alnus latahensis* (Miocene counterpart of *Alnus maritima*, the seaside alder or brook alder); 4) leaves from a second species of alder *Alnus spokanensis* (the fossil equivalent of the modern speckled alder *Alnus incana* subspecies *rugosa*); samaras and leaves from a maple *Acer chaneyii* (the Miocene variety of today's sugar maple *Acer saccharum*); (5) leaves of a buckeye *Aesculus preglabra* (paleotanical genus-species for the living Ohio buckeye *Aesculus glabra*); (6) seeds, needles, and twigs from a pine *Pinus ponderosoides* (Miocene variety of the living Ponderosa pine--also called western yellow-pine--*Pinus ponderosa*); (7) leaves that belong to *Populus bonhamii* (the Miocene variety of *Populus balsamifera*, the balsam poplar); (8) branchlets from a swamp cypress *Taxodium oregonensis* (the Miocene genus-species of *Taxodium distichum*, the modern bald/swamp cypress); (9) leaves of *Lithocarpus nevadensis* (the fossil equivalent to the extant tanbark-oak *Notholithocarpus densiflorus*); (10) leaves from *Platanus bendirei* (this is what paleobotanists call fossil structures that are identical to today's California sycamore *Platanus racemosa*, also referred to as western sycamore); (11) leaves and samaras of *Acer oreganianum* (paleobotanical genus-species for the living bigleaf maple *Acer macrophyllum*); (12) leaves belonging to

Prunus chaneyii (the fossil equivalent to the extant Western chokecherry _Prunus virginiana_ var. _demissa_); (13) leaves from _Acer glabroides_ (a species analogous to the living red maple _Acer rubrum_); (14) winged seeds and cone scales that come from _Abies laticarpus_ (the Miocene genus-species for the modern _Abies magnifica_ var. _shastaensis_--the living Shasta red fir); (15) leaves of _Salix pelviga_ (this is the paleobotanical genus-species for the extant dusky willow _Salix melanopsis_); (16) leaves derived from_Alnus pyramidensis_ (paleobotanical name given to fossil structures identical to the extant alder _Alnus cremastogyne_); (17) leaves that belong to _Betula vera_ (the Miocene equivalent to the modern yellow birch--also called golden birch or swamp birch--_Betula lutea_; (18) leaves of _Salix churchillensis_ (the Miocene binomial name for fossil remains that show close relationship with today's sandbar willow _Salix exigua_ subspecies _exigua_); (19) leaves that belong to _Arbutus idahoensis_ (according to paleobotanist Daniel I. Axelrod, this is a presumably extinct species of madrone whose closest modern-day affinity is possibly with the Texas madrone _Arbutus xalapensis_); (20) foilage and seeds from _Calocedrus masonii_ (name paleobotanists apply to fossil structures identified as indistinguishable from counterparts produced by the extant _Calocedrus decurrens_, the incense cedar--not a true cedar, of course); (21) leaves from _Cladrastis lariverisii_ (the fossil analog for the living Kentucky yellowwood _Cladastris lutea_. The remaining 20 Pryamid Formation species are rather rarely encountered, having been described in the scientific literature from but three or fewer fossil specimens.

Here is the complete list of the 41 fossil plant species recovered from the middle Miocene Pyramid Formation, 15.6 million years old. Number that follows each description is the total number of specimens of that species recovered from the Pyramid Formation:

1) _Abies laticarpus_ (winged seeds and cone scales)--The Miocene genus-species for the modern _Abies magnifica_ var. _shastaensis_--the living Shasta red fir which ranges from 1,400–2,700 meters (4,600–8,900 ft) elevation in Shasta, Siskiyou and Trinity Counties, northwest California, through southwest Oregon. 9.

2) _Picea sonomensis_ (winged seeds)--Fossil name paleobotanists apply to the extant _Picea breweriana_, the Brewer spruce, one of the rarest trees in North America, which now grows in the wild only in the Klamath Mountains of southwest Oregon and northwest California at elevations from 1,000–2,700 m (3,300–8,900 ft). DNA genetic analyses determined that the Brewer spruce lies at the base of the Picea clade, suggesting that spruces originated in North America. 1.

3) _Pinus ponderosoides_ (twigs, needles, seeds)--Miocene variety of the living Ponderosa pine (also called western yellow-pine), _Pinus ponderosa_ that in modern natural habitat ranges as various subspecies variants southward through British Columbia into 16 western US states at elevations from 100–2,700 m (330–8,860 ft). 32.

4) _Pseudotsuga sonomensis_ (seeds and branchlets)--Paleobotanical Miocene counterpart for the extant Douglas-fir, _Pseudotsuga menziesii_, a member of the Pinus (pine) family (not a true fir, hemlock or spruce), naturalized in British Columbia, Canada, southward through Washington, Oregon, California, and Nevada, USA. Elevations typically range from 550m - 2,900m (1,800 to 9,500 ft), though some river bottom populations live at 800 to 900 feet. 2.

5) *Tsuga mertensioides* (seeds)--The fossil variety of today's *Tsuga mertensiana*, mountain hemlock, which presently ranges from the Kenai Peninsula, Alaska, southward to northern Tulare County, California, usually at elevations from: sea level to 1,000 m (3,300 ft)--Alaska; 1,600 to 2,300 m (5,200 to 7,500 ft)--Cascades in Oregon; and 2,500 to 3,050 m (8,200 to 10,010 ft)--Sierra Nevada, California. 1.

6) *Calocedrus masonii* (foliage and seeds)--Name paleobotanists apply to fossil structures identified as indistinguishable from counterparts produced by the extant *Calocedrus decurrens*, the incense cedar (not a true cedar, of course). Present-day native geographic range: central-southwestern Oregon; most of California; extreme western Nevada; and northern Baja California, Mexico. Invariably grows at elevations from 50–2,900 m (160–9,510 ft). 4.

7) *Taxodium oregonensis* (branchlets)--The Miocene genus-species of *Taxodium distichum*, the modern bald (swamp) cypress, now native to the warm, humid southeastern United States with annual precipitation levels of 760 mm or 30 inches (eastern Texas) to 1,630 mm--64 inches (Gulf Coast). 27.

8) *Populus bonhamii* (leaves)--The Miocene variety of *Populus balsamifera*, the balsam poplar (northernmost hardwood in North America), now native to most of Canada and the following US states: Alaska, northeastern Oregon, central and northwestern Idaho, scattered in five isolated areas in Montana, Wyoming, north to central Colorado, northwestern Nebraska, western and northeastern South Dakota, southeastern and northern North Dakota, northern half of Minnesota, northern Iowa, Wisconsin, Michigan, northeastern Illinois, northwestern Indiana, northeastern Ohio, Pennsylvania, northeastern West Virginia, western Maryland, northeastern Connecticut, New York, Vermont, northern half of New Hampshire, and Maine. 30.

9) *Salix boisienis* (leaves)--Fossil genus-species for the living *Salix scouleriana* (Scouler's willow), now endemic to western to central Canada and the following US states: mainly southeastern Alaska, Washinton, Oregon, California (primarily northwestern and the Sierra Nevada area), western Nevada, Idaho, western Montana, western South Dakota, Wyoming, Colorado, Arizona, and New Mexico. 1.

10) *Salix churchillensis* (leaves)--The Miocene binomial name for fossil remains that show close relationship with today's sandbar willow (coyote willow) *Salix exigua* subspecies *exigua*, which currently ranges southward from southern Canada through eastern Washington, eastern Oregon, eastern California, Idaho, Nevada, southwestern Montana, western Wyoming, Utah, Colorado, Arizona, New Mexico, western Texas, and northern Mexico. 5.

11) *Salix inquirenda* (leaves)--The Miocene equivalent of today's *Salix lasiandra*, the Pacific willow, which attains a wide geographic distribution, ranging from Alaska southward through western to central Canada, Washington, Oregon, California, Idaho, Montana, Wyoming, Colorado, Arizona, and New Mexico. 2.

12) *Salix pelviga* (leaves)--This is the paleobotanical genus-species for the extant dusky

willow *Salix melanopsis*, now native to British Columbia and Alberta southward to California and Colorado, preferring moist habitats along riverbanks and subalpine mountain meadows. 8.

13) *Alnus latahensis* (leaves and cones)--The Miocene counterpart to the living *Alnus maritima*, the seaside alder or brook alder now found naturally in Oklahoma, Georgia, Maryland, and Delaware; it is the only North American member of the genus *Alnus* that blooms during autumn--all other alders bloom in spring. 242.

14) *Alnus pyramidensis* (leaves--named in honor of having been first identified from the middle Miocene Pyramid Formation)--Paleobotanical name given to fossil structures that are identical to the extant alder *Alnus cremastogyne,* now endemic to southwestern China along stream banks and forested mountainsides at elevations from 500 - 3,000 meters (1.640 to 9,842 feet). 6.

15) *Alnus spokanensis* (leaves)--The fossil equivalent of the modern speckled alder *Alnus incana* subspecies *rugosa*, which today ranges in natural habit from Canada southward through northern North Dakota, Minnesota, Wisconsin, Michigan, northeastern Iowa, northern Illinois, northern Indiana, northern Ohio, Pennsylvania, western Maryland, eastern West Virginia, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. 161

16) *Betula ashleyii* (leaves)--Bionmial name that paleobotanists give to the extant water birch (red birch) *Betula fontinalis* (synomymous with *Betula occidentalis*), which in natural geographic habitat ranges southward through southern Canada to form scattered occurrences in Washington, Oregon, California, Idaho, Nevada, Arizona, New Mexico, Colorado, Montana, Wyoming, North Dakota, South Dakota, and western Nebraska. 1.

17) *Betula thor* (leaves)--The fossil counterpart to the living paper birch (also called American white birch) *Betula papyrifera*, now native to almost all of Canada and most of Alaska, southward to parts of the following US states: Washington, Oregon, Idaho, Montana, North Dakota, South Dakota, Nebraska, Colorado (southernmost occurrence), Minnesota, Wisconsin, Michigan, Illinois, Iowa, Indiana, Ohio, New York, West Virginia, North Carolina, Pennsylvania, Connecticut, Massachusetts, and Rhode Island. It also occurs throughout all of Connecticut, Vermont, New Hampshire, and Maine. 286.

18) *Betula vera* (leaves)--The Miocene equivalent to the modern yellow birch (also called golden birch or swamp birch) *Betula lutea* (synonymous with *Betula alleghaniensis*). Prefers cooler environmental condisitions, usually in swamps, stream banks, deep woods, and north facing slopes from southeastern Canada southward into northeastern Minnesota, Wisconsin, northeastern Iowa, northernmost Illinois, northern Indiana, northeastern Ohio, Michigan, Pennsylvania, New York, Vermont, New Hampshire, Maine, Connecticut, Massachusetts, Rhode Island, northern New Jersey, northern Maryland, West Virginia, western half of Virginia, Kentucky, Tennessee, western North Carolina, northwestern South Carolina, and northeastern Georgia. 7.

19) *Ostryea oregoniana* (leaves)---This is the paleobotanical designation for today's *Ostrya*

virginiana, **the American hophornbeam. Has wide geographic distribution:: Occurs in Nova Scottia west to Manitoba and then southward into Minnesota, Iowa, Missouria, Arkansas, Lousiana, eastern Kansas, eastern Oklahoma, eastern Nebraska, eastern North Dakota, eastern Texas, western Wyoming, southeastern and western South Dakota, Wisconsin, Illininoid, Michigan, Indiana, Ohio, Pennsylvania, New York, Vermont, New Hampshire, Maine, Rhode Island, Massachusetts, Connecticut, Maryland, New Jersey, West Virginia, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Florida, Alabama, and Mississippi. 2.**

20) *Pterocarya mixta* (leaves)--The Miocene analog to the living Chinese wingnut *Pterocarya stenoptera,* a species commonly cultivated horticulturally for shade and landscaping; it is endemic to the following Chinese provinces on riverbanks or forested mountains from around sea level to 1500 m. (4,921 feet): Anhui, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Liaoning, Shaanxi, Shandong, Shanxi, Sichuan, Yunnan, and Zhejiang. Disjunct populations also found in Taiwan, Japan, and Korea. 2.

21) *Chrysolepis sonomensis* (leaves)--The paleobotanical name for the living giant chinquapin *Chrysolepis chrysophylla*, endemic to southern Washington southward through western Oregon and west-central California, favoring climax forests dominated by redwood, white fir, western hemlock, and Shasta red fir. 3.

22) *Lithocarpus nevadensis* (leaves)--The fossil equivalent to the extant tanbark-oak *Notholithocarpus densiflorus*, presently native to California and southern Oregon. Despite its common name and the fact that it does produce acorns, it is nevertheless not a true oak. 26.

23) *Quercus simulata* (leaves and acorns)--A presumably extinct species whose fossil leaves and acorns match no known modern oak. Several paleobotanists suggest that it's possibly allied with the living willow oak *Quercus phellos*, native to the southeastern United States, or even the silver oak *Quercus hypoleucoides*, presently found in southeastern Arizona, southwestern New Mexico, and northern Mexico. 378.

24) *Platanus bendirei* (leaves)--This is what paleobotanists call fossil structures that are identical to today's California sycamore *Platanus racemosa* (also referred to as western sycamore), a common riparian specimen that ranges mainly from western and eastern California--northernmost occurrence is in Humbolt County, with scattered patches in the Sierra Nevada--south to northern Baja California Mexico. 25.

25) *Ribes standordianum* (leaves)--A Miocene genus-species whose modern-day counterpart is *Ribes nevadense*, the Sierra currant (or, mountain pink currant), mainly native to riparian and forest habitats in California's mountainous regions (Sierra Nevada, Peninsular Ranges, Transverse Ranges, and Klamath Mountains, for example) at elevations between 3,000–10,000 feet (910–3,050 meters); also distributed in western Nevada and Oregon. 1.

26) *Cercocarpus ovatifolius* (leaves)--This is the fossil analog to the living Catalina mahogany/island mountain mahogany *Cercocarpus betuloides* var. *blancheae*, endemic to

coastal southern California, where it's confined in natural development to scattered occurrences in Los Angeles County, Ventura County, Santa Barbara County, San Luis Obisbo County, and the Channel Islands. 2.

27) *Prunus chaneyii* (leaves)--The fossil equivalent to the extant Western chokecherry *Prunus virginiana* var. *demissa*, presently native to northern, southern and central California, preferring in natural habitat rocky slopes at elevations from 0-8200 feet.

28) *Rosa shornii* (leaves)--Named in honor of paleobotanist Howard Schorn, former collections manager of fossil plants in the University California Museum of Paleontology, Berkeley, California; the Miocene analog to the modern California wild rose *Rosa californica* now native to California (notably, coast and foothills up to elevations of 6,000 feet), Oregon, and northern Baja California Mexico. 3.

29) *Sorbus mcjannetii* (leaves)--The Miocene counterpart of today's whitebeam/mountain ash *Sorbus scopulina*, whose native habitat ranges from central and southern Alaska, southward through western Canada to Washington (scattered occurrences), northern Idaho, western Montana, northwestern Wyoming, northern Utah (with scattered occurrences in central southern areas), western South Dakota, northeastern Nevada, Colorado, New Mexico, northeastern Arizona, and northern California (one isolated occurrence in central California). 3.

30) *Cladrastis lariverisii* (leaves)--The fossil analog for the living Kentucky yellowwood *Cladastris lutea* (synonymous with *Cladrastis kentukea*), which today grows in the wild only in Kentucky, Tennessee, Arkansas, Mississippi, Indiana, western Oklahoma, Alabama, western North Carolina, western Virginia, northern Georgia, and southern Missouri. 4.

31) *Sophoroa spokanensis* (leaves)--Paleobotanical name given to the modern Chinese scholar tree (also called Japanese pagoda tree) *Styphnolobium japonicum* (synonymous with *Sophoroa japonica*), native to China, Korea, and Japan where it prefers open country habitats at elevations from 300 and 1000 meters (984 to 3,280 feet). 1.

32) *Acer chaneyii* (leaves and samaras)--This is what paleobotanists call the Miocene variety of today's sugar maple *Acer saccharum*, a geographically widespread botanic specimen that in natural habitat grows in southeastern Canada, southward to Minnesota, eastern Iowa, Missouri, eastern Kansas, southeastern North Dakota, northeastern South Dakota, Wisconsin, Illinois, Michigan, Indiana, Ohio, Pennsylvania, New York, Vermont, New Hampshire, Maine, Connecticut, Massachusetts, Rhode Island, northern New Jersey, northern Maryland, western Virginia, West Virginia, Kentucky, Tennessee, western North Carolina (with scattered occurrences in the central part of the state), Georgia (two isolated areas in the north), and South Carolina (one isolated area in the northwestern portion of the state). 46.

33) *Acer glabroides* (leaves)--A fossil species analogous to the living red maple *Acer rubrum*, presently distributed in geographic range from southeastern Canada southward into the following US states: eastern Texas, eastern Oklahoma, Missouri, Minnesota, Michigan, Wisconsin, Indiana, southern Illinois, Ohio, Pennsylvania, New York, Connecticut, Vermont,

New Hampshire, Maine, New Jersey, Maryland, Rhode Island, Massachusetts, West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida, Mississippi, Alabama, Louisiana, Arkansas, Tennessee, Kentucky. 11.

34) *Acer negundoides* (leaves)-- The binomial paleobonical name given to the fossil representative of the modern box elder *Acer negundo*, one of the most widespread species of tree in America, occurring naturally in every US state, except for Washington, Oregon, Maine, and Rhode Island. It's also present in south-central Canada and ranges as far south as Guatemala. 1.

35) *Acer oreganianum* (leaves and samaras)--Paleobotanical genus-species for the living bigleaf maple *Acer macrophyllum*, found primarily in southern Alaska, extreme western Canada, and then south through the coastal regions of Washington, Oregon,, and California (a disjunct population inhabits the western foothills of the Sierra Nevada) at elevations from sea level to 450 m (1,480 ft), with unusual exceptions to 1,200 m (3,900 feet). 21.

36) *Acer scottiae* (leaves)--The fossil name for the modern yellow-paint maple *Acer pictum*, an Asian species widespread in temperate forests across, China, Korea, Japan, Mongolia, and eastern Russia. 3.

37) *Acer septilobatum* (leaves)--A presumably extinct species of maple that shows some similarities to the extant bigleaf maple *Acer macrophyllum*, which lives in western coastal areas of the US and Canada (with a geographically separated occurrence in the western foothills of California's Sierra Nevada). 1.

38) *Aesculus preglabra* (leaves)--Paleobotanical genus-species for the living Ohio buckeye *Aesculus glabra* whose natural geographic distribution includes populations in Ohio, southern Michigan, eastern Pennsylvania, Tennessee, northern Alabama, Mississippi (one isolated spot near the Alabama border), central to northeastern Texas, eastern half of Oklahoma, northwestern Arkansas, western Kansas, Missouri, southern Iowa, Illinois, and Indiana. 34.

39) *Arbutus idahoensis* (leaves)--According to paleobotanist Daniel I. Axelrod, this is a presumably extinct species of madrone whose closest modern-day affinity is possibly with the Texas madrone *Arbutus xalapensis*, native to Central America, Mexico, and the southwestern United States (Texas and New Mexico). 5.

40) *Arbutus matthesi*i (leaves)--The Miocene analog to the living Pacific madrone *Arbutus menziesii*, native primarily to coastal western North America, from southern Canada south to California--they are rare south of Santa Barbara County, and an isolated population inhabits the western foothills of the Sierra Nevada. 2

41) *Fraxinus caudata* (leaves)--The paleobotanical genus-species for the modern Oregon ash *Fraxinus oregona* (synonymous with *Fraxinus latifolia*), native to the US west coast from western Washington southward through western Oregon to northwest and central California; it prefers moist loose soils at elevations from sea level to 900 m (3,000 feet--in

the north) to 1,700 m (5,600 feet--in California).

Part 2--A visit to the 13.3 to 14.8 million year old middle Miocene Chloropagus Formation.

Next up, I spent a couple of days exploring the geologically younger middle Miocene Chloropagus Formation. At roughly 14.8 to 13.3 million years old, the Chloropagus fossil flora occurs in the vicinity of Reno, western Great Basin Desert, Nevada, and records a significant regional botanic transition, beginning about 15 million years ago, from a landscape previously characterized by deciduous hardwoods allied with today's eastern US Appalachian area to an environment that would have more closely resembled a modern mixed conifer forest along the western slopes of the Sierra Nevada, California. That's when exotic angiospermous hardwoods and bald cypress (*Taxodium*) underwent a rather rapid (geologically speaking) extirpation from mid Miocene western Nevada in response to decreased precipitation during the months of May through August; Chloropagus times received fully five inches less rain during late spring through summer than the Pyramid Formation plants only one and a half million years earlier.

This famous paleobotanic crisis is excellently reflected in nine geologically stratified Chloropagus Formation florules that preserve in superior detail the traumatic transition. Perhaps mid Miocene East Antarctic ice sheet spreading, combined with Australia's separation from Antarctica and a concomitant widening of Drake's passage when Continental Drift also moved South America away from Antarctica, drove colder waters northward toward the tropical districts, strengthening high pressure in the southern United States and Mexico, especially in the ancestral west. Whatever the explanation, relic middle Miocene hardwood forests in Oregon and Washington managed to escape the severe botanic turnover until approximately two to three million years later, as the great drying trend moved inexorably northward.

But of course, over the past 14 million years or so the area's vegetational trend has reflected increasing aridity. Occurring not far from Reno Nevada today, the middle Miocene fossil plant-bearing Chloropagus Formation outcrops at roughly 4,400 feet within the parched western reaches of the Great Basin Desert, receiving perhaps a little as five inches of rain per year, with most of it falling as snow during winter. In general, mean monthly temperatures at the fossil sites today show greater summer and winter extremes than the same seasonal weather conditions estimated for Chloropagus times (all readings in Fahrenheit): January--30 degrees; February--37 degrees; March--43 degrees; April--50 degrees; May--57 degrees; June--66 degrees; July--73 degrees; August--72 degrees; September--63 degrees; October--53 degrees; November--40 degrees; and December--32 degrees. Growing season in the neighborhood of the Chloropagus Formation fossil localities today is no more than four months.

Yet, 14.8 to 13.3 million years ago, based on the known environmental preferences of modern counterparts of the fossil flora, the Reno-vicinity region within which the Chloropagus Formation accumulated stood at an elevation no higher than 2,400 feet and received, initially, an estimated 30-35 inches of precipitation annually--an amount that had dropped to 25 to 30 inches near the conclusion of sedimentary deposition, when May to August rainfall had all but disappeared. During the summer and winter months especially,

middle Miocene Chloropagus climatic conditions would have been characterized by temperate temperature gradients decidedly more moderate than those observed today in the western Great Basin Desert (all figures in Fahrenheit): January--40 degrees; February--43 degrees; March--45 degrees; April--52 degrees; May--59 degrees; June--65 degrees; July 66 degrees; August--63 degrees; September--58 degrees; October--52 degrees; November--47 degrees; and December--42 degrees. The effective growing season likely lasted as long as seven months.

Plants at the fossil sites today reflect the restrictive effects imposed by demanding Great Basin Desert meteorology. Now dominating a landscape that had once held luxuriant green forests of conifers is an association of specialized low spiny plants adapted to scant rainfall (often less than five inches per year) and extreme temperature fluctuations, where summer highs peak at 106 F. and winter lows can drop to minus 26 degrees Fahrenheit. Typical shrubs encountered today include sage (*Artemesia*); saltbrush (*Atriplex*); blackbrush (*Coleogyne*); fireweed (*Kochia*--an introduced non-native species, of course); siltbush (*Grayia*); and horsebrush (*Tetradymia*). The only trees present in the area are Fremont cottonwood (*Populus fremontii*) and various species of willow (*Salix*), invariably concentrated near rare water sources.

This contrasts radically with the abundant and diverse Chloropagus vegetation present in the middle Miocene Reno region 14.8 to 13.3 million years ago, when a lush forested scene featured numerous species of conifers, deciduous trees and shrubs, broadleafed evergreen sclerophylls, and herbaceous perennials such as fir (*Abies*), spruce (*Picea*), pine (*Pinus*), larch (*Larix*), mountain hemlock (*Tsuga*), Lawson cypress, (*Chamaecyparis*), Chinese swamp cypress (*Glyptostrobus*), Douglas-fir (*Pseudotsuga*), juniper (*Juniperus*), giant sequoia (*Sequoiadendron*), maple (*Acer*), alder (*alnus*), birch (*Betula*), scarlet hawthorn (*Crataegus*), Chinese coffee tree (*Gymnocladus*), sycamore (*Platanus*), cottonwood (*Populus*), quaking aspen (*Populus*); extinct species of willow oak (*Quercus simulata*); zelkova (*Zelkova*); serviceberry (*Amalanchier*), moutain mahogany (*Cercocarpus*), ocean spray (*Holodiscus*); dogwood (*Cornus*); chokecherry (*Prunus*); buckthorn (*Rhamnus*); black locust (*Robinia*); wild rose (*Rosa*); highbush blueberry (*Vaccinium*); madrone (*Arbutus*), giant chinquapin (*Chrysolepis*); tanbark oak (*Lithocarpus*); Santa Cruz Island iron tree (*Lyanothamnus*--a species that today grows in the wild only on the Channel Islands off the coast of southern California); canyon live oak (*Quercus*); tobacco brush (*Ceanothus*); a brush-sized mountain mahogany (*Cercocarpus*); toyon (*Heteromeles*); Sierra laurel (*Leucothoe*); Island barberry (*Mahonia*); Tall Oregon grape (*Mahonia*); horsetail (*Equisteum*); broadleaf cattail (*Typhus*); and eagle fern (*Pteridium*).

The middle Miocene Chloropagus Formation fossil plant bonanza was discovered in 1952 by University Nevada Reno Mackay School of Mines geologist/minerologist Dr. Vincent P. Gianella (1886-1983), who delivered a small batch of specimens he'd gathered to paleobotanist Dr. Daniel I. Axelrod, then teaching at the University California at Los Angeles (infamous UCLA--grin: This is the first and only time I will ever mention UCLA in writing; I am a University of Southern California devotee, of course: Enough said, I reckon). It's not clear, though, who actually secured the next Chloropagus finds; on that account, Axelrod is rather vague, noting only that several succeeding collections came while working out stratigraphic relationships in the fossiliferous district. He doesn't directly "confess" to personally

gathering the specimens, though. It should of course be noted at this juncture that in a rather fortuitous earth science connection, professor Gianella served for a number of years as a de facto fossil-finding stringer for Axelrod, who benefitted greatly from Gianella's original field investigations. On not a few occasions, for example, Dr Gianella graciously informed Axelrod of places in Nevada where identifiable fossil leaves could be found, significant paleobotanical spots that Axelrod would have never been aware of otherwise; the wonderful Virginia City-vicinity middle Miocene fossil leaf locality immediately comes to mind in this regard, a district that not only produces numerous identifiable leaves and seeds, but also many insects and occasional frog skeletons, as well.

In 1969, geologist Harold Bonham with the Nevada Bureau of Mines forwarded more Chloropagus Formation fossil plant material to Axelrod, now a professor of botany and paleobotany at the University California Davis in northern California (he became a member of the faculty there in 1968). Axelrod accompanied Bonham to the new plant-bearing areas where they subsequently discovered four remarkable superposed fossil floras, each stacked one atop another in normal stratigraphic succession (that is to say, no unconformities to interrupt a continuous sedimentary column). That instantly re-invigorated the Chloropagus fossil project, and up until 1976 when he "officially" retired from UC Davis, Axelrod regularly took his students in paleobotany and paleoecology on field trips to the "stacked fossil plant place" to collect additional leaves, seeds, needles, fascicles, cones and cone scales, ultimately amassing some 5,295 specimens from nine localities. At one of those especially productive sites, paleobotanist Howard Schorn ably assisted collecting fossil plants for Ax--a well-known nickname for Daniel I. Axelrod, by the way, and in actual fact he actively encouraged its use; while at UC Davis, for example, he had a personalized license place that read PROF AX. And when it came time to assemble for publication his monograph on the middle Miocene Chloropagus plants, Axelrod enlisted Howard Schorn to photograph representative specimens to accompany the text and charts.

All the fossil plants that Axelrod described in his scientific treatise came from minor shale intervals in the middle Miocene Chloropagus Formation; a potassium-argon radiometric reading from a basalt flow near the base (oldest level) of the geologic unit yielded a chronostratigraphic date of 14.8, while another radioactive isotope analysis (presumably K/Ar) from a glassy rhyolitic tuff close to the top (youngest horizon) produced an absolute age of 13.3 million years. In its generalized geologic aspect of outcropping, the Chloropagus is predominantly of volcanic origin, bearing locally prolific paleobotanical remains only within several discontinuous pale brown to black lacustrine shale beds, usually no more than three to seven feet thick (perhaps representing geologically short-lived lake or pond waters that had been impounded due to volcanism), that outcrop in traditionally difficult to spot gulches and gullies eroded into approximately 1,900 feet of reddish-brown to light greenish gray basalt and andesite flows (in individual flow beds 10 to 49 feet thick); adding to their considerable paleontological mystique, the richest fossil-bearing shales are impossible to trace outside of the nondescript, localized erosion channels within which they remain confined.

In the three primary areas where fossil plant material occurs--appropriately labeled sites 1, 2, and 3--the middle Miocene Chloropagus Formation lies in varying stratigraphic relationship to other igneous rock units. Area 1 for example contains two 14.8 million year

old fossil florules situated at the base (oldest horizon) of a Chloropgus Formation section nearly 300 feet thick; directly underlying the thinly bedded plant-bearing Chloropagus lacustrine shales is the middle Miocene Old Gregory Tuff, around 20 feet of rhyolite tuff and breccia dated at 15 million years old. Directly below the Old Gregory Tuff (in unconformable stratigraphic position) is the 22 million year old lower Miocene Alta andesite, probably a little over 300 feet thick, which in turn overlies an undisclosed thickness of welded tuffs belonging to the 28 to 23 million year old Olligocene to lower Miocene Hartford Hill Rhyolite, a once long-established geologic formation name that in the Carson City-Silver City area has been abandoned in favor of the following new rock units, from oldest to youngest: Mickey Pass Tuff; Lenihan Canyon Tuff; Nine Hill Tuff; and Eureka Canyon Tuff. Below the Hartford Hill Rhyolite, separated by a great unconformity that left no trace of the preceding Eocene and Paleocene Epochs, is a Mesozoic basement complex of unestablished thickness composed of Cretaceous-age hornblende biotite quartz diorite and granidiorite, underlain in turn by older Jurassic and Triassic Period metasediments that include dark hornfels, argillite, metamorphosed limestones and some metavolcanics.

At paleobotanical locality 2, four famous superposed fossil localities occur in a 962 foot thick section of the Chloropagus Formation, which unconformably overlies the lower Miocene Alta Andesite, dated by radiometric isotope techniques at 22 million years old, a roughly 300 foot thick sequence of greenish-gray to dark green and dark gray hornblende and pyroxene andesite flows bearing subordinate breccias mottled with blotches of red and green.

Area 3 provides three paleo-florules scattered within about 738 feet of Chloropagus Formation outcropping; one fossil plant zone occurs roughly 100 feet above the unconformably underlying 28 to 23 million year old Oligocene to lower Miocene Hartford Hill Rhyolite, while the remaining two plant-yielding localities--estimated at 13.3 million years of age--lie some 100 feet below the conformably overlying Kate Peak Peak Andestie, which consists of hornblende andesite flows, mudflows, breccias, tuffs, conglomerates and some diatomite beds, all convincingly dated through radiometric methodology at 13 million years old.

Daniel I. Axelrod had the four superposed fossil localities of area 2 under scientific study for some three decades. He noted that each individual florule reflects changing vegetational associations directly influenced by repeated episodes of successional extrusive volcanism over the course of perhaps 100,000 years. The paleobotanical preservations thus provide an extraordinary opportunity to evaluate through a relatively "brief" period of geologic time the effects of volcanic activity on a middle Miocene geography roughly 14 million years ago.

The oldest plant horizon yields a flora composed of fully 84 percent sclerophyllous evergreens, dominated by giant chinquapin (*Chrysolepis*), tanbark oak (*Lithocarpus*), and canyon live oak (*Quercus*); this association suggests a rocky well drained soil profile that developed on rather recent lava flows subjected to erosion. A conifer element comprised of fir (*Abies*), Lawson cypress (*Chamaecyparis lawsiana*), spruce (*Picea*), Douglas-fir (*Pseudotsuga*), and giant sequoia (*Sequoiadendron*) contributed but four percent of the total take, probably inhabiting patches of moister slopes nearby. Pond-lake components such as willow (*Salix*) and cottonwood (*Populus*) are also comparatively rare here, providing

only four percent of the 343 identified specimens, reinforcing the interpretation that recently weathered well drained volcanic soils covered most of the terrain closest to paleobotanical accumulations.

Lying only 10 feet above the oldest florule in successional stratigraphic relations is a three foot thick plant-bearing horizon of gray-black organic shale that bears a significant proportion (36 percent) of riparian plants, principally birch (*Betula*) cottonwood (*Populus*) and willow (*Salix*). Broadleaf evergreen sclerophylls such as madrone (*Arbutus*), mountain mahogany (*Cercocarpus*), and toyon (*Heteromeles*) contributed only 20 percent of the 227 total specimens studied; they were likely confined to drier sites at the edges of volcanic flows in a region of subdued relief. A large mixed conifer element (44 percent) and its associates suggest a relic old growth forest established near a pond or small lake, where fir (*Abies*), Lawson cypress (*Chamaecyparis lawsiana*), spruce (*Picea*), Pine (*Pinus*), Douglas-fir (*Pseudotsuga*), serviceberry (*Amalanchier*), chokecherry (*Prunus*), and mountain ash (*Sorbus*) regularly shed their botanic structures to the sedimentary record.

Roughly 50 feet higher in the section at locality 2 is a third superposed florule. Here members of a rich mixed conifer forest community that probably lived on highly weathered volcanic terrain account for fully 67 percent of the 967 plant specimens studied. Regular gymnospermous elements included fir (*Abies*), Lawson cypress (*Chamaecyparis lawsiana*), spruce (*Picea*), Douglas-fir (*Pseudotsuga*), and giant sequoia (*Sequoiadendron*). Compared with their prominence in the oldest horizon, broadleaf sclerophylls such as madrone (*Arbutus*), mountain mahogany (*Cercocarpus*), toyon (*Heteromeles*), and canyon live oak (*Quercus pollardiana*) became greatly diminished during deposition of the third Chloropagus successional florule, forming only 19 percent of the total; the more xeric vegetation probably grew on less weathered soils than their forest counterparts, or perhaps at the edges of younger volcanic flows which provided access to increased sunlight and much drier environments. A pond-lake border association of birch (*Betula*), cottonwood (*Populus*) and willow (*Salix*) lived near lake level, accounting for 17 percent of the curated paleobotanical material.

The youngest fossil zone at Chloropagus area 2 lies roughly 56 feet above the third florule. In numerical representation of fossil species, it is certainly the most prolific of the four superposed horizons, yielding 36 species of middle Miocene plants identified from 870 specimens. By this time, a conifer forest with subordinate associated taxa had become dominant (74 percent of the fossils examined), a diverse botanic community consisting of fir (*Abies*), Lawson cypress (*Chamaecyparis lawsiana*), spruce (*Picea*), Douglas-fir (*Pseudotsuga*), giant sequoia (*Sequoiadendron*), serviceberry (*Amalanchier*), birch (*Betula*), snowbrush ceanothus (*Ceanothus*), scarlet buckthorn (*Crataegus*), Sierra laurel (*Leucothoe*), black locust (*Robinia*), mountain ash (*Sorbus*), Tall Oregon grape (*Mahonia*), and western chokecherry (*Prunus*). The broadleaf sclerophyllous component of madrone (*Arbutus*), mountain mahogany (*Cercocarpus*), toyon (*Heteromeles*), Island barberry (*Mahonia*), oak (*Quercus*), and tanbark oak (*Lithocarpus*) underwent a reduction (nine percent of the total), occupying more exposed xeric sites on volcanic flows near the basin of deposition. Nearest the lake level lived a thriving deciduous plant association of (*Betula*), cottonwood (*Populus*), and willow (*Salix*) that contributed 17 percent of the fossil specimens known from the

uppermost superposed Chloropagus zone.

Today, four geographic areas support plant communities similar to those preserved in the middle Miocene Chloropagus Formation, Great Basin Desert, Nevada, including: (1) Calaveras Big Trees State Park, western foothills of California's Sierra Nevada, amidst a rich mixed conifer forest, where several conifers, sclerophylls, and shrubs closely allied with fossil types found in the 13.3 to 14.8 million year old Chloropagus Formation in the vicinity of Reno, Nevada, now grow--including: giant sequoia (*Sequoiadendron*), fir (*Abies*), pine (*Pinus*), Douglar-fir (*Pseudotsuga*), madrone (*Arbutus*), tanbark oak (*Lithocarpus*), canyon live oak (*Quercus*), serviceberry (*Amalanchier*), buckbrush (*Ceanothus*), black laurel (*Leucothoe*), Oregon grape (*Mahonia*), western chokecherry (*Prunus*), wild rose (*Rosa*), and willow (*Salix*); (2) Sugar Lake, Salmon Mountains--a branch of the Klamath Mountains--northwestern California, within the southern sector of the Miracle Mile, a world famous square mile of natural "real estate" that holds one of the most diverse conifer assemblages on Earth, including foxtail pine (*Pinus balfouriana*), whitebark pine (*Pinus balfouriana*), western white pine (*Pinus monticola*), Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), Shasta fir (*Abies magnifica*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), Brewer spruce (*Picea breweriana*), mountain hemlock (*Tsuga mertensiana*), Douglas-fir (*Pseudotsuga menziesii*), Pacific yew (*Taxus brevifolia*), incense-cedar (*Calocedrus decurrens*), common juniper (*Juniperus communis*), and western juniper (*Juniperus occidentalis*)--upwards of 32 species of conifers have been identified from the Klamath Mountains region; (3) Along the eastern slopes of Cone Peak, Santa Lucia Range, California, where Shasta red fir (*Abies magnifica*), sugar pine (*Pinus lambertiana*), madrone (*Arbutus*), canyon live oak (*Quercus*), tanbark oak (*Lithocarpus*) , Oregon grape (*Mahonia*), mountain mahogany (*Cercocarpus*), dogwood (*Cornus*), toyon (*Heteromoles*), oceanspray (*Holodiscus*), pigeon berry (*Amalanchier*), western chokecherry (*Prunus*), wild rose (*Rosa*), and buckthorn (*Rhamnus*) now grow; and (4) Northern Idaho, where many conifers and shrubs allied with fossil kinds found in the 13.3 to 14.8 million year old Chloropagus Formation occur, including larch (*Larix*), mountain hemlock (*Tsuga*), fir (*Abies*), Douglas-fir (*Pseudotsuga*), western serviceberry (*Amalanchier*), scarlet hawthorn (*Crataegus*), oceanspray (*Holodiscus*), oregon grape (*Mahonia*), wild rose (*Rosa*), willow (*Salix*), western chokecherry (*Prunus*), and whitebeam (*Sorbus*).

Here is the full list of fossil plant species identified from the middle Miocene Chloropagus Formation as exposed in the neighborhood of Reno, Nevada, Great Basin Desert. The nine numbers that follow the descriptions refer to the numbers of fossil specimens of that species found at each of the nine fossil localities, arranged in order of oldest plant-bearing horizon to youngest (left to right); in other words, first number refers to the oldest zone and the last number is the youngest of the nine horizona:

1) *Chamaecyparis cordillerae* (synonym of *C. sierrae*) (twigs, foliage)--The Miocene equivalent of today's Lawson cypress, *Chamaecyparis lawsiana*, now native to southwestern Oregon and the Klamath Mountains of northwest California at elevations from sea level to 4,900 feet (1,500 m). 3, 18, 3, 20, 42, 36, 3, 7, 0.

2) *Abies nevadensis* (winged seeds)--Paleobotanical counterpart to the extant Sakhalin fir

***Abies sachalinensis* which today growns on Sakhalin island, southern Kurils (Russia), and northern Hokkaido (Japan) at elevations from sea level to 1,650 meters (5,413 feet), preferring some 1,500mm of precipitation annually (about 60 inches). 0, 0, 0, 0, 0, 1, 0, 0, 0.**

3) *Abies laticarpus (*synonym of *A. klamathensis*) (winged seeds)--The Miocene analog to *Abies magnifica* var. *shastaensis*--the living Shasta red fir that in natural habitat ranges from 1,400–2,700 meters (4,600–8,900 ft) elevation in Shasta, Siskiyou and Trinity Counties--northwest California--through southwest Oregon. This species also occurs in the 15.6 million year old Pyramid Formation. 10, 2, 7, 3, 0, 66, 3, 1, 0.

4) *Abies scherrii* (cone scales)--The fossil genus-species of the modern Shasta Lucia fir *Abies bracteata*, now confined in natural habitat to the Santa Lucia Mountains near Big Sur, central California coast, where it grows at elevations from 2,000 to 5,000 feet (610 to 1,520 m). 1, 1, 0, 0, 3, 5, 0, 0, 0.

5) *Larix fernleyii* (winged seeds, twigs, and needles)--Name paleobotanists use to scientifically describe fossil plant structures that closely resemble those produced by the living subalpine larch *Larix lyallii*, whose natural habitat ranges from the Rocky Mountains of British Columbia, Alberta, Idaho, and Montana to an isolated population in Washington's Cascade Range, preferring elevations from 1,500 to 2,900 meters (4,900 to 9,500 feet). 0, 1, 0, 6, 3, 1, 0, 0, 0.

6) *Picea magna* (winged seeds)--A presumably extinct spruce, although a few paleobotanists suggest that it does resemble the living tigertail spruce *Picea torano*, now native to Japan. 0, 220, 6, 12, 0, 0, 3, 52, 0.

7) *Picea sonomensis* (winged seeds)--Fossil binomial name paleobotanists call today's *Picea breweriana*, the Brewer spruce, a rather rare North America tree that now grows in natural habitat only in the Klamath Mountains of southwest Oregon and northwest California at elevations from 1,000–2,700 m (3,300–8,900 ft). DNA genetic analyses placed the Brewer spruce at the base of the Picea clade, suggesting that spruces originated in North America. This species also occurs in the middle Miocene Pyramid Formation. 0, 228, 2, 7, 169, 44, 0, 0, 0.

8) *Picea lahontense* (winged seeds)--A presumed extinct species of spruce whose samaras cannot be matched exactly with any living variety, although they do resemble winged seeds produced by the larger-coned spruces of eastern China. 0, 64, 0, 7, 124, 84, 0, 21, 0.

9) *Pinus balfouroides* (winged seeds, cones)--The paleobotanical genus-species for fossil plant material that is quite similar to the modern foxtail pine *Pinus balfouriana*, endemic to northern California in the Siskiyou, Scott, Salmon, Marble, Trinity, and Yolla Bolly Mountains, usually at elevations from 1,525 to 1,830 m (5000 to 6,000 feet). A disjunct subspecies of foxtail pine called *Pinus austrina* occurs mainly within Sequoia National Park, western slopes of the Sierra Nevada, near the headwaters of the Kings, Kern and Kaweah Rivers. 3, 0, 0, 5, 20, 67, 0, 0, 0.

10) *Pinus quinifolia* (winged seeds, needles)--The Miocene equivalent of the modern

Western white pine *Pinus monticola*, which today grows in Washington state, Montana, Idaho, Nevada, Oregon, California, and Canada (Alberta-British Columbia) at elevations from 1000 m (3,280 feet) in northern regions to 1900-3000 m (6,200 to 9,842 feet) throughout its southern reaches. 0, 78, 0, 23, 111, 0, 19, 28, 0.

11) *Pinus tiptoniana* (needles)--Genus-species designation for paleobotanical structures comparable to the living Allepo pine *Pinus halepensis*, native to Morocco, Algeria, Tunisia, Spain, southern France, Malta, Italy, Croatia, Montenegro, Albania, Greece, Syria, Lebanon, southern Turkey, Jordan, Israel, and Palestine at elevations from sea level to 1,700 m (5,600 feet). 9, 0, 0, 0, 0, 0, 0, 0, 0.

12) *Pseudotsuga sonomensis* (winged seeds, needles)--Paleobotanical counterpart for the living Douglas-fir, *Pseudotsuga menziesii*, a member of the pine family (though it's not a true fir, hemlock or spruce), whose natural habitat includes British Columbia, Canada, southward through Washington, Oregon, California, and Nevada at elevations from 550m - 2,900m (1,800 to 9,500 ft), although river bottom populations can live at 800 to 900 feet. A species also found in the middle Miocene Pyramid Formation. 0, 1, 2, 11, 14, 18, 0, 6, 0.

13) *Tsuga mertensioides* (foliage)--Binomial name applied to fossil preservations that closely resemble structures produced by the extant mountain hemlock whose current natural range extends from southern Alaska, south to western Canada, western Washington, western Oregon, northern and eastern California (Klamath and Sierra Nevada Mountains), northwestern Idaho and northwestern Montana from sea level to 1,000 m (3,300 feet) in Alaska to 2,500 to 3,050 m (8,200-10,010 ft) in California's Sierra Nevada. 0, 3, 0, 0, 0, 1, 0, 0, 0.

14) *Glyptostrobus oregonensis* (foliage and cones)--The paleobotanical analog to today's Chines swamp cypress *Glyptostrobus pensilis*, native to southeastern China, northern Vietnam, and Laos, typically preferring river banks, ponds and swamps; grows in waters up to 60 cm (24 inches) deep. 19, 0, 0, 0, 0, 0, 0, 0, 0.

15) *Sequoiadendron chaneyii* (twigs, foliage)--The fossil analog of the living giant sequoia/Big Tree/Sierra redwood *Sequoiadendron giganteum*, now confined in native habitat to several isolated groves along the moist western slopes of California's Sierra Nevada, where it prefers elevations from 900-2700 m (2,952 to 8,852 feet). 110, 0, 14, 0, 45, 176, 52, 0, 5.

16) *Juniperus desatoyana* (foliage)--Fossil genus-species for paleobotanical material that closely resembles plant structures produced by the modern western juniper *Juniperus occidentalis*, which in natural habitat extends from southeastern Washington to eastern and central Oregon, southwest Idaho, northeastern California and northwest Nevada, usually at altitudes from 800–3,000 meters (2,600–9,800 feet). 0, 0 , 0, 0, 0, 0, 0, 1, 0.

17) *Acer columbianum* (synonymous with *A. trainii*) (leaves and samaras)--Miocene genus-species for the extant Rocky Mountain maple *Acer glabrum var. glabrum* that in natural range occurs in Arizona, Colorado, Idaho, Montana, Nebraska, New Mexico, Nevada, South Dakota, Utah, and Wyoming--often in association with ponderosa pine, Douglas-fir, and

quaking aspen. 0, 0, 0, 0, 1, 0, 0, 0, 0.

18) *Acer middlegateii* (synonymos with *A. chaneyii*) (samaras)--The Miocene variety of today's sugar maple *Acer saccharum* that in natural habitat can be found in southeastern Canada, southward to Minnesota, eastern Iowa, Missouri, eastern Kansas, southeastern North Dakota, northeastern South Dakota, Wisconsin, Illinois, Michigan, Indiana, Ohio, Pennsylvania, New York, Vermont, New Hampshire, Maine, Connecticut, Massachusetts, Rhode Island, northern New Jersey, northern Maryland, western Virginia, West Virginia, Kentucky, Tennessee, western North Carolina (scattered occurrences in the central part of the state), Georgia (two isolated areas in the north), and South Carolina (one disjunct area in the northwestern portion of the state). This species also occurs in the middle Miocene Pyramid Formation. 1, 0, 0, 0, 0, 0, 0, 0, 0.

19) *Acer negundoides* (leaves)--The binomial paleobonical name given to the modern box elder *Acer negundo*, one of the most widespread species of tree in America, occurring naturally in every US state, except for Washington, Oregon, Maine, and Rhode Island. It's also present in south-central Canada and ranges as far south as Guatemala. *Acer negundoides* also occurs in the middle Miocene Pyramid Formation. 1, 0, 0, 0, 0, 0, 0, 0, 0.

20) *Acer scottiae* (leaves)--Fossil genus-species for paleobotanical structures that match closely those produced by today's yellow-paint maple *Acer pictum*, endemic to most of China, in addition to Japan, Mongolia, and eastern Russia. 0, 0, 3, 0, 2, 0, 0, 0, 0.

21) *Mahonia reticulata* (leaves)--The Miocene binomial name for today's Island barberry *Mahonia pinnata* subsp. *insularis*, now found growing in the wild only on Santa Cruz Island off the coast of southern California. 1, 6, 1, 0, 0, 5, 0, 0, 0.

22) *Mahonia macginitiei* (leaves)--Genus-species used to describe the fossil form of the extant Tall Oregon grape *Mahonia aquifolium*, whose natural habitat includes southern Canada south to Washington, western Oregon, Idaho, western Montana, California, and the US Great Lakes region. 0, 4, 1, 0, 2, 2, 0, 1, 0.

23) *Betula thor* (leaves)--The fossil counterpart to the living paper birch (also called American white birch) *Betula papyrifera*, presently native to most of Canada and Alaska and portions of Washington state, Oregon, Idaho, Montana, North Dakota, South Dakota, Nebraska, Colorado (southernmost occurrence), Minnesota, Wisconsin, Michigan, Illinois, Iowa, Indiana, Ohio, New York, West Virginia, North Carolina, Pennsylvania, Connecticut, Massachusetts, and Rhode Island. It also grows throughout all of Vermont, New Hampshire, Maine, and Massachusetts. A species that is also found in the middle Miocene Pyramid Formation. 9, 0, 0, 0, 0, 0, 0, 0, 0.

24) *Betula smithiana* (leaves)--Paleobotanical genus-species for fossil remains of structures that are quite similar to the modern red birch *Betula occidentalis*, native to much of southern Canada and portions of Washington, Oregon, California (mainly northwestern areas and Sierra Nevada), Nevada (isolated populations in central and eastern sectors), northern Arizona, northern New Mexico, Utah, Colorado, Wyoming, Idaho, Montana, North

Dakota, South Dakota, and western Nebraska. 0, 30, 0, 3, 6, 0, 0, 4, 0.

25) *Betula vera* (leaves)--The Miocene equivalent to the modern yellow birch (also called golden birch or swamp birch) *Betula lutea* (synonymous with *Betula alleghaniensis*). Likes cooler environments, typically in swamps, stream banks, deep woods, and north facing slopes from southeastern Canada southward to northeastern Minnesota, Wisconsin, northeastern Iowa, northernmost Illinois, northern Indiana, northeastern Ohio, Michigan, Pennsylvania, New York, Vermont, New Hampshire, Maine, Connecticut, Massachusetts, Rhode Island, northern New Jersey, northern Maryland, West Virginia, western half of Virginia, Kentucky, Tennessee, western North Carolina, northwestern South Carolina, and northeastern Georgia. This species also occurs in the middle Miocene Pyramid Formation. 0, 1, 0, 0, 0, 0, 0, 0, 0.

26) *Betula ashleyii* (leaves)--Bionmial name that paleobotanists give to the living water birch (also called red birch) *Betula fontinalis* (synonymous with *Betula occidentalis*), which in natural habitat ranges southward through southern Canada to form scattered occurrences in Washington, Oregon, California, Idaho, Nevada, Arizona, New Mexico, Colorado, Montana, Wyoming, North Dakota, South Dakota, and western Nebraska. 0, 0, 0, 0, 0, 0, 1, 0, 1.

27) *Arbutus matthesi*i (leaves)--The paleobotanical analog to today's Pacific madrone *Arbutus menziesii*, native primarily to southern Canada south to California--though they are rare south of Santa Barbara County; an isolated population inhabits the western foothills of the Sierra Nevada. *Arbutus matthesi*i also occurs in the middle Miocene Pyramid Formation. 1, 0, 0, 0, 0, 3, 2, 0, 0.

***28) Arbutus idahoensis* (leaves)--According to paleobotanist Daniel I. Axelrod, this is an extinct species of madrone whose closest modern-day affinity is possibly with the Texas madrone *Arbutus xalapensis*, native to Central America, Mexico, and the southwestern United States (Texas and New Mexico). *Arbutus idahoensis* is also found the middle Miocene Pyramid Formation. 0, 0, 0, 3, 3, 0, 0, 0, 0.**

29) *Castanopsis sonomensis* (synonymous with *Chrysolepis sonomensis*) (leaves)--The Miocene name for the living giant chinquapin *Chrysolepis chrysophylla*, presently native to southern Washington southward through western Oregon to west-central California, favoring climax forests dominated by redwood, white fir, western hemlock, and Shasta red fir. *Castanopsis sonomensis* has also been collected from the middle Miocene Pyramid Formation. 0, 0, 1, 0, 4, 0, 0, 0, 0.

30) *Lithocarpus klamathenis* (synonym of *Lithocarpus nevadensis)* (leaves)--The fossil equivalent to the modern tanbark-oak *Notholithocarpus densiflorus*, endemic to California and southern Oregon. Despite its common name and the fact that it does produce acorns, it is nevertheless not a true oak. This genus-species is also found in the middle Miocene Pyramid Formation. 0, 0, 11, 0, 0, 1, 0, 1, 1.

31) *Quercus pollardiana* (leaves, acorns)--A presumed extinct species of oak whose fossil leaves and acorns closely resemble today's canyon live oak *Quercus chrysolepis,* a common

component of mountainous botanical communities in California (Sierra Nevada, Coast Ranges, Klamath Mountains, and San Gabriel Mountains, for example); also occurs in southwestern Oregon, western Nevada, Arizona, southwestern New Mexico, Baja California, and Chihuahua Mexico. Has been found growing at elevations from 500 to 2,700 m (1,600 to 8,852 feet). 11, 0, 275, 0, 3, 1, 440, 0, 4.

32) *Quercus simulata* (leaves)--An extinct species whose fossil leaves and acorns compare with no known modern oak. Not a few paleobotanists suggest that it's possibly allied with the living willow oak *Quercus phellos*, native to the southeastern United States, or even the silver oak *Quercus hypoleucoides*, currently found in southeastern Arizona, southwestern New Mexico, and northern Mexico. 686, 0, 0, 0, 0, 0, 30, 0, 0.

33) *Crataegus gracilens* (leaves)--Paleobotanical genus-species applied to the fossil variety of today's scarlet hawthorn *Crataegus coccinea*, native to most of eastern Canada, south to Connecticut, Illinois, Indiana, Maine, Massachusetts, Maryland., Michigan, Minnesota, North Carolina, New Hampshire, New York, Ohio, Pennsylvania, Rhode Island, Virginia, Vermont, Virginia, and Wisconsin. 0, 0, 0, 0, 0, 2, 0, 0, 0.

34) *Gymnocladus dayana* (leaves)--The fossil counterpart to the living Kentucky coffeetree *Gymnocladus dioicus*, a rather rare tree that is native to northern Kentucky, central and western Tennessee, extreme northwest Alabama, Arkansas, Missouri, Oklahoma, eastern Kansas, Iowa, southern Minnesota, southeastern Wisconsin, southern Michigan, Indiana, western to southern Ohio, western Pennsylvania, central New York, scattered areas in West Virginia, one disjunct place in eastern Nebraska, one isolated spot in western North Carolina near the West Virginia border, and Ontario Canada. Typically favors floodplains and river valleys, though it's known to populate rocky hillsides and limestone woods, as well. 0, 1, 0, 0, 0, 0, 0, 0, 0.

35) *Platanus bendirei* (leaves)--This is what paleobotanists call fossil specimens that match today's California sycamore *Platanus racemosa* (also referred to as the western sycamore), a chiefly riparian specimen that ranges from western and eastern California--northernmost occurrence is in Humbolt County, with scattered patches in the Sierra Nevada--south to northern Baja California Mexico. This species also occurs in the middle Miocene Pyramid Formation. 1, 0, 0, 0, 0, 0, 0, 0, 0.

36) *Zelkova brownii* (leaves)--Genus-species for the paleobotanical analag of the living Japanese zelkova *Zelkova serrata*, native to Japan, Korea, Taiwan, and Manchuria; favors riparian habitats and rich soils at the base of mountains. 0, 1, 0, 0, 0, 0, 0, 0, 0.

37) *Amalanchier nevadensis* (leaves)--The scientific binomial name for fossil plants that show great similarity to today's western serviceberry (pigeon berry) *Amelanchier alnifolia*, which grows naturally in central and southern Alaska, western to central Canada, Washington, Oregon, northwestern California, Nevada (scattered occurrences), Idaho, Montana, North Dakota, South Dakota, northern Nebraska, Wyoming, Colorado, and Utah from sea level (north) to 2,600 m (8,530 feet) in California and 3,400 m (11,200 feet) in the Rocky Mountains. 0, 40, 0, 0, 19, 6, 0, 1, 0.

38) ***Ceanothus leitchii*** **(leaves)--Fossil binomial name for the modern Tobacco brush (snowbrush ceanothus)** ***Ceanothus velutinus*****, widespread in Alberta and British Columbia, south through Washington, Oregon, California, Idaho, Montana, Wyoming, South Dakota, Utah, and Colorado from sea level to elevations from 450 to 3,050 meters (1,476 to 10,000 feet). 0, 2, 0, 0, 5, 6, 0, 0, 0.**

39) ***Rhamnus columbiana*** **(leaves) This is the paleobotanical name given to fossils of the living California coffeeberry (a buckthorn)** ***Frangula californica*** **(used to be called** ***Rhamnus californica*****); presently native to California, southwestern Oregon, southern Nevada, Arizona, western New Mexico, and Baja California Mexico, preferring oak woodlands and chaparral habitats. 1, 0, 0, 1, 0, 0, 0, 0, 0.**

40) ***Amelanchier alvordensis*** **(leaves)--The Miocene designation for the modern western serviceberry** ***Amelanchier alnifolia*****, whose native habitat ranges from Alaska through western to central Canada, and then south to Washington, Oregon, northwestern California, Idaho, mainly western and eastern Montana, North Dakota, South Dakota, western Minnesota, northwestern Iowa, northern Nebraska, Wyoming, Colorado, Utah, and scattered patches in Nevada at elevations from sea level in its northernmost ranges to 2,600 m (8,530 feet) in California) and 3,400 m (11,200 feet) in the Rocky Mountains. 0, 40, 0, 7, 19, 0, 0, 1, 0.**

41) ***Cercocarpus antiquus*** **(synonymous with** ***Cercocarpus nevadensis*****) (leaves)--The binomial term paleobotanists give to the fossil variety of today's mountain mahogany** ***Cercocarpus betuloides,*** **distributed natively in California, Oregon, Arizona, northwestern New Mexico, and Baja California Mexico, where it typically prefers chaparral communities in summer dry foothills and mountains. 2, 43, 2, 36, 172, 0, 1, 7, 0.**

42) ***Cercocarpus linearifolius*** **(leaves)--The fossil representative of the living curl-leaf mountain mahogany** ***Cercocarpus ledifolius*****, now native to extreme southeastern Washington, Oregon, California (mainly western Sierra Nevada foothills), Nevada, northern Arizona, Utah, western Colorado, western Montana, and northern Baja California Mexico, where it typically forms scattered groves in pinyon pine-juniper-sagebrush ecosystems at elevations from 600 to 3,000 m (2,000 to 9,800 feet), preferring well-drained sandy or grainy soils in areas that receive on average 15–26 cm (6 to 10 inches) precipitation per year. 0, 2, 0, 0, 0, 1, 0, 0, 0.**

43) ***Heteromeles sonomensis*** **(synonymous with** ***H. stenophylla*****) (leaves)--The paleobotanical name given to fossil specimens of the extant toyon (also called Christmas berry)** ***Heteromeles arbutifolia*****, native to coastal sagebrush and chaparral communities of southwestern Oregon southward to California's Coast Ranges (beginning in Humbolt County) and Transverse Ranges; a disjunct population inhabits the western foothills of the Sierra Nevada. Its natural range extends to northern Baja California Mexico. 0, 0, 0, 1, 3, 6, 0, 0, 0.**

44) ***Holodiscus idahoensis*** **(leaves)--Paleobotanical binomial name for fossil specimens of the living oceanspray** ***Holodiscus discolor*** **var.** ***glabrescens*****, which in native habitat extends from western Canada south to Washington, Oregon, California, Nevada, Idaho, Montana,**

Utah, and Colorado; prefers old-growth conifer, seral and old-growth hardwood, mixed-riparian, and mixed-shrub environments. 0, 0, 0, 1, 13, 0, 0, 2, 0.

45) *Cornus ovalis* (leaves)--The genus-species provided for fossils that match structures produced by the modern California dogwood/western dogwood *Cornus californica* (synonymous with *Cornus sericea* ssp. *occidentalis*), endemic to California--primarily, the central to northern Sierra Nevada and the northwestern to southern coastal areas at elevations from sea level to 2,438 meters (8,000 feet). 0, 1, 0, 0, 0, 0, 0, 0, 0.

46) *Prunus chaneyii* (leaves)--This is the fossil equivalent to the extant Western chokecherry *Prunus virginiana* var. *demissa*, presently native to northern, southern and central California, preferring in natural habitat rocky slopes at elevations from 0-8200 feet. *Prunus chaneyii* also occurs in the middle Miocene Pyramid Formation. 1, 3, 0, 1 0, 1, 0, 1, 0.

47) *Robinia californica* (leaves)--The paleobotanical analog to the living New Mexican black locust *Robinia neomexicana*, endemic to California (eastern Mojave Desert and San Gabriel Mountains sky island pinyon pine-juniper habitats, usually at elevations higher than 1,524 meters--5,000 feet), southeastern Nevada, southwestern Utah, Arizona, New Mexico, central and southeastern Colorado, New Mexico, extreme western Texas, and northern Mexico at altitudes between 1,200 and 2,600 meters (4,000-8,500 feet) along streams, at the bottoms of valleys, and the sides of canyons. 0, 2, 0, 1, 1, 2, 0, 0, 0.

48) *Rosa shornii* (leaves)--Named in honor of paleobotanist Howard Schorn, former collections manager of fossil plants in the University California Museum of Paleontology, Berkeley, California; the Miocene analog to the modern California wildrose *Rosa californica* now native to California (notably, coast and foothills up to elevations of 6,000 feet), Oregon and northern Baja California Mexico. 0, 1, 0, 0, 0, 0, 0, 0, 0.

49) *Sorbus cassiana* (leaves)--The genus-species designation for fossil plant structures quite similar to those generated by the living whitebeam (mountain ash) *Sorbus pohuashanensis* (synonymous with *Sorbus aucuparia* subsp. *pohuashanensis*), presently endemic to north and northeast China. 0, 0, 0, 1, 4, 1, 0, 0, 0.

50) *Vaccinium sophoroides* (leaves)--Paleobotanical name for the extant *Vaccinium corymbosum*, the northern highbush blueberry, native to Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New York, Pennsylvania, Maryland, New Jersey, West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida, Tennessee, Kentucky, Mississippi, Alabama, Louisiana, Texas, Oklahoma, Kansas, Missouri, Iowa, Wisconsin, Michigan, Illinois, Indiana, Ohio, and Canada. 1, 0, 0, 0, 0, 1, 0, 0, 0.

51) *Leucothoe nevadensis* (leaves)--The fossil genus-species for today's Sierra laurel *Leucothoe davisiae*, endemic to extreme southwest Oregon and the Sierra Nevada and Klamath Mountains of California, inhabiting mountain bogs and wetlands at altitudes from 400--3,000 meters (1,312 to 9,842 feet). 0, 0, 0, 0, 0, 1, 0, 0, 0.

52) *Lyonothamnus parvifolia* (synonymous with *L. cedrusensis*) (leaves)--A presumably

extinct species whose fossil leaves mostly match those produced by the extant Santa Cruz Island Ironwood *Lyonothamnus floribundus* ssp. *asplenifolius*, presently endemic to Santa Cruz Island off the coast of southern California, where it likes chaparral and oak woodlands in rocky coastal canyons at elevations from 100 to 1,600 feet (30 to 487 meters). 2, 3, 0, 0, 0, 0, 2, 5, 2.

53) *Populus cedrusensis* (leaves)--Paleobotanical designation for fossil material that closely resembles the modern guerigo (also called white bark cottonwood) *Populus brandegeei* (synonymous with *Populus monticola*), known in native range from nouthern Baja California to east-central Sonora Mexico. 0, 10, 0, 1, 1, 0, 0, 0.

54) *Populus eotremuloides* (synonymous with *P. bonhamii*) (leaves, one capsule)--The scientific genus-species designation for paleobotanical remains that closely resemble the modern black cottonwood *Populus balsamifera.* subsp *trichocarpa*. which today populates portions of southern Alaska southward through western Canada, Washington, Oregon, California (northwestern, western foothills of the Sierra Nevada, and spotty places in southern areas), northern to central Idaho, western Montana, and northern Baja California Mexico; also documented in scattered patches in southeastern Alberta, eastern Montana, western North Dakota, western Wyoming, Utah, and Nevada. 5, 156, 4, 38, 66, 42, 14, 53, 0.

55) *Populus payettensis* (leaves)--The Miocene analog to the modern narrowleaf cottonwood *Populus angustifolia*, which today has a wide geographic range of natural habitat--southern Canada, southward to Montana, Idaho, Wyoming, Colorado, Utah, Arizona, New Mexico, northeast Nevada, eastern California, southeastern Oregon, western Texas, and northern Mexico--mainly along streams and creeks at elevations from 3,900 to 7,900 feet (1,200 to 2,400 m). 0, 2, 0, 0, 0, 6, 0, 0, 3.

56) *Populus pliotremuloides* (leaves)--Paleobotanical genus-species for fossil leaves that match the living quaking aspen *Populus tremuloides*, one of the most widespread trees in North America, ranging in native populations from Alaska through most of Canada, south to every US state except Kansas, Oklahoma, Arkansas, Louisiana, Alabama, Mississippi, Florida, Georgia, South Carolina, North Carolina, Tennessee, and Kentucky. 0, 10, 0, 0, 0, 2, 0, 1, 1.

57) *Salix churchillensis* (leaves)--The Miocene paleobotanical designation for the modern sandbar willow (coyote willow) *Salix exigua* subspecies *exigua*, which now populates places southward from southern Canada to eastern Washington, eastern Oregon, eastern California, Idaho, Nevada, southwestern Montana, western Wyoming, Utah, Colorado, Arizona, New Mexico, western Texas, and northern Mexico. *Salix churchillensis* also occurs in the middle Miocene Pyramid Formation. 11, 17, 0, 1, 10, 9, 0, 2, 2.

58) *Salix desatoyana* (leaves)--Genus-species paleoboanists give to fossil leaves that show little variation from living foliage of the black willow *Salix nigra*, native to southeastern Canada, southern Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New Jersey, Maryland, North Carolina, South Carolina, Georgia, northwest Florida, Mississippi, Alabama, Louisiana, eastern Texas, Oklahoma, Arkansas, Tennessee, Kentucky, Pennsylvania, New York, southern Michigan, Ohio, Indiana, Illinois, Iowa, Wisconsin, Missouri, southeastern Minnesota, eastern Kansas, central to southern California, Arizona,

New Mexico, southern Utah, and northern Mexico. 0, 16, 0, 2, 6, 2, 0, 1, 0.

59) *Salix inquirenda* (leaves)--The Miocene equivalent of today's *Salix lasiandra*, the Pacific willow, widely distributed from Alaska southward through western to central Canada, Washington, Oregon, California, Idaho, Montana, Wyoming, Colorado, Arizona, and New Mexico. A species that also occurs in the middle Miocene Pyramid Formation. 0, 2, 0, 2, 0, 0, 0, 0, 0.

60) *Salix laevigitoides* (leaves)--The fossil equivalent to the modern red willow *Salix laevigata*, which today is found mainly from Cape Mendocino (California coast), southward into northern Baja California Mexico. It also occurs in the lower elevation western foothills of California's Sierra Nevada, southern Nevada, southwestern Utah, and central Arizona. 0, 15, 0, 10, 12, 18, 0, 80, 2.

61) *Salix pelviga* (leaves)--This is the fossil genus-species for the living dusky willow *Salix melanopsis*, native to British Columbia and Alberta southward to California and Colorado, where it likes moist riverbanks and subalpine mountain meadows. This species is also found in the middle Miocene Pyramid Formation. 1, 8, 1, 23, 20, 68, 1, 0, 3.

62) *Salix storeyana* (synonymous with *S. knowltonii*) (leaves)--Paleobotanical designation for the extant Lemmon's willow *Salix lemmonii*, native to southeastern Washington, eastern two-thirds of Oregon, northern Nevada, Idaho, southwestern Montana, northwestern Wyoming, and eastern California (with an isolated population in inland southern California). 0, 12, 3, 1, 0, 0. 0, 0, 0.

63) *Salix wildcatensis* (leaves)--Scientific bionmial name for leaves that show no appreciable difference from today's arroyo willow *Salix lasiolepis*, which in native habitat currently populates portions of central to southern Washington, Oregon, western Idaho, California, Nevada, central to southwestern Utah, Arizona, southern New Mexico, western Texas, and north Mexico, typically in riparian zones situated in canyons and valleys, pond shores, marshes, and wetlands. 0, 0, 0, 0, 0, 3, 1, 0, 0.

64) *Alnus spokanensis* (leaves, cones): The fossil equivalent of the modern speckled alder *Alnus incana* subspecies *rugosa*, which today ranges in natural habit from Canada to northern North Dakota, Minnesota, Wisconsin, Michigan, northeastern Iowa, northern Illinois, northern Indiana, northern Ohio, Pennsylvania, western Maryland, eastern West Virginia, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. This species also occurs in the middle Miocene Pyramid Formation. 0, 1, 0, 0, 0, 0, 3, 0, 0.

65) *Garrya idahoensis* (leaves): Fossil name given to plant structures that most resemble the living California fever bush *Garrya fremontii*, which inhabits California, western Oregon, and southern Washington in both forested and chaparral associations. 0, 0, 0, 0, 1, 0, 0, 0, 0.

66) *Equisetum* sp. (stems)--Structures that closely resemble stems from the living horsetail, genus *Equisetum*, probably allied with the scouring rush of worldwide geographic botanical

distribution. 1, 0, 0, 0, 0, 0, 0, 0, 0.

67) *Typha lesquereuxii* (leaves)--The genus-species paleobotanists give to fossil structures that match those produced by the extant bulrush (broadleaf cattail) *Typha latifolia*, native to every US state except Hawaii, Canada, North and South America, Europe, Eurasia, and Africa. It is an obligate wetlands botanic specimen, requiring watery environments to propagate. 4, 0, 1, 0, 0, 0, 0, 0, 0.

68) *Pteridium calabazensis* (pinnules)--The paleobonical designation for fossil material that closely resembles the living bracken (eagle fern) *Pteridium aquilinum*, presently found on all continents except Antarctica. 0, 2, 0, 0, 0, 0, 0, 0, 0.

I arrived back home reinvigorated with paleobotanical zeal after my excellent expedition. Consecutive days of solitary isolation amidst ancient strata that told true tales of abundant flourishing vegetation in a land left with arid botanic austerity had inspired a consuming need to learn all that I could of what once existed there all those many millions of years ago, to move through space and time in a quantum-like delirium of amazed revelry, seeing now the infinity of geologic time transpire in a continuum of imagination's revelatory reality, where fir and spruce and maple and birch and giant sequoias rise once again above a cool clear lake in the desert as a distant volcano only awaits its moment to preserve eternity.

Chapter 36

Early Cambrian Fossils Of Westgard Pass, California

Many species of plants and animals have become extinct throughout the geologic past. Ammonites, trilobites, and dinosaurs are among the more familiar types whose vanished representative lineages now famously reside within the rocks of the earth's crust. Still, despite the fact that such sensational, long-lived species died out, the larger grouping or classification of animals to which they belonged continues to survive to this date. The ammonite, for example, was a cephalopod mollusk--rather distantly related to our modern day chambered nautilus; the trilobite, in turn, belonged to a scientific phylum called Arthropoda, a phylum that includes such successful relatives as insects, crabs, crustaceans, and spiders; and the dinosaurs of course were vertebrate animals, whose backboned kinds are very much alive and well.

While each of the above-listed creatures became extinct for varying paleobiological reasons, the broader category, or phylum to which they belonged has survived. And, as far as paleontologists can determine, virtually all the major groups of animals present during the dawn-age Cambrian Explosion of approximately 535 to 510 million years ago, when there occurred a phenomenal unprecedented radiation of biological diversification, are still alive today--despite the fact that capricious culling periodically eliminates innumerable species throughout geologic time.

A notable exception to this pattern of persisting phylum survival is the paleontological occurrence of curious critters paleontologists call *Salterella* and *Volborthella*. They're invertebrate animals exclusive to the Early Cambrian that secreted conical to ice cream cone-shaped shells roughly a quarter inch-long long; and they're now placed into their own unique phylum called Agmata, a phylum that went belly-up, extinct, approximately 510 million years ago--among only a select few of the major taxonomic categories of animals ever to vanish completely, leaving no discernible descendants or relatives.

To put this in perspective, the extinction of an entire phylum such as Agmata is analogous to having all the corals, for example, disappear from our oceans--or, every animal with a backbone suddenly gone forever. By all speculative accounts, this was a terribly traumatic event in the history of our planet. Prime hunting grounds for Agmata small shelly fossils include the Great Basin wilds of western to central Esmeralda County, Nevada.

Yet another fascinating animal preserved in rocks exclusively of Early Cambrian geologic age is the enigmatic archaeocythid, an invertebrate type that along with Agmata *Salterella*-

Volborthella and Olenellid trilobites thrived in earth's warm shallow seas roughly 528 to 510 million years ago. Although none of those creatures survived beyond the Early Cambrian age, only the Agmata represents a complete, unique phylum that went extinct. Olenellid trilobites and archaeocythids belong to the living phyla Arthropoda and Porifera (the sponges), respectively.

Still and all, for many years a consensus of invertebrate paleontologists considered archaeocyathids members of their own unique phylum called Archaeocyatha, preferring to count them among the select few phyla ever to go belly-up, to vanish forever with no known modern biological affinity.

The archaeocyathid was an exclusively marine invertebrate animal that never survived beyond the Early Cambrian of the Paleozoic Era; it goes absent from the geologic record around 510 million years ago. Yet, during a life span of perhaps "only" 18 million years (roughly 528 to 510 million years) it was able to attain worldwide distribution while developing into scores of different species. In morphological aspect, an archaeocyathid has been variously described as a peculiar cross between a coral and a sponge. While it admittedly reveals obvious similarities to both, it is in fact decidedly different in many key morphological comparisons.

Pioneering Early Cambrian investigators separated almost immediately into two warring camps over the exact zoological classification of the archaeocyathid. That is to say: just where exactly should one place the animal--is it a coral or sponge? Some paleontologists argued in favor of the coral category (see the classic 1868 publication _On a remarkable new genus of corals_ in American Journal of Science, 2nd service, volume 46, pages 62-64), while others--the majority opinion, actually--vociferously proclaimed that it most closely resembled a sponge; hence the ubiquitous, "endearing" term "pleosponge" came about to describe the archaeocyathid, a designation still found in many older textbooks on invertebrate paleontology.

Although it's true that both battling camps could adduce compelling evidence to support their views, all the controversy occurred before any exhaustive analysis of the archaeocyathid was undertaken. When some especially well preserved specimens were finally examined with that proverbial fine-toothed comb, paleontologists came to the conclusion that, yes, while the archaeocyathid did show apparent similarities to both corals and sponges, it was indeed sufficiently different from coral coelenterates and typical Porifera to warrant placement in a new, separate phylum--then known as Archaeocyatha.

That zoological classification of archaeocyathids as a distinct, unique phylum lasted for several decades. When somebody named a new species of archaeocyathid, the official peer-reviewed scientific paper in which the formal description appeared always placed an archaeocyathid type specimen within the phylum Archaeocyatha. In later years, though, rigorous cladistic phylogenetic analysis nested archaeocyathids pretty convincingly among the Porifera--the sponges; more specifically, it is now usually considered an extinct calcareous sponge--the first shell-secreting member of the phylum Porifera to appear during the Cambrian Explosion, and the very first known sponge to go extinct, disappear completely from the geologic record.

Since the actual archaeocyathid soft-bodied animal has never been found preserved, researchers base their conclusions concerning the creature on study of the available fossil shell material. The archaeocyathid secreted a conical to cup-shaped calcium carbonate structure typically half an inch to three inches longs, and one-eighth to one inch in diameter. A few aberrant species can reach a foot or more in length, however. Some varieties in the class Irregularia began to sport wildly radiating, branching shell designs, a feature which distinguishes them from all other kinds of archaeocyathids. Most, though, retained their conical, elongated configuration right up to the end of their reign. Apparently the creature led a sessile life attached to the sea floor; some types sometimes formed minor reef-like communities. As a matter of fact, it seems to have been the very first Cambrian Explosion shell-bearing animal to develop a quasi-reef, or biohermal structure on the sea floor, a life-style greatly improved upon by the corals, which succeeded the archaeocyathid in the geologic record during Ordovician Period times.

Typically, archaeocyathids formed "gardens" in the shallow Early Cambrian seas, parallel to the ancient coastlines, where they probably fed by filtering for microscopic plants and animals, similar to the habits of present day sponges, corals, bryozoans, brachiopods, and barnacles. Their shell was extremely fragile--it is indeed miraculous that we have as many complete specimens to study as we do--and they disdained with a passion any degree of muddy water. It is conjectured that they reproduced by giving rise to free-floating larvae that swan about for a time before settling to the sea floor. Additionally noteworthy is that sometimes seen preserved with archaeocyathids are the remains of cyanobacterial blue-green algae, suggesting some degree of symbiotic relationship.

All archaeocyathids became extinct by the close of the Early Cambrian, approximately 510 million years ago. They left no discernible descendants. They remain the only major group of sponges to leave no living representatives. In North America and Australia, extinction of the archaeocyathids coincides with the disappearance of Olenellid trilobites, and this leads to the interesting idea that perhaps the two shared some kind of symbiotic, mutually beneficial

relationship, perishing in tandem when their required conditions for life vanished. Exactly why the archeocyathid died out is a major paleontological mystery, much like the more notorious debate over the demise of the dinosaur. Perhaps the most logical hypothesis is that the archaeocyathid, possessing a very primitive silt filtering system, was unable to adapt to increasingly muddy waters, that corals and siliceous sponges were much more efficient, successful adapters in general, and therefore were primed and ready to claim each available paleo-ecological niche the archaeocyathid was forced to surrender. This idea finds support in the lithology of the rocks in which fossil archaeocyathids are today preserved: They occur almost exclusively in pure limestones that are uncontaminated by silts or muds.

Because archaeocyathids gained worldwide distribution within such a finite, "short" life span--around 18 million years--they are an excellent guide fossil to the Early Cambrian geologic age. Find an archaeocyathid anywhere on the planet and you know immediately that you are dealing with rocks dating from the Early Cambrian. Their remains have been identified from several geographic localities, including Morocco, Sardinia, Mexico, Yukon Territory, British Columbia, Labrador, China, Ural Mountains of Russia, Siberia, East Antarctica, West Antarctica, Australia, and the United States.

In the United States, archaeocyathids occur in Alaska, Washington state, Nevada, and California. As a matter of fact, some of the best archaeocyathid localities in the world occur in western to central Nevada and eastern California. Here, sprawling across an area encompassing hundreds of square miles in Inyo County, California, and neighboring Esmeralda County, Nevada, lies the land of the archaeocyathid. Most occur in a geologic rock unit called the Poleta Formation, lower Cambrian in age of course, a formation named for its extensive and typical exposures in Poleta Canyon a few miles east of Bishop, California. This is a remarkably widespread and distinctive series of strata consisting of alternating layers of limestones, quartzites (heat and pressure-altered sandstone), and shales. And, in keeping with their invariable characteristic distribution in other parts of the world, archaeocyathids occur only in the silt-free limestones. Within the Poleta Formation, these fossil-bearing calcium carbonate accumulations can be found in the lowest, or oldest stratigraphic sections of exposures, below thick deposits of Poleta greenish shales and brownish quartzites which, while barren of archaeocyathids, are noted for locally common trilobites, annelid trails, and echinoderms.

These preserved archaeocyathids represent, in fact, some of the oldest recognizable remains of animals with hard parts from the Cambrian Explosion period, which began 535 million years ago--a moment in geologic time some 965 million years after the appearance of what scientific investigators consider the first undisputed eukaryote (a cell with a nucleus; all complex, modern plant and animal life is eukaryotic) and only about 65 million years

following the first multicellular eukaryotic animals at roughly 600 million years ago (the earth is approximately 4.55 billion years old).

Prime hunting grounds for the fossil include western to central Nevada and the northernmost quarter to third of Inyo County, California. And one of the very best regions in which to paleo-prospect for archaeocyathids lies a few miles east of Big Pine, California, in the White-Inyo Mountains along Westgard Pass. The drive over State Route 168 toward Westgard Pass slices through several thick outcroppings of the fossiliferous limestones lowest in the Poleta Formation, within which occur locally common to abundant remains of archaeocyathids, some in primitive reef form.

To reach an excellent fossil-bearing area where nice specimens of archaeocyathids can be found, first travel to Big Pine, California, a wonderful community in the Owens Valley at the base of the great Sierra Nevada, 15 miles south of Bishop, or 44 miles north of Lone Pine along Highway 395. From the northern outskirts of Big Pine along Highway 395, take State Route 168 east. But be sure to stop to observe the striking specimen of giant sequoia (Big Tree-Sierra Redwood) at the intersection of 395 and State Route 168--it's The Roosevelt Tree, planted July 23, 1913 in honor of US president Teddy Roosevelt, to commemorate the opening of SR 168 to automobile traffic over Westgard Pass. Proceed two and four-tenths miles to the intersection with the Death Valley-Saline Valley Road. Recheck your mileage here, then continue onward along SR 168.

From the junction with Death Valley-Saline Valley Road, travel another nine and nine-tenths miles. At this point route 168 begins to cut through a "narrows" in the limestones of the lower Cambrian Poleta Formation; the limestones here are massive (showing indistinct layering characteristics), blue-gray to orange-mottled, and fossiliferous with the remains of archaeocyathids. For the next six-tenths of a mile the Poleta limestones are prominent and easily accessible on both sides of SR 168. Find a convenient--and safe--pullout on which to park (the road does indeed narrow considerably here; extreme caution must be exercised), then hike to the slopes above the road to the locally fossiliferous calcium carbonate accumulations.

You will need to hike with assiduous attention in order to observe the best-preserved specimens. Remember, obviously, that lots of folks have been here before you, including innumerable geology classes from all over the United States, Canada, and Mexico--in addition to any number of interested amateur paleontology enthusiasts and visiting professional paleontologists from all over the world, as well. And so it is inevitable, then, that everybody must indeed have their own turn at exploring these remarkable Poleta archaeocyathid-bearing exposures, and multitudes who've previously secured a special use permit from the

US National Forest Service invariably collect "a few" sample specimens to take home. Nevertheless, with attentive and dedicated searchings one should be able to spot here many nicely preserved archaeocyathids, some preserved in their original growth positions for roughly 520 million years in isolated reef-like communities. Watch for their distinctive cross-sections approximately a quarter to one-half inch in diameter, an oval to circular section revealing a double outer wall separated by many partitions. In longitudinal, or lengthwise section, most specimens measure around one-half to two inches long. Among the more commonly observed genera in the rocks are *Ethmophylum*, *Ajacicyathu*s, *Archaeocyathus*, *Protophaetra*, *Annulofungia*, and *Robustocyathus*.

Lying in stratigraphic position above the archaeocyathid-bearing limestones are exposures of greenish to olive-gray shales and quartzites representing progressively younger deposits of the Poleta Formation. In these mostly detrital strata occur scattered and localized concentrations of trilobites, including such genera as *Esmeraldina*, *Fremontia*, *Laudonia*, *Nevadella*, *Nevadia*, and *Holmia*. Also identified from the interstratified shales and quartzites have been brachiopods, hyolithids (an extinct lophophorate), and two early forms of echinoderms, *Helicoplacus* and an edrioasteroid--the oldest remains of echinoderms ever discovered. As a matter of fact, both *Helicoplacus* and the Olenellid trilobites here represent the very first shell-bearing members of their respective phyla (Echinodermata and Arthropoda) to appear in rocks deposited during the Cambrian Explosion, and became the first types from their major zoological groups to go extinct. Among the most commonly observed paleontologic specimens in the Poleta Formation shales and quartzites are very conspicuous ichnofossils-- annelid and arthropod trails preserved as sinewy ridges several inches in length, winding their way across the bedding planes. Over in neighboring Esmeralda County, Nevada, by the way, the Poleta Formation Cambrian Explosion sedimentary rocks also yield quality specimens of *Anomalocaris*, an extinct presumably predatory arthropod that probably terrorized trilobites during the Early Cambrian.

While this general area provides excellent opportunities to find archaeocyathids, other sites along SR 168 between "the narrows" and Westgard Pass up ahead (farther north) also often disclose locally common examples of additional Early Cambrian invertebrate fossils preserved in the Poleta Formation and the stratigraphically older underlying Montenegro Member of the Campito Formation--a predominantly detrital unit of greenish to tan shale and brownish quartzite that yields sporadic occurrences of Olenellid trilobites, primarily. Outcropping below the Montenegro Member is the Andrews Mountain Member of the Campito Formation; near the top (youngest horizons) of the Andrews Mountain Member, in strata close to 522 million years ancient, the oldest trilobites in North America--and possibly the world--have been discovered, a Fallotaspid form resembling the Siberian trilobite *Repinaella*.

For those planning a visit to the Westgard Pass area in search of paleontologic specimens, several fine reference publications are available for study. Among the more informative works are: *Guidebook for Field Trip to Pre-Cambrian-Cambrian Succession White-Inyo Mountains, California* by C.A. Nelson and J. Wyatt Durham; *Stratigraphic Distribution of Archaeocyathids in the Silver Peak Range and White and Inyo Mountains, Western Nevada and Eastern California* by Edwin H. McKee and Roland A. Gangloff, Journal of Paleontology, volume 43, number 3, May, 1969; and *Geologic Map of the Blanco Mountain Quadrangle, Inyo and Mono Counties, California*, U.S. Geological Survey Quadrangle Map 529. This last one shows the geographic distribution of outcrops of rock formations in the Westgard Pass area, drawn over a topographic base map--an invaluable reference to consult when exploring here.

In addition to the significant fossils, there are other wonders to explore in the Westgard Pass lands. To the immediate west and north, for example, lie the famous Bristlecone Pine groves in the White Mountains at elevations over 10,000 feet. Here, the oldest continuously living, non-cloning thing on earth--the Bristlecone Pine, a few have been accurately calculated at over 4,000 years old--survives atop a geologic rock formation, the Reed Dolomite, that dates from earth's oldest geological division, the Precambrian of over 550 million years ago. This is certainly a unique and appropriate coincidence.

When hunting for fossils in the Westgard Pass region, be sure to abide by the rules and regulations--don't keep anything found within the Inyo National Forest unless you've obtained a special use permit from the US Forest Service ranger station in Bishop, California. Also, by way of caution, elevations here range from around 7,000 feet to way over 10,000 feet, so try to keep your physical activities moderate until you are well-acclimated. There is a vast area of potential fossil-bearing material to explore and it would be inadvisable--not to mention downright risky--to try to cover it all in a single day. With so much recreation so accessible, this would be an ideal place for a stay of a week or two, preferably during summer when the roads at higher elevations are open.

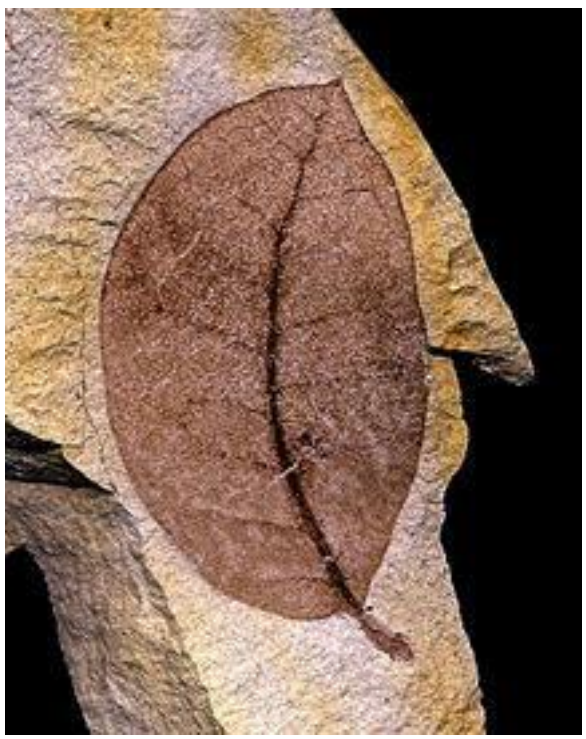
During the Early Cambrian, the Westgard Pass area was a warm shallow sea situated near the equator in which numerous species of now long-extinct animals flourished--among them, the very first shell-bearing examples of three great zoological categories to appear in sedimentary strata deposited during the crucial Cambrian Explosion period of 535 to 510 million years ago--Olenellid trilobites, *Helicoplacus* echinoderms, and archaeocyathids who, individually, belong to the living phyla Arthropoda, Echinodermata and Porifera, respectively.

Perhaps we may never fully understand the exact reasons for their complete disappearance, yet because Olenellid trilobites, *Helicoplacus* echinoderms, and archaeocyathids were the

first of their respective phyla to contribute no more to the geologic record beyond the Early Cambrian of 510 million years ago, their paleontological presence together at Westgard Pass demonstrates that they never really went away; they're still alive, on their way to a kind of immortality--a vanished invertebrate association of Cambrian Explosion creatures who now survive not only in the rocks, preserved in place for over a half billion years, but also in the lives of prehistory explorers, so that we may learn of a time and remember for all time a distant age when multicellular animal life on earth was relatively new, and of perilous existence.

On-Site Images and Photographs of Fossils From Each Field Trip

Images for Chapter 1—Fossil Plants At Aldrich Hill, Nevada



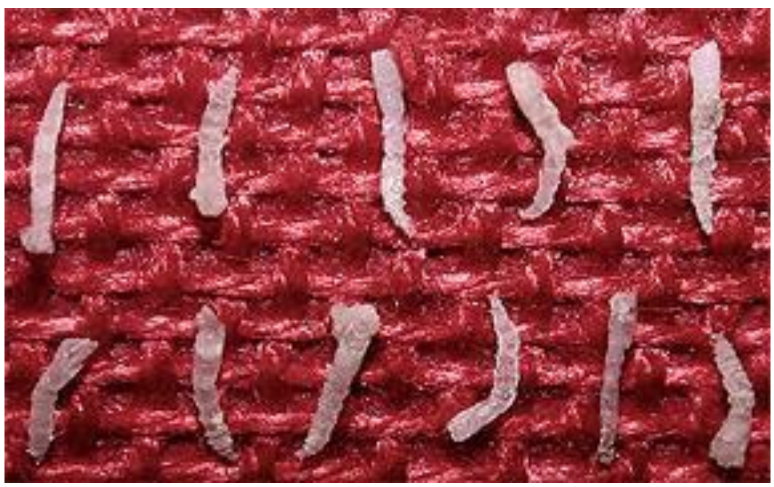
View northeast across the Middle Miocene Aldrich Station Formation at Aldrich Hill, Nevada. Bottom—an evergreen live oak leaf, *Quercus pollardiana* (similar to the modern maul oak native to the western slopes of California's Sierra Nevada) from the middle Miocene Aldrich Station Formation, Aldrich Hill, Nevada.

Images for Chapter 2—A Visit To Ammonite Canyon, Nevada

An explorer of the Mesozoic Era is standing on the ammonoid-bearing upper Triassic section of the upper Triassic-lower Jurassic Gabbs Formation in Ammonite Canyon, Nevada—around 205 to 202 million years old. Lower Jurassic Gabbs Formation strata yield ammonites. Bottom—An ammonite, called scientifically *Psiloceras pacificum* from the lower Jurassic Sunrise Formation, Ammonite Canyon, Nevada.

Images for Chapter 3

Fossils Insects And Vertebrates On The Mojave Desert, California



Parked in Fossil Insect Canyon, Mojave Desert, California. Insect-bearing middle Miocene Barstow Formation is the pale brownish swath at upper left to center; calcareous concretions here bear abundant silicified fresh water arthropods. Bottom—Midge insect pupae dissolved out of concretions from the middle Miocene Barstow Formation of Fossil Insect Canyon. Called *Dasyhelea australis antiqua*. This particular species of midge, interestingly enough, is most closely related to the modern *Dasyhelea australis australis*, now living on Islas Juan Fernandez, about 400 miles west of Santiago, Chile. Pupa at upper right is 4mm long (.16 of an inch).

Images for Chapter 3

Fossil Insects And Vertebrates On The Mojave Desert, California

Typical outcrops of bone-bearing beds in the upper member of the middle Miocene Barstow Formation at Fossil Bone Basin, Mojave Desert, California. Strata here are roughly 15 to 13.4 million years old. Bottom—An astragalus (commonly called an ankle bone) from an extinct species of three-toed horse called *Scaphohippus*; observed in the middle Miocene Barstow Formation, Fossil Bone Basin, California.

Images for Chapter 4

Fossil Plants At Buffalo Canyon, Nevada

Parked in Buffalo Canyon area, Nevada. Leaf, seed, and twig-bearing middle Miocene Buffalo Canyon Formation exposed on ridge at upper left to center. Bottom—A complete leaf from a zelkova (a member of elm family) called scientifically, *Zelkova brownie*, from Buffalo Canyon, Nevada. Leaves from evergreen live oaks and a birch are co-dominants of the Buffalo Canyon fossil flora; zelkova is found far less frequently.

Images for Chapter 5

Ordovician Fossils At The Great Beatty Mudmound, Nevada

Looking at a distance to the great Beatty Mudmound, Nevada, which is the pale gray pod-shaped body just below the skyline at upper center to right. The flanks of the mudmound produce prolific quantities of silicified (replaced by silicon dioxide) invertebrate fossils some 480 million years old; the fossils are preserved in the early middle Ordovician Antelope Valley Limestone. Bottom--complete brachiopod, with both valves intact, called *Pleurorthis beattyensis* from the Beatty Mudmound, middle Ordovician Antelope Valley Limestone. Also found at the Beatty Mudmound are bryozoans, cephalopods, conodonts, ostracods, and trilobites.

Images for Chapter 6

Fossil Plants And Insects At Bull Run, Nevada

A seeker of paleobotanical adventure inspects a plant and insect locality in the upper Eocene Chicken Creek Formation, Bull Run, Nevada. Bottom-- Here is a winged seed from a spruce, collected from the upper Eocene Chicken Creek Formation, Bull Run Basin, Nevada. It appears to most closely resemble a species the late paleobotanist Daniel I. Axelrod called *Picea coloradensis*, a fossil conifer that cannot be compared directly with any one living taxon, although it shows obvious relationships to two modern species--*Picea pungens* and *Picea engelmannii*, the Colorado Blue spruce and the Engelmann Spruce, respectively.

Images for Chapter 7

Field Trip To The Copper Basin Flora, Nevada

A view to Copper Basin, Nevada. Note the prominent outcrops of whitish tuffs of the upper Eocene Dead Horse Tuff lying below the more massive reddish-brown rhyolite. Local concentrations of beautifully carbonized 40-million-year-old leaf impressions occur within tuffaceous shale accumulations interbedded in the predominantly volcanic terrain. Bottom—A complete leaf from a species of alder, *Alnus jarbidgiana*, the most common fossil plant variety encountered in the upper Eocene Dead Horse Tuff at Copper Basin, Nevada. Also found are twileaves from tanbark oak, Oregon grape, and sassafras.

Images for Chapter 8

Trilobites In The Nopah Range, Inyo County, California

A trilobite hunter inspects the primary fossil locality in the lower to middle Cambrian Carrara Formation, Nopah Range, Inyo County, California. Here can be found several species of mostly disarticulated trilobites, although assiduous and dedicated splitting of the shales could well turn up complete specimens. Bottom--Trilobite head shields (also called cephalons) preserved on a slab of slightly metamorphosed shale, collected from the Nopah Range, Inyo County, California. *Ollenellus clarki*.

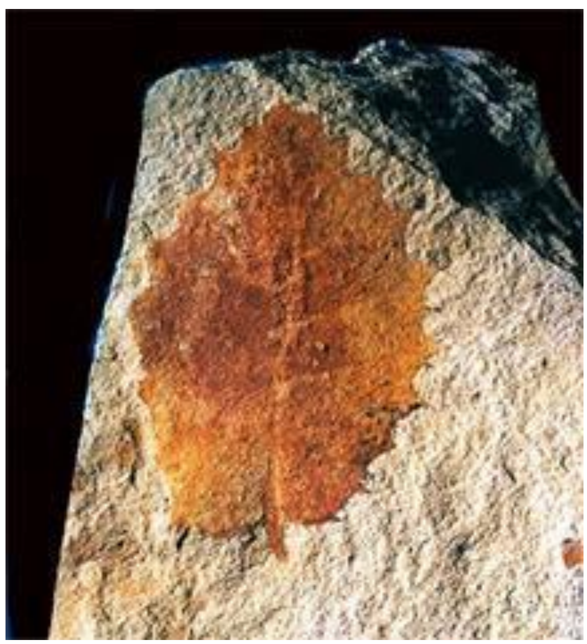
Images for Chapter 9

Field Trip To A Vertebrate Fossil Locality In The Coso Range, California

A desert explorer visits the upper Miocene to upper Pliocene bone-bearing Coso Formation, Inyo County, California. Bottom—A horse tooth from the 3.5 to 3.0 million years old.

Images for Chapter 10

Plant Fossils In The Dead Camel Range, Nevada



A paleobotany enthusiasist inspects the fossil plant locality in the middle Miocene Desert Peak Formation, Dead Camel Range, Nevada. Bottom--A whole evergreen live oak leaf of *Quercus pollardiana* from the middle Miocene Desert Peak Formation, Dead Camel Range, Nevada; it's very similar to the modern canyon live oak now native to the western slopes of the Sierra Nevada and the coastal ranges of California.

Images for Chapter 11

A Visit To The Early Cambrian Waucoba Spring Geologic Section, California

An individual interested in the Cambrian looks eastward to Early Cambrian rocks of the classic Waucoba Spring geologic section, California—nearest slopes at upper left to right. Below—a virtually complete trilobite found in the lower Cambrian Saline Valley Formation, before the Waucoba Spring section became part of Death Valley National Park.

Images for Chapter 12—Fossils In Millard County, Utah

Field Trips To Wheeler Amphitheater And Fossil Mountain

A trilobite hunter examines shales for fossil specimens in the middle Cambrian Wheeler Shale, Wheeler Amphitheater, Millard County Utah—arguably the single most famous trilobite locality in the world. Innumerable *Elrathia kingii* trilobites collected here have found their way into museums and private collections all around the world. Bottom—Two essentially complete trilobites of the genus-species *Elrathia kingii* from the middle Cambrian Wheeler Shale at Wheeler Amphitheater, Millard County, Utah. The extinct 505 million year-old arthropods can be popped free, whole and intact, by gently tapping the shale matrix upon which they reside with a geology rock hammer.

Images for Chapter 12—Fossils In Millard County, Utah

Field Trips To Wheeler Amphitheater And Fossil Mountain

An Early Paleozoic Era student stands on the lower Ordovician Juab Limestone near the base of Fossil Mountain in Millard County, Utah, certainly one the most prolific fossil-bearing Early to Middle Ordovician localities in North America. In the vicinity of Fossil Mountain can be found a great diversity of fossil types from the lower to early middle Ordovician House Limestone, Fillmore Formation, Juab Limestone, Wah Wah Limestone, Kanosh Shale, and Lehman Limestone (all members of the Pogonip Group)--algae, brachiopods, bryozoans, cephalopods, conodonts, corals, echinoderms, gastropods, graptolites, ostracods, pelecypods, sponges, and trilobites. "Cap Stone" at top of pyramidal Fossil Mountain is the middle Ordovician Eureka Quartzite. Bottom--Left to right: first two are isolated pedicle valves of brachiopods; far right is a pedicle valve view of a fully articulated brachiopod, with both pedicle and brachial valves preserved intact; genus-species of all three is *Shoshonorthis michaelis*, from lower Ordovician Kanosh Shale, Fossil Mountain, Millard County, Utah. The specimens are approximately 475 million years old.

Images for Chapter 13

A Visit To Fossil Valley, Great Basin Desert, Nevada

Seekers of the Miocene scene explore paper shales in the middle Miocene Esmeralda Formation at Fossil Valley, Nevada. The shales contain insects, leaves (both evergreen and deciduous varieties), seeds (from pine, fir, spruce, Douglas-fir, and maple), conifer needles, conifer foliage (from giant sequoia and cypress), pollens, bird feathers, and fishes some 14.5 million years old. Bottom—A fly from middle Miocene Esmeralda Formation, Fossil Valley, Nevada; the site is now off limits to unauthorized visitors.

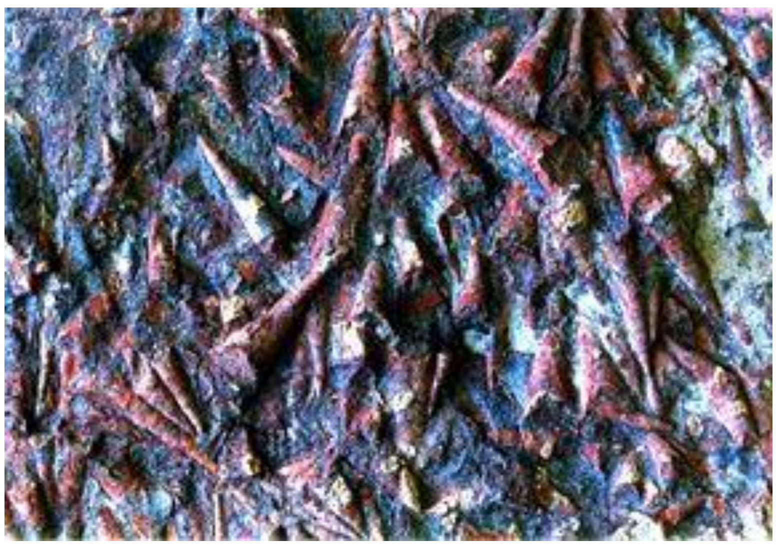
Images for Chapter 14

High Inyo Mountains Fossils, California

A view westward near the High Inyo Mountains fossil locality. Mount Whitney, the highest point in the contiguous United States at 14,495', is the peak just left of center along the Sierra Nevada skyline--a small white cloud touches its tip. Strata in the foreground include the upper Mississippian Chainman Shale, which yields many species of ammonoids, pelecypods, terrestrial plants, and even shark teeth at a unique fossil locality that lies in the vicinity of Cerro Gordo ghost town, Inyo County, California. Bottom—a pelecypod from the upper Mississippian Chainman Shale locality with both valves preserved intact, splayed open along the hinge line.

Images for Chapter 15

Early Cambrian Fossils In Western Nevada



A Cambrian explorer examines fossil-bearing rocks in the Gold Point district, Nevada. The lower Cambrian Harkless Formation here yields the single largest assemblage of Early Cambrian trilobites yet described from North America--at least 12 species of trilobites representing six Families. Bottom—*Salterella* (the "ice cream cone" fossil) preserved on shaly limestone in the lower Cambrian Harkless Formation, Gold Point site, Nevada. *Salterella* is placed in its own phylum Agmata. It never survived Early Cambrian times, some 510 million years ago.

Images For Chapter 16

Field Trip To The Kettleman Hills Fossil District, California

A person fascinated by the Pliocene visits the famous Pecten Zone in the middle Pliocene San Joaquin Formation, North Dome area, Kettleman Hills, California. It is difficult to hike that slope without stepping on perfect sand dollars that have weather out. Abundant scallop shells (pectens) also occur here in the San Joaquin Formation. Bottom--Sand dollars and pectens from the world-famous Pecten Zone of the middle Pliocene San Joaquin Formation, North Dome area, Kettleman Hills, California. Sand dollars are *Dendraster coalingensis*. The pectens are *Pecten coalingensis*.

Images for Chapter 17

Trilobites In The Marble Mountains, Mojave Desert, California

Visitors to the Marble Mountains, California, trilobite quarry search for fossil specimens, long before the area became part of a federal wilderness area, and then Mojave Trails National Monument in 2016. Bottom--A head shield (a cephalon) of a trilobite from the lower Cambrian Latham Shale--the genus-species is *Olenellus gilberti*. Collected from the classic trilobite quarry in the Marble Mountains, California, long before that area became part of a national monument.

Images for Chapter 18

Late Triassic Ichthyosaurs And Invertebrate Fossils In Nevada

Union Canyon at Berlin-Ichthyosaur State Park. View to the A-frame structure that houses the world-famous ichthyosaur bone bed, where nine specimens exceeding 37 feet in length (one measures almost 60 feet long) can be viewed along the floor of a quarry similar in conservation style to the Late Jurassic-age quarry at Dinosaur National Monument, Utah-Colorado. Bottom—*Septocardia* pelecypods from the upper Triassic Luning Formation found outside Berlin-Ichthyosaur State Park, Nevada. All three have been preserved with both valves intact.

Images for Chapter 18

Late Triassic Ichthyoaurs And Invertebrate Fossils In Nevada

A Mesozoic Era adventurer explores outcrop of limestone in "member one" of the upper Triassic Luning Formation at Coral Reep Canyon, Nevada, which is here loaded with all kinds of corals and sponges, all tangled together, forming a reef-like invertebrate complex some 215 million years old. Other invertebrate paleontological specimens found at Coral Reef Canyon include ammonoids, belemnites, brachiopods, crinoids, echinoids, gastropods, ostracods, and pelecypods. Ichthyosaur bone fragments sometimes observed, as well. Bottom-- Terebratulid-type brachiopods from the upper Triassic Luning Formation at Coral Reef Canyon, Nevada. Left and middle specimens are pedicle and brachial views, respectively, of *Plectoconcha aequiplicata*. Specimen at right is a pedicle view of *Plectoconch*a sp. All three specimens have been preserved with both valves intact.

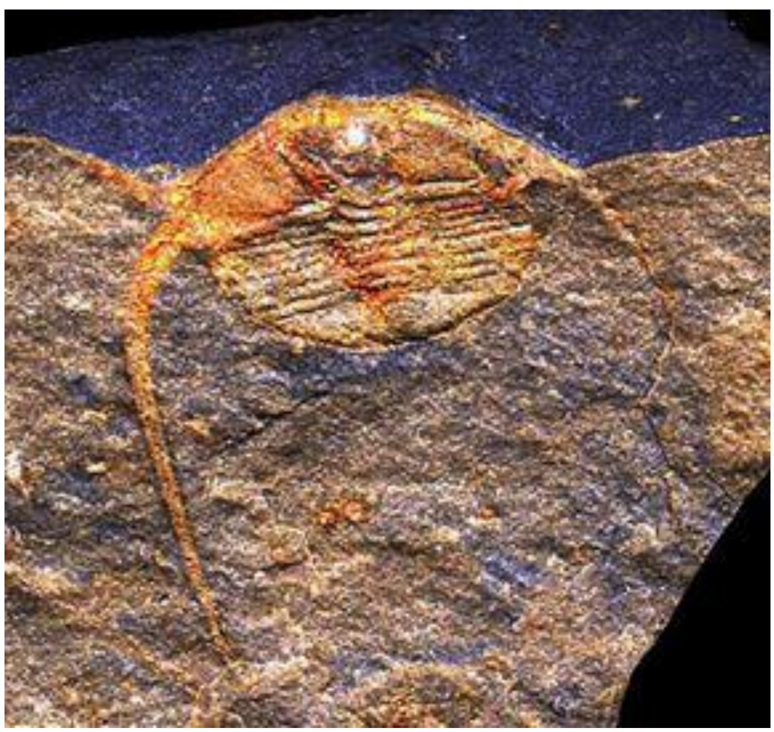
Images for Chapter 19

Field Trip To Pleistocene Lake Manix, Mojave Desert, California

A Mojave Desert aficionado stands in the upper Pleistocene Manix Formation, California. Bottom--Fossil freshwater gastropods from the upper Pleistocene Manix Formation (19,000 years old). Genus *Planorbella*. Scale is in millimeters. All collected before the Manix Formation was first aside as an Area Of Critical Environmental Concern and then later included in Mojave Trails National Monument.

Images for Chapter 20

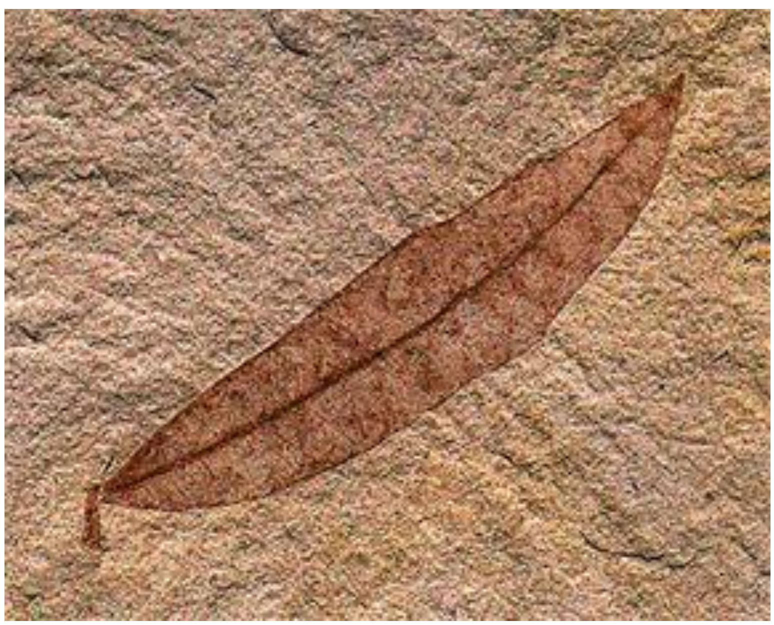
Paleozoic Fossils At Mazourka Canyon, Inyo County, California



Mouth of Mazourka Canyon, California. Sierra Nevada as backdrop. Explorers of the mid Paleozoic Era at camp. Bottom—A trilobite from the lower Ordovician Al Rose Formation, Mazourka Canyon.

Images for Chapter 21

Fossil Leaves And Seeds In West-Central Nevada



A Great Basin Desert adventurer examines the middle Miocene Middlegate Formation, Nevada. The cream white to pale-brownish opaline shales here split easily along their original planes of deposition to yield up a veritable treasure-trove of fossil leaves, winged seeds, twigs, acorn cups, seed pods, and conifer needles. Bottom—A whole, complete leaf of an extinct water oak from the middle Miocene Middlegate Formation. *Quercus simulata*.

Images for Chapter 22

A Visit To The Sharktooth Hill Bone Bed, Southern California

This was once a popular spot for folks to come on in and collect all the shark teeth and miscellaneous marine mammal bones they wanted from the middle Miocene Round Mountain Silt Member of the Temblor Formation, Sharktooth Hill Bone Bed, in the western foothills of California's Sierra Nevada. The bone bed produces the best record of marine Miocene vertebrate fossils in the world. Where to look for the paleontological material was not difficult to figure out; the unmistakable World War I infantry-style trench along the hillside certainly marks the spot. Bottom--Teeth of an extinct Tiger shark from the middle Miocene Round Mountain Silt Member of the Temblor Formation, Sharktooth Hill Bone Bed; approximately 16 to 15 million years old. Called scientifically*, Galeocerdo aduncus*.

Images For Chapter 23

Dinosaur-Age Fossil Leaves At Del Puerto Canyon, California

A visitor searches for fossil leaves at Del Puerto Canyon in upper Cretaceous strata of the upper Cretaceous to Paleocene Moreno Formation, Stanislaus County, California. Bottom--An avocado-like fossil leaf from the upper Cretaceous portion of the upper Cretaceous to Paleocene Moreno Formation, Stanislaus County, California.

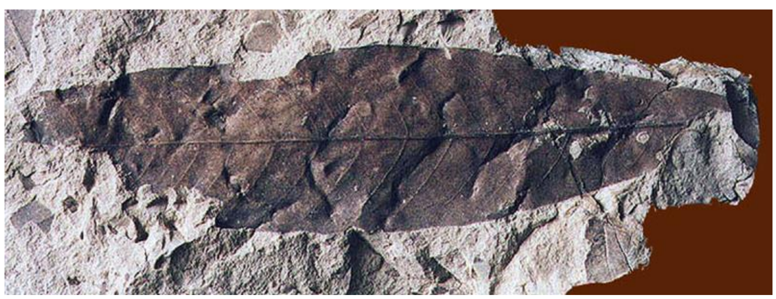
Images for Chapter 24

Early Triassic Ammonoids In Nevada

A cephalopod seeker hikes up a slope in the lower Triassic Thaynes Formation, Nevada. It is not an exaggeration to state that every chunk of rock along that slope contains whole and fragmental ammonoids, roughly 248 million years old. Bottom—An ammonoid (only Jurassic and Cretaceous age types can be called an ammonite) from the lower Triassic Thaynes Formation in Nevada; from a locality that yields the best preserved Early Triassic ammonoids in North America.

Images For Chapter 25

Fossil Plants At The Chalk Bluff Hydraulic Gold Mine, California



A view eastward across the great Chalk Bluff hydraulic gold mine, western foothills of California's Sierra Nevada, showing the auriferous gravels miners blasted with high-pressure water during the mid to late 1800s; middle Eocene leaves and petrified woods occur locally here. Chalk Bluff, proper, is the whitish ridge just below skyline, composed of volcanic rhyolite about 34 million years old. Bottom—a swamp red bay leaf, genus *Persea*, from the middle Eocene auriferous gravels at Chalk Bluff.

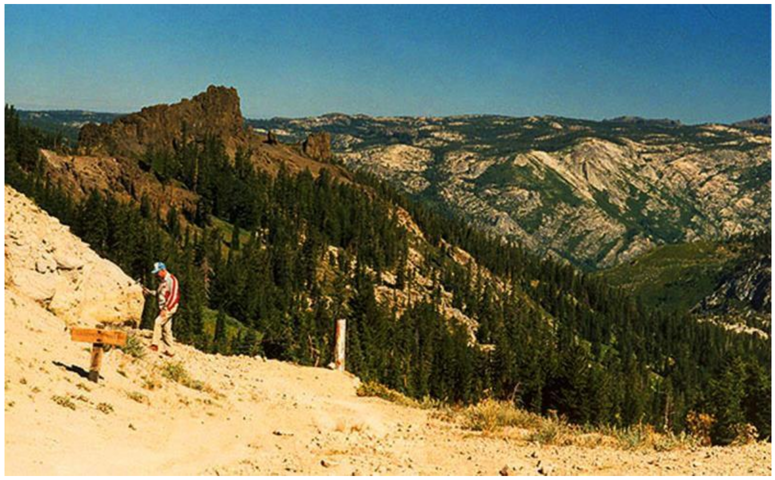
Images for Chapter 26

In Search Of Fossils In The Tin Mountain Limestone, California

Lost Burro Gap in Death Valley National Park. Middle to upper Devonian Lost Burro Formation is lighter colored material to road level. Highly fossiliferous lower Mississippian Tin Mountain Limestone is the darker-colored rock above, forming the skyline. Bottom—"Spaghetti" *Syringopora* coral observed in the Tin Mountain Limestone.

Images For Chapter 27

High Sierra Nevada Fossil Plants, Alpine County, California



An adventurer of the High Sierra Nevada inspects the upper Miocene Disaster Peak Formation. Bottom—A twig from a Douglas-fir, *Pseudotsuga sonomensis*, from the upper Miocene Disaster Peak Formation.

Images for Chapter 28

Ordovician Fossils In The Toquima Range, Nevada

An Ordovician explorer (lower left) searches for graptolites in the middle to upper Ordovician Vinini Formation near Graptolite Summit, Nevada. The shales and siltstones that sandwich a bed of whitish-brown quartzite near Graptolite Summit furnish loads of fascinating graptolite remains, an extinct variety of hemichordate that reached its zenith of adaptation in the Ordovician Period. Bottom--A graptolite colony (distantly related to the modern pterobranch) from the middle Ordovician Vinini Formation near Graptolite Summit, Nevada. *Phyllograptus anna*.

Images For Chapter 29

Late Miocene Leaves At Verdi, Washoe County, Nevada

A view to the western end of the railroad cut near Verdi, Nevada, which yields fossil leaves in the upper Miocene Hunter Creek Formation. Below—A whole fossil cottonwood leaf from the Verdi site. *Populus alexanderi*.

Images for Chapter 30

A Visit To The Fossil Beds At Union Wash, California

The view Is east in the Inyo Mountains at the mouth of Union Wash, California; all rocks in foreground and along the slopes at middle lie in the ammonoid-bearing lower Triassic Union Wash Formation. Paleozoic limestone on skyline. Bottom—A *Meekoceras gracilitatus* ammonoid from the lower Triassic Union Wash Formation.

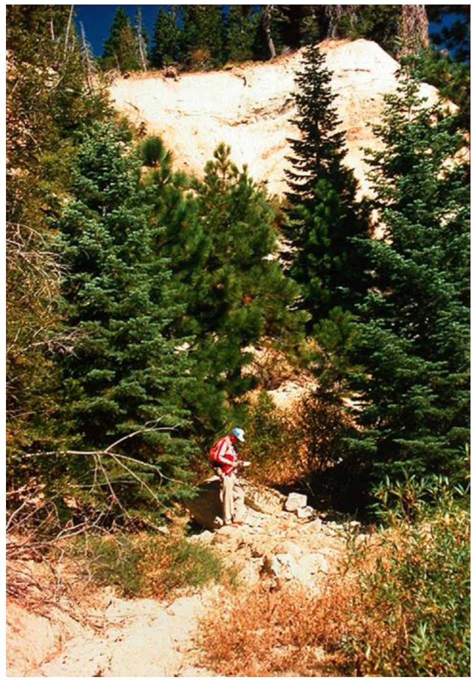
Images For Chapter 31

Ice Age Fossils At Santa Barbara, California

A seeker of Pleistocene times is scrambling up a fossil-bearing roadcut in the middle Pleistocene Santa Barbara Formation, with a spectator in a passing car looking on. Here occur perfectly preserved Ice Age pectens and bryozoans in the Santa Barbara Formation; gastropods and brachiopods also common here. Santa Ynez Mountains along the skyline, in distance. Bottom--A gastropod sampler from the middle Pleistocene Santa Barbara Formation, California—all collected from Ice Age Fossil Hill, Santa Barbara County, California.

Images for Chapter 32

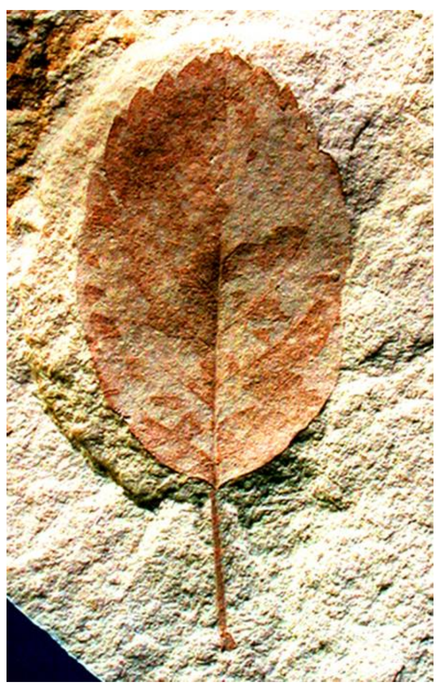
Plant Fossils At The La Porte Hydraulic Gold Mine, California



Top: A fossil plant explorer on site at the La Porte hydraulic gold mine, northern Sierra Nevada, California. Bottom: A fossil leaf from the Upper Eocene La Porte Tuff; an extinct species of Dogwood called *Cornus kelloggi*.

Images for Chapter 33

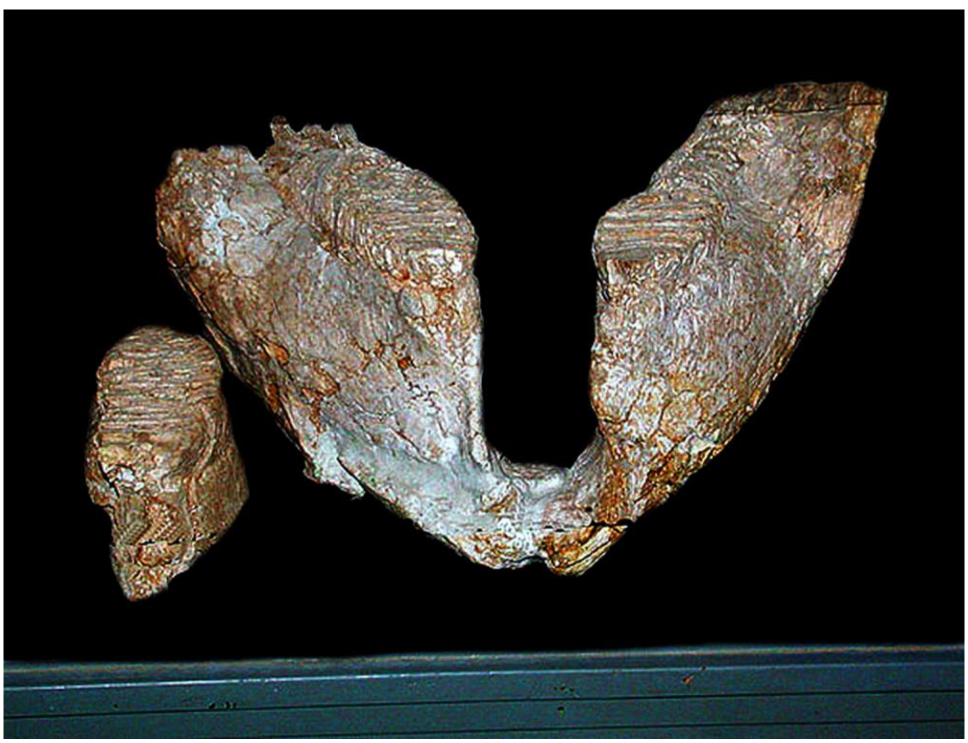
Fossil Plants, Insects, and Frogs in the Vicinity of Virginia City, Nevada



Top: A paleobotany aficionado investigates fossil leaf, insect, and frog-bearing exposures of the middle Miocene Coal Valley Formation near Virginia City, Nevada. Bottom: A fossil leaf from the Coal Valley Formation, from a western serviceberry called *Amalanchier alvordensis*.

Images for Chapter 34

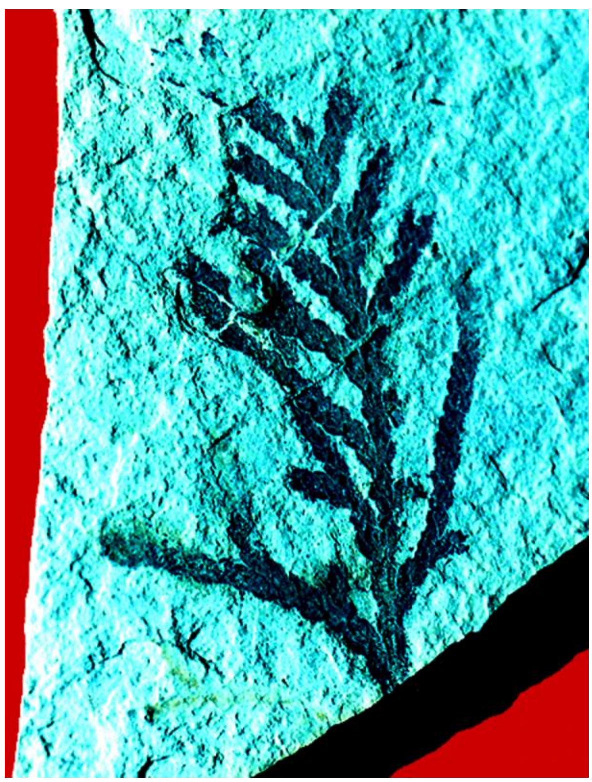
Field Trip To The Alexander Hills Fossil District, Mojave Desert, California



Top: A paleontology enthusiast explores 1.2 billion year old stromatolite-bearing limestones in the Precambrian Crystal Spring Formation, Alexander Hills, California. Bottom: A mammoth tooth and lower jaw from the late Pliocene to Pleistocene Tecopa Lake Beds; specimens on display at the museum in Shoshone, California.

Images for Chapter 35

Plant Fossils In The Neighborhood Of Reno, Nevada



Top: A seeker of fossil plants investigates an outcrop of the middle Miocene Chloropagus Formation not far from Reno, Nevada. Bottom: A twig from the Miocene equivalent of today's Lawson cypress, *Chamaecyparis lawsiana*, from the middle Miocene Chloropagus Formation near Reno, Nevada.

Images for Chapter 36

Early Cambrian Fossils Of Westgard Pass, California

Early Cambrian enthusiasts are parked along Route 168 in the White-Inyo Mountains, California. Exposures of archaeocyathid-bearing limestones in the lower Cambrian Poleta Formation, deposited approximately 520 to 518 million years ago, along the ridge directly behind the camper. Current paleontological consensus is that the archaeocyathid is an extinct variety of calcareous sponge, a member of the phylum Porifera. Bottom—A branching archaeocyathid from the lower Cambrian Poleta Formation.

Geologic Time Scale—Courtesy United States Geological Survey