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Empty Basins, Vanished Lakes

A Field Guide to Afton, Baxter, Tecopa, Shoshone, Pahrump and Kingston

edited by
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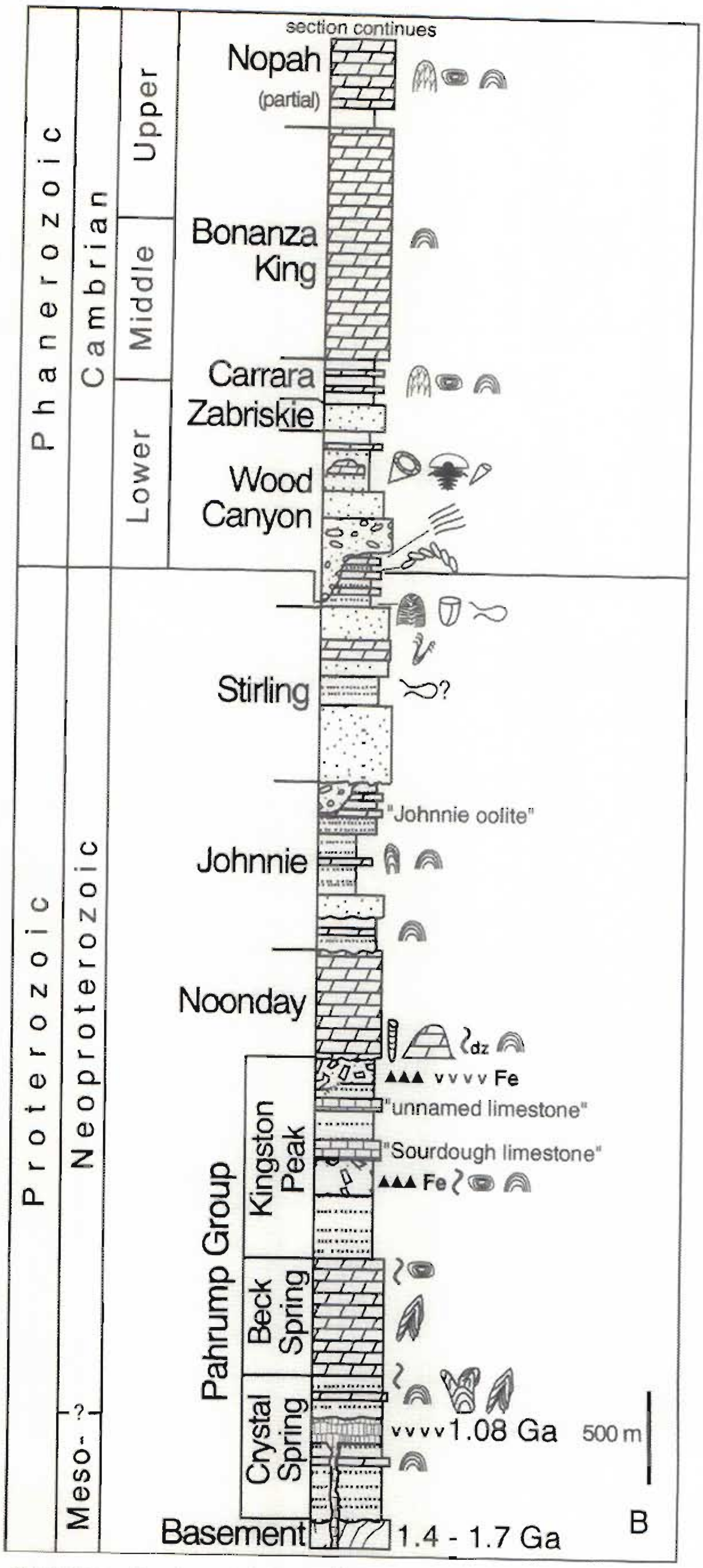

Above: Stratigraphic column of the Death Valley succession. See Awramik, Corsetti and Shaprio, this volume.

Front cover: Ore loading chutes and rock work at Baxter, San Bernardino County. R.E. Reynolds photo.

Back cover: Phainopepla perched in mesquite with mistletoe at Tule Springs, California Valley, Nevada. R. E. Reynolds photo.

Empty Basins, Vanished Lakes

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The Year 2000 Desert Symposium Field Guide

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Introduction

Our three day route will take us through Pleistocene basins, including Manix Basin on the Mojave River, Tecopa Basin on the Amargosa River, and internally-drained basins in Pahrump and Sandy Valleys, Nevada. Rain still falls, the rivers flow, but what happened to the extensive lakes that once filled these basins? We will see evidence of entrenched meanders suggesting slow drainage, and narrow slot canyons suggesting sudden changes in base level causing rapid incision of lake outflows or rapid headward erosion in the gorges that drained the lakes. As we go, we will be able to compare stromatolites (structures built by biological precipitation of calcium carbonate in lake waters) from Proterozic to the Pleistocene times. And as we speed along the roads in our rubber-tired, air-conditioned vehicles, we will be following the paths of mule trains, rustlers, and emigrant wagons moving along the Old Spanish Trail 150 years ago at speeds reaching 2 miles an hour. Many of the springs we will visit on our trip were vital stopping places for the pioneers.

Day 1:

Lake Manix to Spanish Trail Mesa

0.0 (0.0) Exit I-15 at Afton Road. From Afton Road, we can look west along the Mojave River toward Camp Cady. The Old Spanish Trail rain to our north, from Red Pass Lake to Bitter Spring to the vicinity of Camp Cady and then west over the San Bernardino Mountains. An alternate route was through Afton Canyon to Camp Cady.

0.3 (0.3) CONVENE at intersection of Afton Road and I-15. We are at the 1780' shoreline, traveling on a beach bar formed by wave action at the high stand of Manix Lake. TURN RIGHT (south) on the frontage road and proceed west to view onlapping lacustrine sequence of Lake Manix.

0.9 (0.6) PARK and WALK to the wash on the south side of the road.

Stop 1: Tufa-Coated Cobbles. Here we see a contact between silty distal conglomerates and overlying lacustrine sediments (Awramik, Buchheim *et al.*, this volume). This contact increases in elevation to the east as the sediments from Lake Manix moved upslope over time. Return to vehicles. RETRACE to Afton Road.

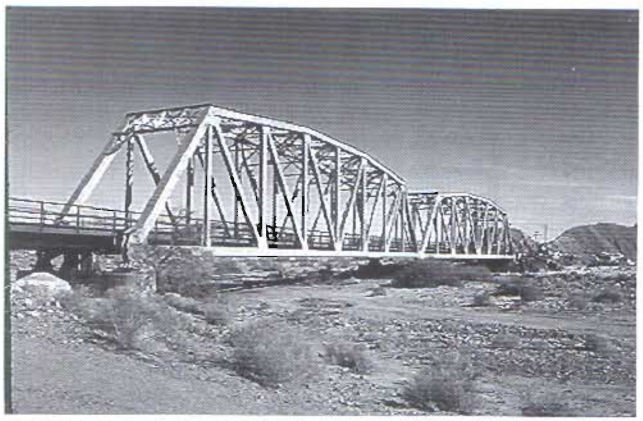
1.4 (0.5) Proceed across intersection of frontage road and Afton Road. and PARK on the east side of Afton Road.

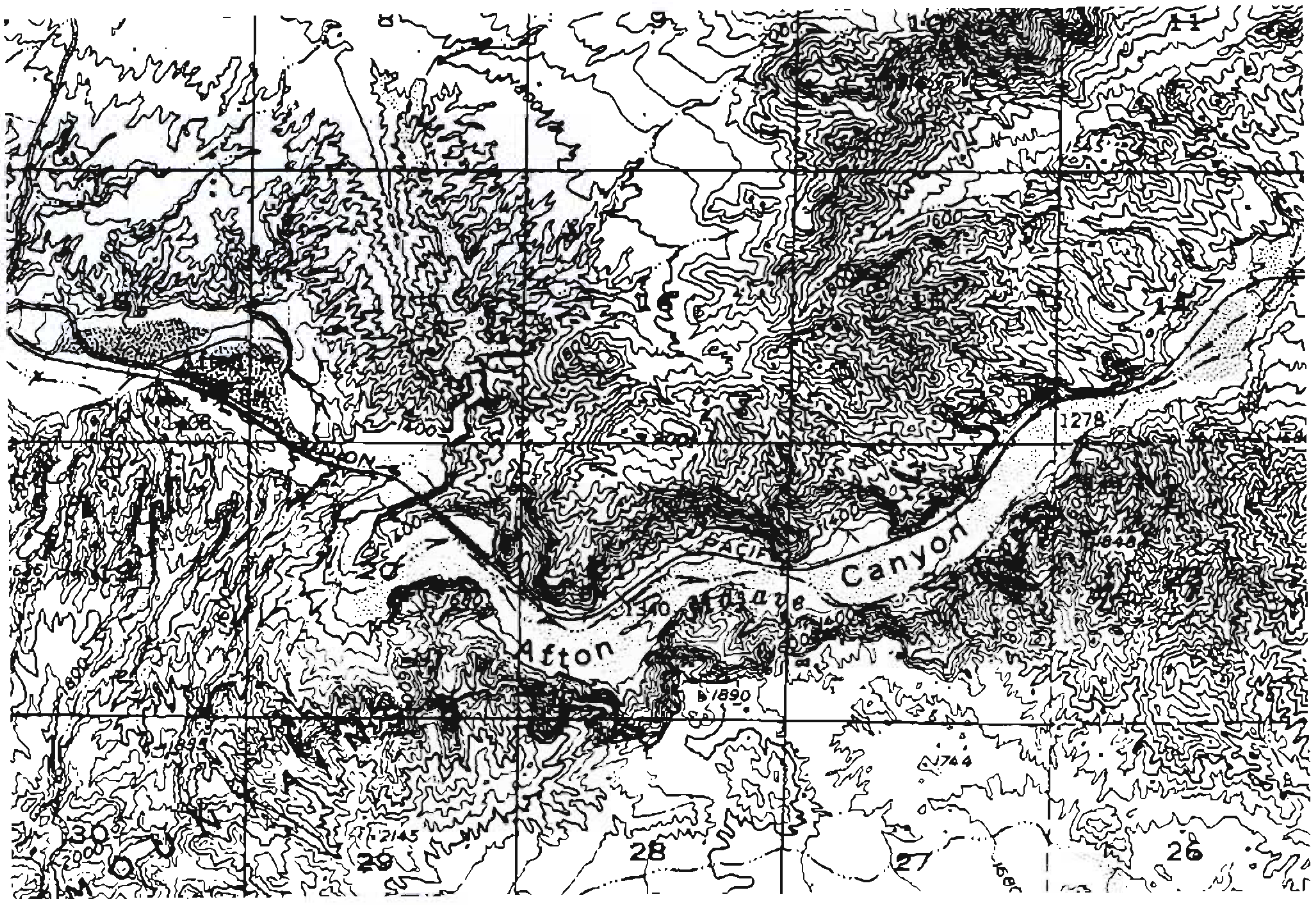
Stop 2: Beach Ridge. We are at the 1780' shoreline. Walk to the channel to see the imbricated flat gravel clasts, or shingles. The flattened stones are characteristic of oscillating wave action on a shingle beach. This beach ridge marks the highest stand of Lake Manix, and shells from other beach ridges at this elevation provide radiocarbon ages from about 21.5 to 18.1 ka. The maximum crest elevation of the ridge is 542.9 m, although the maximum lake stage was normally 2 to 3 m lower. Storm overwash built the beach ridges above the normal lake level, and the ridges migrated shoreward over time. The small playas just to the east of the beach ridges were lagoons at the time of Lake Manix, but they have continued to collect sediments from the local drainages. Freshwater shells are normally found in the beach sands about halfway down the foreshore slope, but in this particular area shells are rare. Because beach ridges are perpendicular to the slopes of alluvial fans, they dam the natural drainage. Ponding, overflow across the lowest swale on the beach ridge crest, and incision are responsible for the transverse drainage through the beach ridge north of the bedrock ridge (Meek, this volume). Note the back bay east of the beach ridge. Return to vehicles, PROCEED SOUTH.

3.0 (1.6) Pass under power lines. Prepare to stop 1/4 mile ahead.

3.3 (0.3) PARK on the lower terrace.

Stop 3: Structural terraces. The lower terrace is heavily cemented with pedogenic carbonates. The Mojave River had not yet reached this region when this terrace was cemented. The terrace surface represents the paleosurface of Afton basin before the first lakes inundated this area. This terrace dips to the south and continues across the Mojave River valley to the other side. The Cady Mountains also did not exist in their present location and elevation when this terrace was the basin floor. Some time after the deposition of these gravels, the Cady Mountains began to rise, shedding volcanic gravels northwards and creating the closed basin now known as Afton basin. Careful examination of the well-developed pavements on the lower terrace indicates that it was once covered with a coating of tufa from the gradual rise of Lake Manix. This


Railroad bridge over the Mojave River at Afton Canyon. R.E. Reynolds photo.



Meanders on the Mojave River in Afton Canyon. Cave Mountain 15' quadrangle.

tufa is believed to be from the initial rise of an OIS 6 lake (~190 ka). Thick green clays once covered all of the lower terrace; they only remain where a subsequent alluvial deposit protects them. The slope between the upper and lower terraces is underlain by the green clays. The upper terrace shows the extent of alluviation into the basin during Sangamon time (OIS 5e). The upper terrace also has a coating of tufa because the terrace was in turn inundated by at least three stands of Lake Manix during the Wisconsinan (OIS 4 and OIS 2). The beach ridges also sit atop this terrace. The upper terrace was probably covered with a thin layer of green clays and beach sands lakeward of the beach ridges, but because they were not protected by a gravel layer, they rapidly eroded from the area following the breaching of Afton basin.

4.9 (1.6) Entrance to Afton campground. Proceed east 0.1 mi along berm.

5.0 (0.1) PARK and walk to the tortoise habitat.

Stop 4: Afton Station. Afton Station was a railroad stop established at the west end of Afton Canyon with eight buildings and a water tank. It was continually inhabited from about 1905 to 1986, and often housed railroad workers. In 1988 the railroad bulldozed the buildings and large willow trees, leaving nothing behind but the foundations. If you walk across the tracks towards the southeast you will eventually come to a small cemetery just north of the main cliffs. It is unclear who is buried here — probably railroad workers and transients. Robert Lowe, resident station manager in 1942 and 1943, did not recall the cemetery being there during his tenure at the station (written communication to Arlene Kallenberger, 1996). The trestle is immediately to our south.

The western pond turtle, *Clemmys marmorata*, is protected by the State of California. Recent surveys (Lovich and Meyer [abs], this volume) confirm that many populations have been extirpated or are declining. Nothing has been published on the ecology of relict, morphologically and genetically distinct populations in the Mojave River of California. A significant portion of the historical range of the turtle in the Mojave River occurs at the Afton Canyon ACEC, where populations are small and tenuous. Much of the Mojave River flood plain has been infested with the exotic pest plant saltcedar, *Tamarix ramosissima*, replacing an estimated 70 percent of the native riparian vegetation in the ACEC. The changes in channel morphology and hydrology associated with saltcedar invation have degraded what little western pond turtle habitat exists in this arid region (J. Lovich, www.werc.usgs.gov/cc/pond-turtle.htm).

Return to vehicles and PROCEED EAST along the flood control berm.

5.1 (0.1) TURN RIGHT diagonally off berm and go through water crossing. Proceed slowly but steadily; if you go too fast or if you stop, your engine may drown.

6.0 (0.9) PARK at the eastern end of a small hilltop that offers a good, easily accessible view of the upper end of Afton Canyon.

Stop 5: Bedrock Meander Notice how the Mojave River passes beneath the trestle and then travels to the south around the large bedrock ridge that blocks its path to the east and makes the Mojave River form a giant meander. Looking east, the railroad tracks pass through a large V-shaped gap in the bedrock obstruction. Prior to 1957 the tracks passed through the ridge in a tunnel. But deteriorating tunnel timbers and repeated rock slides caused largely by aftershocks from the 1947 Manix earthquake (Richter and Nordquist, 1951; Doser, 1990) caused the Union Pacific railroad to daylight the tunnel (Myrick, 1963, p. 674).

North of this stop is a good contact of Miocene rocks overlain by the Mojave River Fm (Buccheim and Spitler, 1986) overlain by sediments of Lake Manix. Looking to the northeast, you can see the mouth of a tributary canyon that has incised into dark reddish-brown and gray crystalline bedrock. This is the canyon that leads into the bay behind North Afton Beach Ridge and Shoreline Hill. This deep incision into solid bedrock has occurred since Lake Manix drained about 18 ka.

The large bedrock meander ridge is an unusual landform. This is the only place the Mojave River path makes a sharp curve downstream of the Manix Wash confluence. The cause of this meander is probably related to the position of a beach ridge that no longer exists. Although Blackwelder and Ellsworth (1936, p. 462) speculate that North Afton Beach Ridge may have once closed off the southeastern end of Afton basin, the rapidly increasing depth of the paleobasin makes such a claim unlikely. Rather, Meek believes another beach ridge formed that connected to the mainland just south of Shoreline Hill and passed directly over the bedrock meander ridge towards South Afton Beach Ridge. When the lake basin was breached, the initial outflows were diverted around the hypothesized beach ridge, and the subsequent incision trapped the river in a meandering channel. In this scenario, the beach ridge has completely eroded, but the river platform indicates where it once formed a local topographic varrier.

The crest of the meander ridge is capped with Mojave River gravels, indicating that the river once flowed above the ridge. There are a series of slip-off terraces atop the bedrock ridge that show how the river meander has gradually increased in size as the canyon has incised.

Return to vehicles and PROCEED down the steep incline and under the trestle. Passengers can look back to the outcrop on the left and see Miocene sediments faulted against gravels. Proceed through water crossing without stopping.

6.3 (0.3) Take the lower road dropping away from tracks but staying parallel on the south side. Downstream to the south, on the right hand channel wall are two openings — the historic “caves” — just above the modern channel floor about 0.3 miles from the trestle. Excavation of the caves has revealed evidence of historic occupation, including square nails and miscellaneous trash. “The Caves” were a stop along the Old Spanish Trail and, later, the Government Road. Dead ahead are the gray colored gravels from the Cady Mts Fm abutted by the Manix/Afton Fault against the red and black Tertiary volcanics (Meek and Battles, 1991).

7.0 (0.7) A magnesite mine is on the south wall of the canyon. Magnesite is magnesium carbonate, once a major source of magnesium used in some ammunition (*e.g.*, flares, incendiary bombs). The Cliffside Magnesite Company opened the mine in 1917 as the price of magnesium rose during World War I. Magnesite ore was transported to the railroad across the river via a 1900-foot aerial tram and shipped to San Diego County. The mine closed in 1918 at the end of WWI.

9.0 (2.0) Round the bend and look at the colorful, fault-disrupted Miocene volcanics and the contact with overlying indurated gravels that may be equivalent to the Mojave River Fm. These gravels received rapid incision, perhaps along fault-generated fractures.

9.6 (0.6) PARK at Bridge No. 194.65, dated 1928.

Stop 6: Slot Canyon (“Norm's Nook”). This slot canyon shows the rapid incision that has occurred since Afton Canyon formed. This tributary has incised in response to the rapidly lowered base level of Afton Canyon. Vertical incision occurred first, and the meandering of the stream from side to side is responsible for the overhangs. When the stream reaches a reasonable longitudinal gradient, a significant widening of the channel develops. Eventually, the overhangs break off and the channel walls become vertical. Return to vehicles, PROCEED EAST toward the buried box car near the termination of the cliffs with gravel dipping 15°. The gravels have a silty component near the cliff case; vertical higher slopes are solid gravel.

“Norm's Nook” slot canyon. R. E. Reynolds photo.

10.5 (0.9) Tamarisk grove.

10.6 (0.1) PARK at road side.

Stop 7: Buried Box Car. Walk to the box car in the Mojave River wash. A recent detailed study by a CSUSB student, Barry McAleer, has shown that the railroad car was probably buried in place by the railroad. The railroad bridges have 1926 and 1928 dates, and a railroad historian has confirmed that the present railroad grade is similar to the 1905 grade. Thus, the boxcar does not sit on buried tracks. Photographs of the 1938 flood do not show a box car in the channel floor in this vicinity. Meek took a photograph of the box car on 22 February 1985 that does not show vegetation in the vicinity and shows the box car roof to be unweathered. Between 1985 and 1992 the box car was gradually buried by aggradation of the Mojave River, but the 1993 floods exhumed it again. Today, the box car roof and sides are highly oxidized and decomposing rapidly. The rate of decomposition since 1985 suggests that the box car could not have been in the channel for many years before that. No documents revealing the burial date have yet been discovered, but it appears that the box car was buried by the railroad, most probably in the early 1980s. Return to vehicles and proceed.

Buried box car in Afton Canyon. R. E. Reynolds photo.

11.1 (0.5) The black magnetite ore dumps at Baxter are on our right. TURN LEFT and cross the railroad tracks at Basin Station. Like the railroad siding at Afton, the siding at Basin was needed to control traffic on the single tracks through the canyon. This station was originally named Baxter, and in 1914 the post office here served 150 residents in the region (Garrett, 1992, p. 8). Railway workers and miners frequented the site, especially after the Pacific Marble Quarries Company opened operations across the river in 1925.

11.2 (0.1) On the north side of the tracks, take the road to the left, pass over the berm, bear right, and proceed across the Mojave River to the marble mines.

11.4 (0.2) Cross the river and PARK in the open area on the north side of the river.

Stop 8: . Look at the rock work and loading chutes (front cover). The metamorphosed Paleozoic limestone has been mined since the 1920s, and the iron deposits since the 1930s (Brown and Monroe, this volume). Return to vehicles and RETRACE to the intersection on the north side of the tracks. The view south above the townsite of Baxter is of a dissected alluvial fan with bar and rill degraded to flat desert pavement. With change in base level of the Mojave River, the drainages in the canyon dissected the toe of the fan, which extended fairly far away from the hillside in times past.

11.7 (0.3) TURN LEFT (north) at the intersection on the north side of the tracks. The road bends south and then east parallel to the tracks.

14.8 (3.1) Pass through reverse intersection.

15.9 (1.1) Pass BLM kiosk.

16.7 (0.8) PARK on the open area at the Basin Road offramp.

Stop 9: Ventifact Hill. Hike east, uphill, to view granitic ventifacts carved by wind blown sand (Laity, this volume). From the top of Ventifact Hill, look north into East Cronese Lake and through the pass toward West Cronese Lake. These "twin lakes" were on an alternate route used by emigrants (Lyman and Walter, 1997) going south of Bitter Springs through Cronese lakes to "the caves" and the water in Afton gorge. Use of the area by Native Americans is well documented (Warren and Schneider, this volume). Return to vehicles and proceed north to the I-15 onramp.

16.8 (0.1) Enter I-15 east, and proceed to Baker.

32.1 (15.3) Exit I-15 at the West Baker exit. Obtain gas, water and supplies. Continue to Highway 127 (Kelbaker Road) in central Baker.

32.7 (0.6) TURN NORTH onto Highway 127.

34.4 (1.7) The Soda Mountains are on the left (Gourley and Brady [abs], this volume).

39.9 (5.5) Pass adobe ruins on the right marking the town of Silver Lake, the terminus of a stage line where O.J. and Della Fisk operated a mercantile store. Oliver James (Jim) Fisk was born in Iowa on August 10, 1873. At age 14 he headed for California, crossing the southern Nevada Mud Hills on foot. He was 20 when he worked as a hoist man on the Gold Bronze Mine in Vanderbilt, California. In 1901 he built an ice place in Manvel which supplied ice to boom camps: Searchlight, Crescent, and Sandy, Nevada; and Hart, California. He then went into partnership with the Rose & Palmer transportation firm which hauled freight from the desert railhead at Ivanpah Dry Lake across Stateline Pass and up the Pahrump Valley to Sandy Valley, Pahrump, Beatty, Bullfrog and Rhyolite, Nevada (see Day 3).

In about 1894 O. J. Fisk and Della May White were married in Redlands. Della, born in Sommerville, Oregon, in 1875, was the daughter of Harsha and Maude Yount White. Della's father managed the Manse Ranch in the Pahrump, developed by Joseph Yount, Della's grandfather. Mr. Yount was a cattleman, and on the ranch he raised and sold hay, and had a vineyard and winery. He later owned a sawmill and valuable timber options in the Charleston Mountains. Eventually Jim Fisk, a mining engineer credited with building and operating some of the largest and most successful ore recovery mills in the gold boom, became involved in the mercantile and lumbering business. He and Della made their home in Greenwater, a copper camp near Death Valley. While Jim was mining, Della ran a general merchandise store.

View south from Baxter showing well-developed desert pavement surface on old dissected fans. R.E. Reynolds photo.

During the mining boom in Goodsprings, NV (Kepper, 2000; Hensher, this volume), Harsha White and Joseph Yount located the Boss Mine and, two years later, the Columbia Mine. Jim went to Goodsprings in 1892 to take over Harsha White's interest in the mines and, with S. E. (Sam) Yount, formed the Boss Gold Mining Company. In 1898 Jim built one of the mills in mining camp Johnnie, NV. He returned 10 years later as master mechanic in the operation.

From Silver Lake to Crackerjack, a mining camp west of the Avawatz Mountains, Jim Fisk built a 30-mile road over which the Rose, Palmer & Fisk stage line made tri-weekly trips, carrying people and mail. For weeks the stages were crowded with outbound, not inbound, miners. Because of the panic of 1907, Crackerjack (only 90 days old) slumped, as did other camps. About 1910 O. J. and Della Fisk moved to San Bernardino where they became active civic leaders.

41.2 (1.3) Pass Edison power line road.

42.9 (1.7) View at 10:00 of Avawatz Mountains, a large fault block of Mesozoic diorite thrust over Tertiary and Quaternary fans (Spencer, 1990).

47.7 (4.8) Pass turn to Riggs (Silurian Hills).

52.5 (4.8) The site of Renoville is on the left. Continue past a right turn to Valjean Valley, Kingston Wash and the Eastern Star Mine.

58.1 (5.6) Continue past Lake Dumont (Anderson and Wells, 1997).

59.6 (1.5) BLM information kiosk and rest rooms at the southern Salt Spring Hills. Salt Spring was a stop on the Old Spanish Trail. Water from the spring forms Salt Creek, a tributary of the Mojave River (Anderson and Wells, 1997). The spring was the site of a significant gold discovery by pioneers in 1849 (Harder, 1997; [abs] this volume). Springs and other water sources in the Mojave Desert have been of critical importance to plants, animals, and humans since Pleistocene times. We will see several types of "springs" or near-surface water on this trip in addition to remains of Pleistocene lakes. These include: (a) water forced to the surface along bed rock structures such as in Afton Canyon, at Salt Spring and Resting Spring; (b) water percolating to the surface through sediments along fault zones, such as Tecopa Hot Springs and Stump Spring, where traces of moisture are marked by mesquite; (c) springs marked by mineralized water, such as travertine deposits at Valley Wells; (d) springs and vegetation perched in valleys where the valley drainage has been blocked by vegetation and silts and clays, daming axial flow and depositing sediments in ponds and marshes, as at Tule Springs; and (e) spring mounds such as in the Las Vegas Valley, where faults on the valley margin produce seepage, and mounds of silt and black mats of organic matter are stabilized on slopes by thick clumps of vegetation.

60.6 (1.0) Continue past the Harry Wade monument.

60.8 (0.2) Cross the Mojave River as it flows north to Amargosa River.

62.8 (2.0) Cross the Amargosa River.

64.8 (2.0) Continue past left turn to Dumont Dunes (Anderson et al 1997)

70.6 (5.8) Continue past left turn to microwave relay on left.

72.5 (1.9) Cross through Ibex Pass, elev. 2090', in the Sperry Hills,.

77.6 (5.1) In the first outcrops of Tecopa Lake sediments is lime green Lava Creek B Ash dated at 0.62 Ma (Hillhouse, 1987; Chesterman, 1973).

78.0 (0.4) Continue past Greenwater Valley Road.

78.6 (0.6) END DAY ONE at Spanish Trail Mesa and the junction of Highway 127 with the turnoff to Tecopa. We will convene here for the start of Day 2. It is 8 miles north to Shoshone where gasoline and services can be found.

Spanish Trail Mesa stop, Parking area is shown to the right of the road; to the right of that is Spanish Trail Mesa. McMackin photo.

Day 2:
Spanish Trail Mesa to Shoshone

0.0 (0.0) CONVENE at junction of Highway 127 and Old Spanish Trail Highway just west of the green highway sign that reads "Tecopa 4 miles".

Stop 1: Spanish Trail Mesa. Because Spanish Trail Mesa is dominated by N50°E joints, the mesa weathers to an elongate shape. The joints are prominently exposed as large parallel surfaces, particularly in Lava Creek Ash A that caps the section (McMackin 1997a; Chesterman, 1973). Return to vehicles; watch for traffic and reenter Spanish Trail Highway towards Tecopa Hot Springs.

View south from Spanish Trail Highway to McClain Peak. Note the sandy Lake Tecopa beds and weakly developed shorelines near the base of the steep slope. McMackin photo.

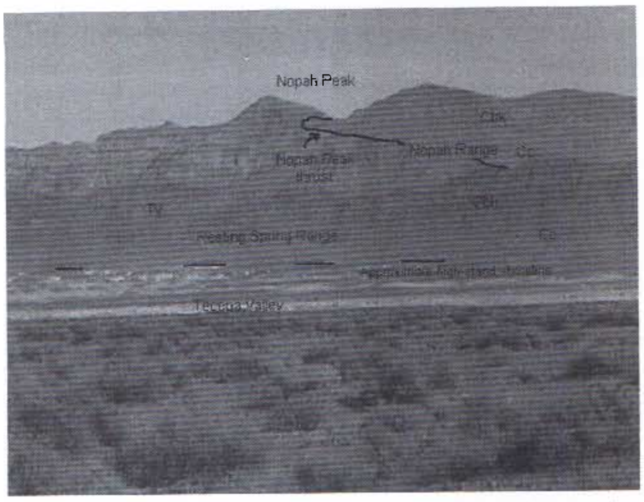
0.4 (0.4) On our right is McClain Peak, an east-dipping Paleozoic section. Stirling Quartzite at the base of the hill is overlain by Wood Canyon Fm in turn overlain by Zabriski Quartzite, which forms the dip slope on the skyline on the east side of the ridge. This east-tilted section is surrounded on its northern side by Tecopa lake beds. If you look carefully near the base of the slope you'll see some very faint, weakly developed shorelines.

1.3 (0.9) The Tecopa lake beds in this area are redder and have more sand than the lighter-colored lake beds at our previous stop. The sandy component is probably from McClain Peak.

1.5 (0.2) To the left we can see the Tecopa Hot Springs area above Grimshaw Lake. Trending north beyond the Hot Springs is the Resting Spring Range topped by dark Tertiary basalt flows. The light area below is a dacite intrusion, formed by bimodal mixing of the basaltic magmas interacting with crustal rocks on their way up to produce, first, flows of basaltic lava flows and then viscous dacite intrusions that formed pod-shaped masses. At the very southern tip of the Resting Spring Range a small clump of trees marks Resting Spring. Northward, the Resting Spring Range has exposures of Wood Canyon Fm, Zabriskie Quartzite, and orange, bedded Carrara Formation overlain by dark gray dolomites of the lower Bonanza King Formation. In the distance is Nopah Peak with dark Bonanza King rocks. Just north at the bottom of the hill, the Bonanza King block is faulted against Stirling Quartzite: the light-colored lower quartzite, a dark middle band and an upper light band, overlain by the Wood Canyon Fm. The Bonanza King Fm forms the skyline. The Nopah Peak thrust brings Neo-Proterozoic quartzites over Paleozoic carbonate rocks such as the Bonanza King Fm.

Immediately south of the Hot Springs is a hill of lower (light-colored), middle (dark) and upper (light-colored) Stirling Quartzite overlain by the Wood Canyon Fm. This low hill presumably was an island during stands of Lake Tecopa, the high stand submerging its top.

2.8 (1.3) To the south at 2:00 are a number of poorly-developed shorelines, suggesting that the lake rose rapidly. The best-developed shoreline is at 1400', the same elevation as a bar just above Grimshaw Lake. The flat-topped bar directly ahead of us also lies at elevation 1400'. We will drive across the top of this bar, named the Huffman Bar after long-time Tecopa resident Junior Huffman.



View northeast toward Nopah Peak. Tecopa Valley lies in the foreground with lines indicating the approximate high stand of Lake Tecopa. The Resting Springs Range is in the midground, with notation indicating the Cambrian Bonanza King Formation (Cbk), the Cambrian Carrara Formation, and Tertiary volcanic rocks. The Nopah Range is in the far distance. The location of the Nopah Peak thrust is indicated along with the upper plate units including the Bonanza King and Carrara Formations. The lower plate contains Upper Cambrian Nopah Formation and the Lower Ordovician Pogonip Formation. McMackin photo.

4.0 (1.2) Cross the Amargosa River incised into light-colored Tecopa Lake sediments. Note the piping (vertical tubes) that is part of the incision feature here.

4.3 (0.3) TURN LEFT at the Tecopa triangle and proceed toward the hot springs.

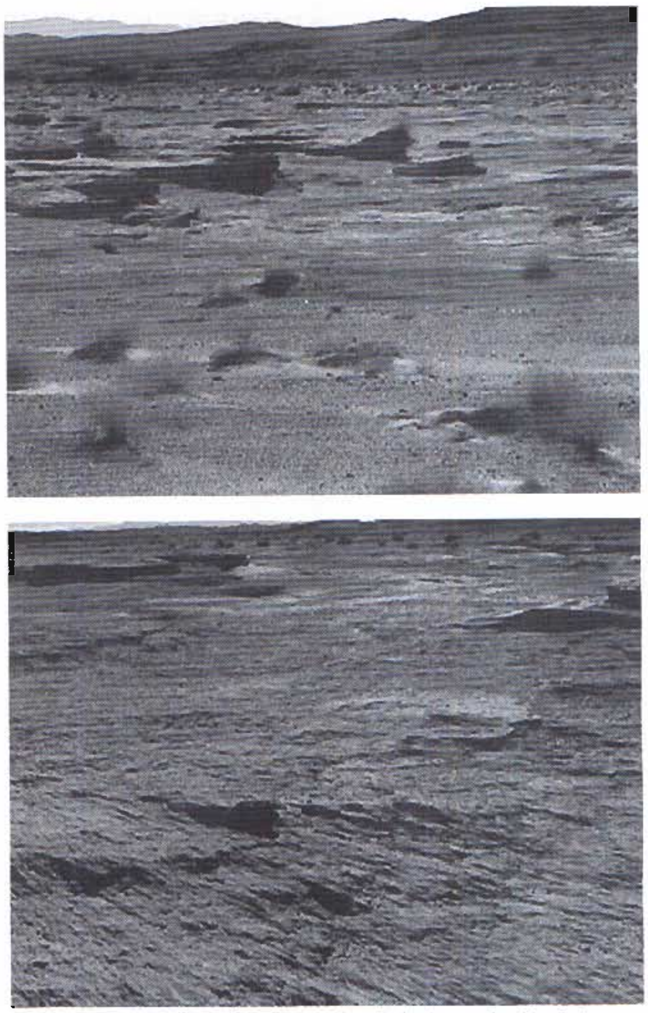
6.0 (1.7) Stop at stop sign near Hot Springs.

6.5 (0.5) TURN RIGHT on dirt road and proceed to yardang field.

7.4 (0.9) Road swings left, easterly. Go around and past the spring with a lone palm tree and tamarisk cluster. Head south across the salt-crusted surface of the Tecopa sand sheet.

7.6 (0.2) Pull right on dirt track and PARK.

Stop 2. Yardangs. The area just east of the Hot Spring Hills appears to be a wind gap where wind velocities are great enough to scour sand and fine sediment from Tecopa lake deposits. Evidence of wind scour is prominent on spring deposits consisting of sand and siliceous sinter capping the spring mounds on the east side of the hills. South of the spring mounds, wind scour is cutting into distal deposits of a fan deposit emanating from the Chicago Valley. The fan from Chicago Valley was deposited during the last stand of Lake Tecopa during the latest Pleistocene. Southward, as the valley east of the Hot Spring Hills becomes wider and the sand is deposited in the lee of brush, locally forming coppice dunes anchored by mesquite. South of the Old Spanish Trail Highway the sand spreads out to form the Tecopa Sand Sheet, which extends as far south as Willow Wash. Return to vehicles and proceed south-southeast toward the Old Spanish Trail.



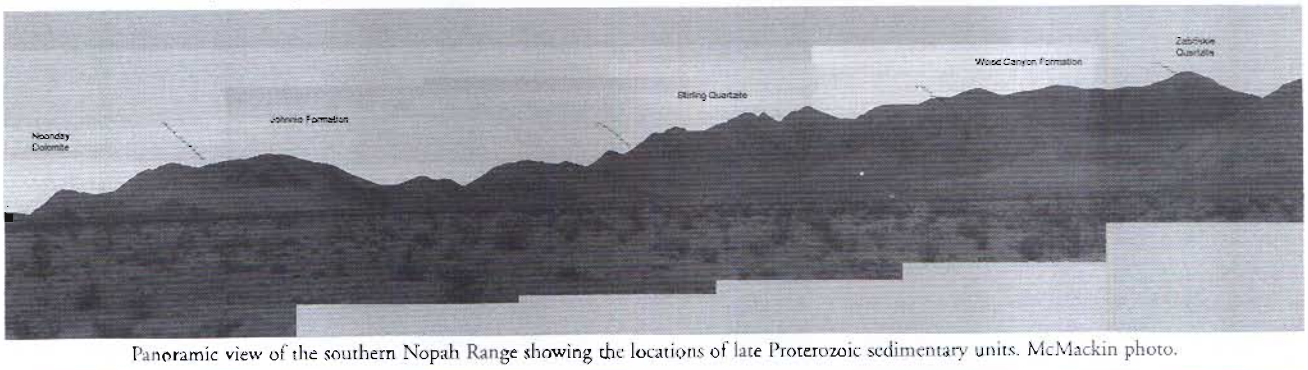
Yardangs (above) and wind-scoured surface (below) near the Hot Springs Hills. McMackin photo.

8.1 (0.5) Note the 1906 berm of a spur running east from Tonopah and Tidewater Railroad in operation from 1877 to 1928 that circles east to Noonday mine (Hensher and Vredenburgh, 1997).

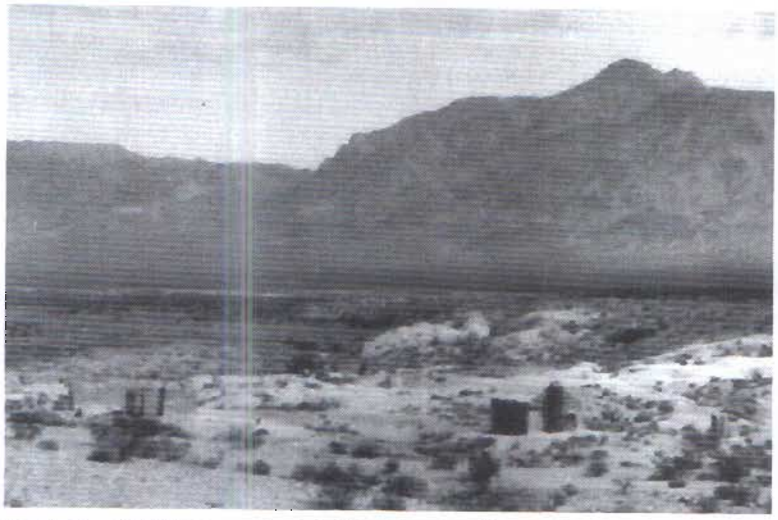
8.3 (0.2) Stop at the intersection with the pavement. TURN LEFT on Old Spanish Trail Highway.

8.7 (0.4) TURN RIGHT on Furnace Creek road and proceed to Tule Springs in California Valley.

9.6 (0.9) We are driving past fan deposits that were shed off the low



Panoramic view of the southern Nopah Range showing the locations of late Proterozoic sedimentary units. McMackin photo.



Smelter site at Old Tecopa, south of the Noonday mine. Kingston Range in distance. California Mining Bureau Report 15, 19197.

hills of Stirling Quartzite just south of the road. Poorly-developed shorelines from the high stand of Lake Tecopa are visible on older fan deposits and bedrock in these hills. Reworked sediment from the older fans and bedrock eroded from these hills plugged the initial Tecopa Canyon drainage, forming a dam that held the last stand of the lake.

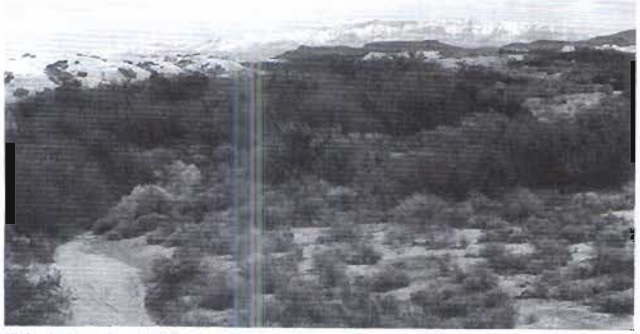
10.5 (0.9) Pass right turn to China Ranch.

12.3 (1.8) View southward to the Alexander Hills and the mines of the Western Talc deposits. These deposits are hydrothermally-altered dolomite converted into talc, a magnesium silicate mineral. This alteration was caused by by intrusion of diabase sills into dolomites of the Proterozoic section.

13.0 (0.7) Pass a right turn to Willow Spring Gorge. On the left are rocks of the Proterozoic basement. Here, a small complex of gold mining diggings known as the Desert Bard mine followed small pockets of gold-bearing quartz veins along the foliation in the Proterozoic gneiss. Quartz veins and pegmatite dikes cut through the darker gneiss and schist.

14.0 (1.0) Ahead are the mines of the Noonday district. The Noonday Dolomite is in depositional contact on the Proterozoic basement. Overlying the Noonday Dolomite is the largely siliciclastic and banded Johnnie Fm. The Johnnie Fm is overlain by the Stirling Quartzite, the Wood Canyon, Zabriskie, orange Carrara and dark Bonanza King. Photo 2-6.

15.5 (1.5) Pass through the site of the Noonday Mill. The road drops downhill into Willow Creek and we can view the 1877 town site of original "Tecopa," which contained a store, blacksmith shop and ore roasting furnace after which this road was named (Hensher and Vredenburgh, 1997).



Tule Springs in California Valley where valley axis deposits are choked with mesquite. R.E. Reynolds photo.

Ahead is the Kingston Range and Kingston Peak, elevation 7323'. The peak is Miocene granite dated at 12.1 million years (Calzia, 1977). On the granite to the right are two steep normal fault escarpments where the range is truncated on its western side by faults that have both normal and oblique slip. Above these scarps surfaces is evidence of deep weathering that produces spheroidal granite boulders. This weathering surface must be Late Miocene in age.

16.3 (0.8) Pass a right turn to site of Old Tecopa and road to the Western Talc Mine.

17.0 (0.7) Pass a cattle guard and a left turn to Donna Loy Mine.

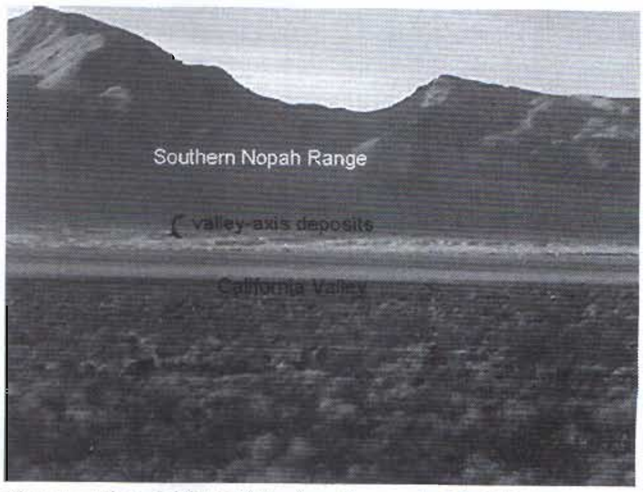
17.6 (0.6) On the left is the Paleozoic/Proterozoic section of the southern Nopah Range. Above the Donna Loy mine is Noonday, Johnnie, Stirling, and Wood Canyon with Zabriskie Quartzite at the top.

17.7 (0.1) TURN LEFT on Mesquite Valley Road which runs northeasterly into California Valley.

20.1 (2.4) TURN RIGHT, then SHARP LEFT on Mesquite Valley Road toward Tule Springs.

20.4 (0.3) PARK in the grove of tamarisk trees at foundation of an old structure.

Stop 3: Tule Springs. The row of springs is marked by a lineament of trees running to the southeast, suggesting ground water percolated along a fault zone. The BLM is in the process of eradicating the non-native tamarisk trees which use much of the available water. Although mesquite, a phreatophyte, is common all along the valley, particularly in the axis, this mesquite, cottonwood, and now tamarisk and palm occur in a lineament that runs east-southeast across the valley. If the axial drainage of a low gradient valley is dammed by vegetation that catches clastic materials, the entire axis can fill with distal, fine-grained deposits that produce a mature, slow drainage. The subsequent silts in the axial trough might include those deposited in marshes and ponds and intermit-



View to north to California Valley from the mouth of Beck Canyon, showing light-colored valley axis deposits. The Mesquite Valley road we will travel on lies along the northwest (distant) side of the light-colored sediments. McMackin photo.

tent dry "pans" and those that grade laterally into stable soil horizons with pedogenic carbonates. The complex interfingering of these microdepositional environments might provide at different outcrops a mixed interpretation of lacustrine, sag pond, peat, black mat, spring mound, fresh water limestones, pedogenic carbonate, and intermittent playa and distal braided stream and terminal fan interpretation. Many of the above may be accurate in the microcosm of deposition which consists of a distally-choked, low gradient axial drainage. Quade and others (1995) suggest such deposits are formed by spring discharge in a distal fan environment where shallow ground water supports a zone of vegetation where fine sediments are trapped and accumulate.

20.7 (0.3) Return to Mesquite Valley Road. TURN RIGHT and proceed northward through California Valley to the pavement of the Old Spanish Trail Highway. We are traveling past spring and pond deposits that extend the length of California Valley. These are axial valley deposits, fine-grained sediments washing out of the fans and accumulating with carbonates in the central part of a valley blocked at its downstream end by sediments stabilized by vegetation around springs. On the left skyline is Stirling, Wood Canyon and Zabriskie, on the left side of a saddle composed of the Carrara Fm, a weak-weathering unit, overlain by the Bonanza King Fm.

23.6 (2.9) The tree on the right marks the site of Davis Well. We are traveling on well-developed pavement of valley terrace gravels. To our left is the appropriately-named Banded Mountain member of the Bonanza King Fm. In the distance, Spanish Trail Highway crosses tan late Tertiary fan deposits.

24.4 (0.8) On our right at 2:00 is a low inselberg of the Bonanza King Fm. On our left, the inselberg of the Banded Mountain member of the Bonanza King Fm suggests that this formation underlies the western part of this valley and that the units are being repeated, presumably on west-dipping listric faults.

26.9 (2.5) Stop, TURN RIGHT on Old Spanish Trail Highway.

27.9 (1.0) The hills ahead to the northeast contain part of the Tertiary Resting Spring Fm, deposited on Paleozoic Bonanza King carbonates.

28.2 (0.3) PARK along the road side.

Stop 4: Upper California Valley. View of the Resting Spring Fm, a volcaniclastic section with flow rocks and dacitic breccias (dated from 12.5 to 11.1 Ma, Calzia, 1997) that dip shallowly east and sit unconformably above older Tertiary lacustrine sediments that include yellow siltstone and, downsection, orange and yellow Tertiary limestones deposited on the dark Paleozoic Bonanza King Fm. On the right side of the road is a section starting with Cambrian Bonanza King, unconformably overlain by Tertiary limestones. A fault in the low saddle repeats the sections. Through the saddle we see the upper part of the section of yellowish siltstones unconformably overlain by dark brown volcaniclastic sands. Ahead we pass through a saddle with the Banded Mountain and the Papoose Lake members of the Bonanza King exhibiting folding that reflects the complex history of this region. The section is repeated on either side of the pass, we infer as a result of a northwest-dipping normal fault. Return to vehicles and resume travel along the Old Spanish Trail Highway.

31.1 (2.9) Cross cattle guard. Left of the road, note the contact between the dark Banded Mountain member and the light Papoose Lake member of the Bonanza King. The east vergent fold is consistent with Mesozoic thrusting; the west-dipping normal faults are probably middle to late Tertiary in age.

32.3 (1.2) Pass through saddle.

33.1 (0.8) PARK on road shoulder.

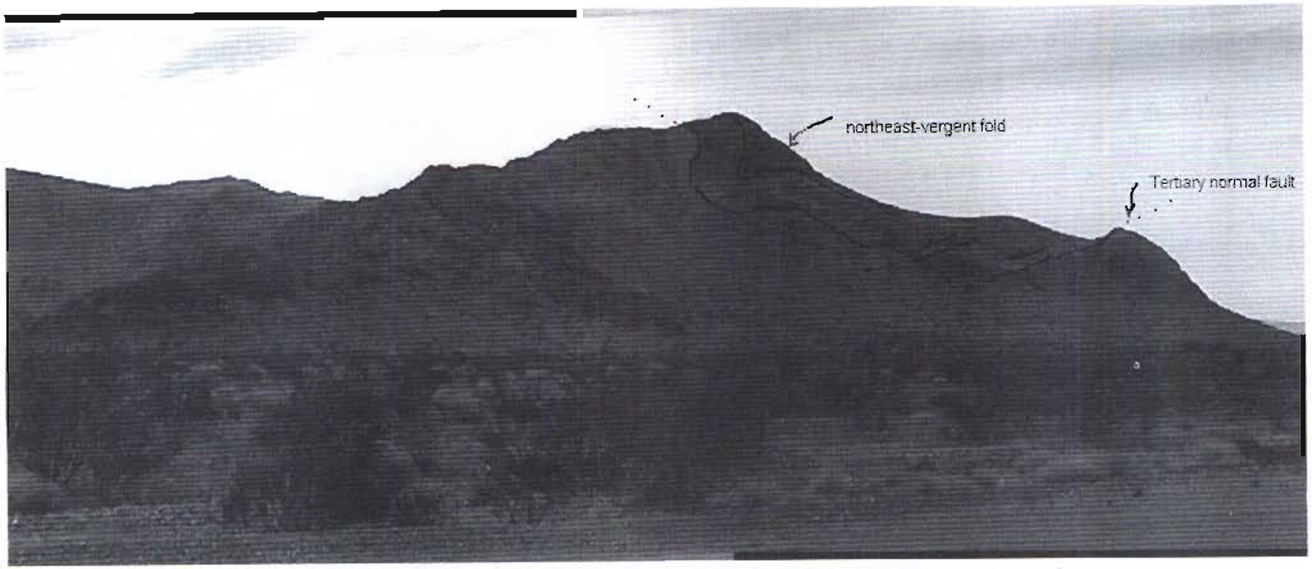
Stop 5: Resting Spring Formation. Pahrump Playa (dePolo and Ramelli, this volume) is to the left. Beyond the playa ahead of us is the escarpment of the Pahrump Valley/Stateline fault, our next stop.

WALK SOUTH, upsection along strike, to examine the Tertiary limestones. The darker beds are conglomeratic; the lighter beds are fresh water limestones and dolomites. The sand to the east is a relict late Pleistocene surface. Return to vehicles and proceed.

36.3 (3.2) Road trends easterly toward Potosi Peak, elevation 8512'. We are crossing the approximate route of the Pahrump Valley "Old Traction Road" running from Stateline, Nevada through Stewart Valley to Ash Meadows. At 10:00, brush-capped hills are Quaternary benches deformed along elevated portions of the Pahrump Valley fault zone. We're heading due east to explore that northwest-trending fault zone.

38.0 (1.7) Pass on the right a green sign for Charleston View and a pink sign for Rose Avenue. Underground storage tanks are on the left. Charleston Peak, elevation 11,918', is to the east.

38.3 (0.3) Pass westbound Charleston View sign.



Folded and faulted Bonanza King north of the road near Luciel Pass; view to the north. McMackin photo.

38.9 (0.6) Pass borrow pit and double lane graded road.

39.5 (0.6) TURN LEFT on double lane graded road. The wood power line pole at the northwest corner has a red reflector. If you reach a residence on the north, or the state line, you have gone too far. Proceed northward. Note the "peds," or polygonal columnar structure in the soil exposed in the road.

40.4 (0.9) TURN 45° LEFT (northwest) on the road that parallels the fault scarp and proceed a short distance.

40.5 (0.1) TURN RIGHT (north 45°E) past a brass-capped section marker on the right and proceed up the hill, crossing mid-Miocene Resting Spring Fm gravels that contain Bonanza King clasts coated with secondary carbonate. These deposits that have been uplifted along the Pahrump Valley fault zone.

40.8 (0.3) PARK on the right side of the road at top of hill.

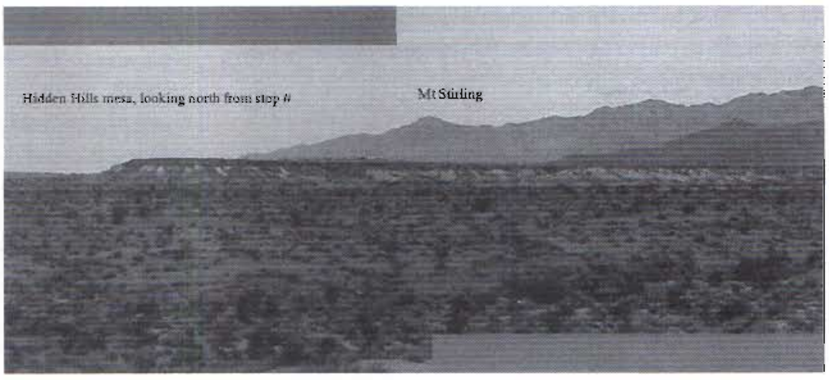
Stop 6: Hidden Hills Ranch. WALK downhill to look at the Tertiary section.

We're standing a deflated surface with clasts primarily of the Banded Mountain member of the Bonanza King with smaller amounts of clasts of yellow Tertiary limestone that we saw west across the valley. We are on the opposite side of the valley axis from those deposits and, due to fault uplift, the drainage from the west side of the valley is now to the northwest into Pahrump playa. Holocene sediments now come westward through gaps in the uplifted ridge of Tertiary/Quaternary rocks. Walk downhill to see that these late Tertiary? gravels rest unconformably on older, middle Tertiary sediments of different composition. A tuff deposit in the older section, exposed in the road, has been dated at 10.76 Ma (Ar/Ar analysis courtesy of Chris Henry, University of Nevada, to M. McMackin). Retrace through Tertiary sediments exposed along the road cut showing thick volcanic ash with lapilli containing datable sanidine.

Looking northward along the trend of the Stateline Fault, we can see that it heads toward Stewart Valley at the northern end of the Nopah Range. The Pahrump Valley/Stateline fault zone aligns directly with the Stewart Valley fault zone, as it's known further north. The hills aligned on the east side of the fault are also middle to late Tertiary sedimentary units that have been uplifted along the fault. Looking southward along the trend of the fault, a large, tan ridge is composed of late Tertiary conglomerates folded into a large anticline. Just beyond is the craggy top of Black Butte. To the north is the Hidden Hills Ranch anticline, where the Quaternary surface is folded, exposing Tertiary rocks in the core.

The Tertiary units are unconformably overlain by Quaternary units that include a well-indurated calcrete with Stage IV morphology. The subhorizontal, resistant calcrete is a prominent unit in the Quaternary section and we will see it at several stops today. The carbonate layers here are parts of pedogenic calcrete that is generally agreed to be approximately >100 ka. The carbonate drapes over the Pahrump Valley Fault without apparent offset. However, McMackin (this volume) suggests that fractures and gentle folds represent Late Pleistocene to Recent deformation on the Pahrump Valley fault zone.

41.2 (0.4) Continue northward, looking into the Hidden Hills Ranch anticline. The Quaternary carbonate that caps the lighter sediments is east-dipping at this point



Hidden Hills mesa, view to the north from the "no trespassing" sign. Hidden Hills mesa is capped by an east-dipping layer of late Pleistocene pedogenic carbonate. Near Stop 6 the carbonate is flat-lying to west-dipping. The underlying units include middle to early Pleistocene and middle Tertiary units exposed in the core of the Hidden Hills anticline. McMackin photo.

41.6 (0.4) TURN RIGHT at intersection and avoid the private property sign of the Hidden Hills Ranch. Within the first tenth of a mile along the road we see the second in a sequence of three prominent escarpments along the fault zone. Incised drainages along the fault scarps favor the growth of phreatophytes, suggesting that ground water is shallow on the uplifted blocks east of the fault. The incisions become coves dominated by mesquite (*Prosopis glandulosa*) and cat claw (*Acacia greggii*). Vegetation and seasonal water support biological diversity. The sites were frequented by Native Americans who left trails, lithic scatter, pottery and a corn cob.

42.3 (0.7) Pass a complex junction. To the right is an incised cove with mesquite.

42.9 (0.6) Cross the highest terrace. The gravel lag deposits on the surface here contain nodules of soil carbonate, angular chert pebbles, and rare Paleozoic limestone pebbles. The chert pebbles are apparently the residue left after dissolution of the Paleozoic clasts that carried the cherts down the fan. Within 300 feet, pass section marker (1/4 corner section 25).

43.0 (0.1) TURN RIGHT (130° south) 150 feet north of the section marker onto Stump Spring Road which crosses the graded road.

43.0 (0.9) Pass mesquite-stabilized coppice dunes on Quarternary pedogenic carbonate.

44.2 (0.3) Stop at Emigrant Pass highway. Watch for traffic and continue straight across the highway toward Stump Spring. As we proceed southward, notice that a number stabilized dunes sit along the escarpment, the easternmost in this zone.

45.0 (0.8) Pass red and brown BLM post marking alternate road to paved highway.

45.2 (0.2) Pass alternate intersection on right. Cross Stump Spring Wash. Look left to an exposed, west-dipping layer of the same calcrete as caps the higher surface. The slope is a scarp of the Pahrump Valley fault zone, but the carbonate layer is not cut by surface faulting. However, fractures and gentle folding are interpreted by McMackin (this volume) as evidence of late Quaternary transpressional deformation. Further along the wash on the right we'll find it dipping back to the east.

45.3 (0.1) Leave the wash and take the left fork in the road. PARK.

Stop 7: Stump Spring. WALK 10 minutes to the old well site and the stump after which the spring was named (Lyman and Walker, 1997) to look at the different levels of deposits (McMackin, this volume). The Quaternary carbonate surface we passed in the wash is now above us on the escarpment. The cut bank has produced a mammoth tooth and charcoal deposits near the stump. Quade and others (1995) report Carbon 14 ages of 8,750±170 for charcoal from the upper part of the Holocene channel deposits and 10,380±380 years for carbonized wood in the lower part. They also report an age for older, inset terraces above the Holocene channel from carbonized wood yielding a date of 31,790±1580/1290 years. Around the spring, casual inspection shows lithic scatter and a lot of old and younger glass. Archaeological material is on the Holocene surface, and the Spanish Trail that passes through here (Lyman and Walker, 1997). Return to vehicles and CONTINUE SOUTH along the Stump Spring Road.

45.9 (0.6) Cross another incised cove. Notice piping beneath the caliche cap. We are driving over the calcrete cap again, exposed in the roadway, above us on our left and below us to the right.

46.0 (0.1) On our left the calcrete cap dips between 10° and 15° to the west.

46.6 (0.6) PARK.

Stop 8: Pahrump Valley Fault Zone. The Holocene alluvium we are standing on consists of Paleozoic carbonate and red Triassic sandstones from the Spring Mountains to the east. The height of the Pahrump Valley/Stateline fault scarp at this point has diminished, perhaps as a result of two factors: either less tectonic throw or fill due to alluvium bypassing the Stump Spring fold (a monocline) and covering its southern margin where we stand. The latter factor would imply the recency of the Holocene? fold.

Look south to Black Butte slightly off of the strike of the fault zone. Black Butte may have been uplifted at a kink in the fault zone (McMackin, this volume). Northwest of Black Butte (to our southwest) is a ridge of Tertiary-Quaternary gravels in the center of the valley that runs sub-parallel to the Pahrump Valley fault. On the skyline, Nopah Peak is to the north-northwest. Charleston Peak is to the northeast. To the east is Mt. Potosi, named for the Potosi lead-zinc mining district in Spain. A plane carrying Carole Lombard, among others, crashed on its west face while on approach to Las Vegas. Devil Peak is south-southeast; Clark Mountain is to the south, and Kingston Peak is to the southwest. RETRACE route past Stump Spring to the Old Spanish Trail Highway.

47.5 (0.9) Pass Stump Spring Wash.

47.7 (0.2) Continue past a fork in the road. Stay to the right for the shorter return to the highway.

48.1 (0.4) Pass through mesquite-stabilized (coppice) dunes that sit above the pedogenic carbonate surface on which we are driving.

48.6 (0.5) Stop at the Old Spanish Trail Highway. TURN RIGHT (east) and take the paved road to Highway 160.

49.8 (1.2) Continue past a left turn to Hidden Hills Ranch.

50.8 (1.0) Pass through deflated Quaternary silts overlain by Holocene gravels with Paleozoic clasts.

51.3 (0.5) Pass a left turn to rifle range.

55.0 (3.7) Stop, TURN RIGHT (southeast) on Highway 160.

60.1 (5.1) In the saddle to the east are red Triassic sandstones that were the source of red clasts in the alluvium south of Stump Spring.

60.6 (0.5) Pass a left turn to Lost Cabin Spring.

62.3 (1.7) Cross the dirt track of the Old Spanish Trail running east to Mountain Spring.

63.3 (1.0) Continue past Lovell Wash.

65.8 (2.5) Continue past a right turn to a borrow pit.

66.4 (0.6) TURN RIGHT (southwest) on the graded road to Sandy Valley.

69.3 (2.8) Cross pole line road. A gravel ridge runs north from Black Butte, ahead.

74.1 (4.9) The ridge of Paleozoic rocks to the south contains the Green Monster thrust which places the Sultan and younger Paleozoic limestones over an overturned section of the same rocks (Hewett, 1956).

75.1 (1.0) South of Black Butte is a line of mesquite along the Stateline Pass fault zone running south-southeast to Stateline Pass. Mesquite Playa is to the west of this feature.

76.5 (1.4) Slow, pass through intersection. The road to the left reaches Sandy, a mill site for the Boss Mine. The Boss Mine (see "Silver Lake," Day 1 of this guide) was operated for platinum in the 1900s and the associated promotional communities that sprung up around Sandy were Platina, Ripley, Mandolin and Kingston (Hensher, this volume).

77.2 (0.7) To the right, the gravel surface on Quaternary silts is elevated on the east side of Stateline Fault.

77.7 (0.5) Pass through mesquite-stabilized sediments, a linear marker that runs southeast to Stateline Pass.

78.4 (0.7) Pass Borax Avenue on the right.

78.5 (0.1) TURN RIGHT on Coal Street.

79.1 (0.6) The dirt road crosses a bridge over the drainage ditch.

79.2 (0.1) TURN RIGHT at a cleared field that approximates the state line. Head northwest.

80.0 (0.8) TURN NORTHERLY at the end of the cleared area at an acute junction with a road from south (left).

80.8 (0.8) **Stop 9: Black Butte.** On the skyline Potosi Peak is east-northeast, Devil Peak is southeast, and Table Mountain is north of that. Kingston Peak is to the west. We are looking at Black Butte (a.k.a. Valley Ridge) to the northeast. The core of Black Butte is formed of a large block of Monte Cristo Limestone faulted obliquely over a Tertiary section that contains basalt, interbedded sandstone and siltstone, tuffaceous sediments and megabreccia, which is in part derived from the Monte Cristo units exposed in the core block. Potassium/Argon age determinations from several volcanic units in this section indicate that these rocks are between 14 and 12 million years old (dates by Fleck, personal communication to McMackin). The Monte Cristo is overlain by a similar Tertiary section that is capped by poorly-sorted boulder conglomerate. The late Tertiary conglomerates are typical of alluvial fan conglomerates and contain interfingered gravels derived from both east and west sides of the valley, suggesting that the valley axis shifted in response to ongoing tectonism in the late Tertiary.

Hewett (1956) suggested that Black Butte is a klippen of Tertiary thrust fault; subsequent workers have speculated that Black Butte might be a megabreccia deposit of landslide origin. McMackin (this volume) suggests that Black Butte may be the result of transpressional uplift wherein Paleozoic basement rocks have been lifted through Tertiary sedimentary cover. Similarly, North Valley Ridge, the northwest-trending ridge of Tertiary gravels lying northwest from Black Butte, is a faulted late Tertiary anticline with middle Miocene rocks exposed in its core. The clasts in the gravels indicate a source in the northwest Kingston Range across the fault with right-lateral deformation. The uplift, folding, and right-lateral offset combined suggest that the Black Butte and North Valley

Ridge are transpressional structures formed in bend or step over in the Pahrump Valley fault zone (McMackin, this volume).

82.2 (1.4) TURN LEFT (east) on an ungraded portion of Coal Avenue.

83.1 (0.9) TURN LEFT (north) on graded Tuskagee Road.

85.0 (1.9) Continue past intersection with road to Sandy Mill and proceed north.

87.0 (2.0) Pass a right turn to the Potosi Mine.

95.2 (8.2) Stop at the pavement of Highway 160. Watch for oncoming traffic and TURN LEFT (westbound).

97.8 (2.6) Cross Lovell Wash.

101.6 (2.8) Pass banded layers of the Moenkopi Fm dissected by erosion to form interesting topography.

107.1 (5.5) Move to the left lane in preparation for a left turn.

107.5 (0.4) TURN LEFT onto Old Spanish Trail Highway.

113.0 (5.5) Pass the entrance to Hidden Hills Ranch.

113.7 (0.7) "No passing" zone is crossed by Stump Spring Road.

114.3 (0.6) Slow for a second "no passing" zone.

114.5 (0.2) PARK on right shoulder.

Stop 10: Terraces. Stage IV calcrete is exposed in the wash just south of the road. Here we will inspect late Pleistocene soil units formed of older Tertiary conglomerates. The older conglomerates exposed in the wash contain clasts of Late Miocene Kingston granite mixed with other rock units exposed in the northern Kingston Range. The presence of these conglomerates east of the fault and well north of the fault is problematic to say the least. The apparent displacement from this point to the Kingston Range would be left lateral! It is likely that the conglomerates exposed here may represent sedimentary transport but that explanation is not entirely satisfactory.

If the sun is shining, we may be able to look west and see shadows of east-facing scarps on the East Nopah Fault. Anderson and others (1996) suggest that the scarps represent a single or a few events in the last 30 to 40 ka. Maximum total offset across several scarps is 12 meters but Anderson and others could not be certain that the full scarp height represents fault displacement. The down-to-the-east geometry of the scarps suggest that the fault is a range-bounding normal fault.

Looking west we also see the Pahrump Valley playa. The valley depocenter represented by the playa has shifted in response to late Tertiary and Quaternary deformation. Compared to late Tertiary units, the depocenter has shifted westward. Mid-Pleistocene playa deposits south of the Spanish Trail Highway may be an older depocenter that now drains northward to the recent Pahrump playa. These observations suggest that basin sedimentation is very responsive to local tectonism. It is important to note that many of these changes appear to have occurred in middle to late Pleistocene time and these are superimposed on similar structures of late Tertiary age. This presents a striking contrast to the Tecopa basin to the west, where the middle to late Pleistocene strata record a history of relative tectonic stability in the same time interval.

114.7 (0.2) Pass an alternate route to Stump Spring.

115.2 (0.5) Pass Mile Post 1.

116.0 (0.8) Drop down the western and lowest scarp which appears to have the best linear development of mesquite-stabilized dunes. The Quaternary surface dips steeply westward.

116.2 (0.2) Cross the California-Nevada border into Inyo County.

116.7 (0.5) Proceed west into Inyo County.

117.4 (0.7) Pass a residence with cottonwoods and pines.

117.6 (0.2) Pass the graded road we took north earlier.

118.8 (1.2) Pass the westbound Charleston View sign.

123.1 (4.8) The road bends southerly.

123.5 (0.4) Pass our earlier hike through the limestones of the Resting Spring Fm.

126.1 (2.6) Enter the headwaters of California Valley which drains southerly to Tule Springs, Willow Gorge and Amargosa Canyon.

129.6 (3.5) Cross a cattle guard.

133.8 (4.2) Pass Mesquite Valley Road; continue east on the Old Spanish Trail highway towards Emigrant Pass. To the left we can see the Banded Mountain member on top of the black, regularly-bedded Papoose Lake member, the lower part of the Bonanza King Dolomite.

137.2 (3.4) Slow prior to turning right off pavement.

137.4 (0.2) Turn out at summit. PARK at base of the gully. Additional parking may be found on top of the hill.

Stop 11: Emigrant Pass Carrara Formation Stromatolites. To the right of the gully is a large hill with Zabriskie Quartzite at its base. The slope is composed of shales and limestones of the Carrara Fm, and the cliff is of Middle Cambrian Bonanza King Fm. The stromatolite-bearing units are visible about halfway up through the Carrara Fm as thin, buff-colored discontinuous lenses. See

Pedogenic calcrete exposed in the wash. Note the prominent carbonate facies including an upper laminar calcrete over indurated carbonate nodules with sand, and sand with nodular carbonates. The underlying conglomerate contains gravel of the Kingston Peak granite mixed with Tertiary volcanic rocks and Proterozoic sedimentary rocks. McMackin photo.

Awramik, Corsetti and Shaprio, this volume, for stratigraphy, lithology, stromatolites, and age.

This east-dipping mountain range is presumed to be a simple basin and range structure bounded by west-dipping normal faults. If you look eastward across the fault you can see the Papoose Lake member of the Bonanza King Dolomite sitting in fault contact on top of the orangish-brown beds of the Carrara Fm. Note that the bedding is truncated. North of the road, the Bonanza King is in depositional contact on the Carrara. To confound the idea of a simple basin and range structure, west beyond the "sharp turn" sign, a section of the Carrara is emplaced over Tertiary sandstone by tectonism or gravity.

From the ridge top, we can look east into California Valley and note the route of the Old Spanish Trail (pavement) and other roads that head to this pass. The steep ascent to the pass makes one wonder why the water and fodder at Resting Spring was worth the effort. Lyman and Walker (1997) indicate that oxen did not do well on the salt grass at Resting Spring. An easier route to Amargosa Canyon lay through California Valley to our south. Our route today passed near important springs along the Old Spanish Trail: from the east, Mountain Spring, Stump Spring, Emigrant Pass, and Resting Spring, en route to Amargosa Gorge.

137.7 (0.3) Stop at pavement. Use caution and TURN RIGHT on the Old Spanish Trail Highway.

138.2 (0.5) To the right is conspicuously bedded Bonanza King and the Tertiary Resting Spring volcanic field. On the distant skyline is Sheeps Head Peak; in the far distance is Telescope Peak in the Panamint Range.

139.6 (1.4) Ahead in Chicago Valley on the east side of the Resting Spring Range is an embayment of light-colored lacustrine sediments deposited when Lake Tecopa rose to a high stand above 1800'. Larsen (this volume) suggests that the highest stand was just after the 0.76 Ma Bishop Ash strata was deposited. Lacustrine sediments were deposited above 1800' at Resting Spring and, from our vantage point, appear to dip south, basinward. Hillhouse (1987) maps silty mudstones at elevation 1950' at the north end of Chicago Valley. This is much higher than any documented shoreline, so these siltstones might be from depositional environments similar to the spring deposits we saw in California Valley, upstream from Tule Springs. The ridge to the left is a stratigraphy quiz: from east to west along the ridge profile are Bonanza King, Carrara, Zabriskie, Wood Canyon, Stirling, Johnnie and Noonday Dolomite.

142.1 (2.5) Ahead at the south end of the Resting Spring Range is a cluster of trees. To their right are Tecopa lake beds of the Chicago embayment. In the wash from Chicago Valley is a dense mesquite thicket. The green trees are salt cedars and palms at Resting Spring, a watering stop on the Old Spanish Trail and now an Arabian horse ranch.

146.0 (3.9) Continue past the turn to Resting Spring Ranch in a dense mesquite thicket. Historically the Old Spanish Trail came down from Emigrant Pass to Resting Spring and then to the Amargosa River Canyon, down to the spring at Salt Spring Hills, and then west to Bitter Spring. Consult the log for Day 3 for a story relating Resting Spring to Horse Thief Spring.

148.8 (2.8) View across the south end of the Tecopa sand sheet.

149.2 (0.4) Pass a left turn to Furnace Creek Road and continue on the Spanish Trail Highway.

150.7 (1.5) TURN RIGHT at Tecopa Triangle.

151.4 (0.7) Pass sign to Grimshaw Lake Natural Area

152.4 (1.0) Stop sign in Tecopa Hot Springs; public baths are on the right.

152.9 (0.5) Continue past Grimshaw Lake ACEC.

155.1 (2.2) Stop, TURN RIGHT onto Highway 127.

160.4 (5.3) Continue past intersection of Highway 178.

160.6 (0.2) STOP at Shoshone Museum. End of Day 2.

Day 3

Shoshone to Kingston

0.0 (0.0) CONVENE at the Shoshone Museum. PROCEED SOUTH on Highway 127.

0.1 (0.1) Watch for oncoming traffic and TURN LEFT at the junction onto Highway 178.

0.7 (0.6) Cross the Amargosa River. In 1/10 of a mile on the left are dugout castles in clay. Prepare to turn right onto the dump road.

1.2 (0.5) TURN RIGHT and PARK near the green sign.

Stop 1: Stratigraphic section. WALK north across the pavement, watching for cars to Stop 1. In the exposures north of the highway we see the Bishop Ash, 0.78 Ma, and the Lava Creek B Tuff, 0.6 Ma (Hillhouse, 1987). Seven depositional environments are shown in the stratigraphic section 1 (Larsen, this volume). Return to vehicles and RETRACE to Highway 178.

1.3 (0.1) Stop, watch for oncoming traffic, TURN LEFT (west) and proceed toward Shoshone.

2.4 (1.1) Stop at junction of 178 and 127. TURN LEFT (south) and proceed to the junction with Hot Springs Road.

6.6 (4.2) Look up the canyons to the bluffs on the right. Notice clumps of mesquite, tamarisk and isolated palms. This vegetation may be along a spring lineament.

7.1 (0.5) On the right is a small cave or hole at the base of a cliff. Water percolating along fractures produces pipes, conduits (sometimes large) that bring water from the terrace tops to cliff bases by devious routes.

7.7 (0.6) Pass the left turn to Tecopa Hot Springs. Proceed south to the site of Zabriskie.

8.3 (0.6) Pull to the right before the road bends to the right. PARK away from the rock structures and next to a hummocky grass area where there is a spring.

Stop 2: Zabriskie. We'll discuss borax mining history at the site of Zabriskie, where borax from Death Valley was processed during summer months and shipped on the Tonopah and Tidewater railroad (Reynolds and Troxel, 1997). HIKE up the canyon to the northwest to look at sedimentary structures. Return to vehicles, DRIVE NORTH back to Hot Springs Road.

9.3 (1.0) TURN RIGHT onto Hot Springs Road and proceed southeast towards Grimshaw Lake.

10.3 (1.0) Pole line marks the Tonapah and Tidewater Railroad grade that runs north to Rhyolite and Goldfield and south through Amargosa Gorge to Fort Soda, across Broadwell Lake to the railhead in Ludlow. Grimshaw Lake Natural Area is on the right.

10.8 (0.5) **Stop 3: Grimshaw Lake.** PARK and WALK north across the road to the source of hot, mineralized spring water. Return to vehicles and PROCEED south toward Tecopa.

Old borax works south of Zabriskie. California Mining Bureau Report 15, 1917.

11.8 (1.0) Stop sign at Tecopa Hot Springs. PROCEED SOUTH to Tecopa.

13.5 (1.7) Stop at the right side of Tecopa triangle. PROCEED SOUTH straight across Old Spanish Trail Highway past the east side of the Tecopa post office.

14.0 (0.5) PARK at mill site on gravel hill.

Stop 4: Fan Gravels. WALK to top of gravel hill to discuss gravels from the fan that choked the Amargosa River drainage between Lakes 1 and 2.

Here, we are standing on the Old Spanish Trail. Antonio Armijo, from New Mexico, was one of the traders who pioneered routes from Santa Fe via southern Utah to Los Angeles between 1829 and 1830. Although Armijo was not Spanish, and the trail was not old, it became known as the Old Spanish Trail (Lyman and Walker, 1997). Trade with Los Angeles supplied Santa Fe with mules and horse stealing, a spinoff, soon became a common practice to increase the profit margin. The Old Spanish Trail route was used by Peter Smith (Jedediah's brother) in 1831. J. C. Fremont reconnoitered the route in 1843, and the route was well used by travelers to the gold fields between 1849 and 1861. Travelers crossed over Emigrant Pass or went around through California Valley to follow the Amargosa River to Salt Spring, Bitter Spring and beyond to the Mojave River.

Return to vehicles and RETRACE to the pavement of Old Spanish Trail Highway.

14.6 (0.6) Stop at the pavement of Old Spanish Trail Highway. TURN RIGHT (east) and proceed through Tecopa. On the right are two silver-painted water tanks on the 1400' high stand of Lake Tecopa.

16.1 (1.5) TURN RIGHT on Furnace Creek Road.

17.9 (1.8) TURN RIGHT on China Ranch Road

18.8 (0.9) PARK at top of grade before reaching the power pole on the left.

Stop 5: Tecopa Hump View. The Tecopa Hump is to the southwest, McClain Peak to the west. An anticlinal fold called the Tecopa Hump (McMackin, 1997b) elevated middle to late Miocene sediments and Pliocene to Quaternary fanglomerate, enclosing the southern end of Tecopa Valley. Willow Wash and the Amargosa Gorge developed as incised meanders through the Miocene sediments of the Tecopa Hump. On the low peak of Noonday Dolomite, about 1 km west, wave-cut terraces mark former shorelines of Lake Tecopa. The terraces are poorly developed and are easier to see under favorable light conditions. These are high stand shorelines of Lake Tecopa, at an elevation of approximately 1800'. Across the canyon similar shorelines are found at the head of older Quaternary alluvial fans on McClain Peak and incised on tilted Pliocene conglomerates closer to the canyon. Minimal tufa deposits are found on parts of the wave-cut terrace in the fanglomerates. The weak development of the shorelines suggest that the lake did not occupy this high stand for long. Evidence regarding the draining of the high stand of the lake is largely lost to erosion of the Amargosa Gorge, leaving considerable room for speculation about the demise of Lake Tecopa.

As we head to China Ranch and at the next stop to the east we will see the incised meanders of Willow Creek into Pliocene Willow Creek fanglomerate, as it attempted to meet the same base level as the downcutting Amargosa River. As the Amargosa River cut through the Tecopa Hump, it also shows incised meanders. One explanation is that this humplike antiform was rising as the Amargosa River tried to drain the Tecopa Basin. A discussion by McMackin (1997b) suggests:

> Interestingly, the China Ranch beds and deposits of a younger basin are found along the canyon where the Amargosa River crosses the Tecopa Hump. This presents the attractive hypothesis that the Amargosa River predated the Tecopa Hump and that the basin deposits represent repeated episodes of damming and

High stand shoreline on Pliocene fanglomerate between the Amargosa River Canyon and McClain Peak. McMackin photo.

> draining of an ancient Lake Tecopa. However, there is no evidence in older sediments to support the idea of through-flowing Amargosa drainage. The most suitable conclusion is that incision of the Amargosa River across the Tecopa Hump occurred during the Plio-Pleistocene and that earlier sediments represent a sequence of closed basin deposits.

Return to vehicles and continue toward China Ranch.

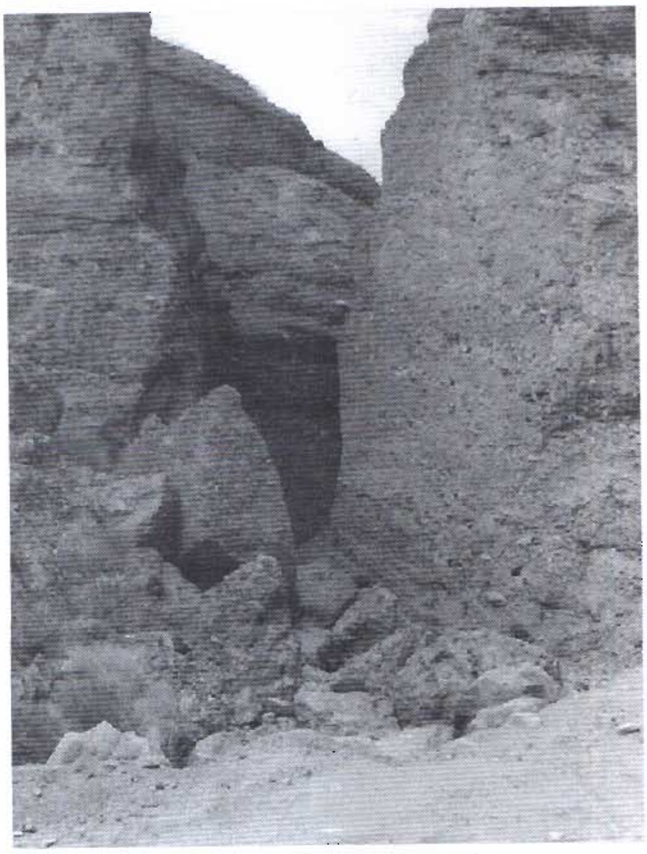
19.3 (0.5) Drive through incised slot canyons and spires in Pleistocene gravels.

19.7 (0.4) Enter tan, thin-bedded Miocene sediments of the China Ranch Beds near the entrance to China Ranch. To the east, Willow Creek enters China Ranch Canyon.

20.3 (0.6) PARK at the China Ranch bakery and gift shop.

Stop 6: China Ranch. The trail east of the bakery follows China Ranch Creek, choked with cottonwoods, willows and cat tails. In addition to local and migratory birds, hikers can see frogs, crayfish and a rare native fish, the speckled dace.

China Ranch was founded here about 1880 by a Chinese laborer who had worked at borax mines in Death Valley. He raised fruits, vegetables and food animals for sale to the surrounding borax and lead-silver mines. Around the turn of the century, the Chinese owner was displaced by a rancher named Morrison. Many subsequent owners produced a variety of crops, including figs, dates and alfalfa, and raised cattle and hogs. The property was purchased by the Brown family in 1970, who expanded the original date palm grove that was planted in the early 1920s by Vonola Modine, the youngest daughter of Death Valley area pioneer R. J. Fairbanks. The adobe home at China Ranch is modern, completed in 1991 (Brown, n.d.).



Slot canyon along China Ranch Road. R.E. Reynolds photo.

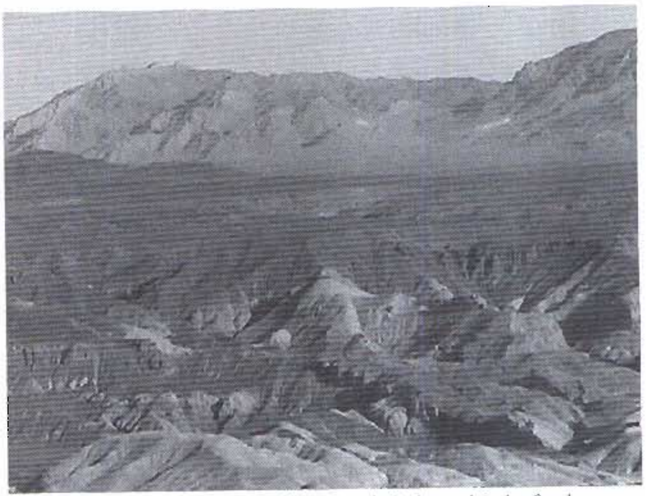


Photo looking east to Miocene China Ranch Beds overlain by fanglomerate of Willow Wash. In the afternoon we will proceed up Beck Canyon (center to the right) in the Kingston Range (in the background of this photo). McMackin photo.

RETRACE to Furnace Creek Road.

22.5 (2.2) Stop at junction of Furnace Creek Road and China Ranch Road. TURN RIGHT and proceed eastward on Furnace Creek Road.

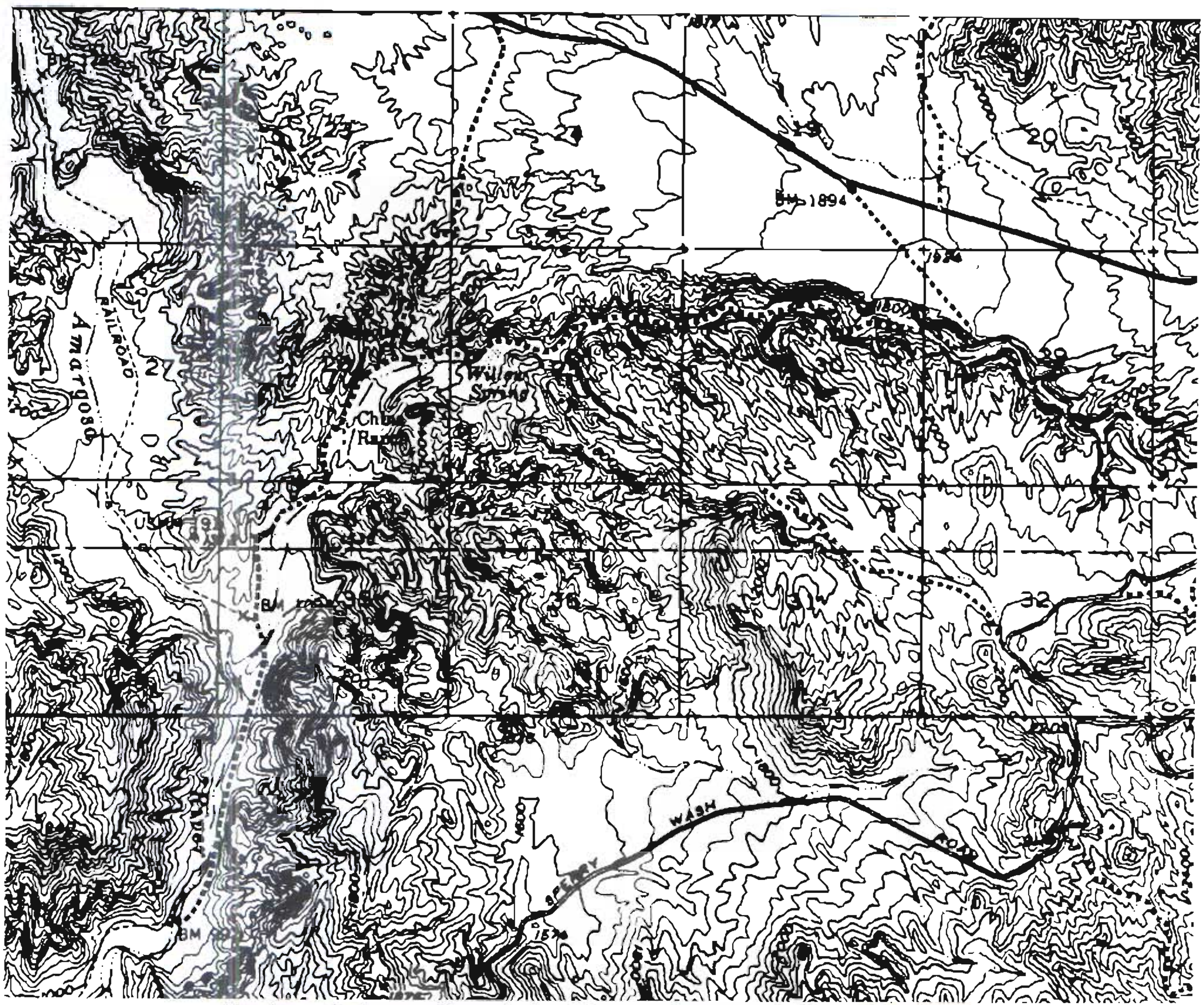
24.5 (2.0) An asphalt batch mixing area is on the right. Prepare to turn right at a pole line that runs right (south). On the left is the Noonday Mine spur from the Tonopah and Tidewater railroad.

25.0 (0.5) TURN RIGHT (south) and follow the pole line road to Willow Wash Gorge.

25.4 (0.4) TURN RIGHT at the last pole before wash and PARK.

Stop 7: Willow Spring. Willow Spring, below, is marked by vegetation. The sediments in the wall of the gorge were deposited

Spire associated with slot canyon along China Ranch Road. R. E. Reynolds photo.



Meanders on the Amargosa River and reflected in surrounding topography. Tecopa 15' quadrangle.

by Willow Creek in Plio-Pleistocene time on top of Miocene China Ranch beds. The fanglomerate from Willow Creek reached the southern end of the Tecopa basin. As the Amargosa River cut through gravels south of Lake Tecopa it readjusted base level on the south side of the Tecopa Hump. Willow Creek was forced to cut downward to that new base level. Note the incised meanders, similar to those in Amargosa Gorge. The incised meanders of some side canyons are formed by piping along high-angle faults in the conglomerate. The meandering pattern of the branch streams reflects the pattern of faults and fractures in underlying pre-Pleistocene gravels. On the south wall of the canyon, high-angle faults cut up an unconformity at the base of the early to middle Pleistocene gravels. Return to vehicles, PROCEED NORTH along pole line road.

25.9 (0.5) Stop at pavement. The cut in the base of the hill to the north is the Noonday Mine railroad. The Desert Bard mine is located here. TURN RIGHT and proceed east to the Noonday Mine.

27.5 (1.6) The road swings northerly. The Noonday Mine is to the north; the Columbia Mine is lower and to the east (Hensher and Vredenburgh, 1977).

27.7 (0.2) Pass a paved road to the left; the road swings right.

28.0 (0.3) Notice the cement building where we will turn left.

28.4 (0.4) TURN LEFT (north) on the dirt road between the cement block building and foundations.

29.0 (0.6) Pass a reverse junction with a road coming in from the right.

29.6 (0.6) The road stops at the dump of the Columbia Mine; the Noonday Mine is to the northeast. TURN 320° LEFT and proceed southwest on the section of paved road.

29.8 (0.2) The once-paved road goes through a cut in a calichified fanglomerate. As you leave the cut, watch for a dirt track to the right.

29.9 (0.1) TURN RIGHT on dirt track.

30.4 (0.5) Proceed past the track that turns to the right.

30.5 (0.1) The road drops into a wash. PARK. The rock cairn to the right is along a center section marker. WALK 1/10 mile to a silicified ridge.

Stop 8: Johnnie Formation Stromatolites. The stromatolites are predominantly in the buff-colored, 1 meter thick layers, but can also be found in the gray layers. Small, branching columns, as well as domical stromatolites, are visible. See Awramik, Corsetti and Shaprio, this volume, for stratigraphy, lithology, stromatolites, and age. Return to vehicles and RETRACE route past the Columbia Mine to the cement block building at Furnace Creek Road.

from the Beck Spring Dolomite, a greenish-orange section of the lower Kingston Peak. Exposures show massive, matrix-supported conglomerate known as a diamictite. Some workers believe that the diamictite here is of glacial origin; others have suggested that it may be formed as debris flows and that question remains unresolved. A number of soft sediment folds in the upper Kingston Peak Fm overly the diamictite. Across the valley to the east, the dark outcrops are the lower member of the Crystal Spring Fm in depositional contact on the Proterozoic basement. Upsection are orangish-gray carbonates of the middle Crystal Spring with a thin layer of talc beneath them. Between the lower and middle Crystal Spring are intrusions of diabase sills. From north to south, the Noonday Dolomite lies upon the Crystal Springs Formation, Beck Spring Dolomite, and Kingston Peak Formation, forming an angular unconformity that marks the northern margin of the Proterozoic Amargosa basin. The Beck Spring Dolomite and Crystal Spring Fm have been removed beneath an angular unconformity and deposited in the basin to the south as sediments of the Kingston Peak Formation. From the point where it is cut out beneath the Noonday Dolomite, the Kingston Peak thickens southward to approximately 4 km thick in the southeast Kingston Range (unpublished mapping of Troxel and Wright).

On the south skyline ridge is a large Proterozoic landslide, more than 1 km long, deposited in the upper Kingston Peak Formation. It contains blocks of blue-grey Beck Spring Dolomite, dark brown lower Kingston Peak Fm, and part of the upper Crystal Spring Fm. Presumably these slid southward as a large block from the Jupiter Peak area to our east in a very large landslide. Upsection the Kingston Peak Fm is composed of fanglomerates interbedded with sandstone and other large landslide breccias.

58.9 (0.4) Continue past a left turn to the Blackwater Mine. The white band of talc to the east is the Snow White Mine on Jupiter Peak.

60.3 (1.4) Pass a left turn to the western Snow White workings.

60.6 (0.3) Pass a complex intersection that leads to the eastern workings of the Snow White Talc Mine. Proceed south on Excelsior Mine Road.

65.9 (5.3) Pass a junction to Kingston Wash. Climb up hill to the Do Not Pass.

74.6 (8.7) Pass the intersection with Kingston Road, Mesquite playa and Sandy Valley.

78.6 (4.0) Pass under power lines.

88.3 (7.7) Junction with Interstate Highway 15 at Cima (Excelsior Mine) Road.

END OF DAY 3

Summary. Late Tertiary tectonism disrupted the long sequence of Paleozoic and Mesozoic strata, setting the stage for the drainages and basins that filled with water during the pluvial Pleistocene. Erosional features such as slot canyons and spires suggesting rapid incision or rapid headward erosion are similar in Afton Canyon and at China Ranch Gorge. The incised meanders in both areas suggest slow incision, but may have been formed at different times by different processes. Along our route we have seem1.1 Ga Proterozoic rocks deposited on metamorphic basement through early Paleozoic rocks, ~550 Ma, that contain abundant invertebrate fossils. We have even seen Pleistocene stromatolites on Lake Manix.

References Cited

Anderson, D.E., Balling, R.C. Jr., Vose, Rus and Wells, S.G., 1997. Modern hydroclimatology and Late Holocene fluvial history of the Amargosa River near Tecopa, California, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 43-48.

Anderson, K. C. and Wells, S.G., 1997, Late Pleistocene and Holocene valley-fill deposits of Lake Dumont, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 29-32.

Anderson, R.E., Crone, A.J., Machette, M.N., Bradley, L.A. and Diehl, S., 1996, Characterization of Quaternary faults, Amargosa area, Nevada and California: U.S.G.S. Open-File Report, 41 p.

Brown, Brian, n.d. China Ranch: A Brief History: undated booklet, China Ranch, CA, 4 p.

Calzia, J. P., 1997, Geology and geochemistry of a middle Miocene rapakivi granite in Death Valley, California, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 49-58.

Chesterman, C. W., 1973, Geology of the northeast quarter of the Shoshone quadrangle, Inyo County, California: California Division of Mines and Geology, Map Sheet 18, scale 1:24,000.

Harder, E. C., 1997, The Amargosa gold mine, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 33-36.

Hensher, Alan and Vredenburgh, L.M., 1997, The early history of the Resting Springs Mining District, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 67-70.

Hewett, D.F., 1956, Geology and Mineral Resources of the Ivanpah quadrangle, California and Nevada: U.S. Geological Survey Professional Paper 275.

Hillhouse, J. W., 1987, Late Tertiary and Quaternary geology of the Tecopa basin, southeastern California: U.S. Geological Survey, Map I-1728, scale 1:48,000.

Kepper, John, 2000, The Yellow Pine Mining District, *in* Reynolds, R.E., editor, Minerals from the Mojave: San Bernardino County Museum Association Quarterly, vol. 47 (1), p. 3-16.

Lyman, Leo and Walker, Cliff, 1997, Water holes to California: emigrant travel over the most difficult portion of the southern route from Utah to California, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 61-66.

McMackin, Matthew, 1992, Tectonic evolution of the Kingston Range, Death Valley, California, unpublished Ph.D. dissertation, Pennsylvania State University, University Park, Pennsylvania, 158 p.

McMackin, Matthew, 1997a, Neotectonic joints at Spanish Trail Mesa, Tecopa Lake Beds, California, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 59-60.

McMackin, Matthew, 1997b, Late Tertiary evolution of the Southern Death Valley Fault System: The origin of the Tecopa Hump, a tectonic dam on the Amargosa River, *in* Reynolds, R.E. and J. Reynolds (eds), Death Valley: The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 37-41.

Munz, P.A., 1974, A Flora of Southern California: Berkeley, University of California Press, 1086 p.

Myrick, D. F., 1991, Railroads of Nevada and eastern California, volume II, The southern roads: Reno, University of Nevada Press.

Quade, J., Mifflin, M.D., Pratt, W. L., McCoy, W.D. and Burkle, L., 1995, Fossil spring deposits of the southern Great Basin and their implications for changes in water-table levels near Yucca Mountain, Nevada, during Quaternary time: Geological Society of America Bulletin, vol. 107, p. 213-230.

Reynolds, R.E. and Troxel, B.W., 1997, Death Valley, The Amargosa Route: San Bernardino County Museum Association Quarterly, vol. 44 (2), p. 3-24.

Spencer, J.E. 1990, Geologic map of the southern Avawatz Mts, northern Mojave Desert region, San Bernardino County, California, scale 2:24.000: Map MF-2117.

Marker Units Suggest Correlation Between the Calico Mountains and the Mud Hills, Central Mojave Desert, California

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Abstract

The early Miocene depositional sequence of volcanic and lacustrine rocks in the central Mojave Desert can be divided into lower, middle, and upper intervals. The middle interval contains marker beds that can be recognized in the Mud Hills, Calico Mountains and at Lead Mountain. Their extent and depositional environment suggest an expanding lacustrine basin in Late Hemingfordian (Late Early Miocene) times. Geologic mapping in the mid 1900s noted that certain sediments in the Calico Mountains were similar lithologically to well-dated sediments in the Mud Hills, northwest of Barstow, California. Fragments of a fossil horse in the Calico Mountains indicate that its biostratigraphic age must correlate approximately with taxa found in the Mud Hills, but the absence of additional fossils left the relationship poorly constrained, at best. Lithostratigraphic correlation is complicated by the intrusion of volcanic domes that caused sediment compression and breccia emplacement. Plio-Pleistocene compression between the Calico Fault, Camp Rock Fault and Lenwood Fault resulted in additional deformation and right-lateral offsets. This study uses several distinctive lithologies and their regular stratigraphic relationships in an attempt to correlate the latest Hemingfordian - earliest Barstovian section that crops out along the southern Mud Hills with units that appear similar in the Calico Mountains. Certain of these lacustrine units transgress topography in the Miocene "Barstow" basin; such transgressions help define basin limits and depth during formation.

Introduction

Field work by this and previous authors along the southern and northern limbs of the Barstow syncline in the Mud Hills has recognized a distinctive sequence of carbonate and strontium-rich sediments.

Tubular carbonate stromatolites noted by members of the Childs Frick parties from the American Museum of Natural History (AMNH; Evander, 1998) lay immediately below the Red Division Quarry, and their presence made that horizon easy for paleontologists to follow eastward. The sequence of algal limestone, thin limestone layers, and strontium bearing beds was noted during mapping of strontium deposits (Durrell,1953). Detailed mapping by Dibblee (1968, 1970, 1980) suggested that the stratigraphy could be broken down into lower, middle, and upper depositional packages, with lacustrine sediments of the lower referred to the Pickhandle Formation (Dibblee, 1970) and the middle and upper members referred to the Barstow Formation. McCulloh (1965) was more conservative, naming the lacustrine sediments in the Calico Mountains west of the Calico Fault the Burcham Formation since mapping could not carry them directly into the section in the Mud Hills.

Dibblee (1970) described an "Oligocene to Miocene" section of Miocene andesitic breccias and Mesozoic detritus that extended from Newberry/Rodman Mountainss to the Calico Basin on the north. He referred this depositional package, including massive tan limestones and lacustrine siltstones, to the Pickhandle formation, deposited earlier than the sequence of marker beds that are the focus of this paper. The sequence of the marker beds is distinct. Although similar isolated beds may occur locally, the sequence of units does not appear to have been repeated elsewhere. The sequence, from oldest to youngest is: massive stromatolite limestone (MSL); brown platy limestone (BPL); and Strontium / borate mineral horizon (SBH).

Description of Marker Units

Massive Stromatolite Limestone

The massive stromatolite limestone (MSL) contains laminated carbonate structures around casts of water reeds, laminated carbonate structures that may represent deposition by domal algal mats, or a combination of both. In the west, the tubular structures are preserved in siltstone matrix, bracketed by coarse sandstone. Gradationally to the east, the matrix surrounding the stromatolite tubes becomes more calcareous. On the south limb of the Barstow syncline, the tubular stromatolites can be traced from Red Division Quarry in Trident Canyon eastward through the loop road exit and entrance, and to Owl Canyon. On the north limb of the syncline,

Figure 1. MSL. The south limb of the Barstow Syncline contains tubular stromatolites deposited around water reeds.

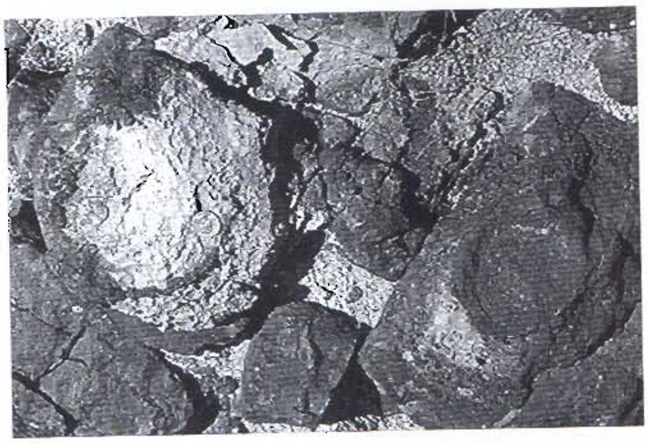

Figure 2. MSL. Partially silicified large algal mounds in the massive stromatolite layer east of Big Borate Canyon, Califoco Mountains.

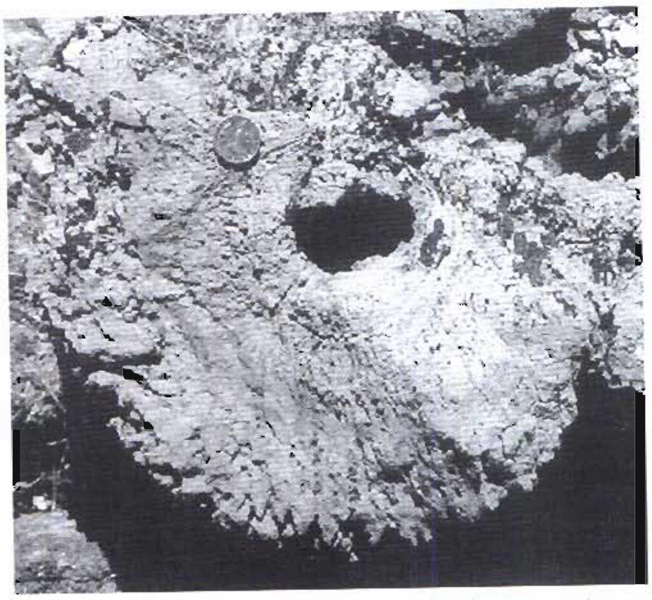

Figure 3. MSL. Cross-section of tubular stromatolite showing central hollow cast of water reed (?), Owl Canyon, Mud Hills.

tubular structures and large domal structures are in a carbonate cemented clastic matrix that can be traced eastward to the Solomon Mine. At Cemetery Ridge, west of Calico Ghost Town, the partially silicified tubular stromatolites are in tan carbonate matrix. North of Little Borate Canyon, and along the drainage divide of the Calico Mountains, the tubular structures in the MSL become rare, and are not known further east. The dominant feature from this point east are large (to one meter diameter) laminated domal structures. East of Big Borate Canyon, the MSL becomes progressively more silicified, until it becomes a resistant chalcedony layer in the Yermo Hills (sec 21, T10N, R2E, SBBM). In this area, the silicified MSL occurs approximately 100 feet up-section from emerald green tufaceous sediments. Further work might correlate this green unit with the emerald green tuff in the Toomey Hills to the southeast, which is located ninety feet below the co-occurrence of *Merychippus carrizoensis* [*Parapliohippus* Kelly, 1995] and *M. stylodontus* [*Acritohippus quinni* Kelly, 1995]. North of Lead Mountain, southeast of the Columbia (American Borax) Mine (sec 25, T10N R2E) the MSL crops out as a thick, resistant ridge of gray massive limestone with silicified laminations. In this area it is overlain by a vesicular volcanic flow breccia.

Brown Platy Limestone

The brown, platy limestone (BPL) occurs as three resistant beds deposited in siltstone that overlies the MSL. It is consistently down-section from deposits that contain celestine (strontium sulfate) which in the east is associated with colemanite deposits. The BPL layers are coarse grained, and sometimes contain a significant portion of sand-sized grains. The layers are 1/8 to three inches thick and sometimes exhibit a columnar cross section that weathers on its surface to a distinctive pitted texture. Plant remains are found within and near the base of the silty limestone. The rich cinnamon-brown color of the BPL is distinctive from the gray MSL and from the massive yellow limestones south of Lead Mountain. In the Calico Mountains and in the Mud Hills, white silicified limestones occur up-section from the BPL. The three beds of BPL extend eastward through the Calico Mountains and Mule Canyon to where they disappear east of Borate and west of the Yermo Hills. They crop out southeast of Borate at the Palm Borate workings on the southeast side of the Calico Mountains. On the north side of Lead Mountain, they appear immediately above the vesicular volcanic breccia above the MSL, and east of the strontium-rich workings of the Columbia Borax Mine. The BPL appears to overlie the MSL at the northwestern tip of the Calico Mountains. The platy limestones can be traced along the south limb of the Barstow Syncline as far west as Red Division Quarry in Trident Canyon and have been

Figure 4. BPL. Three distinct layers of limestone occur in greenigh-gray lacustrine siltstones above the MSL in the Mud Hills.

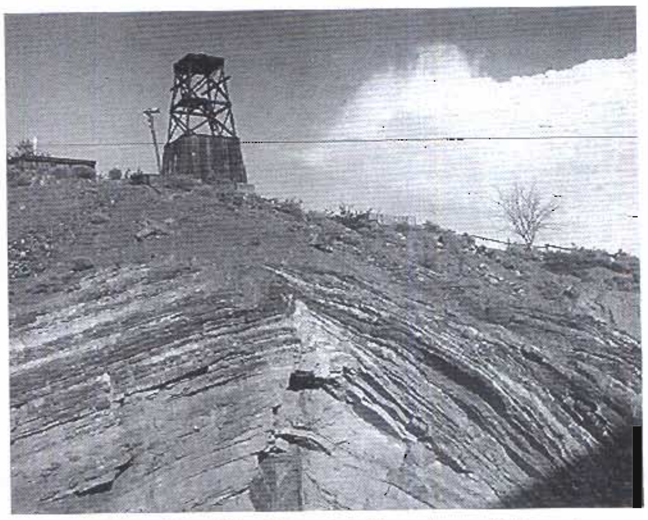

Figure 5. BPL at Calico Ghost Town is visible as chevron folds in the parking lot and can be mapped to the east through Mule Canyon.

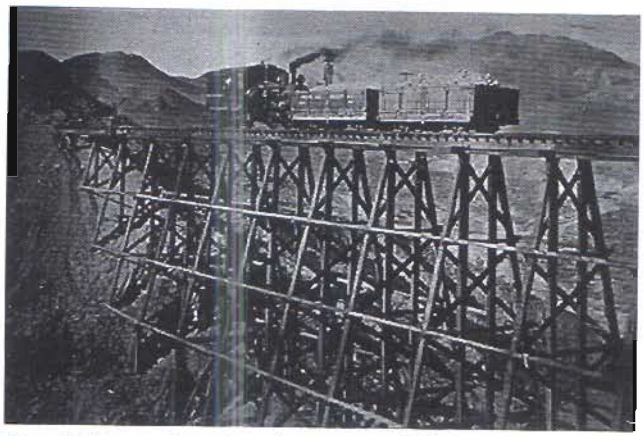

Figure 6. Three marker units at the entrance to Little Borate Canyon, Calico Mountains, view from south. MSL in distance; BPL at left end of trestle; photographer is standing on SBH at the historic Borate mines that produced strontium and borax.

recognized on the north limb of the syncline (Durrell, 1953). In Trident Canyon the BPL is below the celestine horizon. Between this canyon and Coon Canyon to the northwest, two additional layers of brown platy limestone occur above the three mappable BPL layers.

Strontium-Borax Horizon

The strontium-borax horizon (SBH) in the Calico Mountains contains the borate minerals ulexite (sodium calcium borate), colemanite (calcium borate), and howlite (calcium borosilicate) associated with celestine (strontium sulfate). The celestine is found east of Big Borate Canyon and as far west as the area of Odessa Canyon and Phillips Drive. Ulexite and celestine occur at the Columbia Mine north of Lead Mountain. Strontium deposits are recognized on the north limb and on the south limb of the Barstow syncline at the Solomon and Ross mines, respectively, where they have been tied stratigraphically to underlying "thin platy limestones that occur above an algal limestone" (Durrell, 1953). On the north limb, the strontium appears to be 60 feet above the platy limestone, while on the south limb, the strontium horizon is much higher above the BPL. Dark brown botryoidal celestine can be traced as far west as Rainy Day Canyon, east of Trident Canyon on the south limb, where prospects are only tens of feet above the BPL. In all cases, the SBH sits above the uppermost of three BPL layers.

History of the Basin

Although the MSL may have been somewhat time and topography transgressive, it can be used as a regional marker to divide the overlying sedimentary section from that which lies below. From Calico Ghost Town, through the Calico Mountains to the Yermo Hills on the east, the section below the MSL consists of siltstones and shales and occasional thin white tuffs underlain by volcanic breccias. Stickleback fish (Eschmeyer *et al.*, 1983; McGinnis, 1984) have been recorded from siltstones of the Toomey Hills (Reynolds, 1991) and these suggest that the basin in mid-Hemingfordian time was part of a drainage system that was connected to the Pacific Ocean (Reynolds, 1991; Woodburne, 1991). In the vicinity of Lead Mountain and Elephant Mountain, the MSL overlies siltstone, tuff breccia, and a thick section of yellow, thick-bedded limestones. To the west-northwest, on the south limb of the Barstow Syncline, the tubular stromatolites are bracketed by coarse red fluvial sandstones which up-section give way to lacustrine siltstones approximately at the first appearance of the lowest layer of BPL. Therefore, it appears that a water-holding basin of limited extent was present in the Calico-Lead Mountain area prior to a water-holding basin in the Mud Hills. The MSL indicates a point in time when the basin enlarged to hold water in both areas, even though the western area continued to be inundated by red gravels until the deposition of the BPL.

The working hypothesis of this research is that the following sequence took place in the area of the Calico Mountains and Lead Mountains.

- Development of a limited, deepening basin contained yellow massive limestones and volcanic breccias.
- Deposition of lacustrine siltstones including the emerald tuffs, and then the sequence of MSL, BPL, and SBH followed by deposition of more siltstone with white silicic ash.
- Synchronously in the west, a basin was being filled by the Owl Conglomerate and red sandstones of the Red Division. The MSL is the first continuous lacustrine horizon to be seen in these coarse sediments. A competent, water- holding basin developed about the time the lowest layer of the BPL was being deposited.
- In the Calico Mountains, at a time that may correspond to the late Hemingfordian Land Mammal Age, andesite domes from Borate to Calico Peak formed, causing compressional deformation of soft siltstones and brittle deformation of the limestones. As the domes grew, they shed breccias from older, 17.3 my (U. S. Borax, unpubl. data, 1999) deposits across the lacustrine sediments, filling the basin and excluding further lacustrine deposition.
- Lacustrine deposition continued in the west from 16 mya until 13 mya (Woodburne, 1991; McFadden et al, 1990).

Depth of Deposition

Algae that precipitates calcium carbonate to form lamellar stromatolite structures grows near the surface of a body of water that is clear enough to transmit sunlight. Carbonate casts around water reeds or woody plants suggest that deposition was near the margin of the water body, since these plants prefer to grow in shallow water or along fluctuating lake margins. The absence of the tubular structures and an abundance of large lamellar domes suggests deposition in deeper, clear water. A combination of both forms suggests a gradational depositional environment or mixing by storm or wave action. The morphology of the MSL east of Borate in the Calico Mountains, at Lead Mountain, and in the northwestern Calico Mountains suggests deposition in relatively deep and clear water. The mixed occurrence of large mound structures and tubes west of Tin Can Alley and on the eastern end of the north limb of the Barstow Syncline suggest an intermediate depositional environment or zone of mixing. The tubular structures deposited in siltstone, but bracketed by coarse sandstone west of the Loop Exit, suggest a fluctuating margin during basin expansion.

The BPL apparently does not encroach into the fluvial section, although the layers are often sand-rich. The BPL layers are perhaps more limited in extent than the MSL, since the BPL is not found much farther east than Borate. The deposition of BPL may have been limited to water depths that are shallower than those suggested by the large lamellar domes in the MSL, but equivalent to or deeper than the depth of the tubular structures in the MSL. The deposition of the BPL may be associated with conditions that produced the lacustrine sandstones, and the combination of plant remains, animal tracks and partially articulated skeletons suggests a shallow, near-shore environment.

Summary

A distinct set of marker beds, the MSL, the BPL and the SBH, occur in the Mud Hills, Calico Mountains and at Lead Mountain. These types of deposits are useful as marker beds that connect the forming early Miocene (Late Hemingfordian LMA) basin, and in providing constraints concerning basin depth and configuration.

Acknowledgments

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References Cited

Dibblee, T. H., Jr., 1970, Geologic map of the Daggett quadrangle, San Bernardino County, California: U. S. G. S. Misc. Investigations Map I-592, scale 1:62500.

___, 1968, Geology of the Opal Mountain and Fremont Peak quadrangles, California: California Division of Mines and Geology Bulletin 188, 64p.

___, 1980, Cenozoic rock units of the Mojave Desert, *In* Fife, D. L. and Brown, A. R., eds., Geology and Mineral Wealth of the Mojave Desert: South Coast Geologic Society, p. 41-68.

Durrell, Cordell, 1953, Geologic investigations of strontium deposits in southern California: California Division of Mines and Geology Special Report 32, 48p.

Eschmeyer, W.N., Herald E.S., and Hammann, H., 1983, A field guide to Pacific Coast fishes of North America: Houghton Mifflin Co., Boston, 336 p.

Evander, R., 1998, The development of quarry sites at Barstow: AMNH notes.

Kelly, T. S., 1995, New Miocene horses from the Caliente Formation, Cuyama Valley Badlands: N.H.M.L.A.C. Contributions in Science, No. 455, 33p.

McCulloh, T. H., 1965, Geologic Map of the Nebo and Yermo quadrangles, San Bernardino County, California: U. S. G. S. Open File Map 65-107, scale 1:62,500.

McFadden, B. J., Swisher, C. C. III, Opdyke, N. D. andWoodburne, M. O. , 1990, Paleomagnetism, geochronology and possible tectonic rotation of the middle Miocene Barstow Formation, Mojave Desert, California: G. S. A. Bulletin, v. 10, p. 478-493.

McGinnis, S.M., 1984, Freshwater fishes of California: California Natural History Guide 49, University of California Press, 316 p.

Reynolds, R. E., 1991, Hemingfordian / Barstovian Land Mammal Age faunas in the central Mojave Desert, exclusive of the Barstow Fossil Beds: San Bernardino County Museum Association Quarterly, vol. 38 (3&4), p. 88-90.

Woodburne, M. O., 1991, The Mojave Desert Province: San Bernardino County Museum Association Quarterly, vol. 38 (3&4), p. 60-77.

Woodburne, M. O., and Swisher, C. C., 1995, Land mammal high-resolution geochronology, intercontinental overland dispersals, sea level, climate, and vicariance, *In* Berggren, W. A., Kent, D. V., Aubry, M. P., and Hardenbol, J., eds., Geochronology, Time Scales and Global Stratigraphic Correlation: Society for Sedimentary Geology (SEPM) Special Publication 54, p. 335-364.

Oncoids of the Late Pleistocene Manix Formation, Mojave Desert region, California

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Introduction

Pluvial lakes are a prominent feature of the Quaternary history in the Great Basin. Lakes Lahontin and Bonneville are the largest and the most studied of the more than 100 pluvial lakes that formed in the topographic lows of the Basin and Range physiology (Smith and Street-Perrot, 1983). Carbonate deposits are relatively common in some of these lakes and are often referred to as tufa or algal tufa (Benson, 1994). Some of these tufa deposits are of microbial origin (Arp *et al.*, 1999) and, therefore, can best be called stromatolites. A systematic study of tufa deposits in Great Basin lakes is lacking and provides an excellent opportunity for further research.

One of these lesser known pluvial lakes, Lake Manix, formed about 500 to 18 Ka in the southernmost region of this extensive pluvial lake system. The Manix Formation was deposited in, and around, Lake Manix. The formation is more than 39 m thick and is predominantly conglomerate, sand, silt, and clay. Carbonate is rare and occurs in what has been called tufa (Jefferson, 1985; Meek, 1990). We interpret these carbonate structures as oncoids, a type of stromatolite, based on the encapsulated nature of the laminae and their close resemblance to oncoids described from other lacustrine deposits (Lindqvist, 1994). The Lake Manix oncoids formed during major transgressive phases of Lake Manix.

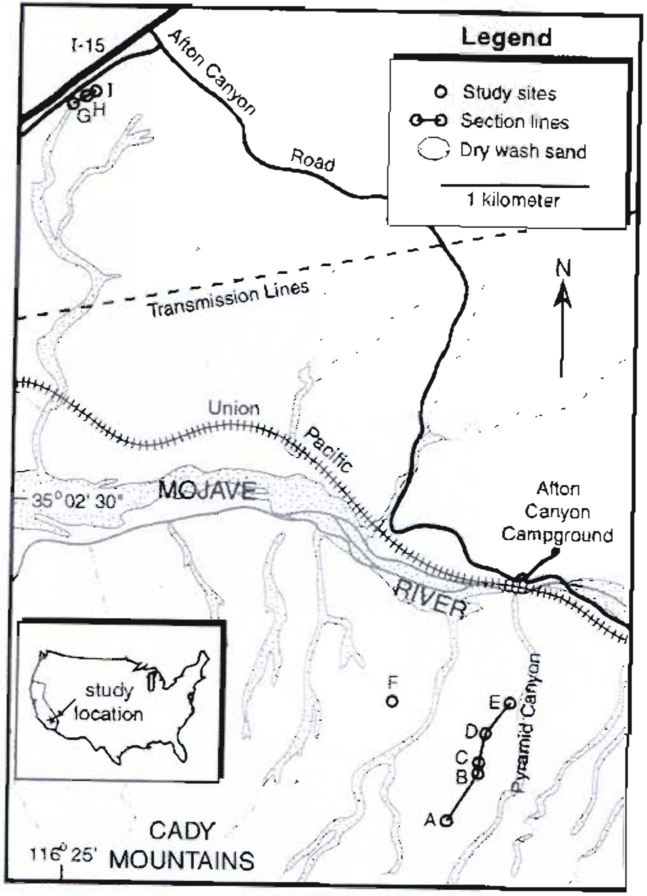
General Geology and Stratigraphy

The Manix Basin is a tri-lobate basin that occupies an area of approximately 400 km^2 (Jefferson, 1987b) east of Barstow, California, in the Mojave Desert block. The block is bounded on the northwest by the Garlock fault and on the southwest by the San Andreas fault (Sylvester, 1988). The eastern boundary is not well defined. Northwest-southeast oriented right-lateral, strike-slip faults occur within the block (Schermer et al., 1996); however, in the region of the Manix Basin, east to east-northeast, possibly left-lateral, strike slip faults occur (Garfunkel, 1974). Late Cenozoic faulting produced the various mountain ranges that border and define the basin. Deposition in this basinal setting began by late Pliocene time, post-dating andestic volcanics and olivine basalt in the Cady Mountains (Jefferson, 1985), and continues today. The basin post-dates the extensive Miocene tectonic activity and basin formation in the region of the Calico Mountains that border it to the northwest (Glazner *et al.*, 1994).

The total thickness of sediments in the Manix Basin is unknown. It probably exceeds 140 m, based on well log data reported in Meek (1990). The basin has remained tectonically active throughout its history of deposition. Gravels of possible Pliocene age are upwarped on the flanks of the Alvord Mountains (Byers, 1960; Meek, 1990). In 1947, a magnitude 6.2 earthquake occurred, producing up to 5 cm of movement on the Manix fault (Buwalda and Richter, 1948).

The oldest sedimentary unit studied thus far in the Manix Basin has been informally called the "Mojave River Formation" (Nagy and Murray, 1991). It consists of 80+ m of conglomerate, sandstone, siltstone, claystone, caliche-rich layers (with nodules), and volcanic ash that conformably underlies the Manix Formation in at least one location (Nagy and Murray, 1991). The "Mojave River Formation" was deposited from 2.48 to 0.92 Ma and unlike the Manix Formation, formed in a closed basin as suggested by the evaporite deposits (Nagy and Murray, 1991; Puhar *et al.*, 1991).

Strata now recognized as the Manix Formation were first described by Buwalda (1914). Later, Thompson (1929) described them as the Manix Lake Beds. Although Jefferson used the term



Source: Dunn Quadrangle, USGS 7.5', 1986.

Figure 1. Location map showing the study sites and section lines.

Manix Formation in his thesis (Jefferson, 1968) and in a subsequent paper (Jefferson *et al.*, 1982), it wasn't until 1985 that he formally described the unit (Jefferson, 1985). It is the only unit in the Manix Basin that has been formally defined. The Manix Formation consists of lacustrine, fluvial, and alluvial fan deposits with an exposed thickness of 39 m (Jefferson, 1985). Jefferson (1985) subdivided the formation into four members. The following description of the members is based on Jefferson (1985, 1999). Member A is a wedge-shaped unit composed of cobble and boulder conglomerate interbedded with silty, fine- to coarse-grained lithic arenite. It is considered a fanglomerate. Member B consists of claystone, siltstone, and silty arenite. It is interpreted as alluvial to fluvial. Member C is claystone and siltstone, and interpreted as lacustrine. Member D consists of arkose and granule to cobble conglomerate deposited in a fluvial setting. The uppermost conglomerate bed in Member A interfingers with Member C to the west and north, and with Member B to the north and northeast (Jefferson, 1999). Member D conformably overlies Member C in the type region, about 15 to 20 km west southwest of Afton Canyon (Jefferson, 1985) and pinches out to the south and southeast against Members A and B (Jefferson, 1999). Oncoids occur in Members B and C where layers of clasts are coated by the oncoidal carbonate.

The relationship between the Manix Formation and the underlying "Mojave River Formation" is often disconformable (Jefferson, 1985). Nagy and Murray (1991) indicated that there is a conformable relationship at one locality. The Manix Formation is disconformably overlain by younger lacustrine deposits a few meters thick (Jefferson, 1985). The formation has received considerable attention due to its rich invertebrate and vertebrate fauna known as the Camp Cady local fauna (Jefferson, 1968, 1987a).

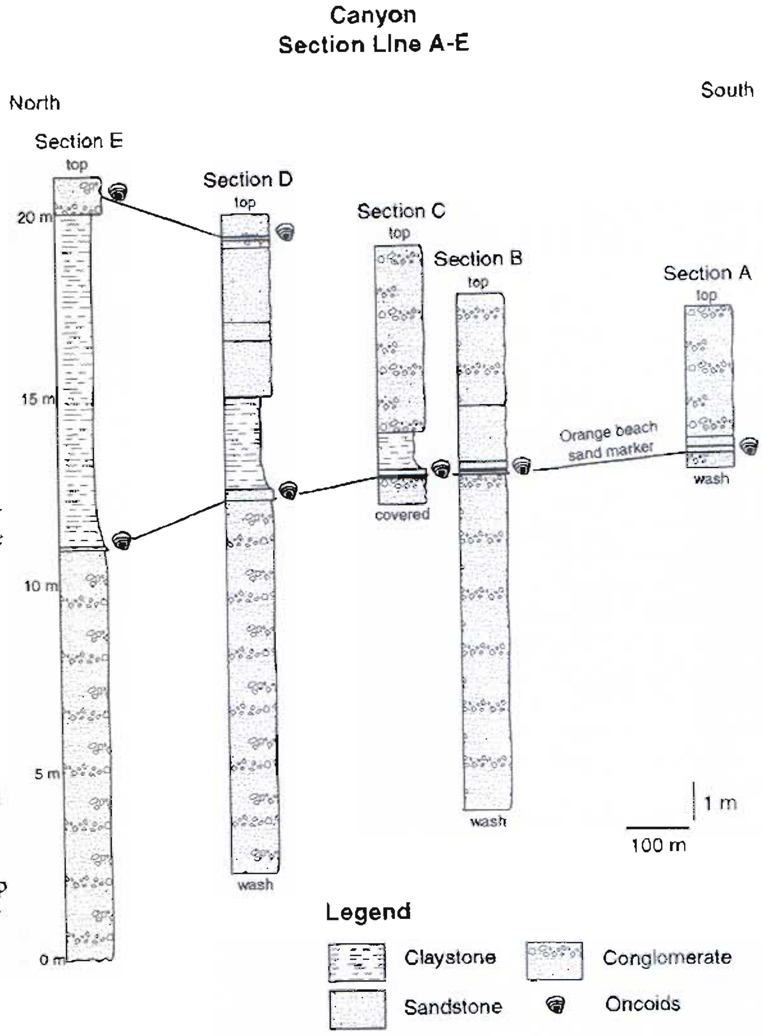


Figure 2. Correlation of sections A-E on the south margin of Lake Manix near Afton Canyon (Fig. 1). The orange sand marker containing oncoids marks the base of a major transgression of Lake Manix. The grain size of the overlying lake sediments decreases toward basin center. The oncoids formed around surface cobbles of the underlying fanglomerate. Another layer of oncoids also occurs stratigraphically higher in sections D and E.

The Manix Formation was deposited in, and adjacent to, Lake Manix, a perennial freshwater lake that occupied the basin from about 500 Ka (Jefferson, 1991) to about 18 Ka (Meek, 1999). A freshwater lake is suggested by the invertebrate fauna and the lack of primary evaporites. The fossil ostracods, clams, and snails indicate freshwater (Jefferson and Steinmetz, 1986; Jefferson, 1987a). The ancestral Mojave River was the main water source and flowed into Lake Manix from the west. The primary drainage for the lake was to the east, in the Afton Canyon region (Jefferson, 1991). Occasional ponding of the Mojave River upstream interrupted flow into Lake Manix, and may have caused lake level fluctuations. At least six transgressive/regressive events occurred throughout its history (Jefferson, 1998).

We studied the oncoids of the Manix Formation from several sites (Fig. 1). Stratigraphic sections were measured in two areas (Figs. 2, 3, 4a-e). The sedimentology and stratigraphy of these sections were studied in the field and hand samples were taken back to the lab for further analysis. Selected oncoids were slabbed and thin sectioned.

The Oncoids

Oncoids are usually considered to be unattached stromatolites with encapsulating laminae (Walter, 1972). However, because oncoids form as a result of microbial carbonate accretion on some type of clast, the adjective "unattached" should be abandoned. The stromatolites of the Manix Formation are isolated structures that consist of laminated calcite encrustations of clasts (Fig. 4f). In all but a very few of the samples studied, the lamination completely envelops the clast. Consequently, these stromatolites are properly called oncoids. Oncoids usually exhibit a penecint arrangement of laminae (laminae partially enclosing a body; Hofmann, 1969) with numerous micro-unconformities (Wright, 1983). The Manix oncoids usually show two sets of lamination (Figs. 5a and d). The first set has laminae that can be traced continuously around the clast. The second set has laminae that thicken in the up-direction and thin or terminate in the down-side direction (Figs. 5a and d). Because of the complete coating of the first set of laminae and the infrequent nature of micro-unconformities in the laminae, we interpret these oncoids to have formed *in situ* without the periodic movement of the structure (although they formed in a high energy environment; see below). This is another reason to abandon the adjective "unattached."

Although referred to as "tufa" or "algal tufa" in the literature on the Manix Formation (Jefferson, 1985), these are incorrect terms for these structures. Tufa is carbonate that has a spongy, porous, and

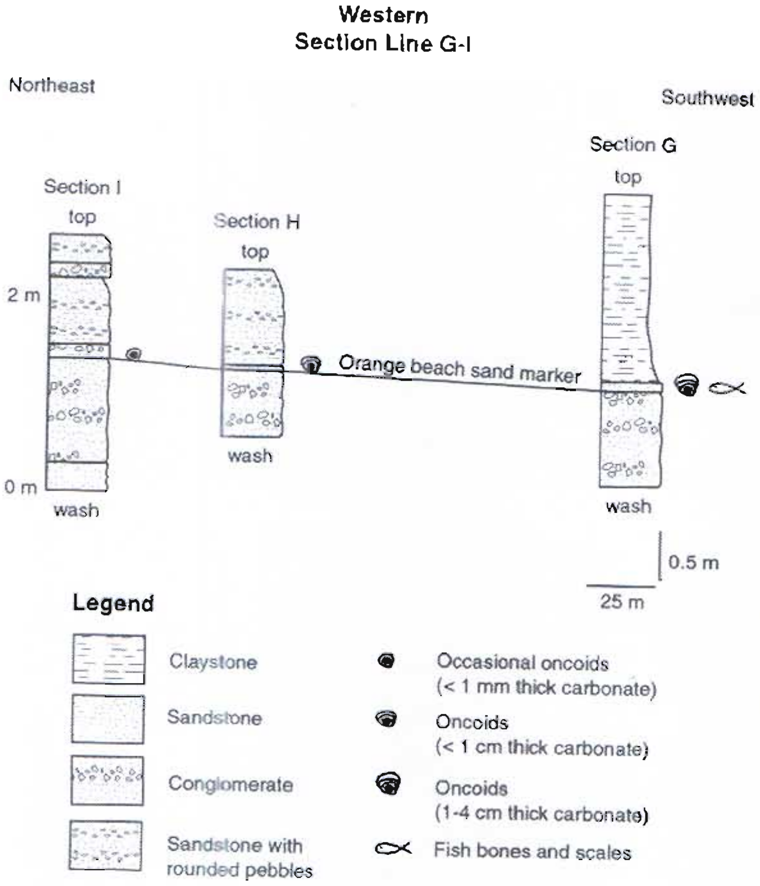


Figure 3. Correlation of sections G-I along the northern margin Lake Manix near Interstate 15 (Fig. 1). The orange sand marker containing oncoids marks the base of a major transgression of Lake Manix. The thickness of the oncoidal carbonate increases toward basin center, whereas the grain size of the overlying lake sediments decreases toward basin center. The oncoids formed around surface cobbles of the underlying fanglomerate.

friable nature (Bates and Jackson, 1987; Humphreys et al., 1995) and is often associated with springs. Bates and Jackson, 1987, actually define tufa as a variety of travertine, which is a spring deposit. The Manix oncoids are slightly porous, somewhat friable, and are not associated with springs. The porous nature probably resulted from vadose-leaching of the pre-existing limestone (Woo *et al.*, 1999).

The Manix oncoids range from <1 to > 70 cm in diameter. They occur in beds ranging from thin, one oncoid-thick beds (a few cm thick) to beds 40 to 60 cm thick composed of many oncoids. Clasts consist of rounded to angular pieces of andesite, basalt, granite, sedimentary rock, and more rarely, of clams and limestone. The limestone clasts consist of a peloidal grainstone/packstone composed of peloids and gastropods organized into a porous limestone. Detrital minerals such as quartz and feldspar also occur in the limestone clasts.

The larger oncoids (>15 cm) often have relatively large clasts compared to the thickness of the carbonate. In contrast, the carbonate may be significantly thicker than the clast diameter in smaller oncoids. Carbonate coating the clasts ranges in thickness from < mm to > 7 cm thick. The carbonate is usually laminated with laminae ranging in shape from slightly wavy to laminae arranged into small columns a few millimeters in diameter with some columns branching (Figs. 5a and b). The stratigraphic up-direction of the oncolite usually has the thickest carbonate while the down-direction is the thinnest. Thickness parallel to bedding can range from slightly thicker than the down-side to almost as thick as the upper surface coating.

In addition to differences in thickness, the upper surface usually has a more pronounced knobby surface whereas the lower surface is smoother (Figs. 5c and d). The upper surface often exhibits two orders of surface topography: larger (>cm) low-relief hemispherical domes covered with small (<cm) protrusions that are actually small, columnar to columnar branching stromatolites. The protrusions give the upper surface a mammilate to cauliflower appearance (Fig. 5c).

In thin section, the carbonate consists of laminated micrite (Figs. 5e and f). The lamination is characterized by alternating dark- and light-colored layers, between 30 and 2000 µm thick. The dark-colored layers are mostly composed of micrite and occasionally exhibit a poorly developed clotted fabric. The light-colored layers also consist predominantly of micrite, but with some acicular calcite crystals. Although micrite is considered to be the product of microbial activity, in particular due to cyanobacterial precipitation (Thompson *et al.*, 1990), no microbial remains, either filaments or coccoids, have been found.

Paleoenvironments of the Oncoids

Oncoids mark the initiation of two major lake transgressions of Lake Manix, as indicated by a vertical sequence of lithofacies (lithofacies succession): conglomerate, oncoids and sand, sandstone, and claystone. The oncoids are associated with a high-energy, near-shore environment based on the presence of a well-sorted, well-rounded quartz sand that forms the matrix of the oncoids. In addition, small oncoids and fragments of oncoids occur in disoriented positions within the sandstone. The oncoids were buried by beach and long shore sand that is a continuation of the same type of sand that forms the matrix between the oncoids. Sand deposition was influenced by the lake transgression and associated deepening of the lake. Deeper water and the absence of clasts as stable substrates in the sand facies did not favor oncoid formation. Further deepening of the lake resulted in clay deposition, the final lithofacies in the fining upward lithofacies sequence.

The angularity of the clasts encrusted by the oncoidal carbonate suggests that Lake Manix transgressions occurred fairly rapidly. Time was insufficient for the development of disc-shaped pebbles and cobbles so frequently associated with beach environments in lakes. The paucity of cobbles and pebbles in the sand that buried the oncoids suggests that the lake was transgressing (deepening) without the local input of fanglomerates and that depositional rates on the fans were relatively low. This would suggest that climatic change favoring precipitation over evaporation was largely responsible for the initiation of the major lake transgressions of the lower and upper oncoid-bearing units. This presents a paradox. A rapid transgression would indicate substantially increased precipitation. Normally, this would activate fanglomerate deposition (alluvial fans would have deposited progradational wedges of fanglomerate into the lake with associated oncoids). This did not occur. It is more likely that precipitation in the Mojave River drainage basin increased sufficiently such that flow into the Manix Basin was substantially greater than outflow, causing rapid transgression.

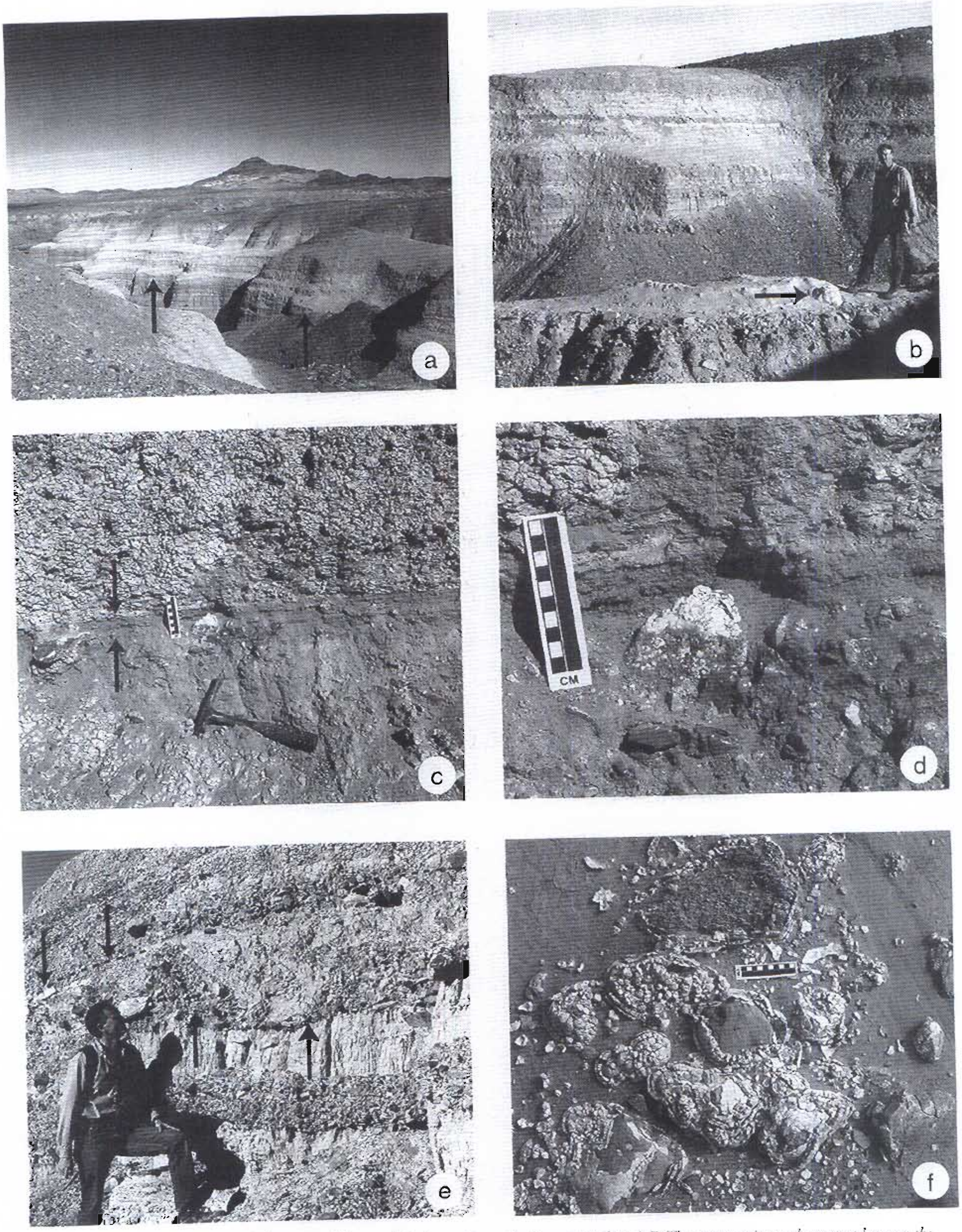


Figure 4. *Outcrop photographs of the lower oncoid unit. a) A view to the north along section line A-E. The arrows point to the contact between the Manix Lake green claystone and the underlying fanglomerates. The lacustrine claystone thicken to the north (toward lake center). b) The arrow points to a large oncoid in the orange sand marker (site F). c) Arrows mark the top and bottom of the orange sand marker. The lacustrine green claystone is above the orange sand marker, and the fanglomerate is below. To the right of the scale is a small oncoid (site G). d) Close up photograph of the same oncoid illustrating the relationship between the oncoids, claystone, sand, and fanglomerate (site G). e) A channel cut into the fanglomerate, which contains reworked oncoids. The dotted line and downward pointing arrows mark the contact between claystone and conglomerate (the lower oncoid unit). The upward pointing arrows mark the base of the channel, which contains reworked oncoids (site F). f) Plan view of some lower horizon oncoids showing their spatial distribution.*

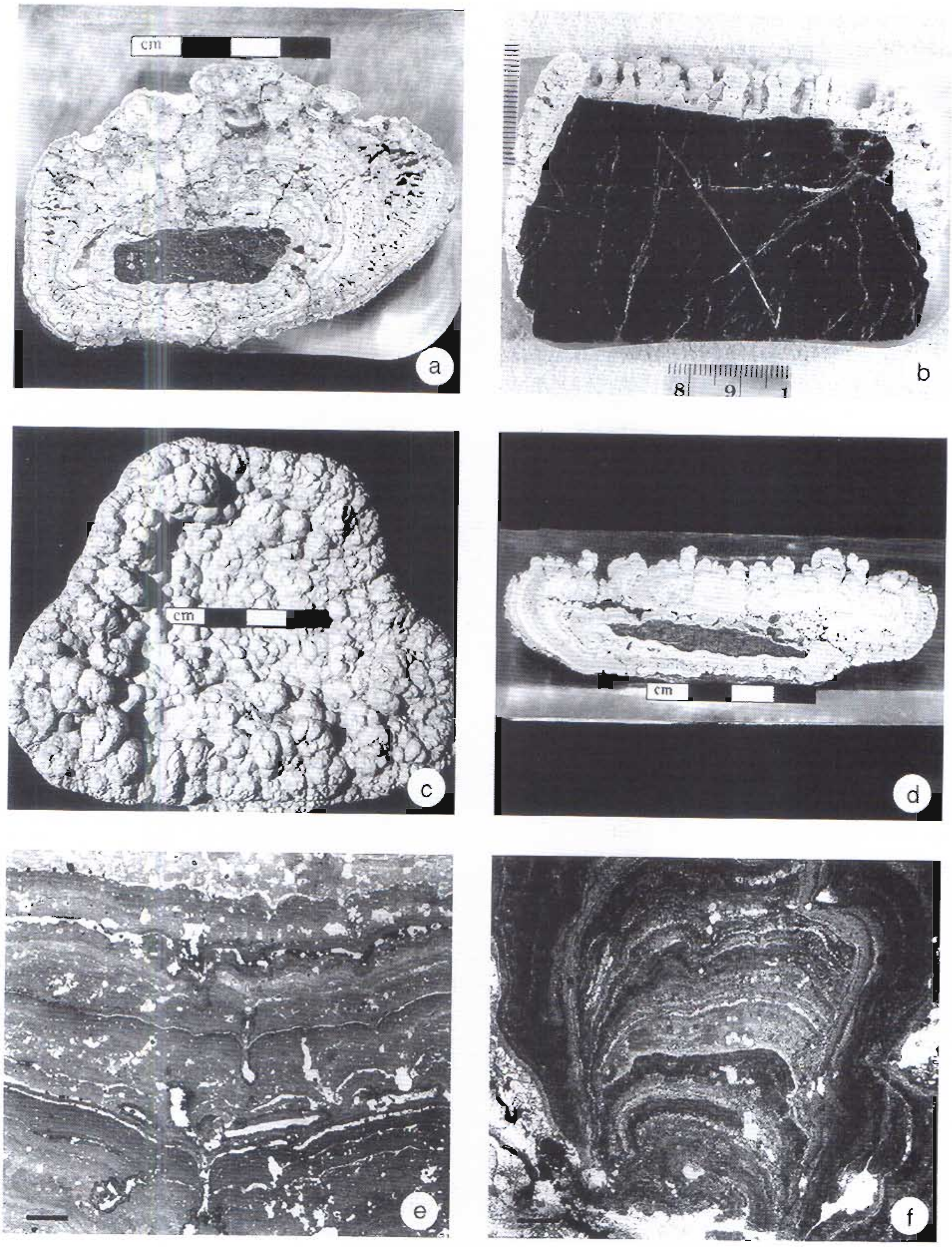


Figure 5. Hand specimen, slabs, and thin section photomicrographs of oncoids; a), b), and d). Slabs of oncoids; c) Upper surface of oncoid (slab in d from this specimen; e) and f) photomicrographs of oncoids ; scale bar in c = 1 mm; scale bar in f = 0.5 mm.

Empty Basins, Vanished Lakes

motifs appear to be very similar to rock-art motifs in the Mojave Desert — a spiral, an anthropomorphic figure, two circles connected with a line, and a quadruped often thought to be a bighorn sheep — some doubt has been raised about the authenticity of these features.

Along the rim of Afton Canyon, especially on its south side, are well-formed desert pavements within which there are frequent lithic scatters and other evidence of stone working. In addition, there are stone features such as rock circles and rock alignments. Many of these appear to be of considerable age. There has been, however, no systematic archaeological study of either the artifacts or features on and within the pavement surfaces.

In summary, the major human presence within Afton Canyon has been scientifically documented as being within about 100 years of A.D. 1000, with some evidence that the time of occupation goes back somewhat earlier, possibly to about A.D. 600 (Schneider 1989). It is likely that earlier occupation occurred, but archaeological data supporting this view have not yet been obtained. The data that are available suggest that the canyon was well-traveled by the ancestral Mohave and the subsistence resources associated with the Mojave River were important parts of the pattern of seasonal rounding of the indigenous peoples who lived along the river to the south and in the San Bernardino Mountains.

References Cited

Casebier, Dennis G.
1975. The Mojave Road. Norco, California: Tales of the Mojave Road Publishing Company.

Coues, Elliot
1900. On the Trail of a Spanish Pioneer: the Diary and Itinerary of Francisco Garcés. New York: Francis P. Harper.

Davis, C. Alan, and Gerald A. Smith
1981. Newberry Cave. Redlands: San Bernardino County Museum Association.

Kroeber, Albert L.
1925. Handbook of the Indians of California. Washington, D.C.: Bureau of American Ethnology Bulletin 78.

Laird, Carobeth
1976. The Chemehuevis. Banning: Malki Museum Press.

Rector, Carol H., James D. Swenson, and Philip J. Wilke
1983. Archaeological Studies at Oro Grande, Mojave Desert, California. Redlands: San Bernardino County Museum Association.

Rogers, Malcolm J.
1929. Report of an Archaeological Reconnaissance in the Mojave Sink Region. San Diego Museum of Man Papers No. 1.
n.d.. Unpublished site records, field notes, and maps. San Diego Museum of Man.

Schneider, Joan S.
1989. The Archaeology of the Afton Canyon Site. San Bernardino Museum Association Quarterly 36(1).

Smith, Gerald A.
1963. Archaeological Survey of the Mojave River and Adjacent Regions. Bloomington: San Bernardino County Museum Association.

Wallace, William J.
1958. Archaeological Investigations in Death Valley National Monument 1952-1957. Berkeley: University of California Archaeological Survey Reports No. 42:7-19.

1977. Death Valley National Monument's Prehistoric Past: An Archaeological Overview. Report on file at N.P.S. Western Archeological and Conservation Center, Tucson.

Warren, Claude N.
1984. The Desert Region. In: California Archaeology by Michael J. Moratto, pp. 339-430. Orlando: Academic Press.

Ventifacts in the Mojave River Corridor and at "Ventifact Hill"

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The easily accessible ventifacts at "Ventifact Hill," east of Afton Canyon, are just a few of the many spectacular examples of sand-blasted rocks that are to be found in the east-central Mojave Desert. They have formed in a corridor of wind transport which moved sand from the Mojave River eastward through the Devil's Playground, and ultimately towards the Kelso Dunes (Clarke and Rendell, 1998). Most of the ventifacts in this region are fossil or relict in nature, attesting to a time of greater sediment availability and possibly higher velocity winds. Today, areas of active ventifact formation are limited to a few hill crests where dune sand is being reworked by bidirectional winds.

Ventifact Form

Ventifacts are wind-eroded rocks of varying size, form, and material composition. They range in size from small pebbles to large boulders. Small rocks (less than a height of 8 cm) develop the classic faceted form (Maxson, 1940). The term facet refers to a relatively plane surface that has been cut at right angles to the wind, regardless of the original stone shape. Facets join along a sharp ridge or keel, and the number of keels (kante) is used to describe the stones as einkante, zweikanter, dreikanter (one-,two-, three-ridged), etc. These terms are generally not used to describe large ventifacts.

Rock surfaces are commonly smoothed and polished by sand abrasion. The degree of polish is a good indication of the relative age of the ventifact, with actively forming ventifacts showing considerable sheen, and older ventifacts lacking polish or appearing dull owing to weathering processes. Granitic rocks are often subject to consider granular disintegration of the surface and do not preserve fine features well. Spalling of the crust may occur. As a result, only the largest, most intensely abraded fossil granitic ventifacts are preserved.

Large ventifacts show a variety of surface forms, including pits, flutes, grooves, helical forms and etching, all of which can be observed in the Mojave River aeolian corridor (Laity, 1994, 1995).

Figure 1. Deep pitting covers the east face of the approximately 1.25 m high ventifact on "Ventifact Hill."

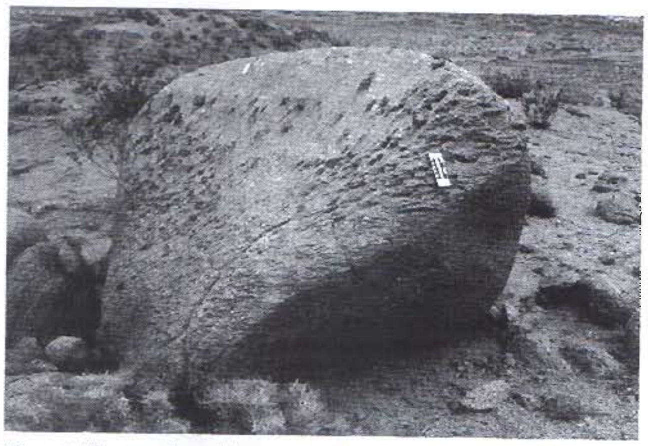

Figure 2. The west face of the same 1.25 m ventifact attests to strong westerly winds in the past. Note the flutes that cover the receding face. The absence of sand and the surface weathering suggest the ventifact is fossil.

Pits occur on surfaces that are inclined at high angles to the wind (55° to 90°), as can be seen on the east face of the 1.25 m ventifact at "Ventifact Hill" (Fig. 1). *Flutes* are scoop-shaped in plan, open at the downwind end and closed at the upwind end, and broadly U-shaped in cross section. Flutes become shorter and deeper as the inclination of the surface steepens. These features can also be observed at "Ventifact Hill" (Fig. 2). *Grooves* are longer than flutes and develop on surfaces gently inclined or parallel to the wind. Grooves are broadly parallel to one another and indicate the direction of the winds. The scale of grooves depends on the material and the wind velocity, and varies from fine lineations, with a wavelength measured in millimeters, to long and deep grooves, 0.3 m or more in length and 11 cm or more in width. Very large flutes and grooves developed on ridge crest ventifacts in the area between Afton Canyon and Soda Lake, eroded by the flux of sand which was deflated from the Mojave River wash (Fig. 3). *Etching* occurs when the composition of the rock mass is not homogeneous and the wind selectively erodes less resistant strata or foliations. Excellent examples are to be found in flow-banded basaltic rocks south of Soda Lake, where wind erosion has exploited vesicle-rich bands. *Helical forms* begin as shallow grooves or flutes, deepen and spiral in a downwind direction, and terminate in a sharp point. Such forms are relatively rare, but can be seen in the Little Cowhole Mountains, east of Soda Lake.

Wind Speed, Topography, and Ventifact Formation

Topographic enhancement of wind speed strongly influences ventifact distribution and form. High wind speeds cause hilltops to be a favorable ventifact locale. As wind passes over a hill, a compression of streamlines in the boundary layer causes accelera-

Figure 3. Ventifact from the Mojave River wash area, about 10 km east of "Ventifact Hill," off Rasor Road. The scale of the flutes on this large ventifact suggest a high sand flux and winds of higher intensity than today.

tion towards the crest of the slope, increasing sand transport and particle velocity. The shape of the hill and its height affect velocity acceleration, sand transportation, wind flow direction, and zones of erosion and deposition, and thereby determine the orientation of grooves, the intensity of ventifaction, and the location of ventifacts. The effect of velocity enhancement increases with the height of the hill: wind speeds at the hill crest may be as much as twice that at the base. For high velocity winds, increased mass removal by abrasion near hill crests causes deep grooving and pitting of rocks, particularly on large boulders that present high angle faces to the winds. As a result, ventifacts are often found on the windward upper slopes or summits of hills, the most intensely abraded rocks occurring near the crest (Laity, 1987). This effect can be clearly seen at "Ventifact Hill."

Erosion Profile

The magnitude of ventifact erosion depends on the susceptibility of the rock material to erosion (density, hardness, and fracture-mechanical properties) and to the properties of the impacting grain (diameter, density speed, and angle of incidence). Ventifacts develop within the curtain of saltating sand grains, which rarely exceeds 1 m on level terrain. Abrasion generally increases with height, owing to an increase in particle velocity. In Sharp's (1964, 1980) experimental plots, erosion maxima were recorded 0.10 to 0.12 m above the surface in Lucite rods exposed to the wind for 15 years. This level is exceeded on hilly terrain, where the maximum abrasion height can be 1–1.5 m above the surface. Note that at "Ventifact Hill" abrasion increases up to the 1.25 m height of the boulder. As a consequence of the increase in abrasion up to the maximum level, many ventifacts ultimately develop semi-planar faces, with the upper part of the abrasion face receding more rapidly than the lower part. Flutes and grooves may cover the receding face.

The large ventifact on "Ventifact Hill" gives evidence that wind abrasion on the western face was greater than that on the eastern. Evidence of the dominance of strong long-term westerly flow is apparent in ventifacts throughout the region (Laity, 1991), in the movement of dunes through the Devil's Playground, and in the orientation of linear wind streaks.

Agent of Abrasion

Sand is the most effective agent of abrasion in the Mojave Desert, and the distribution of ventifacts is clearly associated with its presence. Sediment samples collected from a number of sites show that the abrading agent is fine- to medium-sized aeolian sand which is well to moderately well sorted. The relative absence of sand on "Ventifact Hill" is one indicator of the fossil nature of the ventifacts.

Summary

"Ventifact Hill" provides an example of past aeolian activity in the Mojave River wind corridor. Throughout the region, evidence of abrasion on granitic ventifacts is generally patchy and discontinuous, as coarse-grained rocks do not preserve erosion well, owing to granular disintegration and spalling. Thus, there is a paucity of ventifacts at "Ventifact Hill" relative to comparable sites with different lithologies. As at most other localities, maximum abrasion occurs near the hill crest, where wind velocities are highest. Owing to its large size and deep erosional features, the largest boulder at the crest of "Ventifact Hill" preserves a good record of past activity. The boulder demonstrates the increase in abrasion that occurs with height, resulting in a receding face on the west side. Maximum abrasion occurs at the top of the boulder, a height of about 1.25 m. Winds from the east effectively pitted the boulder, but lacked strength to cause recession of the face. The absence of aeolian sand and of small ventifacts, and the weathered, stained and spalling surface of the large ventifact, suggests that abrasion is no longer an ongoing process.

The evidence at "Ventifact Hill" is mirrored at other sites throughout the Mojave River aeolian corridor. Boulders with even deeper flutes and grooves occur on hills near the Mojave River wash area, testifying to a more intense wind regime in the past.

References

Clarke, Michele L. and H. M. Rendell, 1998, Climate change impacts on sand supply and the formation of desert sand dunes in the south-west U.S.A: *Journal of Arid Environments* , v. 39, p. 517-31.

Laity, J.E., 1987, Topographic effects on ventifact development, Mojave Desert, California: *Physical Geography* v.8, no. 2., p. 113-132.

___, 1991, Ventifact evidence for Holocene wind patterns in the east-central Mojave Desert: *Zeitschrift für Geomorphologie, Supplement Band* , v. 84, p. 1-16.

___, 1994, Landforms of aeolian erosion, *In* A.D. Abrahams and A.J. Parsons (eds.), *Geomorphology of Desert Environments*: Chapman and Hall, London, p. 506-535.

___, 1995, Wind abrasion and ventifact formation in California, *In* V.P. Tcharkerian (ed.) *Desert Aeolian Processes*: Chapman and Hall, London, p. 295-321.

Maxson, J.H., 1940, Fluting and faceting of rock fragments: *Journal of Geology*, v. 48, p. 717-751.

Sharp, R.P., 1964, Wind-driven sand in Coachella Valley, California: *Geological Society of America Bulletin* , v. 75, p. 785-804.

___, 1980, Wind-driven sand in Coachella Valley, California: Further data: *Geological Society of America Bulletin*, v. 91, p. 724-730.

Archaeology in the Cronese Basin: A History

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In the years 1928 through 1930 Malcolm J. Rogers conducted field reconnaissance in eastern San Bernardino County. This fieldwork led him to the turquoise mines in the Turquoise Mountains east of Silver Lake Playa. One question that he addressed was: who were the prehistoric turquoise miners of the Turquoise Mountains? Rogers thought the limited evidence he recovered from the mines indicated that they were first worked by Puebloan peoples from the east. Since water was unavailable at the mines, and drinking water was a necessity for the miners, Rogers turned his efforts toward searching for the locations where the miners lived. This search took him to the Mojave Sink and the Cronese Basin where he discovered a number of residential sites (Rogers 1929, 1931, 1933, 1939, 1945).

Rogers developed a cultural sequence for the Cronese Basin that included Nevada Basketmaker, Desert Mohave, and Chemehuevi. Radiocarbon dating, however, was not yet available and the residential sites lacked stratigraphy. Byt ceramics were plentiful in the Cronese Basin and the ceramic sherd types were part of the data from which Rogers developed his sequence. Nevada Basketmaker was characterized by the presence of pottery sherds at the turquoise mines and at at least one site in the Basin. The major occupation of the Basin, Rogers soon realized, was represented by a people that he called the "Desert Mohave." The Desert Mohave cultural pattern recognized by Rogers was characterized by cremation of the dead; the Puebloan people did not cremate their dead. In addition, a plain grey pottery was often buried with the cremated remains. Although the pottery was very similar to Puebloan pottery, Rogers soon learned that it was made of local clays and temper, whereas the Puebloan pottery, brought to the area from southern Nevada, was made from different clays and contained very different temper. Furthermore, although the ceramics of both groups were grey in color, that of the Desert Mohave was of a darker grey and often contained mica. Rogers used ceramic cross-dating based on intrusive Puebloan pottery found in Desert Mohave sites and cremations to date the Desert Mohave of the Cronese Basin and the Mojave Sink to as early as Pueblo II and Pueblo III times.

Rogers further recognized that the Desert Mohave were the middlemen in a major exchange system involving the trade of shell beads, ornaments and other items, such as pelican bone whistles, from the California coast and ceramics from the Puebloan areas to the east. The turquoise mined locally in the Turquoise Mountains also moved through this trade network. As far as can be determined, all of the locally mined turquoise was traded to Puebloan and other peoples of the Southwest. This period of intensive trade coincided with a period of increased precipitation during which the Cronese Lakes filled and supported populations of fish and freshwater mussel (*Anodonta* sp.). There is ample archaeological evidence that the mussels were collected and eaten by local people.

Rogers also recognized a third cultural pattern in the Cronese Basin. This pattern was poorly represented, usually consisting of sparse flake scatters associated with hearths, occasionally with some pottery, milling implements, and projectile points. Rogers thought that these sites were occupied sporadically for short periods of time. He assigned this cultural pattern to the protohistoric Chemehuevi, a people who replaced the Desert Mohave after the desiccation of the lakes in the Cronese Basin.

In 1945 Rogers published *An Outline of Yuman Prehistory* in which he summarized his views on the prehistory of the Mojave Sink region. (The reader should be aware that in his 1945 publication, Yuman is equivalent to his 1931 Mohave.) He identified a pre-ceramic Yuman pattern that extended from western San Bernardino County across the desert to the east as far as the Colorado River and into Mohave County, Arizona; the Cronese Basin and the Mojave River Sink is included. This "pattern needs only the addition of native pottery to make it Yuman: an element which it eventually acquires" (Rogers 1945:174).

During the late 1930s through the 1950s very little fieldwork was conducted in the central Mojave Desert. In the mid-1930s, Elizabeth and William Campbell recorded sites on both West Cronese and East Cronese lakes, but never published the results of this research. In 1939 Gerald Smith and Ritner Sayles surveyed the shoreline of East Cronese Lake and conducted limited excavations at one site (Smith 1963). In 1950 Adan Tregenza and Arnold Pilling of San Francisco State College and the University of California Archaeological Survey conducted a reconnaissance of the entire shoreline of East Cronese Lake.

The next significant archaeology in the Cronese Basin was that carried out in the 1970s by Christopher Drover (1979). Drover conducted minimal fieldwork, taking a few field samples and making a number of observations. He did, however, obtain a small number of radiocarbon dates applicable to archaeological sites. Drover's main thesis, within the cultural-ecology focus of the times, stated that "(t)he nature of the Cronise (sic) Basin occupation would seem to require lacustral periods simply for drinking water if not a variety of plant and animal foods . . ." (Drover 1979:151). He then attempted to reconstruct the minimal requirements for flood conditions that would fill the Basin by comparing the tree-ring record with the modern rainfall record. Drover argued that the sites in the Cronese Basin were occupied during single wet years and, based on tree-ring records, selected a number of individual wet years that roughly corresponded to the radiocarbon dates he had obtained.

Drover's argument proved faulty when it was pointed out by Enzel and others (1992) that the Holocene lakes that formed in the Cronese Basin probably resulted from a number of wet years occurring together, i.e., multiyear relatively high precipitation episodes. This position is further supported by Schneider's work at East Cronese Lake in which she analyzed the *Anodonta* mussels and found that the *Anodonta* in the middens were mature individuals as were others which died in place in the lake sediments. Since *Anodonta* populations take several years to reproduce and mature, the lake must have been present and viable during all of those years (Schneider 1994).

Subsequent work in the Cronese Basin has been confined to cultural resource management projects that have explored archaeologically only small portions of the basin. One investigated several sites in the mesquite-covered sand dunes in the southwestern portion of the Basin (York 1989). The second was recent work in preparation for selection of an area for expansion of Fort Irwin; this project touched the western portions of West Cronese Lake (Bryd *et al.* 1998).

References Cited

Byrd, Brian F.

1998. Springs and Lakes in a Desert Landscape: Archaeological and Paleoenvironmental Investigations in the Silurian Valley and Adjacent Areas of Southeastern California. Prepared by ASM Affiliates, Inc. for the U.S. Army Corps of Engineers, Los Angeles District. Volumes 1 and 2.

Drover, Christopher J.

1979. Late Prehistoric Human Ecology of the Northern Mohave Sink, San Bernardino County, California. Unpublished Ph.D. dissertation, University of California, Riverside.

Enzel, Yehuda, W. J. Brown, R. Y. Anderson, L. D. McFadden, and S. G. Wells

1992. Short Duration Holocene Lakes in the Mojave River Drainage Basin, Southern California. Quaternary Research 38:60-73.

Rogers, Malcolm J.

1929. Report of an Archaeological Reconnaissance in the Mojave Sink Region. San Diego Museum Papers No. 1.

1931. Report of Archaeological Investigations in the Mojave Desert Region during 1930. Bureau of American Ethnology, National Anthropology Archives, Catalog No. 2104 (Part I), Washington, D.C.

1933. The Aborigines of the Desert. In: Edmund C. Jaeger, The California Deserts. Palo Alto.

1939. Early Lithic Industries of the Lower Basin of the Colorado River and Adjacent Desert Areas. San Diego Museum Papers No. 3.

1945. An Outline of Yuman Prehistory. Southwestern Journal of Anthropology 1(2):167-197.

Schneider, J. S.

1994. Fresh Water Mussels and Paleoenvironment at East Cronese Lake. In: Kelso Conference Papers 1987 -1992. A Collection of Papers and Abstracts from the first Five Kelso Conferences on the Prehistory of the Mojave Desert, G. D. Everson and J. S. Schneider, eds., pp. 42-51. Museum of Anthropology, California State University, Bakersfield, Occasional Papers in Anthropology No. 4.

Smith, Gerald A.

1963. Archaeological Survey of the Mojave River and Adjacent Regions. Redlands: San Bernardino County Museum Association.

York, Andrew L.

1989. Archaeological Investigations at CA-SBR-6017,-6018, and 128, near East Cronese Lake, San Bernardino Co. CA. Report prepared by Dames and Moore, San Diego, for U.S. Sprint.

Geology and Mineral Deposits in the Baxter–Basin Area South of Cave Mountain, San Bernardino County, California

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Introduction

Cave Mountain is a prominent landmark located just south of Interstate 15 between Barstow and Baker, California, in the central Mojave Desert (Figure 1). On the south side of Cave Mountain, which rises 2000 feet above the alluvial valleys, a variety of rock types are exposed near Basin Siding which range from Precambrian to Quaternary in age, and include highly deformed Paleozoic metasedimentary rocks and several varieties of Mesozoic intrusive rocks. An active small scale iron mine is present in the area as are several inactive limestone quarries.

This study contributes new information on the distribution and stratigraphic correlation of Paleozoic Miogeoclinal strata in the local area. In addition the work further documents intense pre Cretaceous multiphase folding and faulting of the Paleozoic rocks. Also included is a description of the mineral deposits and recent mining activity in the area.

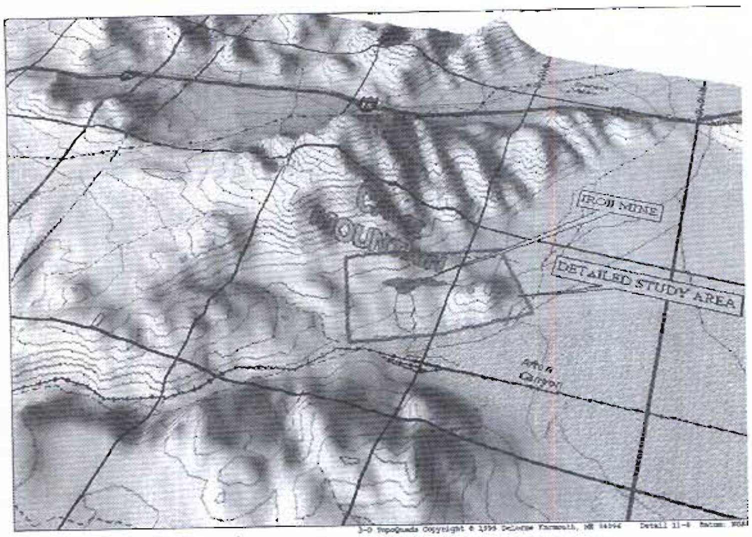


Figure 1. Index map, aerial view

Regional Geologic Setting

Rocks exposed in the general area include those of Paleozoic, Mesozoic and Cenozoic age. Paleozoic rocks in the region are inner Miogeoclinal shallow water sediments and include Late Precambrian and Cambrian clastic dominated sequences, Cambrian and Devonian dolomites and Upper Paleozoic limestone-dominated formations. Figure 2 is a generalized geologic map of the area, modified from Danehy and Collier (1958).

During early and middle Mesozoic time sedimentary and volcanic rocks were deposited, and during middle Mesozoic time the region underwent intense deformation including folding, thrust faulting and metamorphism, and was intruded by a variety of plutonic rocks. Uplift, erosion and volcanism were dominant processes during Cenozoic time. The region continues to be seismically active.

Paleozoic Strata

Paleozoic rocks in the study area include Upper Paleozoic limestone and calcite marbles. The rocks are typical inner Miogeoclinal strata and are correlated on the basis of lithologic similarity and stratigraphic sequence with Miogeoclinal formations exposed in numerous ranges in the Mojave region (Brown 1981, 1982, 1986, 1991). Figure 3 is a stratigraphic column of the Paleozoic rocks present in the area. Formations exposed include Devonian Sultan Limestone, Mississippian Monte Cristo Limestone and Pennsylvanian-Permian Bird Spring Formation.

Devonian Sultan Limestone

The Crystal Pass member of the Sultan Limestone of Devonian age is prominently exposed along the south side of the ridge north of the Mojave River bed. The Crystal Pass member is the upper most unit in the Sultan Limestone, and is composed of 350 feet (tectonic thickness) of medium to thin bedded white calcite marble in layers up to 40 feet thick, which is interbedded with buff dolomite and grey limestone layers up to 10 feet thick. The white marble is often thinly laminated and porcelain textured, and is commonly stained with iron oxide on fractures. Exposures are typical of the metamorphosed Crystal Pass, exposed in several ranges in the Mojave from the San Bernardino Mountains to the southwest and extending east beyond the state line into Nevada.

Mississippian Monte Cristo Limestone

The Monte Cristo Limestone is abundantly exposed and includes from oldest to youngest, the Dawn, Anchor, and Bullion Members.

The Dawn Member is composed of dark grey, thin to medium bedded limestone. The rock is variably cherty near the upper contact with the Anchor Member. The lower contact is abrupt and contrasts with the white Sultan Limestone. Tectonic thickness is up to 35 feet, although usually thinner.

The Anchor Member is composed of lower grey, and upper white, very cherty and/or siliceous limestone and calcite marble. Tectonic thickness is up to 50 feet although usually thinner.

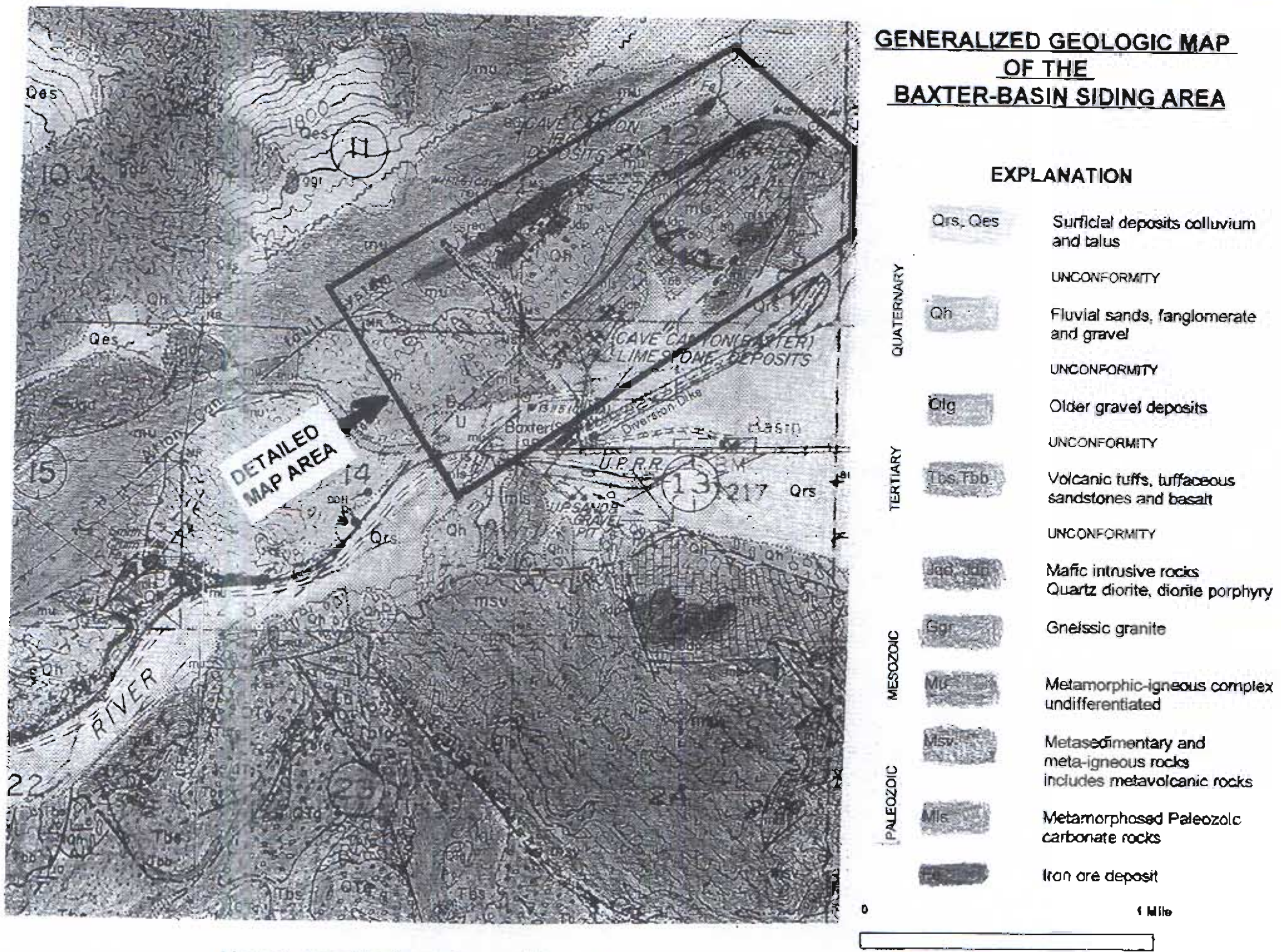


Figure 2. Generalized geologic map of the area.

The Bullion Member is prominently exposed and is composed of about 200 feet (tectonic thickness) of medium-bedded, white weathering, generally pure calcite marble. The rock is medium to fine grained and color on fresh surface ranges from white to creamy white and buff.

Pennsylvanian-Permian Bird Spring Formation

The Bird Spring is abundantly exposed in the eastern part of the main ridge, and forms the upper plate of a low angle fault. All exposures show evidence of intense folding. Three informal units were differentiated. The lower unit is composed of 30 feet of white to buff siliceous marble with some dolomitization. The middle unit is 150 feet of dark grey, very cherty and siliceous limestone. Overlying is 150 feet of buff colored limestone with prominent dark brown silicification and brown silty siliceous hornfels beds and bands.

Mesozoic Intrusive Rocks

Intrusive rocks are abundantly exposed in the detail map area and several varieties are present. To the north of the study area, the main mass of Cave Mountain is composed of generally dark colored gneissic granite and metamorphic rocks. Within the study area, however, intrusive rocks were classified as felsic (light color) or mafic (dark color), on the basis of color.

Felsic intrusives weather pink to light brown, are medium grained and range from nonfoliated to foliated. More than one intrusion may be present. The felsic intrusives, although in contact with the carbonate rocks, do not form dikes. The felsic intrusives are clearly older than the mafic intrusives, and are of probable middle Mesozoic age.

Mafic intrusive rocks form dark green to black weathering, nonfoliated to foliated, steeply dipping dikes and sills (parallel to foliation) and irregular intrusive blobs popping up through the carbonates. The dikes and sills are generally less than 20 feet thick, and sometimes form a border zone between felsic intrusives and carbonate rocks. Several ages of mafic intrusives may be present but are not differentiated.

In the northeastern portion of the map area the mafic intrusives appear to be associated with iron mineralization along a low angle fault contact with the carbonate rocks. In the main active iron mine area, mafic intrusives also appear to be associated with the iron mineralization.

In general the mafic intrusives appear to be younger than the felsic intrusives, and are assumed to be late Middle Mesozoic age.

Cenozoic Rocks

Cenozoic rocks include several sequences of fluvial sands, fanglomerate, gravels, carbonate clast alluvial terraces, younger granitic-dominated alluvial deposits, colluvium, talus and stream wash, thought to be of Pleistocene and Recent age. To the south of the study area are exposures of Tertiary age sandstones, tuff beds, fanglomerate and basalt.

Metamorphism

Paleozoic rocks in the area have been variably recrystallized and metamorphosed to lower greenshist grade. Many of the limestones have been recrystallized to calcite marble, and rocks of the Crystal Pass member of the Sultan have well developed mosaic metamorphic fabric. Rocks of the Bullion member of the Monte Cristo Limestone have been only slightly recrystallized, and only partly bleached white, often still retaining their original creamy tan color. Tremolite was noted in some rocks which have been dolomitized. In general metamorphism is low grade, and probably associated with regionally widespread metamorphism and Mesozoic intrusive activity, and is likely Jurassic and or Cretaceous in age.

Geologic Structure

Geologic structure in the area is very complex, the result of multiple episodes of deformation including folding and faulting. The description of structures is related primarily to the deformation of the Paleozoic rocks. Structures present include folds of two or more generations, low angle faults, high angle faults and gravity slides.

Folding

At least two phases of folding occurred. Phase 1 folds are northeast-trending and southeast-verging overturned to recumbent, and are most common in the Bird Spring Formation which forms the upper plate of a low angle fault. South-verging folds have been noted elsewhere in the Mojave (Brown 1981, Walker 1990). Walker (1990) indicated that the age of folding is between 154 and 169 m.y. (Late Middle Jurassic) in the Cronese Hills, 6 miles northwest of the study area.

Phase 2 folds are prominently exposed in the lower plate of the low angle fault, and are northeast-trending, very tight to isoclinal upright to slightly overturned to the south, with a northwest vergence. Phase 2 folds on the overturned limb of a Phase 1 fold form inverted folds in which the stratigraphic sequence is upside down.

Phase 2 folds have an opposite sense of vergence than Phase 1 folds suggesting a separate deformational event. Phase 2 folds predate intrusion of the felsic intrusives. Walker (1990) indicated post kinematic plutonic rocks in the Cronese Hills are 155 m.y. Thus the Phase 2 folds predate the Late Jurassic intrusives and post date the Late Middle Jurassic Phase 1 folds, and an Early Late Jurassic age is suggested.

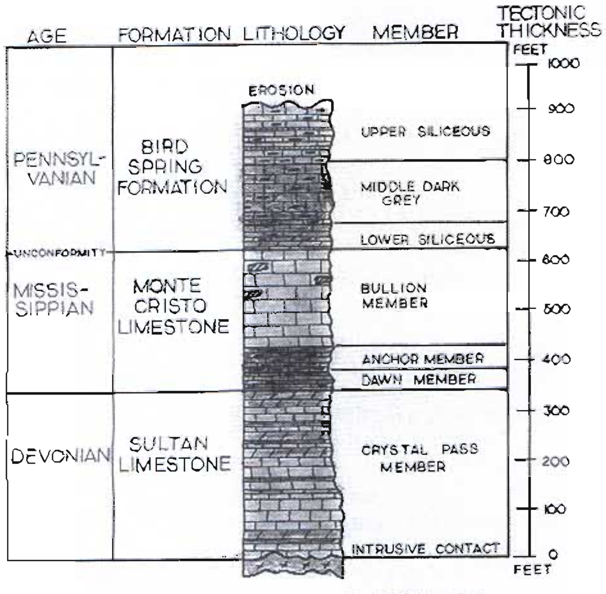


Figure 3. Stratigraphic column.

Phase 3 folds were noted near a low angle fault in the eastern part of the study area. Phase 3 folds plunge 25 degrees to the southeast and may have formed during low angle faulting.

Faults

Numerous faults include low angle and high angle faults, as well as gravity slides.

Several low angle faults are present. A prominent low angle fault system in the eastern part of the study area juxtaposes recumbently folded Bird Spring Formation in the upper plate over tight isoclinal upright inverted folds in the lower plate. In some outcrops the nearly flat lying Bird Spring Formation is faulted over vertically dipping Monte Cristo Limestone. The fault appears to cut some of the felsic intrusive rocks, while the mafic intrusives may have intruded along the fault. The low angle faults are considered to be post felsic intrusive and possibly pre-mafic intrusive, and a possible pre-Late Jurassic age is suggested.

A shallow, south-dipping gravity slide is present on the south side of the main ridge. Upper plate rocks of the Bird Spring Formation have slid down and over the lower plate rocks. Rocks in the slide block are highly brecciated near the contact, but internal deformation is slight, and the block appears to have slid as a coherent mass. The gravity slide is cut by a younger high angle fault

High angle faults of several generations are present. The most prominent are northeast-trending and both normal faults, reverse faults, and lateral slip faults. The high angle faults cut the low angle faults. Several northeast-trending linear ridges and valleys are fault bounded. Numerous high angle faults are present in the iron ore deposit, and it appears to be fault bounded to both the north and the south. Previous mapping has indicated that Pleistocene gravels and sands have been faulted against the Paleozoic rocks, and thus several of the northeast-trending high angle faults are likely of Late Pleistocene or Quaternary age.

Geologic History

The geologic history of the study area is complex: numerous events occurred over a long period of geologic time. Carbonate and clastic sedimentary rocks were deposited during Paleozoic time. During Middle Mesozoic time the rocks were multiply deformed by folding and low angle faults, were intruded by at least two phases of plutonic rocks and were metamorphosed. During Cenozoic time volcanic rocks were extruded and the rocks were repeatedly uplifted and eroded, forming a complex series of gravels and terraces. The area has continued to be seismically active into geologically recent time.

Mineral Deposits

The long and complex geologic history of the area included the formation of mineral deposits. An active iron mine is present and several formerly mined limestone quarries are also in the area.

High Purity Limestone Deposits

Limestone deposits formed in the Crystal Pass Member of the Sultan Limestone of Devonian age and in the Bullion Member of the Monte Cristo Limestone of Mississippian age. The Crystal Pass forms variably pure white calcite marble, and the Bullion forms quite pure calcite marble, both of which have been bleached white by metamorphism.

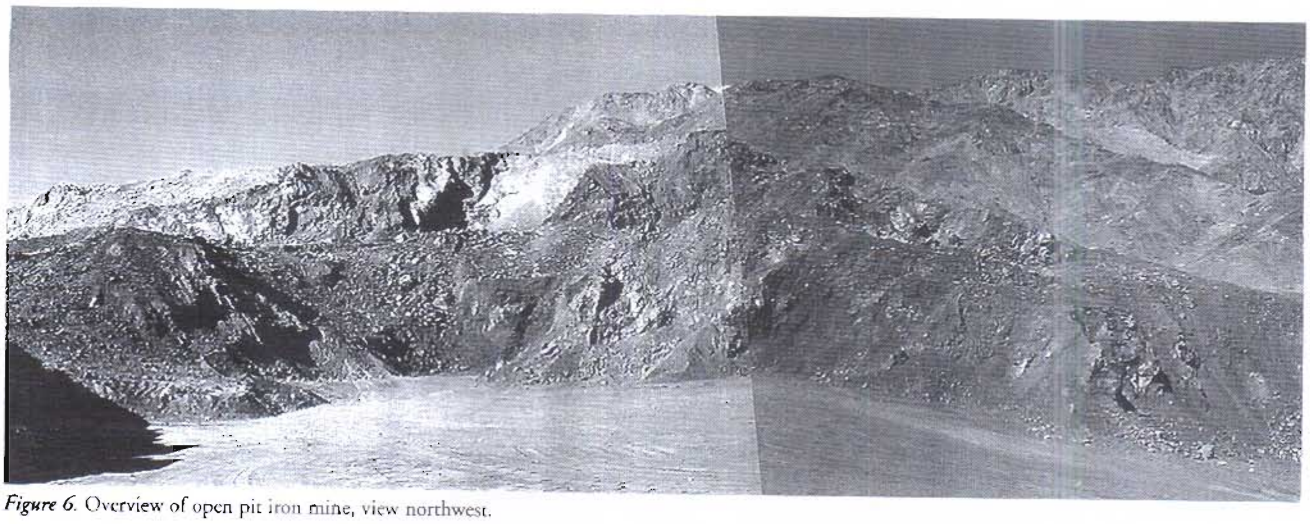


Figure 6. Overview of open pit iron mine, view northwest.

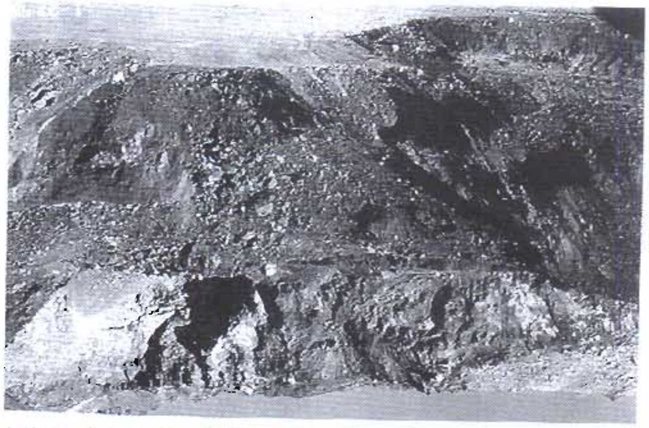


Figure 7. Iron ore exposed in open pit, view northwest.

Figure 8. Northeast-trending high angle fault forming north boundary of deposit.

known, but the pit is up to 70 feet deep, and ore continues into the floor. The tenor of the ore is about 50% iron, and the ore is composed of Hematite and Magnetite. Within the ore zone is interburden waste rock, and mining must be selective to maintain quality.

The open pit is about 1000 feet long and up to 250 feet across, although generally less. The ore is drilled and blasted, loaded, and hauled to the crusher where it is crushed and conveyed to a surge pile. Crushed ore is loaded by conveyor from the surge pile into enclosed bulk trucks and hauled to the consumers. The operation runs all year.

References Cited

Brown, H. J., 1981, Stratigraphy and structure of a portion of the Bristol Mountains, San Bernardino county California, *in* Howard, K., Carr, M. D., and Miller D. M., eds., Tectonic framework of the Mojave and Sonoran Deserts, California and Arizona: U.S. Geological Survey Open file report 81-503, p. 10-11.

____, 1982, Stratigraphy and structure of a portion of the Piute Mountains, San Bernardino County California: Geological Society of America Abs. W. Prog., v. 14, p. 152.

____, 1986, Detailed geologic map of the eastern New York Mountains, San Bernardino County California: Geological Society of America Abs. W. prog. v. 18, p.89.

____, 1991, Stratigraphy and paleogeographic setting of Paleozoic rocks in the San Bernardino Mountains, California, *in* Cooper J. D. and Stevens, C. H., eds., Paleozoic paleogeography of the western United States II: Pacific Section SEPM, v. 67, p. 193-207.

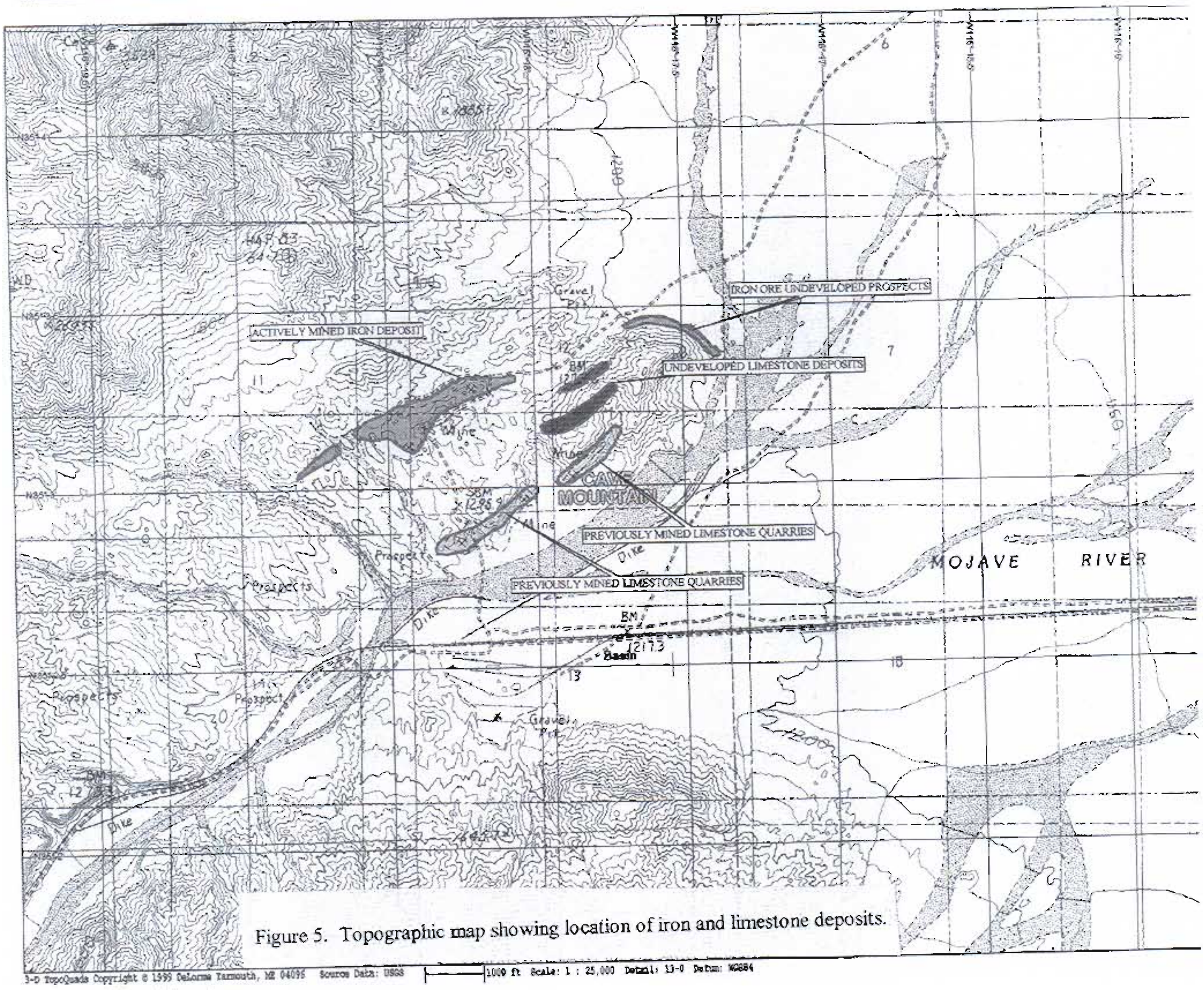
Danehy, E., A., and Collier, J. T., 1958, Geology and mineral resources T. 11 N., R. 5, 6 E., SBBM: Southern Pacific Mineral Survey Report and Map, scale 1:24,000.

Lamey, C. A., 1948, Cave Canyon iron ore deposits, San Bernardino County California: Calif. Division of Mines and Geology, Bulletin 129, p. 59-67.

Logan, C.A., 1947, Limestone in California: California Journal of Mines and Geology, v. 43, p. 151.

Walker, J. D., Martin, M. W., Bartley, J. M. and Coleman, D. S., 1990, Timing and kinematics of deformation in the Cronese Hills, California and implications for Mesozoic structure of the southern cordillera: Geology, v. 18, p. 554-557.

Wright, L. A., Stewart, R. M., Gay, T. E., and Hazenbush, G. C., 1953, Mines and minerals of San Bernardino County California: California Journal of Mines and Geology, v. 49 (1 and 2), p. 93.



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 1000 ft Scale: 1 : 25,000 Detail: 13-0 Datum: WGS84

Figure 5. Mineral deposit map.

Formation of the limestone (calcite marble) deposits is related to the deposition of originally pure limestone in restricted shallow marine environments, followed by recrystallization and bleaching to form white marble during metamorphism. The easily accessible Crystal Pass limestone has been mined from several quarries near the base of the ridge, and close to the rail siding, while more pure deposits of the Bullion Limestone have not yet been developed, largely due to more difficult access.

Logan (1947) and Wright and others (1953) reported that the quarries in the Crystal Pass were extensively mined during the 1920s and utilized in the processing of sugar beets. They indicated that production reached as much as 65,000 tons per year. Cumulative production from the quarries is estimated to be several hundred thousand tons. The deposits have been idle for many years. Several million tons of reserves of Crystal Pass Limestone and Bullion Limestone remain.

Iron Deposits

The Cave Canyon iron mine, also known as the Basin Mine and the Baxter iron mine, has been in operation since 1930, and has been continuously mined for a number of years. Lamey (1948) originally examined the iron deposit about 50 years ago. The mine is located on patented claims owned by California Portland Cement Company, and is operated by a contractor.

Current production is about 75,000 tons per year (personal communication, John Rains, California Portland Cement Company, 2000). The iron ore is utilized as an additive in the manufacturing of Portland Cement. Typically cement utilizes 3-5% iron which reduces the reactive temperature in making the cement product. The iron ore is shipped to several cement plants in the Southern California area.

Iron mineralization is reported to occur as replacement deposits along a northeast-trending shear zone. The iron deposit is said to be steeply dipping (Lamey 1948). The deposit appears to be fault bounded to both the north and south by high angle faults. The steeply dipping to vertical mineralization continues on strike to the west, and also to the east beyond the current mining area. Outcrops of iron mineralization at the east end of the study area are likely the continuation of the iron ore deposit and appear to be associated with mafic diorite intrusives along a low angle fault zone. Various ages have been assigned to the mineralization but observable relationships in the mine area and comparison with other similar deposits in the Mojave Desert suggest that it is probably of Mesozoic age.

Total length of the mineralization may be up to one mile on strike. The mineralized zone is up to 300 feet wide, but is mostly 100 feet or less, and appears to thin to less than 20 feet at the western and eastern limits of the exposures. Depth extent is not

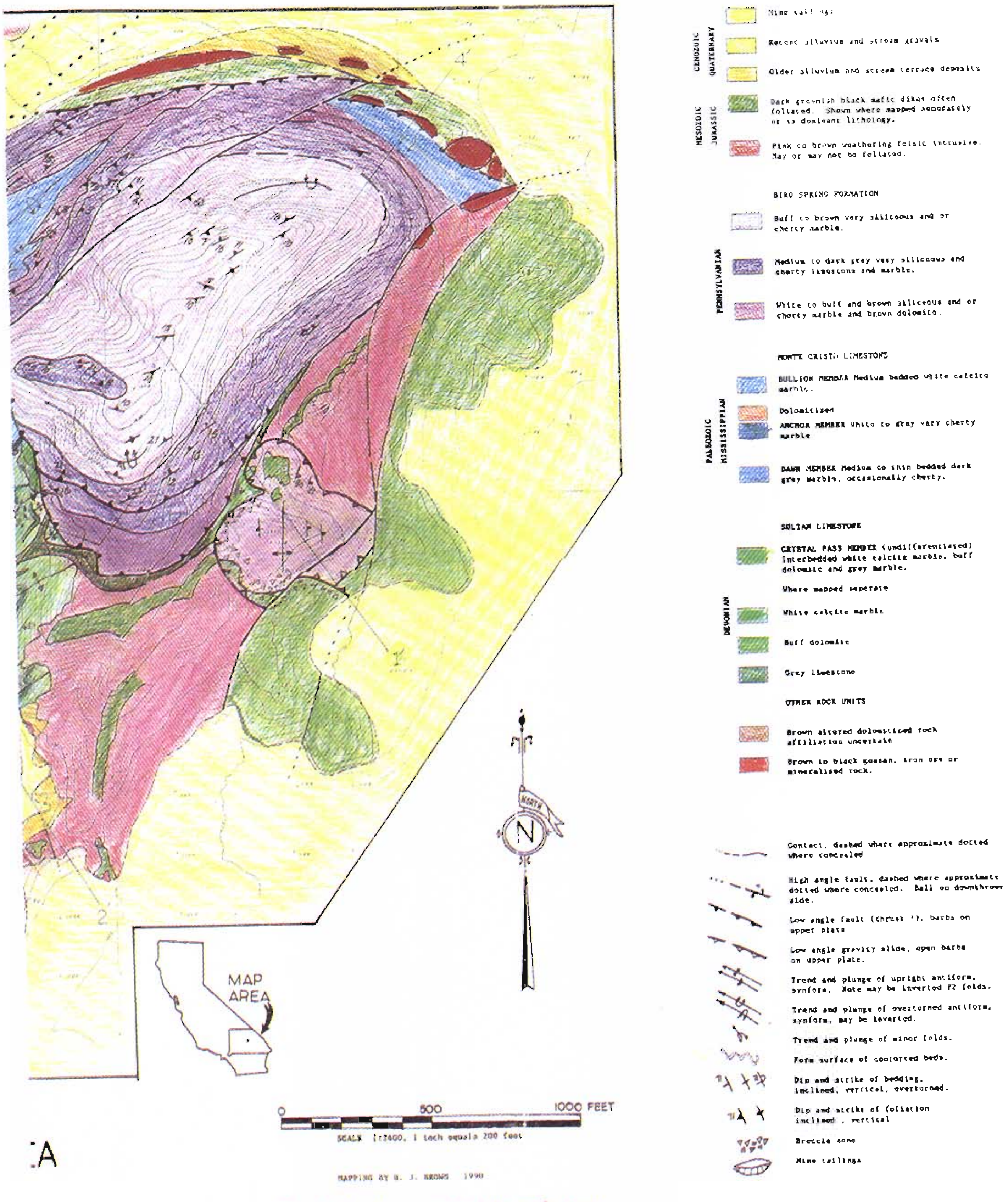
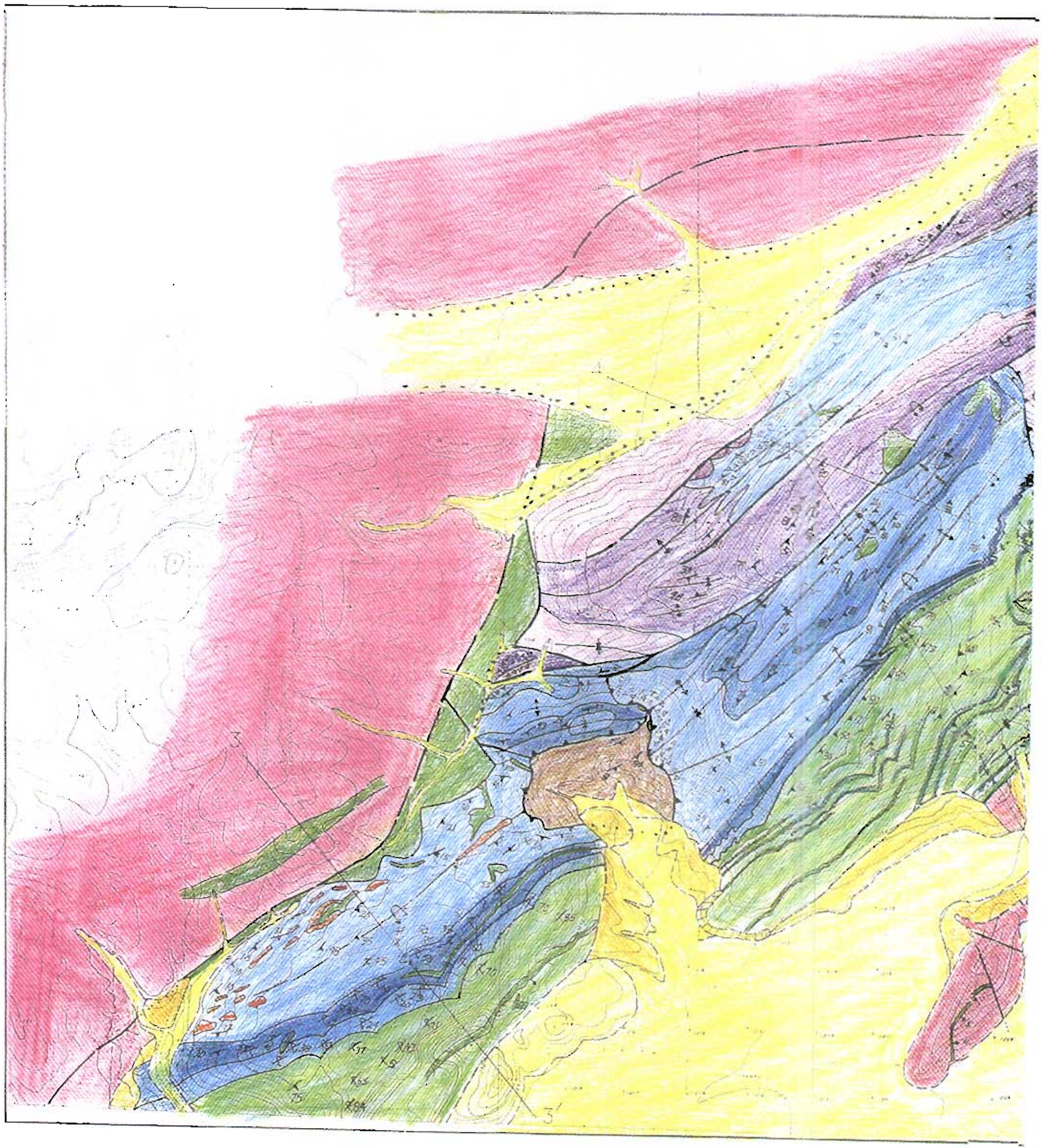


Figure 4. Detailed geologic map of the study area.
Reduced from original mapping at scale of 1 inch = 200 feet.



GEOLOGY OF A PORTION OF THE CAVE MOUNTAIN ARE
SAN BERNARDINO COUNTY, CALIFORNIA

Some Brief Notes on the Geology of Pahrump Valley

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Depositional History

Pahrump Valley is filled with Tertiary and Quaternary sediments that can be divided into two groups, basin deposits and piedmont deposits. Surficial deposits from both groups correlate regionally, and are almost identical to those on the east side of the Spring Mountains (cf., Bell and others, 1998). Basin deposits can be correlated to stratigraphic units of Haynes (1966) and Bell and others (1998, 1999) in northern Las Vegas Valley and to some older, mid to late Pleistocene deposits (Lundstrom and others, in press). Subsurface basin deposits may correlate to Miocene Horse Springs or Muddy Creek Formations found in the basin to the east of the Spring Mountains (Lundstrom and others, in press), and have a maximum thickness of 2200 m (Blakely and others, 1999). Tertiary sediments in the southern part of the valley have an interbedded crystal tuff that has yielded an Ar/Ar age of 10.76 ±0.09 Ma (McMackin, 1999 and this volume).

The oldest deposits exposed in the central part of Pahrump Valley make up a northwest-aligned chain of hills capped by a gravelly basin fill alluvium. The gravels are composed of predominately limestone clasts derived from Paleozoic rocks in the Spring Mountains (Lundstrom and others, in press). Also included are sparse granitic and volcanic rocks, probably derived from the Kingston Range to the south (Lundstrom and others, in press). The gravels are angular to subrounded, and are made up of clasts that range in size from granules to boulders.

Late Quaternary sediments that crop out in the south-central part of the valley near Browns Spring are known as the basin fill of Browns Spring, and have been dated using U-series and thermoluminescence methods at about 275 to 400 ka (Lundstrom and others, in press). These deposits consist of brown muds, marls, sands, and some minor beds of pebble gravel (Lundstrom and others, in press). Within the basin fill of Browns Spring is a massive, 2-4 m thick limestone which forms a resistant escarpment northeast and southwest of Browns Spring. Younger basin units crop out near the town of Pahrump and correlate with Haynes' (1967) Units D and E; this is where we've studied these deposits. Unit D consists of up to 6 m of light-gray organic muds and silts with a typical 30 to 50 cm thick cemented calcareous top. Radiocarbon ages from Unit D in Pahrump Valley range from ~20 to 24 ka. Unit E is made up of light-brown silts and green clayey silts up to 3 m thick. These deposits are from paleosprings, paludal, eolian, and possible local lacustrine settings, and have yielded a radiocarbon date of about 12 ka. Younger basin-fill deposits, Units F and G, are also present. These are dominantly eolian and floodwater deposits, generally less than 1 m thick.

Piedmont deposits consist principally of fanglomerates made up of sandy coarse-pebble gravels, with increasing cobbles and boulders in the proximal parts of the fans. Piedmont deposits are divided into three groups, a mid to early Pleistocene group (Qo), a late Pleistocene group (Qi), and a latest Pleistocene/Holocene group (Qy). Older alluvium (Qo) is characterized by deep dissection and discordant rounded remnants (ballenas), moderately to well developed pavement with whitish calcrete litter abundant, and deeply etched carbonate clasts. Outcrops of massive calcic horizons several meters thick are common. In general, the upper soil horizons have been erosionally stripped. The intermediate-age group (Qi) are fan terrace remnants that are characterized by a tightly packed pavement, dark rock varnish on non-carbonate clasts, and strongly etched carbonate clasts. Soils have a reddened and well-structured argillic horizon and a 1 to 1.5 m thick Bk horizon with up to Stage IV carbonate development. Intermediate-age deposits are commonly well-dissected and elevated above the surrounding fan surface, although all surfaces merge in the distal fan areas. The younger group (Qy) is made up of fan remnants with surfaces ranging from subdued bar and swale morphology to fully smoothed with well-developed pavement. Soil profiles range from Av-Bk-C to Av-Bw-Bk-C and are about 30 to 40 cm thick; carbonate development is Stage I to II. Near Pahrump, the piedmont is not rapidly aggrading. Where exposed along Wheeler Wash, mid to early Pleistocene alluvial deposits are only several meters below younger late Pleistocene alluvial deposits.

There is some debate as to whether a late Pleistocene lake occupied Pahrump Valley. Such a lake is indicated by Snyder and others (1964), and possible strandlines and a possible delta were mapped by dePolo and others (1999). However, a core from the southern part of the playa in Pahrump Valley indicated that perennial water was not present during the last discharge cycle around earliest Holocene (Quade and others, 1995).

Locally, Holocene eolian deposits in the form of sand deposits and sand dunes occur in Pahrump Valley.

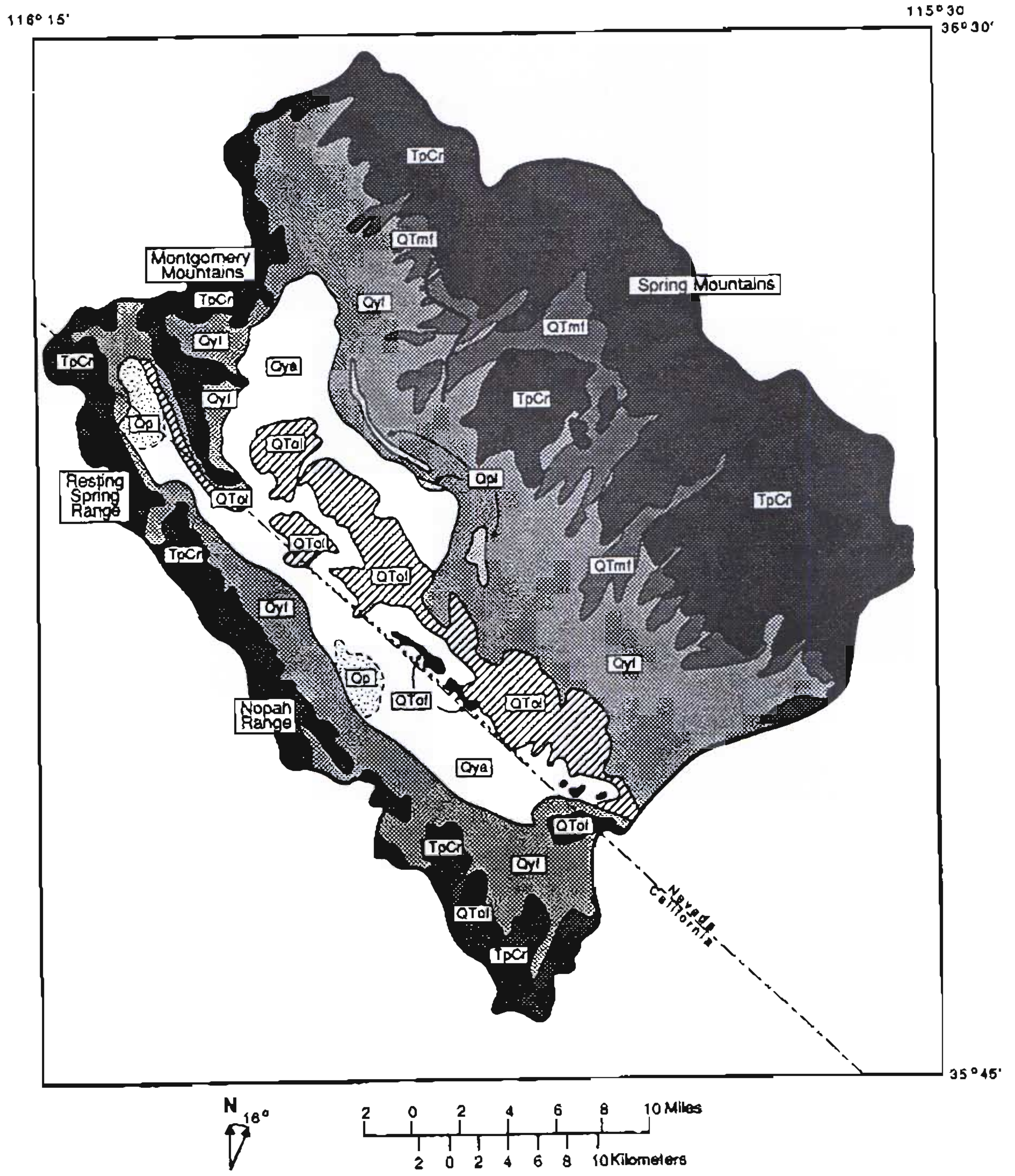
Cenozoic Structure of Pahrump Valley

Blakely and others (1998) developed a three-dimensional model of the pre-Cenozoic basement beneath Pahrump Valley. Their synopsis follows,

> Pahrump Valley is underlain by two deep, steep-sided sub-basins separated by a narrow basement ridge aligned parallel to the state line. The Pahrump Valley sub-basins also formed as transtensional pull-apart basins, accommodated in part by displacement along the northwest-striking State Line fault zone. The state-line ridge at Pahrump Valley is on strike with a narrow basement ridge beneath Ash Meadows, also lying along the state line and within the State Line fault zone. Both ridges are associated with late Cenozoic faulting. The ridges may have formed as transpressional structures, caught slightly askew of the northwest-directed strain that formed the sub-basins.

The mapped surficial geology is consistent with the narrow basement ridge modeled from geophysics (Lundstrom and others, in press). The gravity high coincides with the oldest units exposed in the valley that form the northwest-aligned hills just southwest of the stateline.

There are both strike-slip and normal-slip Quaternary faults in Pahrump Valley, indicating a complex contemporary tectonic setting. Faults in the central and western parts of the valley appear



to be dominantly northwest-striking right-lateral strike-slip faults (Pahrump Valley fault system and the East Nopah Range fault), whereas faults on the east side of the valley appear to be dominantly normal-slip faults (West Spring Mountains fault and the Eastern Pahrump Valley fault zone). The main fault system in the valley is the Pahrump Valley fault system, which consists of the Stewart Valley fault to the north, the Pahrump Valley fault zone within central Pahrump Valley, and the Stateline fault zone that extends from southern Pahrump Valley, through Mesquite Valley, to Ivanpah Valley in the south. This is a complex system of presumably right-lateral strike-slip faults, and secondary normal-slip faults.

The northwest-striking Pahrump Valley fault system has a total length of over 100 km. The Quaternary portion of the Pahrump Valley fault system is at least 55 km in length, from Stewart Valley southward through southern Pahrump Valley. Whether Quaternary activity extends further southward into Mesquite and Ivanpah Valleys has not been studied in detail; a structural zone continues to the south but some of the obvious Quaternary features that are present in Pahrump Valley are missing. The Pahrump Valley fault system was first identified as having possible Quaternary activity by Liggett and Childs (1973) using satellite imagery. The main studies of the system are Hoffard (1991), Anderson and others (1995), and Louie and others (1998). Evidence for Quaternary activity along the Pahrump Valley fault zone consists of fault scarps, scarplets, sapped fault scarps, and vegetation and tonal lineaments. The late Quaternary lateral slip rate of the fault zone is estimated to be about

0.1 m/kyr in southern Stewart Valley, based on a shallow 3D geophysical survey that indicated an 18 m minimum offset of Wisconsin-age deposits (Louie and others, 1998). The Pahrump Valley fault zone has the potential to produce earthquakes with magnitudes up to about 7.3 (dePolo, unpublished research); detailed paleoseismic studies are needed, however to understand whether the zone is segmented with respect to earthquake ruptures.

The East Nopah Range fault is located in the eastern piedmont of the Nopah Range, and is expressed by fault scarps in mid to late Quaternary alluvium. The zone is about 19 km long and is a right-normal-oblique-slip fault. The lateral slip is inferred from the linearity of the fault trace, possible juxtaposed alluvial deposits, possible right-lateral offsets of drainages, and left-stepping fault traces (Hoffard, 1991). The zone was first mapped by McKittrick (1988) and was additionally studied by Hoffard (1991) and Anderson and others (1995). Vertical slip rates are estimated to be a few hundredths of a m/kyr (Hoffard, 1991; Anderson and others, 1995), but the potential lateral slip rate has not been explored. It is possible that earthquakes between magnitude 6.5 to 6.8 are generated by this fault zone (dePolo, unpublished research).

References:

Anderson, R.E., Crone, A.J., Machette, M.N., Bradley, L, and Diehl, S.F., 1995, Characterization of Quaternary and suspected Quaternary faults, Amargosa area, Nevada and California: U.S. Geological Survey, Open-File Report 95-613, p. 8-13.

Bell, J.W., Ramelli, A.R., Caskey, S.J., 1998, Geologic map of the Tule Springs Park Quadrangle, Nevada: Nevada Bureau of Mines and Geology, Map 113, scale 1:24,000.

Bell, J.W., Ramelli, A.R., dePolo, C.M., Maldonado, F., and Schmidt, D.L., 1999, Geologic map of the Corn Creek Springs Quadrangle, Nevada: Nevada Bureau of Mines and Geology, Map 121, scale 1:24,000.

Blakely, R.J., Morin, R.L., McKee, E.H., Schmidt, K.M., Langenheim, V.E., and Dixon, G.L., 1999, Three-dimensional model of Paleosoic basement beneath Amargosa Desert and Pahrump Valley, California and Nevada: Implications for tectonic evolution and water resources: U.S. Geological Survey, Open-File Report 98-496, 29 p.

dePolo, C.M., 1998, A reconnaissance technique for estimating slip rates of normal-slip faults in the Great Basin and application to faults in Nevada, USA: University of Nevada, Reno, PhD Dissertation, 199 p.

dePolo, C.M., Ramelli, A.R., and Bell, J.W., 1999, Geologic map of the Pahrump Quadrangle, Nevada: Nevada Bureau of Mines and Geology, Open-File Map 99-14, scale 1:24,000.

Haynes, C.V., 1967, Quaternary geology of the Tule Springs area, Clark County, Nevada, in Wormington, H.M. and Ellis, D, eds., Pleistocene studies of southern Nevada: Nevada State Museum Anthropological Paper No. 13, p. 1-104.

Hoffard, J.L., 1991, Quaternary tectonics and basin history of Pahrump and Stewart Valleys, Nevada and California: University of Nevada, Reno, M.S. Thesis, 138 p.

Liggett, M.A. and Childs, J.F., 1973, Evidence of a major fault zone along the California-Nevada state line, 35 30' N. latitude: Argus Exploration Company, NASA Report of Investigation CR-133140, E73-10773, 13 p.

Louie, J, Shields, G., Ichinose, G., Hasting, M., Plank, G., and Bowman, S., 1998, Shallow geophysical constraints on displacement and segmentation of the Pahrump Valley fault zone, in dePolo, ed., Proceedings of a conference on seismic hazards in the Las Vegas region: Nevada Bureau of Mines and Geology, Open-File Report 98-6, 79-85.

Lundstrom, S., Mahan, S.A., Blakely, R.J., Paces, J.B., Young, O.D., and Dixon, G.L., in press, Geologic map of the Mound Spring Quadrangle, Nye and Clark Counties, Nevada, and Inyo County, California: U.S. Geological Survey, print on demand MF map.

Malmberg, G.T., 1967, Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump valley, Nevada-California: U.S. Geological Survey, Water-Supply Paper 1832, 47 p.

McKittrick, M.A., 1988, Surficial geologic map of the Resting Spring and Nopah Ranges, Inyo County, California, and Nye County, Nevada: U.S. Geological Survey, Miscellaneous Field Studies Map, MF-1941, scale 1:62,500.

McMackin, M.R., 1999, Geology of the Stump Spring Quadrangle - Evidence of late Quaternary transpression on the southern segment of the Pahrump Valley fault zone, Nevada and California, in Slate, J.L., ed., Proceedings of Conference on status of geologic research and mapping in Death Valley National Park, Las Vegas, Nevada, April 9-11, 1999: U.S. Geological Survey, Open-File Report 99-153, p. 162.

Quade, J., Mifflin, M.D., Pratt, W.L., McCoy, W., and Burckle, L., 1995, Fossil spring deposits in the southern Great Basin and their implications for changes in water-table levels near Yucca Mountain, Nevada, during Quaternary time: Geological Society of America Bulletin, v. 107, p. 213-230.

Snyder, C.T., Hardman, G., and Zdenek, F.F., 1964, Pleistocene lakes in the Great Basin: U.S. Geological Survey, Miscellaneous Geologic Investigations, Map I-416, scale 1:1,000,000.

Geology of the Stump Spring Quadrangle:

Evidence of Late Quaternary Transpression on the Southern Segment of the Pahrump Valley Fault Zone, Nevada and California

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Previous studies have noted the lack of clear evidence of late Quaternary slip on the Pahrump Valley fault zone (Hoffard, 1991; Anderson et al., 1996). Detailed mapping in the Stump Spring area at the south end of Pahrump Valley confirms the observations of previous workers, who have focused their attention largely on the northern and central segments of the Pahrump Valley fault zone. In the southern part of Pahrump Valley, at least two clearly defined fault scarps mark the southern extension of the Pahrump Valley fault zone into the area just north of Black Butte (also known as Valley Ridge). Although these fault scarps are up to six meters in height, they are significantly rounded by weathering. The scarps are sealed by a 1 to 2 meter thick pedogenic carbonate layer that drapes over the eroded scarps but reveals no evidence of cross-cutting faults. Anderson and others (1996) suggest that the carbonate, with Stage III-IV carbonate morphology, is greater than 100 k.y. old. However, evidence presented here suggests that the pedogenic carbonate is gently folded about northwest-trending axes to form two anticlines that are subparallel to the fault zone, indicating younger deformation without apparent surface ruptures. The most prominent folds are two anticlines subparallel to northwest-trending fault scarps in the northern half of the quadrangle.

Evidence of folding of the carbonate layer includes fold limbs dipping up to 10°, although it is difficult to separate initial inclination of the carbonate layer along the fault scarp from actual tilting due to deformation. Less equivocal dips are approximately 5°. Well-formed fractures in the carbonate layer also suggest that the folding is of tectonic origin. Well-formed planar fractures are observed in the carbonate layer subjacent to the fault scarps and throughout the apparent folds. Cumulative analysis of planar fractures greater than 1 meter in length reveals dominant orientations N50°E and N40°W, corresponding to cross-strike and strike-parallel fractures in a northwest-trending fold. Fractures in the carbonate horizon control the surface drainage pattern as well as shallow subsurface piping. The folding appears to have disturbed the patterns of surface drainage resulting in the abandonment of older channels, while other streams are entrenched across the axis of the anticline. Gravel deposits from an abandoned channel contain carbonized wood that was dated at 31,790 +1520/-1290 by Quade et al (1995), who noted that this is probably a minimum age due to the possibility of contamination. The folding the pedogenic carbonate and the resulting effects are difficult to interpret but they imply that late Quaternary deformation has progressed as transpressional deformation, albeit at a reduced rate compared to the deformation indicated by earlier fault scarps.

The folding of the presumed late Pleistocene carbonate layer is compatible with the deformation observed in middle to late Tertiary rocks that are more strongly deformed by faults and folding along the trace of the fault. Miocene sedimentary rocks are exposed in the core of one of the anticlines in the northern part of the map area. Sanidine from an interbedded crystal tuff yielded an Ar/Ar age of 10.76 ± 0.09 Ma (courtesy of C. Henry). The older units units are more strongly deformed. Bedding inclined up to 50° and clay gouge faults, with oblique slip striae, can be observed in clean exposures in recent gullies. In the southern part of the map area in the low hills surrounding Black Butte, Tertiary rocks are folded and uplifted along buried faults with no evidence of Quaternary displacement. The faults in the southern part of the area are poorly exposed or concealed but it is difficult to infer a simple alignment with the Pahrump Valley fault zone extending through the hills around Black Butte.

It has been suggested that the Pahrump Valley Fault is contiguous with the Stateline Fault, which can be traced through Mesquite Valley to the south. A possible explanation of the apparent shift in late Quaternary deformation may be that late Tertiary to early Quaternary deformation of the fault in the area around Black Butte has resulted in a misalignment of the Pahrump Valley fault zone with faults further south in the Mesquite Valley. Misalignment of the Pahrump Valley and Stateline faults in the area around Black Butte may impede lateral slip resulting in a change in the expression of ongoing regional deformation.

References Cited

Anderson, R.E., Crone, A.J., Machette, M.N., Bradley, L.A, and Diehl, S., 1996. Characterization of Quaternary faults, Amargosa area, Nevada and California: USGS Open-File Report, 41p.

Hoffard, J.A., 1991, Quaternary tectonics and basin history of Pahrump and Stewart Valleys, Nevada and California: Reno, University of Nevada, unpublished M.S. thesis, 138p., 5pls.

Quade, J., Mifflin, M.D., Pratt, W.L., McCoy, W.D., and Burkle, L., 1995. Fossil spring deposits of the southern Great Basin and their implications for changes in water-table levels near Yucca Mountain, Nevada, during Quaternary time: Geological Society of America Bulletin, v.107, p.213-230.

Where Legend Became Reality: Sandy, Nevada

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Although rich deposits of minerals still remained undiscovered in the late 19th century, some prospectors wanted adventure, too. The search for lost mines and buried treasure was one way to satisfy that urge.

While searching for a mythical Spanish mine, Jonas Taylor, a well-known prospector from San Bernardino County, found a rich vein of gold at the southern end of the Spring Mountains, in Lincoln County, Nevada, in March of 1888. He called the discovery the Keystone Mine. Other prospectors found deposits of gold, copper, silver, and lead in the mountains there, where the Yellow Pine Mining District was organized.

The Keystone emerged as the leading mine, producing $35,000.00 in ore from August through December, 1892, when Taylor cut his force from 20 to three. Still, a post office was established at the mine on January 23, 1893, and the county commissioners appointed a justice of the peace and a constable in early March. Meanwhile, another camp, later known as Goodsprings, was springing up several miles to the northwest, where a store was opened in May.

Taylor's inability or unwillingness to engage in large-scale mining rankled several capitalists, who saw a fortune to be made from this "veritable bonanza." One such investor was Isaac C. Blake, of Denver, who was building a branch railroad — the Nevada Southern Railway — from Goffs to the New York Mountains, in the eastern Mojave Desert, where he owned the Sagamore Mine, a promising copper, silver, and gold deposit. He was also building a bank and smelter in Needles. Blake bought a one-quarter interest in the Keystone in early March. The other principal was Samuel T. Godbe, who owned several other mines in the district. Apparently, he bought Taylor out that summer, taking over as the general manager.

The conditions then were enough to give many mine operators second thoughts. A severe nationwide depression struck in June. Stock prices dropped; banks began to topple; and metal prices fell. And by August, one mine owner reported, the weather was "something awful. Nothing but sharp, shining sand and brilliant sunshine, the thermometer ranging from 90 degrees to 120, water four cents a gallon and everything to eat, drink or use packed fifty limes through sand hub deep, make an undesirable combination."

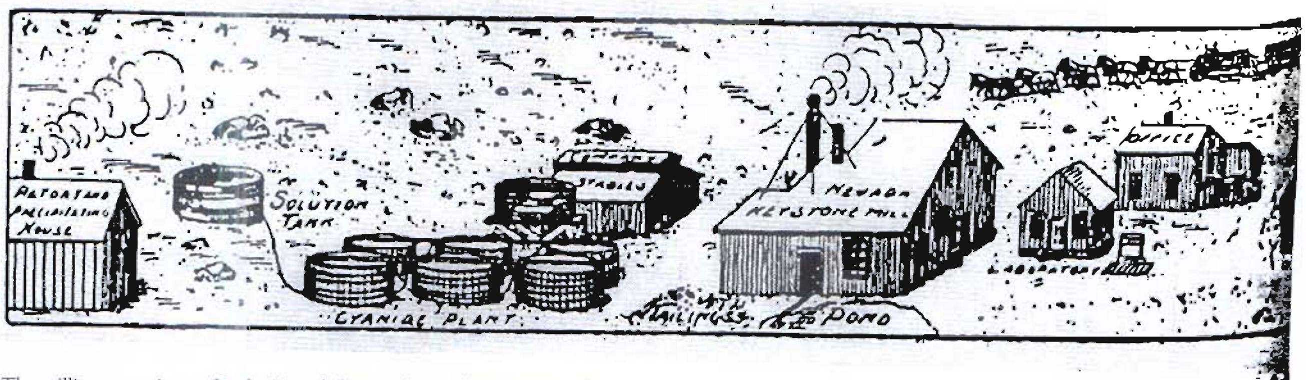
But Godbe remained undaunted. That summer, he rushed out materials to build a 10-stamp mill at Mesquite Well (soon renamed Taylor's Well), seven or eight miles west of the mine. The mill started up in late September or early October, turning out $8,000.00 in bullion in 33 days.

Running night and day, the mill became the nucleus of a camp, at first called Keystone, later called Sandy. A dozen tents and houses had arisen by early November. Within a few weeks, the settlement contained stores, saloons, a blacksmith and other shops, and an office and boardinghouse for the mill, "around which all of the various interests of the district can congregate."

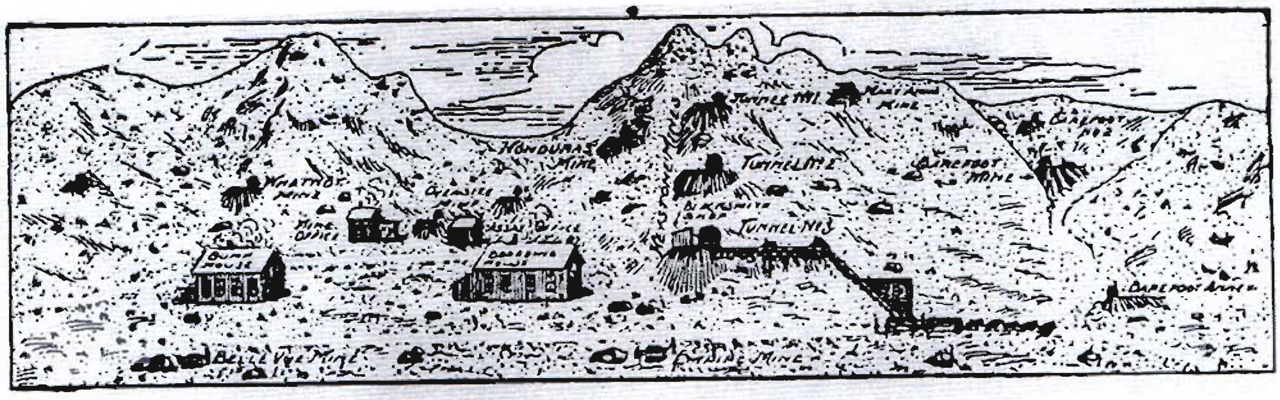
After breaking a strike in 1894, Godbe made rapid progress. By July, the main shaft had been sunk 400 feet on an incline, and the mill was processing 15 tons of ore a day. Fifty men were living at the mine and mill. A post office was established at Sandy on January 23, 1896.

But Godbe still had to reckon with the depression. Metal prices continued to decline. The Keystone Mining Company fell into debt. At first, the property was leased to another company, but it had to be sold in May, 1896, to pay off $64,050.00 in judgments. Though Sandy survived as a supply center, the mine, apparently, had to shut down, losing its post office on June 28, 1897.

The depression faded away in the late 1890s, when metal prices began to rise. Several small mines began sending copper and silver-lead ores to smelters in Colorado and other states. A stage was running twice a week from Manvel to Sandy and Goodsprings, where a post office opened on April 6, 1899. Although a proposed smelter at Sandy was never built, when the Keystone was sold in November, the new owner put a crew to work, sacking rich ore for shipment to smelters. By then, the inclined shaft had been sunk to 700 feet.



The milling operation at Sandy. From left: retorting and precipitating house, solution tank, tanks of cyanide plant, company stables (behind cyanide plant), mill, tailings pond (in front of mill), [assay] laboratory, and company office. Inset from advertisement in the Los Angeles *Mining Review*, Feb. 21, 1903.



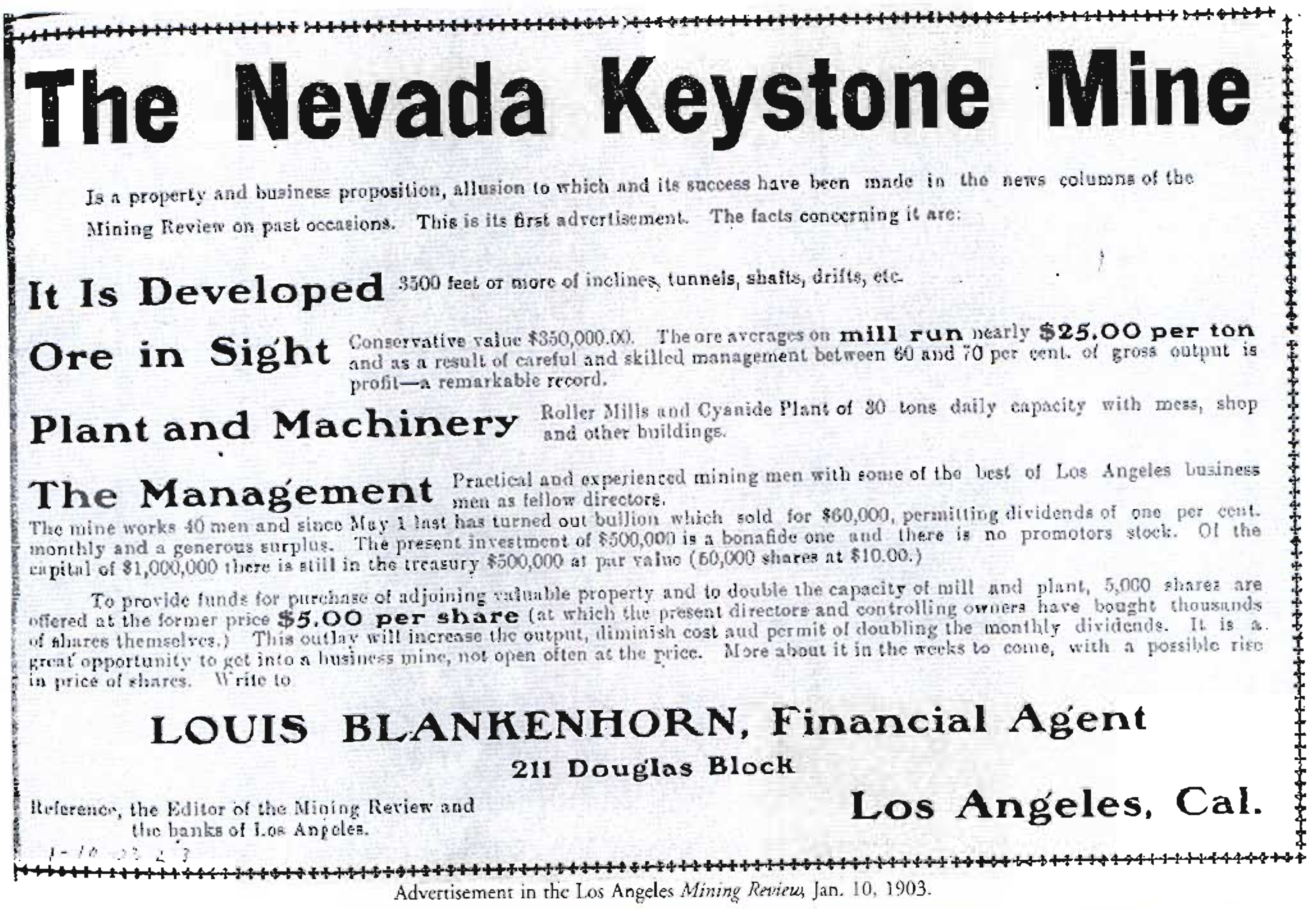
Operation at the Keystone Mine. From left: bunkhouse, office, assay office, boarding house, blacksmith shop (at tramway of tunnel No. 3), chute and ore bin. Inset in advertisement in the Los Angeles *Mining Review*, Feb. 21, 1903.

Though its ore bodies were said to be depleted, the Keystone soon enjoyed an important revival. Leasing the mine, F. M. Doak, an officer of a smelting company at St. Louis, tore out the mill in September, 1901, and apparently interested a well-known promoter, Carl F. Schader. Though barely 30 years old, Schader had worked in surveying, merchandising, and banking before switching to mining in 1896. Schader easily rounded up a variety of investors, organized the Nevada-Keystone Mining Company in May, 1902, and took over the lease. Under Carl Anderson, an experienced superintendent, the company installed a roller mill (which operated like a gristmill), cyanide plant, steam engine, and pumps at the old mill site. An office, mess hall, shops, tracks, tramways, 10-ton ore bin, headframe, and gasoline-powered hoist were put in at the mine, where a crew of 40 or 50 was at work by late March, 1903. The Keystone produced $97,440.00 in gold that year.

By then, the ore bodies were petering out, as Schader was figuring out. During the winter of 1903-1904, he and a partner bought the Johnnie Mine, to the north, and began building it up. The mill operated day and night throughout the summer of 1904, processing ore of decreasing value: as little as $7.00 a ton by September.

Afterward, the Nevada-Keystone company turned the operation over to lessees. The lessees kept up regular shipments of ore and bullion, even when the county sold the properties for $47.00 in back taxes in July 1907 and even when a depression closed most of the district's mines in October. At last, however, the mine and mill were shut down, probably in 1908.

Soon, Sandy became a relic, too. After the completion of several railroads, the camp had lost its importance as a stage stop. The discovery of large zinc deposits to the north, meanwhile, had made



The Nevada Keystone Mine

Is a property and business proposition, allusion to which and its success have been made in the news columns of the Mining Review on past occasions. This is its first advertisement. The facts concerning it are:

It Is Developed 3500 feet or more of inclines, tunnels, shafts, drifts, etc.

Ore in Sight Conservative value $350,000.00. The ore averages on **mill run** nearly **$25.00 per ton** and as a result of careful and skilled management between 60 and 70 per cent. of gross output is profit—a remarkable record.

Plant and Machinery Roller Mills and Cyanide Plant of 30 tons daily capacity with mess, shop and other buildings.

The Management Practical and experienced mining men with some of the best of Los Angeles business men as fellow directors.

The mine works 40 men and since May 1 last has turned out bullion which sold for $60,000, permitting dividends of one per cent. monthly and a generous surplus. The present investment of $500,000 is a bonafide one and there is no promotors stock. Of the capital of $1,000,000 there is still in the treasury $500,000 at par value (60,000 shares at $10.00.)

To provide funds for purchase of adjoining valuable property and to double the capacity of mill and plant, 5,000 shares are offered at the former price **$5.00 per share** (at which the present directors and controlling owners have bought thousands of shares themselves.) This outlay will increase the output, diminish cost and permit of doubling the monthly dividends. It is a great opportunity to get into a business mine, not open often at the price. More about it in the weeks to come, with a possible rise in price of shares. Write to

LOUIS BLANKENHORN, Financial Agent
211 Douglas Block
Los Angeles, Cal.

Reference, the Editor of the Mining Review and the banks of Los Angeles.

1-10-03

Advertisement in the Los Angeles *Mining Review*, Jan. 10, 1903.

Goodsprings the main camp of the Yellow Pine district. In August, 1908, a townsite named Mandolin was laid out in the Mesquite Valley, where a large influx of settlers led to the formation of a short-lived school district in 1909. After another townsite was laid out just to the southwest of the mill, Sandy's post office was moved there and renamed Ripley on September 23, 1910. Several mines were later revived, but Sandy did not.

Sources

Stanley Paher gives brief accounts of Sandy and other camps in his *Ghost Towns and Mining Camps of Nevada* (Berkeley: Howell-North Books, 1970). The mineral resources of the Yellow Pine Mining District are well described in D. F. Hewett's *Geology and Ore Deposits of the Goodsprings Quadrangle, Nevada* (United States Geological Survey Professional Paper 162, 1981). Richard Lingenfelter gives the background of Carl Schader in *Death Valley and the Amargosa: A Land of Illusion* (Berkeley: University of California Press, 1986).

Several mining magazines and newspapers carried frequent reports from the district. The formative period was covered by the Pioche *Record*: Feb. 2, Feb. 16, March 9, March 30, April 27, May 4, May 11, May 25, July 13, July 27, Aug. 31, Sept. 7, Sept. 14, Sept. 21, Nov. 9, Nov. 16, Nov. 23, and Dec. 14, 1893. Though often reprinting the *Record*, the *Mining & Scientific Press* (San Francisco) published articles of supplementary value: Jan. 7, Feb. 18, March 18, March 25, April 29, May 13, May 27, Aug. 19, Sept. 9, Oct. 4, 1893; July 28, 1894; March 7, May 2, 1896. The Los Angeles *Mining Review* reported on the revival of the Keystone Mine, especially under the Nevada-Keystone company: April 10, April 21, April 28, Nov. 18, 1899; Sept. 14, 1901; Sept. 14, Oct. 11, 1902; Jan. 3, Jan. 24, March 21, March 28, May 2, May 20, Dec. 26, 1903; Jan. 23, Feb. 27, July 9, Oct. 8, 1904. The *Searchlight* (Searchlight *Bulletin*) carried not only articles but also advertisements from such camps as Sandy: June 26 (ad.), July 24, Oct. 3, 1906; June 8, Nov. 16, 1906.

The post offices and school are listed in James Gamett and Stanley W. Paher, *Nevada Post Offices: An Illustrated History* (Las Vegas: Nevada Publications, 1983) and in the biennial reports of the Nevada superintendent of public instruction.

Dust Unto Dust: The Colonies of the Mesquite Valley

Alan Hensher
593 Collins Drive #3, Merced CA 95348

It must have taken a starry-eyed optimist to look upon the Mesquite Valley, a 400-square-mile basin straddling the California-Nevada line, as a promising place to settle. Its water, though abundant in places, usually was too mineralized to support people, livestock, or crops. Much of its soil was unsuitable for cultivation. And the heat and dust came down in full force.

In 1901, a promoter from Los Angeles laid out the townsite of Lincoln City, about three miles south of Sandy. Land worth perhaps only $1.25 an acre was subdivided into small lots and sold for $50 each, much to the dismay of a nearby mine manager in July. "There are some people in this world who are willing to part with their money on any terms, and it looks as though the Lincoln City lot seller knows where those people are located," he reported. A store opened at the townsite, but no town developed.

Even so, many believed that thousands of acres of fine land and "an inexhaustible water supply" were there for the taking. In the spring of 1906, several men from Los Angeles sank three wells and began small-scale cultivation near Sandy; a French company, meanwhile, made plans to install pumps and plant a large vineyard. " ... From these modest beginnings a prosperous agricultural community may be built up before many years go by," a Searchlight editor ventured to guess. This settlement failed to last, but a townsite named Mandolin was laid out between Sandy and the state line in August, 1908. A well was sunk to 230 feet, and by the end of December, more than 100 families had taken up land. A school district was organized at Sandy in 1909.

Then, when it appeared that the Santa Fe Railroad, headed by Edward P. Ripley, might extend its branch line from Ivanpah station, a townsite was established just to the southwest of Sandy. The Sandy post office was moved there — probably to a ranch — and renamed Ripley on September 23, 1910. Again, nothing materialized. The school district was abolished in 1912, "and the faithful few settled back to the daily monotony of life ...," a Goodsprings editor recalled.

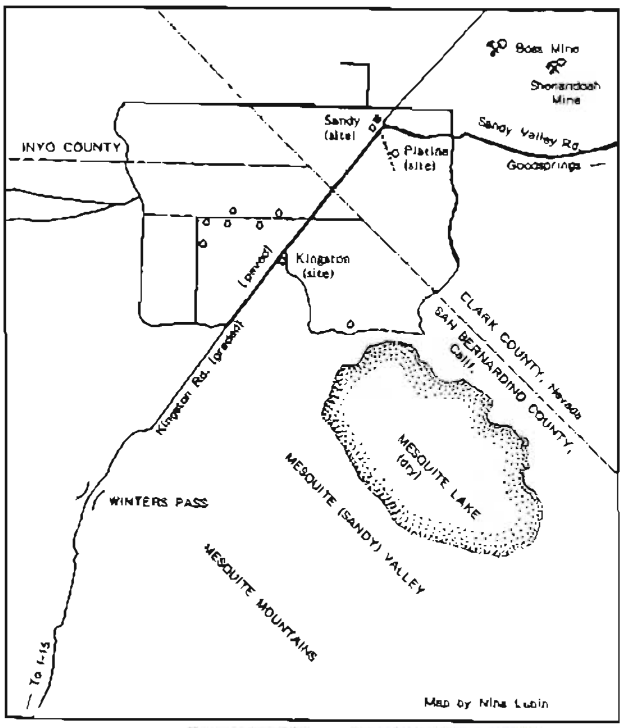
The discovery of platinum in the Boss Mine, three miles east of Sandy, in early 1914 finally gave rise to a town. The operators of the mine, Sam Yount and Oliver J. Fisk, sold an 80-acre tract at Sandy to Los Angeles promoters, who laid out a townsite named Platina, near the Ripley post office. A rival townsite near the Boss Mine never got off the ground, but a hotel, a saloon, several stores, and houses were built at Platina; an auto stage ran from Jean, Nevada, the nearest railroad station. The Ripley post office was renamed and moved to Platina on January 3, 1916. The population reached a reported 200, but the Los Angeles Realty Board stopped the sale of lots, declaring that "there is no excuse for a town." The boom collapsed, and "nobody made a dollar out of it but a few of the liveliest of the promoters," the Goodsprings *Gazette* lamented. Serving only a scattered population by then, the post office was closed on May 31, 1917.

Platina should have been the last of the settlements. After the end of World War I, crop prices fell, and the homesteading movement ran its course.

But a proposal to build an automobile route from southern California to southern Utah led to one last boom. A leg from Jean to Barstow would pass through Goodsprings (which was then enjoying a mining revival), the Mesquite Valley, and Silver Lake, a station on the Tonopah and Tidewater Railroad. Apparently, when the Automobile Club of Southern California endorsed the route in early 1922, Elmore Funk, a pioneer of the Goodsprings mines, saw an opportunity. He encouraged a few men and women to take up homesteads in the valley. Most of the settlers were Californians, including some veterans. Several vineyards were planted to cater to the bootlegging trade.

Nevada highway engineers soon chose another route, through Wheaton Wash (Mountain Pass) and Baker, but a sort of community arose around a store opened by Funk in the northeastern corner of San Bernardino County, 14 miles southwest of Goodsprings. A post office, named after the Kingston Range, was established in the store on July 14, 1924. During the next two years, county officials founded an emergency school, contracting with the Cima School District to hold classes at a nearby ranch; established two library branches, one for the school and the other for the community; and created a voting precinct. Thirteen settlers voted in November 1926.

Although the population dwindled to two families by 1929, the onset of the Depression led to an influx of the unemployed, trying their luck at dry-land farming. Seventy-five families were said to be



Mesquite Valley, from *Ghost Towns of the Mojave Desert* by Alan Hensher (1991).

living in the valley by October, 1930, when Funk supervised the construction of a frame community hall, measuring 26 by 36 feet. The hall may have been used as a schoolhouse and branch library. The only other building of importance was Funk's store, which not only housed the post office but also sold gasoline and served as a government weather station.

Kingston reach its peak during the early Depression. Thirty-two voted in November, 1930. The enrollment at the school — about a dozen — was large enough to induce the county supervisors to urge the formation of a joint school district, but the Inyo County supervisors rejected the proposal in early 1931. The election of November, 1932, again brought out 32 votes, including four Republicans, 23 Democrats, three Socialists, and two Prohibitionists.

That was the last hurrah. The rainfall, after all, remained unpredictable, ranging from 1.4 to 9.5 inches a year. Prohibition ended in 1933. The library branches ranked with those of the county hospital and jail in importance, receiving only the best discards of the system. The school operated only intermittently. Only 17 turned out to vote in late 1934. In one act of indignity, a couple awakened Funk early one morning in April of 1935 to buy gasoline, then robbed the post office of $100.00 in cash, stamps, and money orders. Funk, who was then 83, was left outside, tied up and gagged with tape; friends found him an hour later. Funk stayed on, but the post office was closed on May 14, 1938. The weather station was shut down about 1941. Funk was still running his store as late as July, but after only five voters turned out in November, the supervisors abolished the precinct in January, 1943. Kingston, however, remained on some road maps well into the 1960s.

Sources

The information on the colonies is very sparse. A short account appears in Stanley Paher's book *Nevada Ghost Towns and Mining Camps* (Berkeley: Howard-North Books, 1970). The natural conditions are described in detail by Gerald A. Waring, a former mine owner: *Ground Water in Pahrump, Mesquite, and Ivanpah Valleys* ... (United States Geological Survey Water-Supply Paper 450-C, 1920).

The story of the Nevada settlements has been pieced together from a wide variety of sources, including Paher's work: "Sandy Camp, Nevada," Los Angeles *Mining Review*, July 6, 1901 (v. 10); "Mines Flourishing About Goodsprings," *Searchlight*, June 8, 1906, p. 8; "Goodsprings," Las Vegas *Age*, Jan. 2, 1909, p. 6; "Platina P.O. Will Be Discontinued," May 26, 1917 p. 1; L. Burr Belden, "Platinum Strike Touches Off Big But Brief Boom," San Bernardino *Sun-Telegram*, June 9, 1957, p. 26; and D. F. Hewett, *Geology and Ore Deposits of the Goodsprings Quadrangle, Nevada* (U. S. Geological Survey Professional Paper 162, 1931).

The information on the post offices and school is taken from James Gamett and Stanley Paher, *Nevada Post Offices: An Illustrated History* (Las Vegas; Nevada Publications, 1983), and the biennial reports of the Nevada superintendent of public instruction.

Edward Leo Lyman has written a history of the road that helped make Kingston possible: "The Arrowhead Trails Highway: Predecessor to Interstate 15," *Southern California Quarterly*, fall, 1999 (v. 81), pp. 315-340. Besides Paher's history of Nevada ghost towns, Frank Williams has provided a first-hand account of Kingston in his unpublished autobiography (typescript), Department of Special Collections, University of Nevada, Las Vegas. Brief references can be found in D. F. Hewett's *Geology and Mineral Resources of the Ivanpah Quadrangle* ... (U.S. Geological Survey Professional Paper 275, 1956) and in the Las Vegas *Review-Journal*: "Personal: Building Hall," October 11, 1930, p. 2, and "Postoffice at Kingston Robbed," April 27, 1935, p. 1.

The information on Kingston's institutions has been compiled from H. E. Salley, *History of California Post Offices, 1849-1990*, edited by Edward L. Patera (2nd ed., Lake Grove, Oregon: The Depot, 1991), and from several agencies of San Bernardino County: county board of supervisors, minutes; library department, quarterly reports; registrar of voters, great registers; and superintendent of schools, annual reports.

Sedimentology and Stratigraphy of the Plio-Pleistocene Lake Tecopa Beds, Southeastern California: A Work in Progress

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Introduction

The Lake Tecopa beds (Allogroup of Morrison, 1999) of southeastern California (Fig. 1) are a Plio-Pleistocene basin-fill sequence that has been extensively dissected by late Pleistocene incision of the Amargosa River (Morrison, 1991, 1999). Prior to late Pleistocene breach of the Tecopa basin, Lake Tecopa was the terminal lake for discharge of the ancestral Amargosa River during Quaternary and late Tertiary time (Dohrenwend et al., 1991; Morrison, 1999). The general stratigraphy of the deposits has been established by Sheppard and Gude (1968) and Hillhouse (1987), and refined by Morrison (1991, 1999). Dating of the Lake Tecopa beds is mainly based on numerous volcanic ash beds, six of which have been correlated to well-dated volcanic events (Sarna-Wojcicki *et al.*, 1987). The Tecopa beds have also been the subject of numerous paleomagnetic investigations (Hillhouse, 1987; Valet et al., 1988; Larson and Patterson, 1993); however, silicate mineral authigenesis appears to limit the temporal resolution of this technique.

Despite the many studies of the Lake Tecopa beds, none have systematically focused on detailed sedimentology. This contribution reports results of an on-going study of the detailed stratigraphy and sedimentology of the lacustrine and fluvial deposits in the Lake Tecopa beds. The ultimate goals of this work are (1) to clarify relationships between depositional processes and authigenic mineral precipitation in saline, alkaline-lake settings, such as that at Tecopa (Larsen, 1997), and (2) to develop a high resolution lake-level history applicable to the paleohydrology of the south-central Great Basin during late Pliocene to mid-Pleistocene time.

Stratigraphy

Ten detailed stratigraphic sections have been measured to date, five of which are shown in Figure 2. Most of the sections are located along the central axis of the Tecopa basin (Fig. 1), although in some cases shorter sections were also measured along the basin margin. The sections were measured in areas with moderate to good exposure and were trenched or scraped to reveal stratigraphic detail. Following the practice of other workers (Morrison, 1991, 1999; Hillhouse, 1987), the three major tuffs (Lava Creek B, Bishop, and Huckleberry Ridge) are used for correlation of the sections across the basin. Other tuffs and lithologically distinct mudstones are used to correlate basin-center to basin-margin sections.

Depositional Facies

The depositional facies in the Lake Tecopa beds include a variety of mudstone, siltstone, sandstone, conglomerate, tuff, and tufa (subaerial and freshwater limestone). Many of the fine-grained sedimentary facies are tuffaceous, but the coarser grained facies are

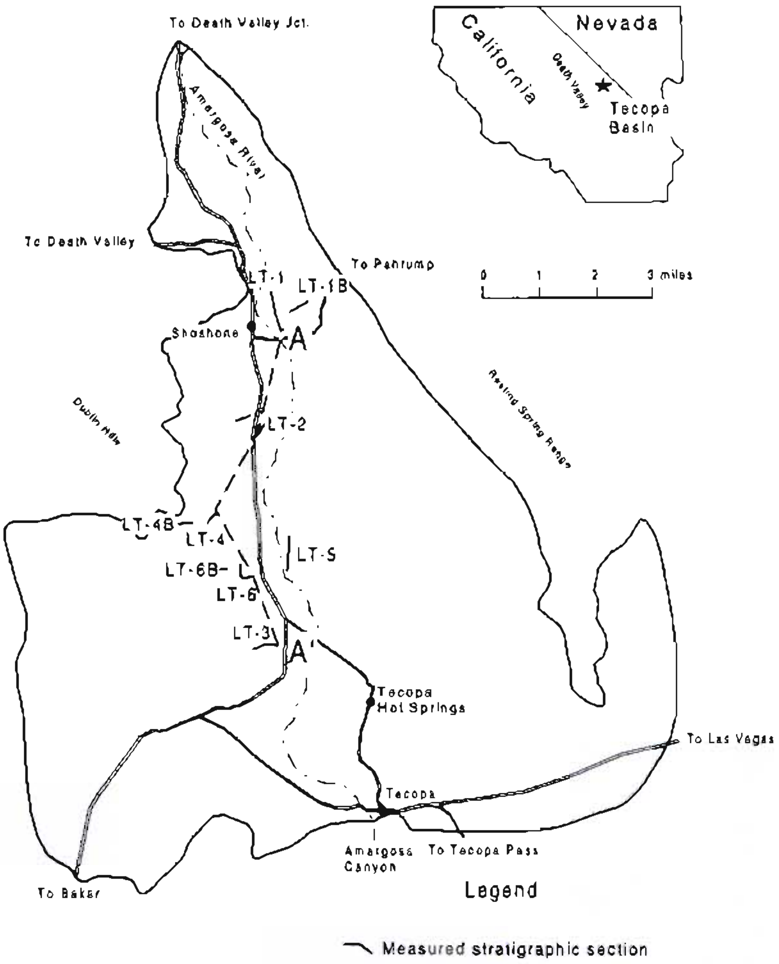

Figure 1. Map of the Tecopa basin illustrating the locations of measured stratigraphic sections and of correlated sections (line A-A') in Figure 2.

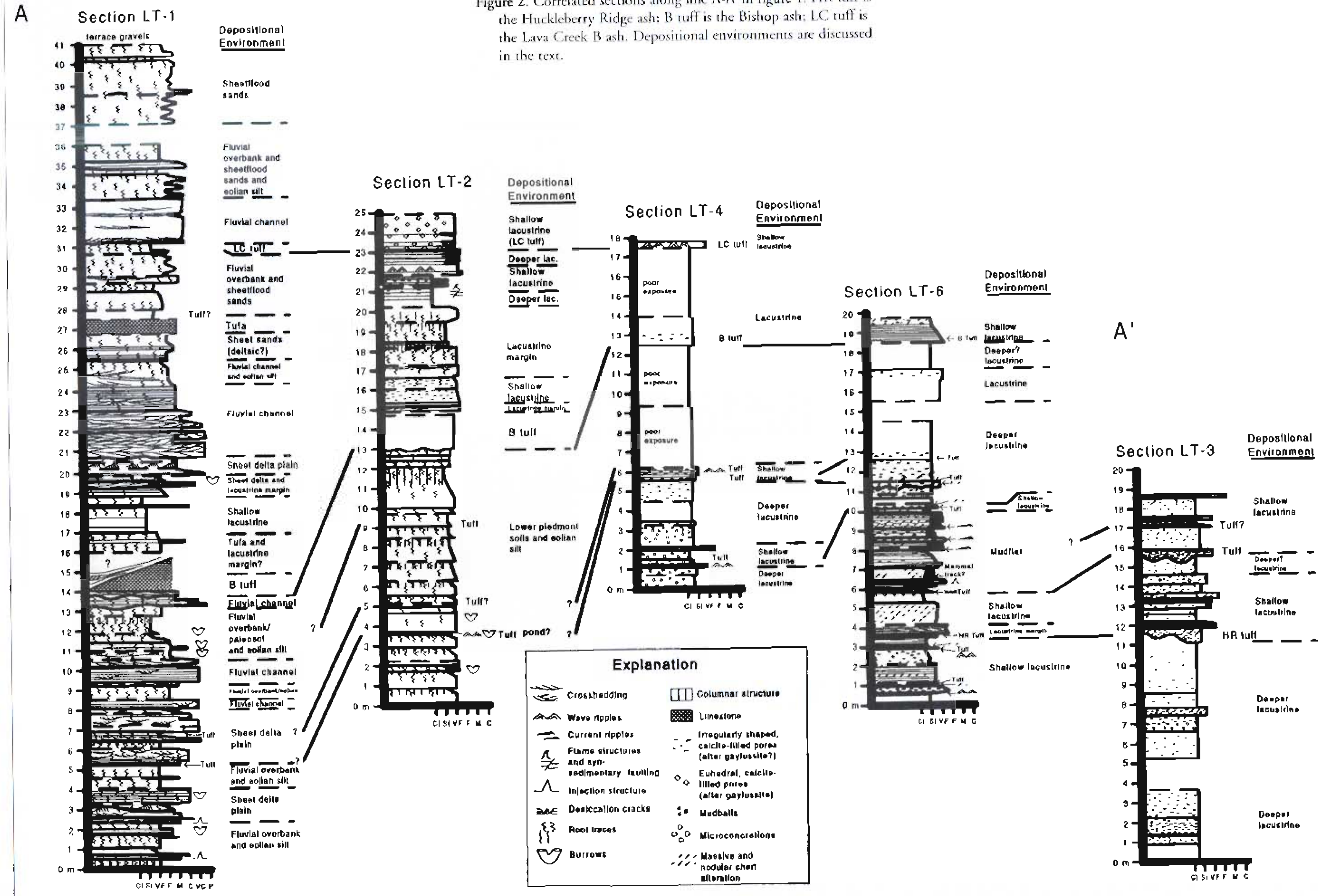

Figure 2. Correlated sections along line A-A' in figure 1. HR tuff is the Huckleberry Ridge ash; B tuff is the Bishop ash; LC tuff is the Lava Creek B ash. Depositional environments are discussed in the text.

composed of epiclastic detritus derived from local bedrock and the ancestral Amargosa River drainage basin. Invertebrate fossils are rare, but vertebrate remains are present in numerous localities (Reynolds, 1991; Woodburne and Whistler, 1991; Whistler and Webb, this volume). Trace fossils are abundant in the terrestrial and lacustrine-margin facies and guide paleoenvironmental interpretations. Lacustrine mudstone, sandstone, and tuff are diagenetically altered to clay minerals, zeolites, potassium feldspar, and other authigenic minerals in concentric patterns due to chemical reactions in a saline, alkaline lake (Sheppard and Gude, 1968; Starkey and Blackmon, 1978).

Mudstone

Mudstone is the dominant lithology in much of the interior of the Tecopa basin. The colors range from light gray and greenish-gray to pinkish gray (Munsell soil colors). Bedding thickness ranges from approximately 5 cm to 1 m. Mudstone with common to abundant root traces and vertical to subvertical centimeter-diameter burrows (Fig. 3A) are interpreted to be subaerial or lacustrine-margin deposits. Mudstone with abundant root traces, darker colors, blocky columnar structure, and slickenslides in the upper part of the bed are interpreted to be paleosols, similar to buried vertisols described by Gustavson (1991). Mudstone bearing common root traces, especially strongly vertical root traces, and fine millimeter-sized pores are interpreted to be lacustrine-margin deposits. Mudstone with common to abundant centimeter-sized pores, some in the shape of euhedral gaylussite crystals, flame structures, and soft-sedimentary deformation are interpreted to be lacustrine deposits. Irregularly shaped chert nodules, 5 to 10 cm across, and complete chert replacement (Fig. 3B) are common in some beds. In one location (section LT-5, 17 m), calcite pseudomorphs after radiating, bladed trona crystals are preserved in the mudstone (Fig. 3C).

Siltstone and silty very fine-grained sandstone

Siltstone is mainly present in exposures around the margin of the basin. Beds of siltstone and silty very fine-grained sandstone are crudely bedded to massive, and contain few to common fine root traces and elongate to spherical 2 to 20 centimeter-size calcite concretions (Fig. 3D). The siltstone and silty very fine-grained sandstone are light greenish-gray in color and have a comparatively low density. They are interpreted to be deposits of windblown silt and sand that experienced limited soil development.

Sandstone

Sandstone is mainly present in exposures around the margin of the basin, although thin beds are also interbedded with basin-interior mudstone. Most sandstone is light gray to light brownish-gray and ranges in grain size from very fine-grained to very coarse-grained. Sandstone bearing common to abundant root traces and vertical to subvertical centimeter-diameter burrows is interpreted as a subaerial or lacustrine-margin deposit (Fig. 3B, E). Subaerial or lacustrine-margin sandstone with moderate sorting and planar bedding, low-angle cross-bedding, or ripple cross-lamination represents deposits of perennial stream and deltaic processes (Fig. 3E). Subaerial or lacustrine-margin sandstone with poor sorting and crude centimeter-scale horizontal bedding or low-angle cross-bedding represents deposits of ephemeral stream and flood processes. Sandstone bearing common to abundant millimeter-size pores and extensive diagenetic alteration is interpreted as a lacustrine or lacustrine-margin deposit. These sandstones are generally very fine- to medium-grained, moderately sorted and have planar bedding, cross-bedding, or wave-ripple cross-lamination (Fig. 3B). They are associated with flood or oscillatory-wave depositional processes. Locally, pebbly very coarse-grained sandstone with tabular cross-bedding and grain coatings represents lacustrine bars and beach deposits (see Morrison, 1999).

Conglomerate

Conglomerate is present along the ancestral trace of the Amargosa River and around the margins of the Tecopa basin. Conglomerate along the ancestral trace of the Amargosa River is composed of rounded polymict gravel and sand. Conglomerate units are typically trough-crossbedded and horizontal bedded with erosional bases and are interpreted as channel-fill deposits (Fig. 3E). Basin-margin conglomerate is typically composed of angular to subangular poorly sorted cobbles, gravel, sand, and silt. This conglomerate is crudely bedded in tabular bodies and is interpreted as deposited by debris-flows or sheet floods.

Tuff

Tuff is present throughout the Tecopa basin. It is typically white, light gray, or light reddish brown fine ash tuff that shows variable degrees of diagenetic alteration (see Sheppard and Gude, 1968). Fine pumice lapilli are locally present in the Bishop tuff. Where interbedded with subaerial or lacustrine-margin deposits, the tuff commonly has current-ripple cross-lamination, 1- to 10-cm thick horizontal bedding (Fig. 3D, F), or wave-ripple cross-lamination along with minor root traces. Where interbedded lacustrine deposits, the tuff is commonly massive or has 1- to 50-cm thick beds, light gray to greenish-gray chert nodules, and millimeter- to centimeter-scale pores. Meter-scale ball and pillow soft-sediment deformation is present in some tuff and tuffaceous sandstone within the lacustrine deposits. Tuff within the lacustrine deposits is typically dense with extensive zeolite or potassium feldspar alteration.

Tufa

Tufa is present in numerous forms in the Tecopa basin: truck-sized pillows in the axis of the basin east of Shoshone (Fig. 3F), mounds and flaggy beds around the margin of the basin (especially along the Resting Spring Range), and injection spring pipes (Morrison, 1999). In the present study, only the pillows east of Shoshone and flaggy beds have been investigated. The pillows have little interior structure and are composed of dense, laminated to massive limestone. In figure 3F, the underlying Bishop tuff beds are deformed by the pillows. The flaggy tufa forms 2- to 10 cm-thick porous limestone beds and is gradational in character to enclosing tufa-cemented sandstone and conglomerate, some of which contain evidence for wave working.

Depositional Environments

The depositional facies and their distribution in the Lake Tecopa beds are interpreted in terms of seven depositional environments. Examples of stratigraphic intervals representing these environments are illustrated in Figure 2.

Relatively deep-water lacustrine

The relatively deep-water lacustrine environment is dominated by diagenetically altered mudstone with common pores and calcite-filled cast remnants of gaylussite and trona. The mudstone shows no evidence for exposure and has extensive soft-sedimentary deformation. Gaylussite and trona grew displacively in the lake muds by chemical reactions with a sodium-carbonate brine, much as they do presently in Lake Bogoria, east Africa (Renaut and Tiercelin, 1994). Wave-worked sand is generally not present, although muddy, very fine-grained sands are present and probably represent subaqueous fallout from hyperpycnal flows. The absolute depth of the water cannot be determined, but this environment was isolated from sand sources and was probably at least 5 to 10 m deep.

Relatively shallow-water lacustrine

The relatively shallow-water lacustrine environment is characterized by interbedded mudstone and laminated or wave-ripple cross-laminated very fine- to fine-grained sandstone. The mudstone and sandstone commonly contain centimeter- to millimeter-sized pores, either from dissolved evaporite minerals or gas accumulation. Wave-rippled sandstone beds are typically less than 5 cm thick and in very thin beds that represent individual bedforms. These sandstone beds are interpreted as sands that were transported to shallow lacustrine environments during storms or from flood-related turbid flows and then reworked into wave ripples during subsequent fair weather conditions. Chert nodules and bed replacement in tuffaceous intervals are interpreted to be associated with diagenetic alteration of magadiite cherts, similar to those observed at lakes Magadi and Natron in east Africa (Hay, 1968; Eugster, 1980) and locations in the western U.S. (Sheppard and Gude, 1986). Magadiite is present in some mudstone samples from the Lake Tecopa beds (Starkey and Blackmon, 1978).

Lacustrine margin

The lacustrine margin environment is characterized by sandstone and mudstone that contain evidence for nearshore, shoreline, marsh, and deltaic sedimentation. Nearshore and shoreline environments are indicated by winnowed, cross-bedded, pebbly sandstone, commonly with coated grains, that represent shallow lacustrine bars and beach foresets (see Morrison, 1999, for discussion of beach deposits). Marsh environments are indicated by mudstone and sandstone with common millimeter-sized pores, vertical burrows, and root traces. Parts of sandstone beds that are not bioturbated are typically wave-ripple cross-laminated. The root traces are commonly vertical, suggesting shallow groundwater conditions. These deposits show variable degrees of diagenetic alteration (Larsen, 1997), presumably reflecting a dominance of fresh water (unaltered) or lake water (altered). Deltaic environments are represented by horizontal and low-angle cross-bedded sandstone, climbing ripple cross-laminated sandstone and silty mudstone, all with variable amounts of root traces and vertical to subvertical burrows. Good examples of this facies are observed in the lower part of section LT-1 (Fig. 2). These beds are commonly arranged in tabular lensoid fining-upward sequences, suggesting crude lobe development and abandonment. At section LT-1, the ripple cross-lamination foresets climb to the south, consistent with discharge of sediment-laden Amargosa river waters into the lake. Silty drapes over sandstone laminae and beds are common and indicate slack-water deposition. The root traces are commonly filled with gypsum, suggesting interaction with sulfate-rich groundwater. Large-scale clinoforms, typical of late Pleistocene deltaic deposits in other western U.S. lake basins (Born, 1972), are not observed. The character of the deposits suggests a "wet" sheet delta system similar to that described by Smoot and Lowenstein (1991) from Holocene Lake Cahuilla, southern California.

Mudflat

The mudflat environment is represented by interbedded cherty sandstone, siltstone, and mudstone with evidence for desiccation and dry conditions. The sandstone includes individual wave-ripple cross-laminated beds and lenses (as much as 20 cm high and 6 m across) with horizontal bedded and ripple cross-laminated beds; the latter may represent eolian dunes. The extensive cherty replacement is interpreted to be associated with magadiite precipitation by wetting and drying of the mudflat floor and subsequent chert or opal C-T replacement.

Piedmont

The piedmont environment is characterized by interbedded sandy mudstone, typically with evidence for weak paleosol development, and crudely bedded sheetflood sandstone. Thin (less than 0.5 m) intervals of low-angle cross-bedded medium- to coarse-grained sandstone are locally present and represent small ephemeral stream channels. The crudely bedded sandstones are poorly sorted and bioturbated, consistent with deposition from sheet-like or poorly channelized flow across the piedmont landscape. The root traces are very fine to medium textured and are consistent with desert grasses and shrubs. Centimeter-sized burrows in the mudstone and sandstone are similar to locust burrows present in modern desert soils in the southwestern United States.

Alluvial fan

Alluvial fan deposits have not been described in the sections measured to date, but are present in exposures west of Shoshone. The alluvial fan environment is characterized by interbedded debris-flow conglomerate, poorly sorted, crudely bedded or low-angle cross-bedded ephemeral stream deposits, and weakly developed silty paleosols. Conglomerate and pebbly sandstone fine down gradient (over disances of 100 to 200 m) into sandy and silty deposits. The conglomerate and sandstone beds contain angular to subangular clasts with a more limited variety of clast compositions (mainly from Paleozoic carbonate and Tertiary volcanic rocks) than ancestral deposits of the Amargosa River. Weakly cemented conglomerate and sandstone are often interbedded with tufa-cemented sandstone and conglomerate suggesting that spring discharge periodically affected fan deposition.

Perennial stream

Perennial stream deposits are present east of Shoshone and reflect sedimentation by the ancestral Amargosa River. Channel-fill conglomerate and scour-fill pebbly sandstone are inset in pedogenically modified sandy siltstone and pebbly sheetflood sandstone. These deposits grade toward the margins into piedmont deposits and toward the south into sheet delta deposits. Tufa-cemented sandstone is also locally present and suggests that spring discharge periodically affected stream deposition.

Loess

Loess and eolian sand dune deposits are present in the strata exposed along the eastern margin of the Dublin Hills. These deposits aggraded where vegetation and moisture forced sedimentation of wind-blown silt and sand. The elongate carbonate concretions in the loess probably precipitated (remobilized pedogenic carbonate?) from groundwater during wetter conditions following deposition.

Discussion

Lake level history

The lake level history inferred from this work generally follows the results of other investigators (Morrison, 1991; Larson et al., 1991; Morrison, 1999), but some differences are noted. The basin fill history recorded in the sections illustrated in Figure 2 extends

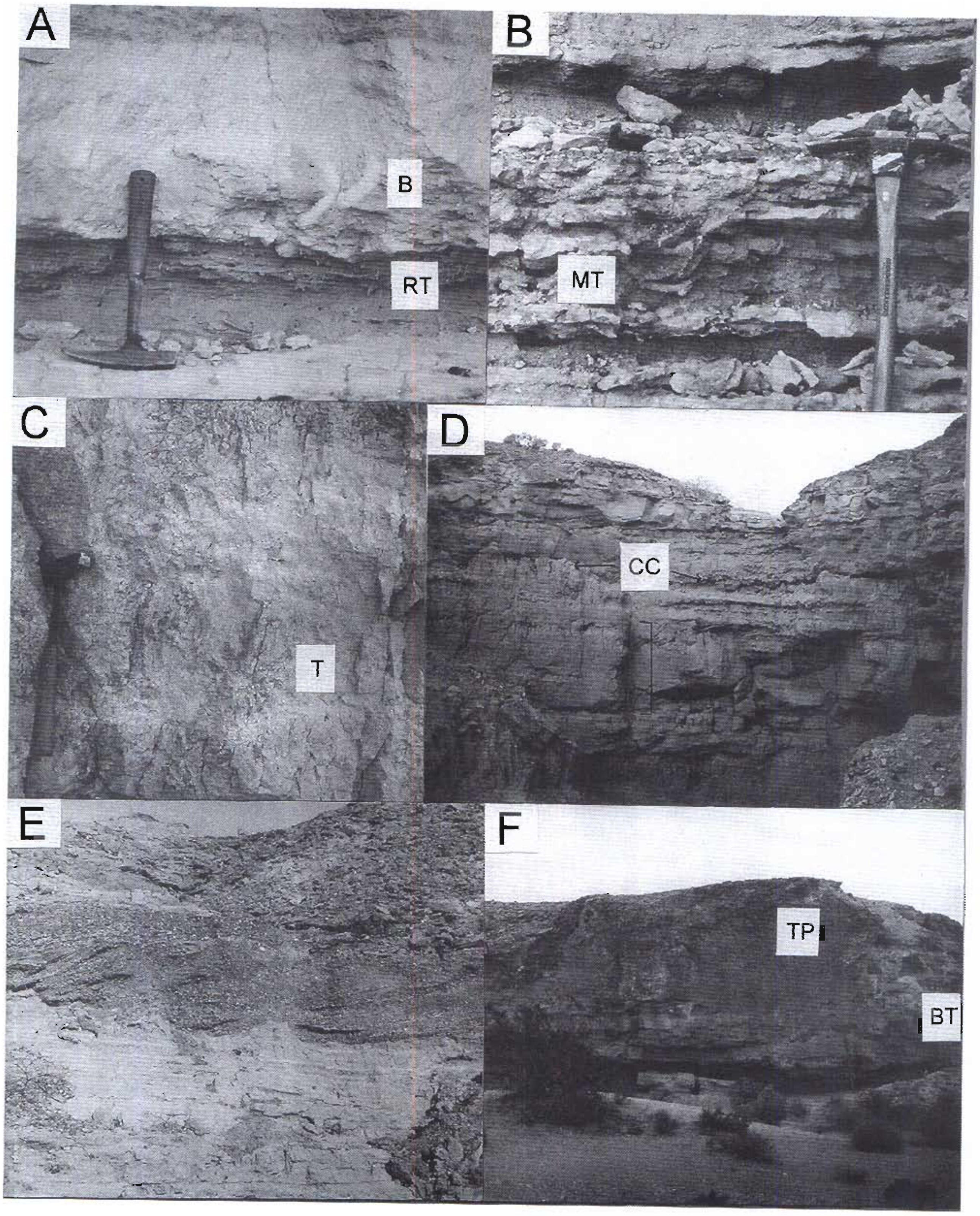

Figure 3. Photographs of depositional facies discussed in the text. (A) Cross-laminated sandstone overlain by sandy mudstone with subvertical burrows (B) and gypsum-filled root traces (RT); section LT-1, 2.5 m. (B) Finely interbedded mudstone and cherty mudstone, siltstone, and very fine-grained wave rippled sandstone; section LT-6, 6.5 m. Note deformed area (MT) which is thought to be a mammal track. (C) Mudstone with radiating calcite pseudomorphs after trona (T); section LT-5, 17 m. These deposits are interpreted as relatively deep-water deposits. (D) Silty very fine-grained sandstone with calcite concretions (CC) overlain by altered Bishop tuff; section LT-6B, 19 to 24 m. Note broad low-angle cross-beds in sandstone interpreted as eolian sheet and low-angle dune deposits. Contact with overlying tuff is erosional; tuff was deposited in shallow lacustrine environment. Staff is 1.8 m long. (E) Ripple cross-laminated medium-grained sandstone overlain by cross-bedded to horizontal-bedded pebbly conglomerate; section LT-1, 20 to 22 m. Conglomerate fills channel scour in underlying sheet delta sandstone. (F) Tufa pillow (TP) overlying Bishop tuff (BT); section LT-1, 13 to 16 m. Note that Bishop tuff beds are deformed to right of tufa pillow. Staff is 1.8 m long.

from sometime before the 2.02 Ma Huckleberry Ridge ash to sometime after the 0.665 Ma Lava Creek B ash. Pre-Huckleberry Ridge depositional conditions are represented by basin-center exposures of strata reflecting relatively shallow to deeper water lake environments. Lake level during this time is difficult to reconstruct because of the basin-center exposure; however, a perennial lake of varying extent is inferred based on analogy with younger deposits. This contrasts with Morrison's interpretation that only playa and shallow-lake deposits are represented below the Huckleberry Ridge ash.

Lake level lowered rapidly during and following emplacement of the Huckleberry Ridge ash. Much of the central basin floor appears to have been an extensive mudflat, subject to alternating wetting and drying conditions. Lacustrine deposits are present at section LT-5, but contain calcite pseudomorphs after trona and cherty alteration suggesting more concentrated brines and lower lake levels in the basin center. This episode of dramatically lower lake level roughly corresponds to the 1.6 to 0.9 Ma interval of "dry lake" conditions identified by Larson et al. (1991) and discussed by Morrison (1999).

Lake level appears to have risen from approximately 1.0 Ma to sometime after the 0.76 Ma Bishop ash. Two pronounced peaks in lake levels are recorded in the post-Bishop ash strata: one immediately following emplacement of the Bishop ash and the other immediately prior to the 0.665 Ma Lava Creek B ash. Judging from the extent of lacustrine incursion at section LT-1, the highstand immediately following the Bishop ash appears to have been the higher of the two. Lake level fell after emplacement of the Lava Creek B ash, but late Pleistocene-age wave-cut terraces around the basin margin argue for later highstands prior to the ultimate demise of Lake Tecopa, approximately 0.200 Ma (Morrison, 1991; Anderson et al., 1994).

Sedimentary processes

The clastic sediment in the Lake Tecopa beds is interpreted to derive from three sources: the ancestral Amargosa River, locally derived epiclastic sediment, and eolian silt and sand. Sediment from the Amargosa River aggraded fluvial deposits, built deltas, and contributed to lacustrine margin sediments (beaches, bars, etc.). The locally derived epiclastic sediment was deposited as debris flows and sheet floods on fans, piedmonts, and mudflats, and contributed to lacustrine-margin sedimentation. Much of the fine sand and silt in the subaerial and lacustrine-margin deposits is interpreted to be eolian in origin. The clay mineralogy of these deposits is dominated by saponite (Larsen, 1997; Starkey and Blackmon, 1978), a trioctahedral smectite that is likely not locally derived, but could be from deflation of older lake deposits west and north of the Tecopa basin. The importance of eolian processes may also contribute to the absence of well-developed soil horizons, as observed by Morrison (1999). Periodic pulses of eolian aggradation would have limited soil development on the landscape, resulting in stacks of weakly developed paleosols, such as those observed in the lower part of section LT-2.

Chemical sedimentation occurred in the form of calcite tufa at and near springs and as authigenic minerals in the lake sediments. The tufa deposits are aligned along structural features and appear to have been formed during and after Lake Tecopa sedimentation (Nelson et al., 1997). Tufa mounds are distinguished from injection spring pipes, which appear to have formed initially by earthquake-induced liquefaction and injection followed by later carbonate sedimentation by discharging groundwater (Morrison, 1999). Saline, alkaline lake-water chemistry is indicated by gaylussite molds and calcite pseudomorphs after trona in mudstone, and authigenic silicate alteration patterns in mudstone and tuff (Sheppard and Gude, 1968; Starkey and Blackmon, 1978; Larsen, 1997). The extensive magadiite-type chert in the mudflat and shallow-lacustrine deposits is also consistent with this interpretation. A ^{40}Ar/^{39}Ar date of authigenic potassium feldspar from an ash immediately below the Huckleberry Ridge ash is statistically indistinguishable from that of the Huckleberry Ridge ash (Steve Nelson, personal communication, 1999). This result along with correlation between sedimentary facies and alteration patterns (Larsen, 1997) indicate that alteration was contemporaneous with lake bed deposition.

In summary, through much of the history recorded in the Lake Tecopa beds, Lake Tecopa was a perennial saline, alkaline lake. A modern sedimentary analog to ancient Lake Tecopa is Lake Bogoria, Kenya rift valley, east Africa. Lake Bogoria is a perennial saline, alkaline lake with a single major feeder stream and delta (Sandai River and its delta), several enclosing alluvial fans, and vegetated (marsh) margins (Renaut and Tiercelin, 1994). The surface area of Lake Bogoria is approximately an order of magnitude smaller than that of Lake Tecopa at its highest late Pleistocene level (~235 km^2; Morrison, 1991), but might be comparable to Lake Tecopa during late Pliocene or middle Pleistocene time. Water depths in lake Bogoria are as much as 11.5 m during historic highstands. Lacustrine margin sedimentation is dominated interbedded sands, silts, and muds, commonly bearing root traces. Deeper water sediments are dominantly muds with dispersed gaylussite, nahcolite, and trona crystals, and rare centimeter-thick intervals of trona and associated evaporites. During the low, early Pleistocene lake levels (1.6 to 0.9 Ma) of Lake Tecopa, the lake may have appeared similar to a slightly "wetter" version of modern-day Lake Magadi, east Africa. Lake Magadi is a saline, alkaline lake with extensive enclosing sandflats and mudflats, in which magadiite precipitates in the lacutrine-margin deposits but is replaced on the mudflats by flaggy cherts, typically containing gaylussite or trona molds (Eugster, 1980). In contrast to the east African lakes, eolian depositional processes appear to have been much more important at Tecopa.

Conclusions

The Plio-Pleistocene Lake Tecopa beds represent deposits in and around an ancient perennial saline, alkaline lake. During most of the history recorded in the lake beds, sedimentation occurred in fluvial, deltaic, alluvial-fan, piedmont, and eolian environments around the lake and relatively shallow- to deep-water environments in the lake. Extensive mudflats were only present during a protracted early Pleistocene lowstand.

The late Pliocene and early Pleistocene lake levels appear to have been lower than middle Pleistocene lake levels, with a prominent lowstand occurring from 1.6 to 0.9 Ma (Larson et al., 1991). Based on the present work, late Pliocene and early Pleistocene lake levels are interpreted to be higher than the "playa and shallow lake" levels described by Morrison (1991; 1999). Two middle Pleistocene highstands are prominent: one immediately following emplacement of the 0.76 Ma Bishop ash and another immediately preceding emplacement of the 0.665 Ma Lava Creek B ash.

The sedimentary environments represented by the Lake Tecopa beds are similar to those present in and around saline, alkaline lakes Bogoria and Magadi in east Africa. Eolian processes are suspected to have been important agents of sedimentation in the Tecopa basin that distinguish it from the east African lakes and many Pleistocene Great Basin pluvial lake basins. Authigenic mineral precipitation and alteration appear to have been concurrent with sedimentation and clearly reflected in the depositional environments.

Acknowledgements

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References

Anderson, D. E., Poths, J., and Wells, S. G., 1994, Cosmogenic ^{3}He ages of wave-cut scarps in the Lake Tecopa basin of SE California: Implications for sampling strategy and the age consistency of isochronous surfaces [abs]: EOS, Transactions of the American Geophysical Union, v.75, p. 288.

Born, S. M., 1972, Late Quaternary History, Deltaic Sedimentation, and Mudlump Formation at Pyramid Lake, Nevada: Reno, Desert Research Institute, 97 p.

Dohrenwend, J. C., Bull, W. B., McFadden, L. D., Smith, G. I., Smith, R. S. U., and Wells, S. G., 1991, Quaternary Geology of the Basin and Range Province in California, *in* Morrison, R. B., ed., Quaternary Nonglacial Geology; Conterminous U.S., Decade of North American Geology vol. K-2: Boulder, Geological Society of America, p. 321-352.

Eugster, H. P., 1980, Lake Magadi, Kenya, and its precursors: *in* Nissenbaum, A., ed., Hypersaline Brines and Evaporitic Environments: New York, Elsevier Scientific Publishing Company, p. 195-232.

Gude, A. J., 3rd, and Sheppard, R. A., 1986, Magadi-type chert – A distinctive diagenetic variety from lacustrine deposits: *in* Mumpton, F. A., ed., Studies in Diagenesis, United States Geological Survey Bulletin 1578, p. 335-346.

Gustavson, T. C, 1991, Buried vertisols in a lacustrine facies of the Pliocene Fort Hancock Formation, Hueco Bolson, west Texas and Chihuahua, Mexico: Geological Society of America Bulletin, v. 103, p. 448-460.

Hay, R. L., 1968, Chert and its sodium-silicate precursors in sodium-carbonate lakes of east Africa: Contributions to Mineralogy and Petrology, v. 17, p. 255-274.

Hillhouse, J. W., 1987, Late Tertiary and Quaternary geology of the Tecopa basin, southeastern California: United States Geological Survey Miscellaneous Investigations Map I-1728, 16 p.

Larsen, D., 1997, Relationships between depositional facies and authigenic minerals in the Plio-Pleistocene Lake Tecopa Beds, Southeastern California [abs]. Geological Society of America Abstracts with Programs, v. 29, p. A126.

Larson, E. E., Patterson, P. E., and Luiszer, F., 1991, Paleoclimatic record from 2.4 to 0.5 Ma, Tecopa basin, southeastern California: Geological Society of America, Abstracts with Programs, v. 23, p. 120.

Larson, E. E., and Patterson, P. E., 1993, The Matuyama-Bruhnes reversal at Tecopa basin, southeastern California, revisited again: Earth and Planetary Science Letters, v. 120, p. 311-325.

Morrison, R. B., 1991, Quaternary stratigraphic, hydrologic, and climatic history of the Great Basin, with emphasis on Lakes Lahontan, Bonneville, and Tecopa, *in* Morrison, R. B., ed., Quaternary Non-glacial History, Conterminous U.S., Decade of North American Geology vol. K-2: Boulder, Geological Society of America, p. 283-320.

___, 1999, Lake Tecopa: Quaternary geology of Tecopa valley, California, a multimillion-year record and its relevance to the proposed nuclear-waste repository at Yucca Mountain, Nevada, *in* Wright, L. A., and Troxel, B. W., eds., Cenozoic Basins of the Death Valley Region: Geological Society of America Special Paper 333, p. 301-344.

Nelson, S. T., Peters, M. T., and Karlsson, H. R., 1997, Preliminary interpretations of finely divided tufa deposits from Lake Tecopa, southeastern California: Geological Society of America Abstracts with Programs, v.29, p. A262.

Renaut, R. W., and Tiercelin, J. -J, 1994, Lake Bogoria, Kenya Rift Valley-A sedimentological overview, *in* Renaut, R. W. and Last, W. M., eds., Sedimentology and Geochemistry of Modern and Ancient Saline Lakes: SEPM Special Publication No. 50: Tulsa, Society for Sedimentary Geology, p. 101-124.

Reynolds, R. E., 1991, The Shoshone zoo: a Ranchlabrean assemblage from Tecopa, *in* Crossing the Borders: Quaternary Studies in Eastern California and Southwestern Nevada: Redlands, California, San Bernardino County Museum Special Publication, p. 158-162.

Sarna-Wojcicki, A. M., Morrison, S. D., Meyer, C. E., and Hillhouse, J. W., 1987, Correlation of upper Cenozoic tephra layers between sediments of the western United States and eastern Pacific Ocean and comparison with biostratigraphic and magnetostratigraphic age data: Geological Society of America Bulletin, v. 98, p. 207-223.

Sheppard, R. A., and Gude, A. J., 3rd, 1968, Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California: United States Geological Survey Professional Paper 597, 38 p.

Smoot, J. P., and Lowenstein, T. K., 1991, Depositional environments of nonmarine evaporites: *in* Melvin, J. L., ed., Evaporites, Petroleum, and Mineral Resources: Amsterdam, Elsevier, p 189-347.

Starkey, H. C, and Blackmon, P. D, 1979, Clay mineralogy of Pleistocene Lake Tecopa, Inyo County, California: United States Geological Survey Professional Paper 1061, 34 p.

Valet, J. -P., Tauxe, L., and Clark, D. R., 1988, The Matuyama-Brunhes transition recorded from Lake Tecopa sediments (California): Earth and Planetary Science Letters, v. 87, p. 463-472.

Woodburne, M. O., and Whistler, D. P., 1991, The Tecopa Lake beds, *in* Crossing the Borders: Quaternary Studies in Eastern California and Southwestern Nevada: Redlands, California, San Bernardino County Museum Special Publication, p. 155-157.

Fossil Vertebrates of the Plio/Pleistocene Tecopa Lake Beds, Inyo County, California

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Introduction

The Tecopa lake beds comprise a series of lacustrine and, marginally, fluviatile deposits that accumulated in what is today called the Tecopa basin (Chesterman, 1973; Hillhouse, 1987). The lacustrine deposits are composed dominantly of gypsiferous mudstones in a succession that is about 50-60 meters (150-200 feet) thick. The lacustrine sequence also contains a number of distinctive volcanic tuff layers that have been extensively studied and correlated to source areas of well-constrained ages (Sarna-Wojcicki *et al.*, 1984; Shepard and Gude, 1968). The ashes within the lake bed sequence yield dates ranging from a little over 2 million years before present to a little younger than 600,000 years before present.

Fossil vertebrates are known from several stratigraphic levels within the sediments deposited in the Tecopa Lake Basin (James, 1985; Reynolds, 1987, 1991; Woodburne and Whistler, 1991). The fossils recovered from the lake beds are from below a distinctive tuff layer that has been correlated with the approximately 2 million year old Huckleberry Ridge tuff (Sarna-Wojcicki *et al.*, 1984). This would place these fossils near the boundary between the Pliocene and Pleistocene. Based on biostratigraphic correlations, fossils from the marginal fluviatile deposits are considerably younger (less than 500,000 years old) (Reynolds, 1987).

Paleontology

Most of the fossils from the lake beds have been recovered from a restricted area in the southeast portion of the basin. Faunal lists for these assemblages were provided in Woodburne and Whistler (1991). The larger animals are dominated by a diversity of four different extinct camels ranging in size from a short-legged form the size of a large goat to a long necked, long legged form the size of a modern giraffe. Two horses are present, one burro sized, the other quarter horse sized. Both mammoths and mastodons were present, as was a small species of North American prongbuck antelope. Birds are represented by a flamingo. The only carnivore in the fossil assemblage is a moderate sized fox. The small vertebrates are represented by two shrews, a rabbit, ground squirrel, kangaroo rat, white footed mouse, cotton rat and pack rat.

The small vertebrate fossil assemblage was recovered from a restricted lense with the bones scattered throughout the bed. Most of the other fossils were recovered as isolated specimens scattered over an approximately 4 square kilometer area. Preservation was unusual in that the most common material recovered is feet and lower legs. Body skeletal parts are rare. One fossil quarry in particular demonstrates this unusual form of preservation. Fully articulated feet, and in some cases, parts of legs, of at least 15 individual camels (young and old individuals) were found imbedded in standing position in the lake muds in a restricted area of 5x12 meters. Highly fractured and weathered partial skeletons were found connected to only two sets of the feet. Within 100 meters of this fossil quarry were found five other occurrences of camel legs and feet preserved in standing position. Because of this peculiar mode of deposition, this fossil-producing area was dubbed "standing camel basin".

This unusual mode of preservation has been interpreted as the result of animals becoming mired in the muds along the shore of ancient Lake Tecopa. Once trapped, the animals probably struggled until they died of starvation. The legs mired in the mud were

Figure 1. Restoration of goat-like camel from the Tecopa lake beds.

subsequently preserved, while the bodies and skulls became subject to predation and weathering. One phenomenon present with the Tecopa Lake Basin today may further explain these unusual fossil occurrences. Thermal springs are present along a lineation that crosses the basin. These springs produce a localized wet area that tends to collect fine sand and silt moved around by aeolian processes. This fine material supports a localized area of vegetation (mostly grasses), and the two combined form a somewhat firmer "caprock" over the source of upwelling spring water. Below the "caprock" is an area of water-saturated lake mud. This "caprock" can support the weight of smaller animals, but heavier ones (such as a human!) break through the cap and find themselves immediately imbedded deeply in saturated "quick mud". If these springs existed 2 million years ago, the vegetation would have attracted animals who would unwittingly become trapped.

The Tecopa "Goat-Camel"

Possibly most unusual among the fossils animals recovered from the lake beds is a peculiar camel with mountain-goat like adaptations. Camels are typically long-legged (and long-footed) animals, and this is the only known camel to have developed short, goat-like proportions in the legs and feet (Figure 1). An analysis of this new genus of camel has revealed that its closest ancestor within the Family Camelidae is a group that lived in the earlier Miocene (20 million years). Evidently this lineage of camels lived undetected for more than 20 million years in mountainous terrain of western North America. Based on the excellent material recovered from the Tecopa lake basin, two other isolated bones, one from a cave deposit in northern Nevada, and one from an unknown locality in southern Nevada, can now be referred to this new genus.

References Cited

Chesterman, C.W. 1973. Geology of the northeast quarter of Shoshone Quadrangle, Inyo County, California. California Division of Mines and Geology, Map Sheet 18.

Hillhouse, J. W. 1987. Late Tertiary and Quaternary geology of the Tecopa Basin, southeastern California. United States Geological Survey Miscellaneous Investigation Map I-1728.

Reynolds, R. E., 1991. The Shoshone Zoo: a Rancholabrean assemblage from Tecopa. *In*: Reynolds, R. E., Crossing the borders: Quaternary studies in eastern California and southwestern Nevada. Special Publication, San Bernardino County Museum Association, pps 159-62.

Sarna-Wojicicki, A. M., H. R. Bowerman, C. E. Meyer, P. C. Russell, M. J. Woodward, G. McCoy, J. J. Rowe, P. A. Baedecker, F. Asaro, and H. Michael, 1984. Chemical analyses, correlations, and ages of Upper Pliocene and Pleistocene ash layers of east-central and southern California. United States Geological Survey Professional Paper 1293:1-40.

Shepard, R. A. and A. J. Gude III. 1968. Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California. United States Geological Survey Professional Paper 597;1-37.

Woodburne, M. O. and D. P. Whistler. 1991. The Tecopa lake beds. *In*: Reynolds, R. E., Crossing the borders: Quaternary studies in eastern California and southwestern Nevada. Special Publication, San Bernardino County Museum Association, pps 155-57.

Stromatolites and the Pre-Phanerozoic to Cambrian History of the Area Southeast of Death Valley

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Introduction

The Proterozoic through early Paleozoic rocks southeast of Death Valley in San Bernardino and Inyo Counties, California (Fig. 1), the "Death Valley succession" (Corsetti et al., in press; Figs. 2 & 3), have long been known to contain a sedimentary succession spanning one of the most interesting intervals of Earth history: the Precambrian-Cambrian boundary. However, the apparent lack of key fossils and high-resolution chronometric data has hindered the construction of the geologic history for the region. As a result, this succession remained one of the more enigmatic, readily accessible Proterozoic-Cambrian sequences in the world.

By the mid-1990s, new fossil finds, radiometric age dating, and chemostratigraphic techniques began to illuminate the Proterozoic geologic history of the region. Rare Ediacaran fossils (*Ernietta*, Horodyski, 1991; *Swartpuntia*, Hagadorn and Waggoner, 2000), and *Treptichnus (Phycodes) pedum* (Horodyski et al., 1994; Corsetti and Hagadorn, 2000), the trace fossil used to correlate the Precambrian-Cambrian boundary (Narbonne et al., 1987), were discovered. A diabase sill near the base of the succession produced a U/Pb age of 1.08 Ga on badellyite (Heaman and Grotzinger, 1992). Chemostratigraphic techniques have been used to constrain further the age of the Proterozoic units (Corsetti and Kaufman, 1994; Corsetti et al., in press). Diamictites from the Kingston Peak Formation that are interpreted to be of glaciogenic origin (Miller, 1985) are now focusing attention on the region as an important area to test hypotheses surrounding the idea of a Neoproterozoic "Snowball Earth" (Kirschvink, 1992; Hoffman et al., 1998). It is becoming clear that the Death Valley region contains one of the best records of Earth history from Neoproterozoic through Cambrian time.

These thick strata, deposited over a time span of almost 500 million years, contain an outstanding record of stromatolites. All the major categories of stromatolite morphology are present: stratiform (wavy laminated), domical, columnar, columnar branching, conical, thrombolitic, dendrolitic, and oncoidal. These stromatolites provided some of the earliest biostratigraphic data on ages for the Proterozoic portions of the succession (Cloud and Semikhatov, 1969). Although not high in temporal resolution, the

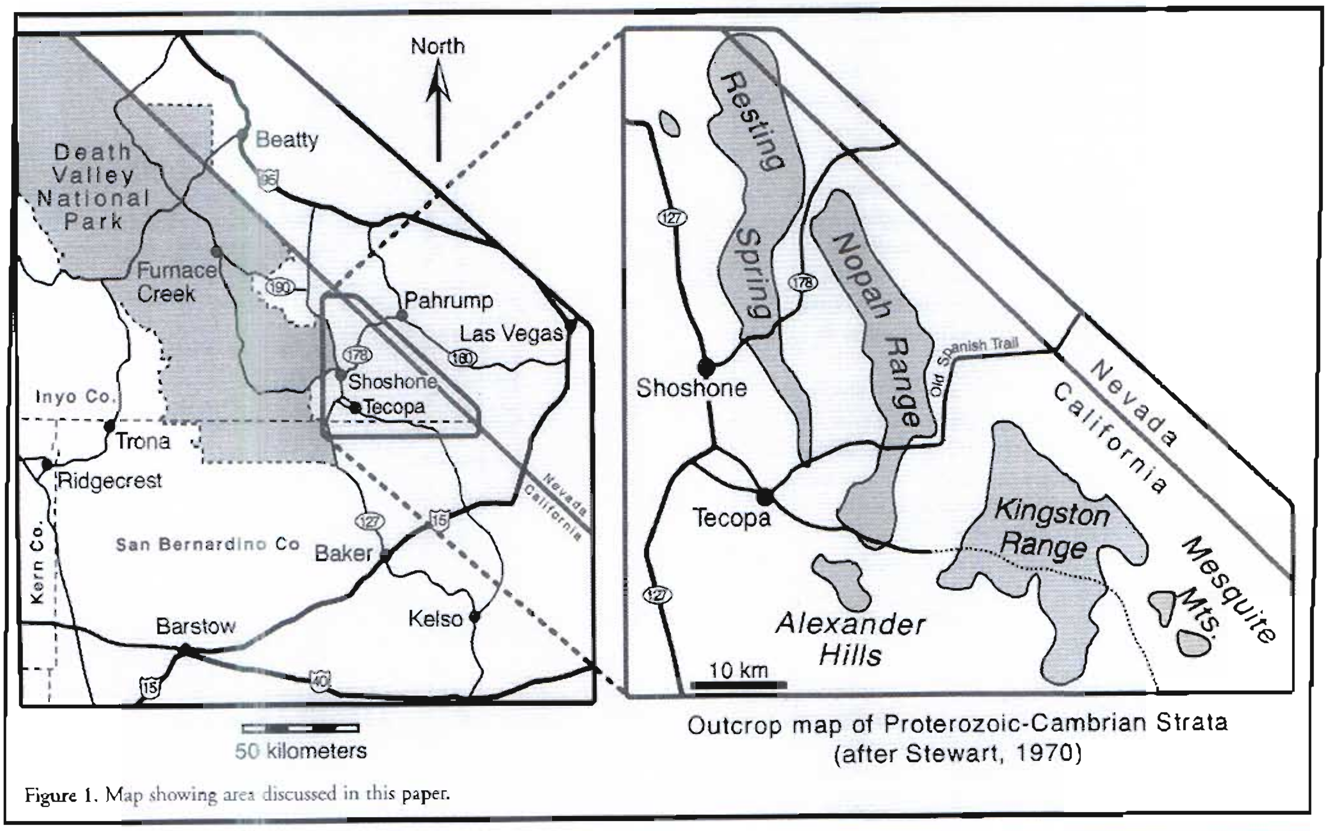

Figure 1. Map showing area discussed in this paper.

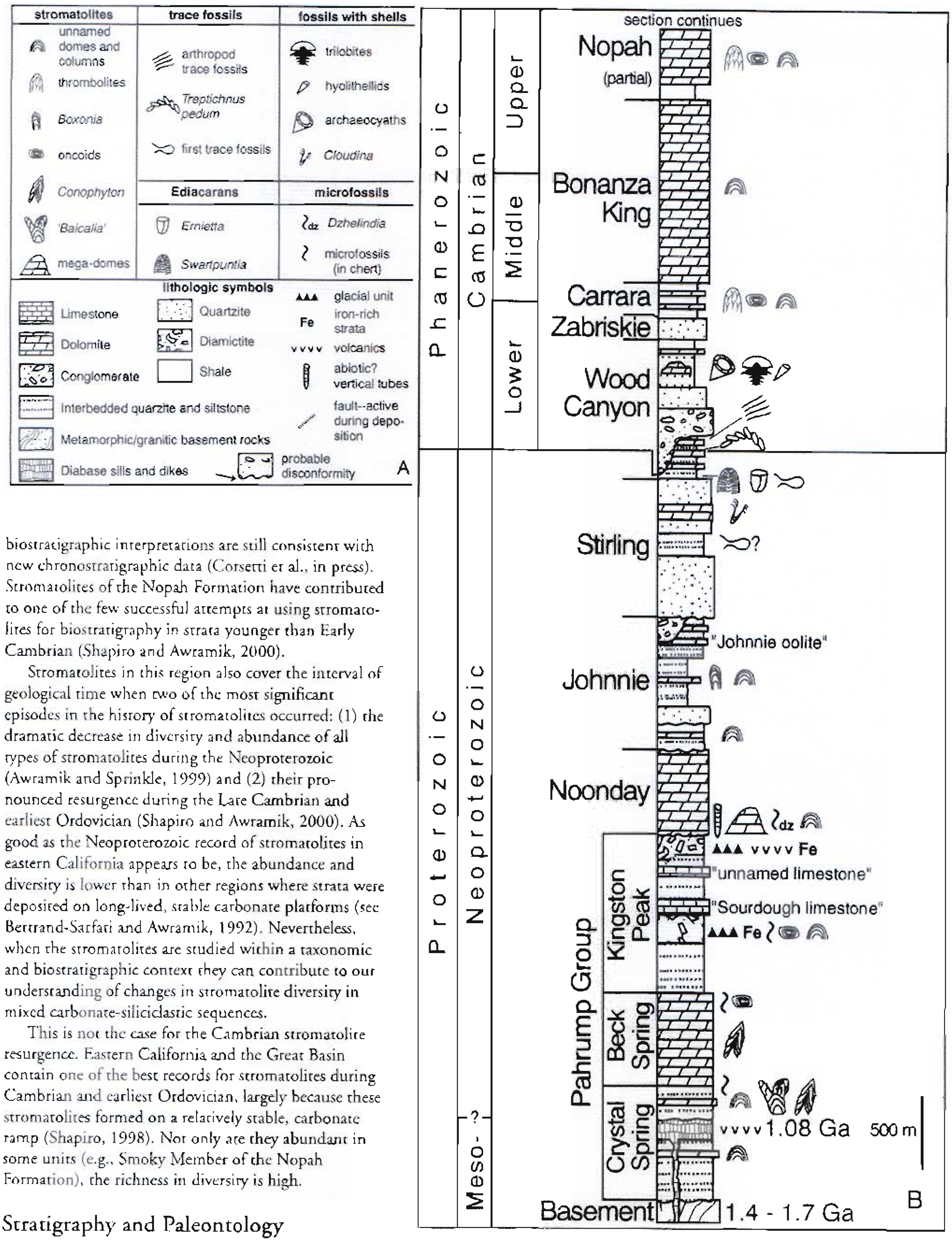

Figure 2. Generalized columnar section of Neoproterozoic through Cambrian strata of the Death Valley succession. A. Key to symbols used in the stratigraphic section. B. Generalized stratigraphic section. (after Corsetti et al., in press).

biostratigraphic interpretations are still consistent with new chronostratigraphic data (Corsetti et al., in press). Stromatolites of the Nopah Formation have contributed to one of the few successful attempts at using stromatolites for biostratigraphy in strata younger than Early Cambrian (Shapiro and Awramik, 2000).

Stromatolites in this region also cover the interval of geological time when two of the most significant episodes in the history of stromatolites occurred: (1) the dramatic decrease in diversity and abundance of all types of stromatolites during the Neoproterozoic (Awramik and Sprinkle, 1999) and (2) their pronounced resurgence during the Late Cambrian and earliest Ordovician (Shapiro and Awramik, 2000). As good as the Neoproterozoic record of stromatolites in eastern California appears to be, the abundance and diversity is lower than in other regions where strata were deposited on long-lived, stable carbonate platforms (see Bertrand-Sarfati and Awramik, 1992). Nevertheless, when the stromatolites are studied within a taxonomic and biostratigraphic context they can contribute to our understanding of changes in stromatolite diversity in mixed carbonate-siliciclastic sequences.

This is not the case for the Cambrian stromatolite resurgence. Eastern California and the Great Basin contain one of the best records for stromatolites during Cambrian and earliest Ordovician, largely because these stromatolites formed on a relatively stable, carbonate ramp (Shapiro, 1998). Not only are they abundant in some units (e.g., Smoky Member of the Nopah Formation), the richness in diversity is high.

Stratigraphy and Paleontology

The Death Valley succession contains a package of Proterozoic to Cambrian sedimentary rocks locally over 10 km thick (Stewart, 1970; Fig. 2). The succession consists of the Pahrump Group, the Noonday, Johnnie, Stirling, Wood Canyon, Zabriskie, Carrara, Bonanza

King, and Nopah formations. The Ordovician to Permian package of marine strata total over 3100 m thick. Mesozoic metasediments and volcanics total 2400 m in thickness. Tertiary terrestrial deposits exceed 1800 m. A great deal of Earth history is recorded in the rock record in this region.

The post-Pahrump Group strata are thought to have formed in response to the Neoproterozoic (Stewart, 1972; Cooper and Fedo, 1998b) to possibly Early Cambrian (Levy and Christie-Blick, 1991) rifting of Laurentia and the formation of a passive continental margin (Fig. 3). Shallow marine to marginal marine/continental braidplain deposits were deposited on this margin (Stewart, 1970; Wright et al., 1974; Fedo and Cooper, 1990; Fedo and Prave, 1991; Cooper and Fedo, 1998a). The succession is riddled with unconformities of unknown temporal magnitude (e.g., Christie-Blick and Levy, 1989; Heaman and Grotzinger, 1992). The Early to Middle Cambrian Carrara Formation marks a transition in the region from a lower sequence of mixed carbonate and siliclastics (rapid subsidence) to an upper sequence dominated by relatively clean carbonate (slower subsidence).

Pahrump Group

The Pahrump Group forms the base of the entire sedimentary succession. It rests on 1.7 Ga crystalline basement intruded by 1.4 Ga granitoid rocks (Lamphere and Wasserberg, 1962), and consists of the Crystal Spring, Beck Spring, and Kingston Peak formations. The Pahrump Group contains numerous stromatolites and a variety of microbial fossils preserved in chert.

Crystal Spring Formation

Lithologic and Stratigraphic Description

The Crystal Spring Formation, named by Hewitt (1940), is the basal member of the Pahrump Group and ranges in thickness from about 450 to 1200 m. Diabase sills, a few meters to 457 m thick, intrude the formation. Roberts (1976) has divided the formation into seven members: (1) the basal arkose member (~191 m thick) composed of interbedded conglomerate and sandstone; (2) the feldspathic sandstone member (~191 m thick) composed of red sandstone, siltstone, and shale that is cyclical and has fining-upward sequences; (3) the mudstone member (averaging 36 m thick) composed of massive purplish mudstone; (4) the dolomite member, 60 to 137 meters thick, with cyclically bedded dolomite and wavy-bedded dolomite with chert that is commonly intruded by the diabase sills; (5) the algal member, which is 76 to 110 meters thick, composed of cyclically-bedded, limestone and dolomite, and contains columnar stromatolites; (6) the 0 to 150 meter-thick chert member; and (7) the upper member, a 60 to 600 meter-thick sequence of interbedded siltstone, sandstone, conglomerate, and dolomite. Unconformities have been recognized within the formation (Prave, 1994). Where the diabase sills intrude impure dolomite, talc and tremolite are alteration products, and the talc has been mined (Wright and Troxel, 1954).

Stromatolites and Other Fossils

The stromatolites of the Crystal Spring Formation have not been studied in great detail. The algal member contains the only columnar examples in the formation (Fig. 4A); dolomite in other members contains wavy-laminated, stratiform stromatolites. Three taxa have been discussed in the literature: '*Baicalia*' Krylov 1963, which was identified by Howell (1971), '*Jacutophyton*' Schapovalova 1965, also identified by Howell (1971), and '*Conophyton*' Maslov 1937, recorded by Roberts (1976). Howell (1971) and Roberts (1976) didn't formally identify the stromatolites, but simply indicated that they had affinities with *Baicalia*, *Jacutophyton*, and *Conophyton*. We recognize, but have not yet formally described, two columnar stromatolites, *Baicalia* and *Conophyton* (a cylindrical columnar stromatolite with conical lamination). The misidentification of *Jacutophyton* was likely based on the presence of conical laminae within *Baicalia*, which is not unknown in this columnar-branching stromatolite. Although comparisons are often made with the Apache Group, Bertrand-Sarfati and Awramik (1992) noted that the stromatolites from the two groups have no taxa in common, except for a possible *Conophyton* collected from the Mescal Formation (Apache Group). Filamentous microbial fossils preserved in chert replacing the carbonate have been found (Pierce and Awramik, 1994), but also not formally described. No microbial fossils have been detected in siliciclastics.

Age of the Crystal Spring Formation

The age of the Crystal Spring Formation and the Pahrump Group as a whole has been debated for years. The diabase sills petrochemically resemble sills in the Apache Group in Arizona that have been dated at 1.2 Ga (Wrucke, 1972). Howell (1971) pointed out that the stromatolites suggested an age between 0.9 to 1.3 Ga based on comparisons to similar stromatolites in the former USSR. Roberts (1976) suggested an age of 1.2 to 1.35 Ga for the Crystal Spring Formation based on a correlation of the sills to sills dates at 1.2 Ga in Arizona and suggested Middle Riphean age (1.3 to 0.95 Ga) for *Baicalia-Conophyton* stromatolite assemblages. Pierce and Cloud (1979), building on all of these suggestions and adding what they considered distinctive microbial fossil data, concluded that the Pahrump Group was approximately 1.3 Ga. Successful radiometric age determinations of 1.08 Ga for Pahrump Group rocks were finally produced on a baddeleyite from sills of the Crystal Spring Formation (Heaman and Grotzinger, 1992). However, this age, if applied to the Pahrump Group as a whole, is very misleading as there is now strong evidence that age of the Kingston Peak Formation is around 750 Ma (Prave, 1999; Corsetti et al., in press). We concur that there are major hiatuses within Crystal Spring Formation and in the Pahrump Group as a whole (e.g., Heaman and Grotzinger, 1992).

Beck Spring Dolomite

Lithologic and Stratigraphic Description

Hewitt (1940) named the Beck Spring Dolomite, the middle formation of the Pahrump Group, for a gray, thick-bedded dolomite near Beck Spring in the Kingston Range. It is up to 500 m thick in the Kingston Range and thins to 50 meters in the Silurian Hills (but see Prave, 1999). The Beck Spring Dolomite rests on the Crystal Spring Formation with apparent conformity, and its base is placed at the top of a red shale (Gutstadt, 1968). We have recognized this bed in the Alexander Hills where it is reddish-colored, siliciceous carbonate, commonly with chert, and it represents a transition from the Crystal Spring Formation into the Beck Spring Dolomite.

Gutstadt (1968) divided the formation into three members: (1) a lower laminated member, 150 to 200 m thick, composed of alternating, millimeter-thick laminae of medium- to coarse-crystalline dolomite and peloidal dolomite; (2) the middle oolitic member, 150 to 200 m thick, consists of medium- to coarse-crystalline, oolitic, pisolitic, and grapestone dolomite; and (3) the upper cherty member, 100 to 150 m thick, which is similar to the oolitic member, but includes stromatolites. The upper boundary of the Beck Spring Dolomite appears to be conformable with the Kingston Peak Formation in some areas, but in the southern Panamint Range, the Beck Spring Dolomite appears to be absent.

Stromatolites and Other Fossils

Beck Spring Dolomite stromatolites (Fig. 4B) have not been studied in great detail. Tucker (1983) estimated that nearly 70% of the formation is made up of stratiform stromatolites ("cryptalgal laminates"). We are not sure this is an accurate interpretation of these laminated carbonates; however, the characteristic thick (mm-thick) light gray and gray lamination is unusual. In the most detailed studies of the stromatolites, Marian (1979) and Marian and Osborne (1992), recorded the presence of *Baicalia*-like forms, *Conophyton*, domical forms, and a variety of wavy-laminated to stratiform structures (some called *Stratifera*).

A well-preserved microbiota has been discovered in chert from the upper cherty member of the Beck Spring Dolomite (Licari, 1978). Horodyski and Mankiewicz (1990) described *Melanocyrillium*, a vase-shaped microfossil, and *Tennocharta cloudii*, carbonate sheets that may represent calcified microbes, from units transitional between the Beck Spring Dolomite and Kingston Peak Formation. In addition, Horodyski and Knauth (1994) have found evidence of what they interpret as the oldest evidence of a terrestrial (micro)biota in Beck Spring Dolomite chert. No microbial fossils have been detected in siliciclastics.

Age of the Beck Spring Dolomite

The age of the Beck Spring Dolomite is poorly constrained. It is bracketed below by the diabase sill (1.08 Ga) in the Crystal Spring Formation and above by the Precambrian-Cambrian Boundary in the Wood Canyon Formation (~544 Ma). Others (e.g., Stewart, 1972) have suggested that glaciomarine sediments found in the overlying Kingston Peak Formation correlate with "Sturtian" (~750-700 Ma) glacial units distributed globally. Corsetti (1998) and Prave (1999) concur with this correlation based on carbon isotope chemostratigraphy. Thus, the Beck Spring Dolomite is younger than 1.08 Ga but probably not younger than ~700 Ma.

Kingston Peak Formation

Lithologic and Stratigraphic Description

The Kingston Peak Formation (named by Hewitt, 1940) is a thick sequence of conglomerate, diamictite, quartzite, sandstone, siltstone, and shale (Stewart, 1970). The thickness is quite variable. It ranges from 50 m in the Silurian Hills to 1000 m in areas east of Death Valley. In some places, the Kingston Peak Formation rests conformably on the Beck Spring, while in other places, it rests unconformably on lower units. Regional facies patterns suggest that deposition took place during extensional tectonics (Miller, 1985). In many places, an angular unconformity separates the Pahrump Group from the overlying strata (Wright et al., 1974), whereas in other areas, the contact is conformable (Corsetti et al., in press).

Two unusual and characteristic lithologies occur within the Kingston Peak Formation: (1) Diamictites (conglomeratic mudstone) with striated pebbles and dropstones suggest deposition under glacial conditions (Miller, 1982, 1985); (2) Iron-formation occurs with the diamictite (Graff, 1985). The association of diamictite with iron-formation is not uncommon on a global scale at approximately 750 Ma (Young, 1976).

Stromatolites and Other Fossils

The stromatolites and oncoids (Fig. 4C) of the Kingston Peak Formation occur in meter-thick dolomite beds or lenses within the diamictite. The stromatolites are small, centimeter-diameter columns that originate from oncoids. Oncoids range in size from millimeters to centimeters, and some silicified examples contain a well-preserved microbiota (Pierce and Cloud, 1979; Pierce and Awramik, 1994). No microbial fossils have been detected in siliciclastics.

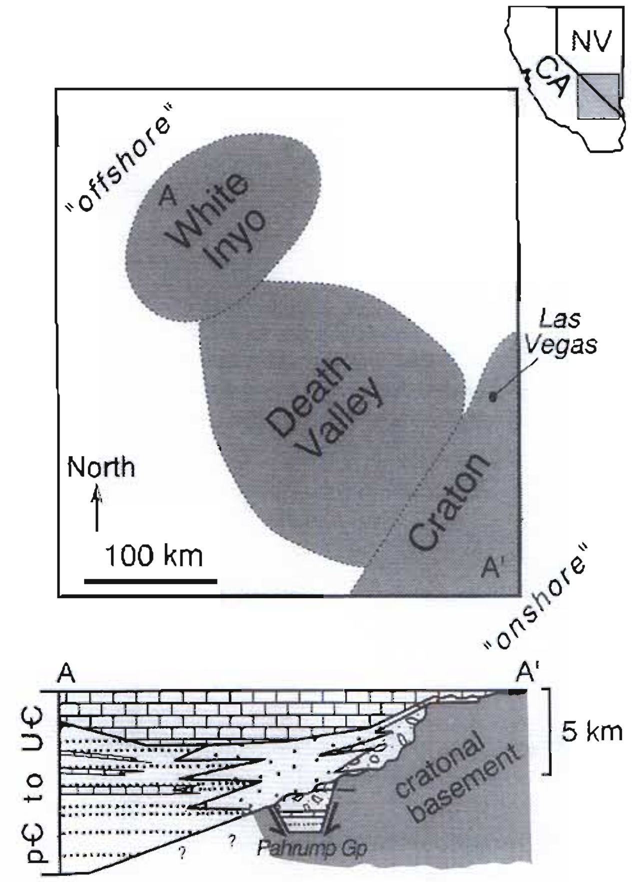

Figure 3. Onshore – offshore relationship between Death Valley and White-Inyo successions, California and Nevada.

Age of the Kingston Peak Formation

Age constraints for the Kingston Peak Formation are similar to the Beck Spring Dolomite. No fossils of biostratigraphic utility are currently known from the Kingston Peak Formation. However, Stewart's (1972) hypothesis that the diamictite/iron-formation association correlate with "Sturtian" (~750-700 Ma) glacial units has been corroborated using carbon isotope chemostratigraphy (Corsetti, 1998; Prave, 1999).

The Noonday Dolomite

Lithologic and Stratigraphic Description

The Noonday Dolomite, named by Hazzard (1937) at the Noonday Mine in the southern Nopah Range, is dominantly a light pink, cliff-forming dolomite with a total thickness of ~450 meters. In the Kingston Range/Nopah Range area, the Noonday Dolomite can be divided into two parts: a lower part, the "algal dolomite member," and an upper part, the "sandy dolomite member" (Stewart, 1970). The upper part of the formation consists of sandy, cross-bedded dolomite. The lower, algal dolomite, is discussed below. To the west, the Noonday Dolomite grades into a "basinal facies" known as the Ibex Formation, and is composed of carbonate-rich debris flows (Wright et al., 1976).

Stromatolites and Other Fossils

One of the characteristic and curious aspects of the Noonday Dolomite is that in its lower part, the "algal dolomite member," the formation contains large "domes," up to 200 m in diameter, that are thought to be of a stromatolitic origin (Cloud et al., 1974). Calcareous, clotted structures ("*Dzhelindia,*" in Cloud et al., 1974) are reported to be common throughout the dolomite domes. Very regularly and closely spaced, vertical, tubular structures, up to 30 cm in length and up to 3 cm in diameter, cross-cut the flanks of the domes and define the vertical direction in that part of the dome. Some well-preserved tubes display concave, sediment filling. Possible explanations for the tubes include gas and/or fluid escape structures, dissolution pipes, and metazoan activity (Cloud et al., 1974; Wright et al., 1978). The anomalous nature of the tubes (particularly their extremely close-packed distribution) precludes a simple explanation. Similar tubular structures are found in the dolomites of the Bildah Member of the Buschmannsklippe Formation, Nama Group, in southern Namibia (Hegenberger, 1987), and the Maieberg Formation of the Otavi Group in northern Namibia (Hoffman et al., 1998). These are similar in age to the Noonday Dolomite (Corsetti et al., in press).

The domes and tubes form a mud-mound association in which a calcareous microbe played a major binding role. The domes are more appropriately called mud-mounds and may represent the oldest mud-mounds presently known. No microbial fossils in any lithology have been found. Whether "*Dzhelindia*" is a calcimicobe or not is uncertain.

Age of the Noonday Dolomite

The precise age of the Noonday Dolomite is unclear. Its stratigraphic position, above the Kingston Peak Formation with an age of about 750 Ma, sets the lower limit. Using chemostratigraphy, Prave (1999) suggested an age of ~600 Ma. Corsetti and others (in press) refined the chemostratigraphic correlation and suggest an age of older than ~700 Ma.

The lower Noonday Dolomite and its domes appear to represent a "cap carbonate" atop the glacial units of the Kingston Peak Formation. Cap carbonates are an enigmatic, characteristic facies that are found immediately following Neoproterozoic glacial events (see Hoffman et al., 1998).

Johnnie Formation

Lithologic and Stratigraphic Description

The Johnnie Formation, named by Nolan (1929), consists of mixed siliciclastic-carbonate strata. It has been informally subdivided by Stewart (1970) into six members (a nomenclature that works well for the Nopah Range). However, Summa (1993) demonstrated a complex sequence stratigraphic history for the Johnnie Formation and showed much lateral variation throughout the Death Valley region. Using Stewart's nomenclature, the transitional member (the lowest member of the Johnnie Formation) is ~70 m thick and contains conglomerate, cross-stratified quartzite, siltstone, and minor sandy dolomite horizons. The conglomerate layers within this member may indicate a more significant stratigraphic break (C. Summa, pers. com., 1993). The quartzite member consists of cross-stratified quartzite with minor pebbly horizons and averages ~70 m thick. The lower carbonate member, at ~8 m, is very thin in the Nopah Range and consists of wavy laminated to columnar stromatolitic dolomite with minor oolitic interbeds. The siltstone member is ~200 m thick and contains siltstones with minor quartzite. The upper carbonate-bearing member is ~200 m thick, and contains dolomite, stromatolitic dolomite, siltstone, and quartzite layers. The Rainstorm Member is ~130 m thick and consists of parallel-laminated siltstone and minor carbonate, including a regionally-persistent, 2 m thick oolite bed. The oolite, known informally as the "Johnnie oolite," is a prominent marker bed within the Rainstorm Member and crops out over 16,000 km^2. It is visible as a prominent, thin, orange-tan stripe just below the contact with the overlying Stirling Quartzite. An incision with as much as 150 meters of erosional relief is found in the upper part of the Rainstorm Member (Summa, 1993; Charlton et al., 1997). Large stromatolitic blocks from the lower carbonate member (as well as distinctive pisolite from the Beck Spring Dolomite) are found in random orientation within these incised valleys. The overlying Stirling Quartzite incises into the top of the Johnnie Formation, as well.

Stromatolites and Other Fossils

The columnar branching stromatolites ***Boxonia*** **aff.** ***B. gracilis*** and *Linella* aff. *L. ukka* were described in Cloud and Semikhatov (1969). Other columnar stromatolites, as well as other stromatolite morphologies (Fig. 4D), have been observed; however, they have not been studied. No microbial fossils in chert or siliciclastics have been found. The Johnnie Formation has been examined (in excruciating detail) for any evidence of metazoan activity. To date, none have been found (even though presumably "appropriate" rock-types are present).

Age of the Johnnie Formation

The incision (sequence boundary) has been correlated across the Great Basin to strata in Utah (Christie-Blick and Levy, 1989; Summa, 1993; Chartlon et al., 1997). In Utah, the Brown's Hole Formation (above the incision) produced a ^{40}Ar/^{39}Ar date of ~580 Ma. Thus, the pre-incision Johnnie Formation is considered older than 580 Ma. Charlton and others (1997) and Abolins and others (1999) discovered what may be glacially derived diamictite within the upper part of the Rainstorm Member and suggested that the incision is related to Neoproterozoic glacial events. Based on an integrated chemostratigraphic and paleontological study, Corsetti and others (in press) suggest that the age of the Johnnie Formation ranges from about 700 Ma to slightly greater than 580 Ma and that the Johnnie Formation contains several major unconformities within it.

Stirling Quartzite

Lithologic and Stratigraphic Description

The Stirling Quartzite, named by Nolan (1929), is a cliff-forming, quartzite unit, with minor siltstone and carbonate. It crops out over a large region of the southern Great Basin and is about 1300 meters thick in eastern California but thins to zero meters in Utah (Stewart, 1970). Stewart (1966) divided it into five members. Fedo and Cooper (1999) use an informal three-member subdivision that includes a lower trough cross stratified quartzite unit, a middle siltstone unit (with minor carbonate) and an upper quartzite unit. Rare carbonate beds are found in the upper unit (Stewart's "d-member"). Athough Wertz (1982) interpreted the Stirling Quartzite to represent marine paleoenvironments, Fedo and Cooper (1999) suggest that it is predominantly non-marine with rare marine incursions represented by the middle siltstones and the "d-member" carbonates. The contact between the Stirling Quartzite and the overlying Wood Canyon Formation is sharp.

Stromatolites and Other Fossils

No stromatolites are known from the Stirling Quartzite. However, *Cloudina*-like shelly fossils have been reported from the "d member," along with very simple *Planolites*-like trace fossils (Langille, 1974). J.Hagadorn (pers. com., 2000), however, considers these alleged trace fossils to be dubiofossils. No microbial fossils in any lithology have been found.

Age of the Stirling Quartzite

The presence of a cloudinid fossil, stratigraphically below Ediacaran fossils of the Wood Canyon Formation, indicates a latest Neoproterozoic age for the Stirling Quartzite.

Wood Canyon Formation

Lithologic and Stratigraphic Description

The Wood Canyon Formation was named by Nolan (1929) for a 1300 meter thick, mixed siliciclastic and carbonate strata that occurs in the southern Great Basin (Stewart, 1970). Three members are recognized. The lower member contains medium- to fine-grained quartzite and siltstone, with three regionally persistent dolomite units. The dolomite units appear to cap three shoaling-upward parasequences within the lower member (Prave et al., 1991; Horodyski et al., 1994). Sedimentary structures indicate a marine intertidal to subtidal environment. Mostly non-marine conglomerates of the middle member incise into the lower member (see Cooper and Fedo, 1995). In fact, the lower member is absent in many eastern localities due to incision by the middle member (Cooper and Fedo, 1995). The upper member is lithologically similar to the lower member. However, carbonates in the upper member contain ooids, as well as echinoderm "shellbeds." The contact with the overlying Zabriskie Quartzite is gradational.

Stromatolites and Other Fossils

No stromatolites or microbial fossils are known from the Wood Canyon Formation. The Ediacaran-style fossils *Ernietta* (Horodyski, 1991) and *Swartpuntia* (Hagadorn and Waggoner, 2000) are now known from the basal lower member. The trace fossil *Treptichnus* (*Phycodes*) *pedum*, the fossil used to correlate the Precambrian-Cambrian boundary (Narbonne et al., 1987), has been found in the upper part of the lower Wood Canyon Formation (Horodyski et al., 1994; Corsetti and Hagadorn, 2000). Thus, the Wood Canyon Formation straddles the Precambrian-Cambrian boundary.

The upper member contains the first appearance of conventional Cambrian body fossils, including olenellid trilobites, archaeocyathans, hyoliths, brachiopods, helicoplacoid echinoderms, and the small shelly fossil *Volborthella*. The upper member also contains large, several cm-wide and many cm-long vertically oriented burrows that may be the largest Early Cambrian burrows known (Roush, in prep.).

Age of the Wood Canyon Formation

As summarized above, the lower member of the Wood Canyon Formation straddles the Precambrian-Cambrian boundary (~544 Ma) (e.g., Corsetti and Hagadorn, in press). The upper member contains the *Nevadella* to *Bonnia-Olenellus* trilobite zone boundary, indicating a "middle to upper" Early Cambrian age (Hunt, 1990; Mount et al., 1991).

Zabriskie Quartzite

Lithologic and Stratigraphic Description

The Zabriskie Quartzite was named by Hazzard (1937) for light-colored, cliff-forming quartzite that occurs throughout the southern Great Basin (Stewart, 1970). The unit is only 33 meters thick in the east but thickens to over 300 meters in the west. Recent paleoenvironmental interpretations suggest that the quartzites reflect nearshore marine deposition, overlain by continental braidplain deposits, in turn, overlain by lagoon/tidal flat sediments. The well-known Tapeats Sandstone in the Grand Canyon area of Arizona is the on-shore lithologic equivalent to the Zabriskie Quartzite (Stewart, 1982). The contact with the overlying Carrara Formation is conformable and transitional.

Stromatolites and Other Fossils

No stromatolites, microbial fossils, or body fossils have been recovered from the Zabriskie Quartzite. However, "piperock" (*Skolithos*-burrowed quartzite) is relatively common in some parts of the formation.

Age of the Zabriskie Quartzite

The Zabriskie Quartzite is contained within the *Bonnia-Olenellus* trilobite zone, indicating a "middle to upper" Early Cambrian age (Palmer and Halley, 1979).

Carrara Formation

Lithologic and Stratigraphic Description

The Carrara Formation was named by Cornwall and Kleinhample (1961) for a mixed siltstone and carbonate unit that is transitional from quartzites below (the Zabriskie Quartzite) and relatively clean carbonates above (Bonanza King Formation, Nopah Formation; Stewart, 1970). It is generally about 400 to 650 meters thick. Nine members have been established. The Eagle Mountain Shale Member is in sharp contact with the underlying Zabriskie Quartzite. The Zabriskie Quartzite forms a prominent ridge and the Eagle Mountain Shale Member is green and slope-forming. The Golden Ace Limestone Member is limestone that forms a tall (+3 m), gray cliff that contains abundant trace fossils, ooids, and oncoids. The upper member up is the Pyramid Shale Member, which crops out as fissile green shale.

Stromatolites and Other Fossils

Oncoids are common in the carbonate units. Stromatolites of columnar, domical, and other shapes (Fig. 4E), and thrombolites are found in the upper limestone lenses within the Pyramid Shale Member (Anderson, 1991) and in the Jangle Limestone Member (Halley, 1975; Anderson, 1991, 1997; Hartman and Anderson, 1995). The Jangle Limestone's thrombolites are domical and ellipsoidal in shape, and approximately 1 to 2 m tall (Anderson, 1997). Mesocopically, the thrombolites are composed of digitate mesoclots. Some thrombolites have a stromatolitic rind.

Trilobite fragments are not uncommon in the shales, while oncoids and burrows occur in the limestone/dolomite layers. No microbial fossils in any lithology have been found.

Age of the Carrara Formation

Biostratigraphic constraints place an Early to Middle Cambrian age on the Carrara Formation. The Lower-Middle Cambrian boundary, based on trilobite assemblages, occurs within the Pyramid Shale Member (*Olenellus* Zone in the lower part; Palmer and Halley, 1979).

Bonanza King Formation

Lithologic and Stratigraphic Description

The Bonanza King Formation was named by Hazzard and Mason (1936) from outcrops in the Marble Mountains and redefined by Palmer and Hazzard (1956). Later, it was applied to strata in the Nevada Test site (Barnes and Palmer, 1961). The formation is divided into a lower Papoose Lake Member and an upper Banded Mountain Member. The Papoose Lake Member is dominated by massive black pelletal dolomite (Kepper, 1981). The thickness of the Banded Mountain Member ranges from 400 m to the east and 1100 m in the west (Montañez et al., 1996). The Banded Mountain Member is composed of shallowing-upward cycles that were deposited under peritidal conditions. These cycles are easily recognized in the field and on aerial photographs as repeating bands of light and dark gray. Common lithotypes include burrowed and mottled dolomite, flaser bedded dolowackestone, and areally restricted dendrolite boundstones (Shapiro, 1998). The upper contact of the Bonanza King Formation is sharp and taken at the break between the cliff-forming dolomites below, and the recessive, ledge-forming limestones of the basal Nopah Formation above.

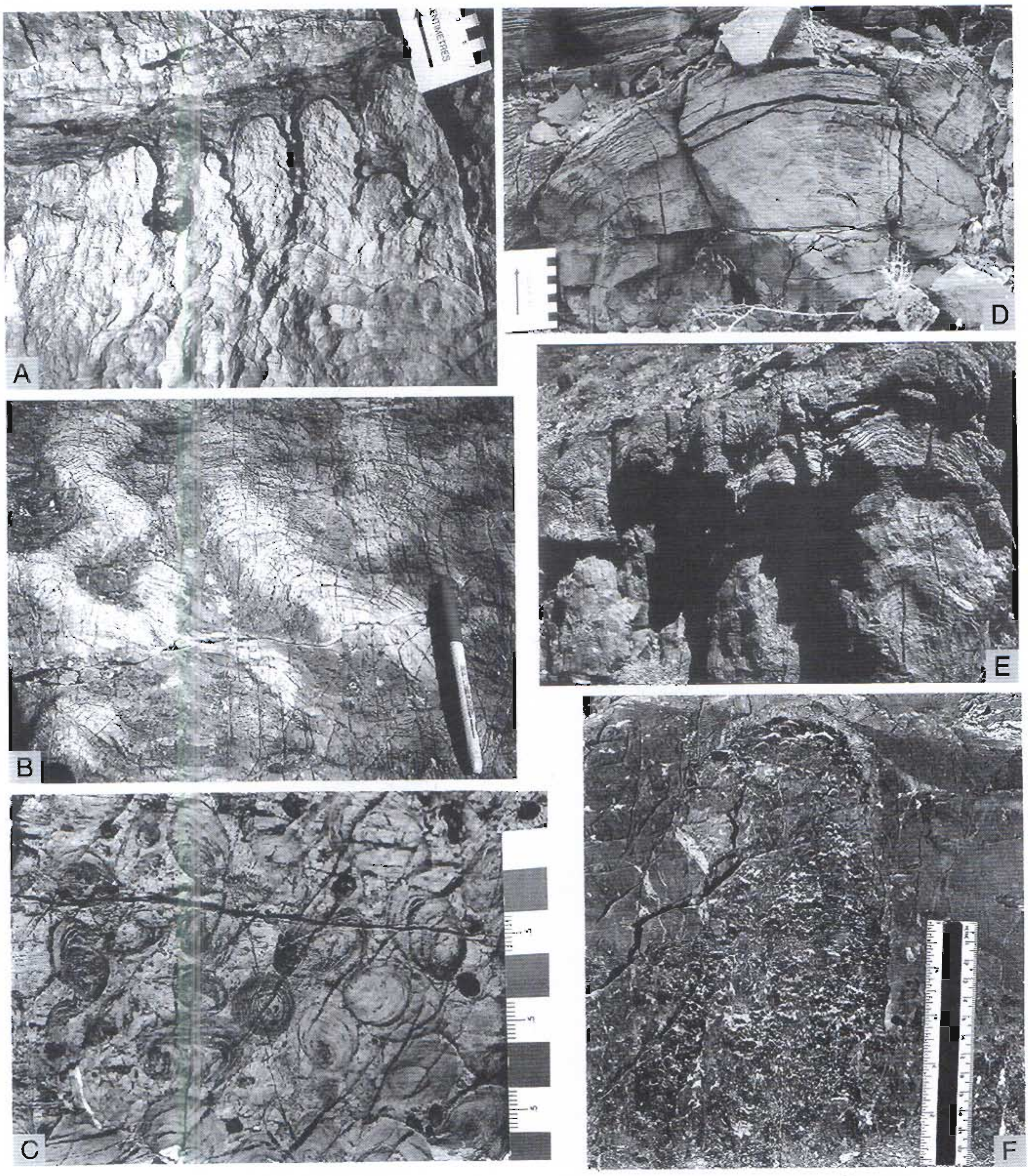

Figure 4. Stromatolites of the Death Valley succession. A. Columnar to infrequently branching columnar stromatolites from the Crystal Spring Formation, Alexander Hills. Columnar branching stromatolites from this unit have been called 'Baicalia' Krylov 1963 (Howell, 1971). B. Pseudocolumnar stromatolite from the Beck Spring Dolomite, Alexander Hills. White dolomite accents the convex laminae making the structures appear more columnar than they are. C. Oncoids from carbonate interbeds of the diamictite of the Kingston Peak Formation, Kingston Range. Some of the oncoids are elongated in one direction but have not yet formed columnar stromatolites. D. Domical stromatolite from the Johnnie Formation, Nopah Range. E. Columnar layered stromatolite from the Carrara Formation, Nopah Range. F. Columnar thrombolite from the Nopah Formation, Dry Mountain (Death Valley National Park).

Stromatolites and Other Fossils

The Papoose Lake Member contains a diverse stromatolite assemblage (Kepper, 1972; Shapiro, unpubl. data). Dendrolites (a type of stromatolite composed of dendritic clusters of calcimicrobes; Riding, 1991) occur as biostromes comprising isolated columns and domical hemispheroids (Shapiro, 1998). A calcimicrobe similar to *Renalcis* forms the dendrolites. Other fossils are very rare but include trilobite fragments and silicified anthaspidellid sponges (Shapiro, 1998).

No microbial fossils have been found in any lithology.

Age of the Bonanza King Formation

Based on biostratigraphy, the Bonanza King Formation is Middle Cambrian to earliest Early Cambrian in age (Barnes and Palmer, 1961). The Middle-Upper Cambrian boundary occurs in the Banded Mountain Member.

Nopah Formation

Lithologic and Stratigraphic Description

The Nopah Formation was named by Hazzard (1933; 1937) from exposures in the Nopah Range, eastern California. The Nopah Formation is about 370 meters thick in eastern California and rests conformably on the massive dolomites of the Bonanza King Formation and is conformably overlain by the Pogonip Group. It is divided into three members: the Dunderberg Shale, Halfpint, and Smoky Members. The lowest, the Dunderberg Shale, is a saddle-forming package of trilobite-rich limestone, siltstone, and olive-green calcareous shale.

The Dunderberg Shale is a persistent unit that can be traced across the Great Basin (Palmer, 1960; 1965). The Halfpint Member is a ledge- and cliff-former composed of pelloidal and ooidal grainstones and boundstones. The Smoky Member is a thick, cliff-former easily recognized by its banded appearance. The contact between the top of the Smoky Member and the overlying Pogonip Group is a paraconformity. To the east of Death Valley, more strata are missing from the underlying Smoky Member.

Stromatolites and Other Fossils

The Nopah Formation contains a diverse assemblage of stromatolites, thrombolites (Fig. 4F), and oncoids (Griffin, 1987; 1989; Shapiro, 1998; Shapiro and Awramik, 2000). These occur in a predictable, biostratigraphic order that can be traced across the Great Basin (Shapiro and Awramik, 2000). Isolated patch reefs of stacked, domical stromatolites have been found within the limestone intervals in the Dunderberg Shale through the southeastern Great Basin (Cooper and Edwards, 1991; Shapiro, 1998). As noted by Griffin (1989), McCutcheon and Cooper (1989), and Shapiro (1998), the Smoky Member contains the most diverse stromatolite assemblage of the Nopah Formation, and perhaps the most diverse assemblage found in the Phanerozoic in the region. The stromatolites grew in unrestricted, open-marine subtidal conditions in an environment that is comparable to Lee Stocking Island, Bahamas, where large, subtidal stromatolites are forming in normal marine waters (Dill et al., 1986). A rare, low-diversity biota of trilobites, inarticulate brachiopods, hyoliths, and eocrinoids may be found in non-boundstone units. Exceptions to the paucity of an invertebrate fauna are abundant conodonts high in the section (A. Harris, pers. comm., 1994) and a 50 to 100 m thick interval containing silicified molds of gastropods and chitons. Microbial fossils have been discovered in silicified carbonate associated with the stromatolites (Awramik, 1982).

Age of the Nopah Formation

The age of the Nopah Formation is primarily constrained by recognition of Steptoean Age (=*Dunderbergia* Zone) trilobites (Palmer, 1965) and conodonts (Miller et al., 1981) in the basal Dunderberg Shale and by recognition of early Ordovician conodonts in the overlying Pogonip Group (J. Cooper, pers. comm., 1995). There is little age control throughout the Smoky Member. Shapiro and Awramik (2000) correlated the strata using microbialite biostratigraphy to show that the Halfpint Member probably contains the Steptoean-Sunwaptan Boundary and that the post-*Saukia* zone strata are missing.

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References

Abolins, M., Charlton, R.L., Wernicke, B.P., and Ripperdan, R.L., 1999. Three distinct Neoproterozoic glacial intervals recorded in western Laurentia and Australia. Geological Society of America, Abstracts with Programs, 31: 485.

Anderson, T.B., 1991. Environmental significance of stromatolites in the Pyramid Shale Member of the Cambrian Carrara Formation, Emigrant Pass, southern Nopah Range, California. Geological Society of America, Abstracts with Programs, 22(3): 3.

___, 1997. Middle Cambrian thrombolite bioherms in the Jangle Limestone Member of the Carrara Formation, southern Nopah and Resting Springs ranges, southeastern California: American Association of Petroleum Geologists Bulletin, 81(4): 679.

Awramik, S.M., 1982. Late Cambrian microbial endoliths of the Nopah Formation, Death Valley, California. Geological Society of America, Abstracts with Programs, 14(4): 146.

Awramik, S.M. and Sprinkle, J., 1999. Proterozoic stromatolites: The first marine evolutionary biota. Historical Biology, 13: 241-253.

Barnes, H. and Palmer, A.R., 1961. Revision of stratigraphic nomenclature of Cambrian rocks, Nevada Test Site and vicinity, Nevada. U.S.G.S. Professional Paper 424C, Article 187: C100-C102.

Bertrand-Sarfarti, J. and Awramik, S.M., 1992. Stromatolites of the Mescal Limestone (Apache Group, middle Proterozoic, central Arizona): Taxonomy, biostratigraphy, and paleoenvironments. Geological Society of America Bulletin, 104: 1138-1155.

Charlton, R.L., Wernicke, B.P., and Abolins, M.J., 1997. A major Neoproterozoic incision event near the base of the Cordilleran Miogeocline, southwestern Great Basin. Geological Society of America, Abstracts with Programs, 29(6): 197.

Christie-Blick, N. and Levy, M., 1989. Stratigraphic and tectonic framework of the upper Proterozoic and Cambrian rocks in the western United States. In: N.Christie-Blick and M.Levy (Eds.), Late Proterozoic and Cambrian Tectonics, Sedimentation, and Record of Metazoan Radiation in the Western United States. American Geophysical Union, Fieldtrip Guidebook T331: 7-21.

Cloud, P. and Semikhatov, M.A., 1969. Proterozoic stromatolite zonation. American Journal of Science, 267: 1017-1061.

Cloud, P.E., Wright, L.A., Williams, E.G., Diehl, P., and Walter, M.R., 1974. Giant stromatolites, and associated vertical tubes from the Upper Proterozoic Noonday Dolomite, Death Valley Region, Eastern California. Geological Society of America Bulletin, v. 85: 1869-1882.

Cooper, J.D. and Edwards, J.C., 1991. Cambro-Ordovician craton-margin carbonate section, southern Great Basin: a sequence-stratigraphic perspective. In: J.D.Cooper and C.H.Stevens (Eds.), Paleozoic Paleogeography of the Western United States II, vol. 1: Pacific Section Society of Economic Paleontologists and Mineralogists, Book 67, p. 237-252.

Cooper, J.D. and Fedo, C.M., 1995. Base of the Sauk sequence in the southern Great Basin and eastern Mojave Desert. Geological Society of America, Abstracts with Programs, 27: 331.

____, 1998a. Anatomy of a craton margin hinge zone: sequence stratigraphy of Upper Neoproterozoic-basal Cambrian succession, eastern Mojave Desert, California: Guidebook to Field Trip #1, Cordilleran Section of the Geological Society of America, California State University Long Beach, 26 p.

____, 1998b. Early evolution of the Cordilleran Miogeocline revisited. Geological Society of America, Abstracts with Programs, 30: 10-11.

Cornwall, H.R. and Kleinhample, F.J., 1961. Geology of the Bare Mountain quadrangle, Nevada. U.S. Geological Survey Geologic Quadrangle Map GQ-157, scale 1:62,500.

Corsetti, F.A., 1998. Regional correlation, age constraints, and geologic history of the Neoproterozoic-Cambrian strata, southern Great Basin, USA: Integrated carbon isotope stratigraphy, biostratigraphy, and lithostratigraphy. [Ph.D. Thesis] University of California Santa Barbara, 235 p.

Corsetti, F.A. and Hagadorn, J.W., 2000. The Precambrian-Cambrian transition, Death Valley, USA. Geology.

Corsetti, F.A. and Kaufman, A.J., 1994. Chemostratigraphy of Neoproterozoic-Cambrian units, White-Inyo region, eastern California and western Nevada. Palaios, 9: 211-219.

Corsetti, F.A., Awramik, S.M., Pierce, D., and Kaufman, A.J., in press. Carbon isotope chemostratigraphy of Neoproterozoic-Cambrian strata, southern Great Basin, USA: looking for the missing rift. International Geology Review.

Dill, R.F., Shinn, E.A., Jones, A.T., Kelly, K., and Steinen, R.P., 1986. Giant subtidal stromatolites forming in normal salinity waters. Nature, 324: 55-58.

Fedo, C.M. and Cooper, J.D., 1990. Braided fluvial to marine transition: the basal Lower Cambrian Wood Canyon Formation, southern Marble Mountains, Mojave Desert, California. Journal of Sedimentary Petrology, 60: 220-234.

____, 1999. Polygenetic origin for arenites of the Neoproterozoic Stirling Quartzite, southeastern California. Annual Meeting of the Geological Association of Canada and Mineralogical Association of Canada, Abstracts with Programs, 24: 38.

Fedo, C.M. and Prave, A.R., 1991. Extensive Cambrian braidplain sedimentation: insights from the southwestern USA Cordillera. In: J.D.Cooper and C.H.Stevens (Eds.), Paleozoic Paleogeography of the Western United States – II. Society of Economic Paleontologists and Mineralogists, Pacific Section Guidebook, p. 227-235.

Graff, D.A., 1985. Paragenesis of iron formation within the Kingston Peak Formation, southern Death Valley region, California. [M.S. thesis] University of California, Davis, CA, 170 p.

Griffin, K.M., 1987. A comparison of the depositional environments of Upper Cambrian thrombolites and stromatolites of the Nopah Formation, Death Valley region, California, and modern stromatolites of the Bahamas. Geological Society of America, Abstracts with Programs, 19: 684.

Griffin, K.M., 1989. Microbial reefs on a carbonate ramp: A case study from western North America with a global perspective. In: J.D.Cooper (Ed.), Calvacade of Carbonates. Pacific Section Society of Economic Paleontologists and Mineralogists, Book 61, p. 101-112.

Gutstadt, A.M., 1968. Petrology and depositional environments of the Beck Spring Dolomite (Precambrian), Kingston Range, California. Journal of Sedimentary Petrology, 38: 1280-1289.

Hagadorn, J.W. and Waggoner, B.M., 2000. Ediacaran fossils from the southwestern Great Basin, United States. Journal of Paleontology.

Halley, R.B., 1975. Peritidal lithologies of Cambrian carbonate islands, Carrara Formation, southern Great Basin. In: R.N.Ginsburg (Ed.), Tidal Deposits: A Casebook of Recent Examples and Fossil Counterparts. New York, N.Y., Springer-Verlag, p. 279-288.

Hartman, T. and Anderson, T.B., 1995. Variations in morphology and structure of thrombolites in the Middle Cambrian Jangle Limestone Member of the Carrara Formation, southern Nopah Range, California. Geological Society of America, Abstracts with Programs, 27(5): 25.

Hazzard, J.C., 1933. Notes on the Cambrian rocks of the eastern Mojave Desert, California, with a paleontological report by Colin H. Crickmay. University of California Publications, Bulletin of the Department of Geological Sciences, 25: 57-70.

____, 1937. Paleozoic section in the Nopah and Resting Springs mountains, Inyo County, California. California Journal of Mines and Geology, 33: 273-339.

Hazzard, J.C. and Mason, J.F., 1936. Middle Cambrian formations of the Providence and Marble Mountains, California. Geological Society of America Bulletin, 47: 229-240.

Heaman, L.M. and Grotzinger, J.P., 1992. 1.08 Ga diabase sills in the Pahrump Group, California: Implications for development of the Cordilleran miogeocline. Geology, 20: 637-640.

Hegenberger, W., 1987. Gas escape structures in Precambrian peritidal carbonate rocks. Communication of the Geological Survey of S.W.Africa/Namibia, 3: 49-55.

Hewett, D.F., 1940. New formations to be used in the Kingston Range, Ivanpah quadrangle, California. Washington Academy of Sciences Journal, 30: 239-240.

Hoffman, P.F., Kaufman, A.J., and Halverson, G.P., 1998. Comings and goings of global glaciations on a Neoproterozoic tropical platform in Namibia. GSA Today, 8: 1-9.

Horodyski, R.J., 1991. Late Proterozoic megafossil from southern Nevada. Geological Society of America, Abstracts with Programs, A163.

Horodyski, R.J. and Knauth, L.P., 1994. Life on land in the Precambrian. Science, 263: 494-498.

Horodyski, R.J. and Mankiewicz, C., 1990. Possible Late Proterozoic skeletal algae from the Pahrump Group, Kingston Range, southeastern California. American Journal of Science, 290-A: 149-169.

Horodyski, R.J., Gehling, J.G., Jensen, S., and Runnegar, B., 1994. Ediacara fauna and earliest Cambrian trace fossils in a single parasequence set, southern Nevada. Geological Society of America, Abstracts with Programs, 26: 60.

Howell, D.G., 1971. A stromatolite from the Proterozoic Pahrump Group, eastern California. Journal of Paleontology, 45: 48-51.

Hunt, D.L., 1990. Trilobite Faunas and Biostratigraphy of the Lower Cambrian Wood Canyon Formation, Death Valley Region, California. [Masters thesis] University of California, Davis 140 p.

Kepper, J. C., 1972. Paleoenvironmental patterns in Middle to lower Upper Cambrian interval in eastern Great Basin. American Association of Petroleum Geologists Bulletin, 56: 503-527.

____, 1981. Ramp and platform deposition during the Middle Cambrian, eastern California and western Nevada. In: M.E.Taylor (Ed.), Short Papers for the Second International Symposium on the Cambrian System. U.S. Geological Survey Open-File Report 81-743: 102-105.

Kirschvink, J.L., 1992. Late Proterozoic low-latitude global glaciation: the snowball Earth. In: J.W.Schopf and C.Klein (Eds.), The Proterozoic Biosphere: A Multidisciplinary Study. Cambridge, Cambridge Univ. Press, p. 51-52

Langille, G.B., 1974. Earliest Cambrian-Latest Proterozoic ichnofossils and problematic fossils from Inyo County, California. [Ph.D. Thesis] State University of New York, Binghamton, NY.

Lanphere, M. and Wasserburg, G.J., 1962. Age measurements of the Precambrian rocks of the Death Valley-Mojave Desert region, California. Journal of Geophysical Research, 67: 1645.

Levy, M. and Christie-Blick, N., 1991. Tectonic subsidence of the early Paleozoic passive continental margin in eastern California and southern Nevada. Geological Society of America Bulletin, 103: 1590-1606.

Licari, G.R., 1978. Biogeology of the late pre-Phanerozoic Beck Spring Dolomite of eastern California. Journal of Paleontology, 52: 767-792.

Marian, M.L., 1979. Sedimentology of the Beck Spring Dolomite, eastern Mojave Desert, California. [Masters Thesis] University of Southern California, Los Angeles, CA, 216 p.

Marian, M.L. and Osborne, R.H., 1992. Petrology, petrochemistry, and stromatolites of the Middle to Late Proterozoic Beck Spring Dolomite, eastern Mojave Desert, California. Canadian Journal of Earth Sciences, 29: 2595-2609.

McCutcheon, K.F. and Cooper, J.D., 1989. Environmental carbonate stratigraphy and cyclic deposition of the Smoky Member of the Nopah Formation (Upper Cambrian), Nopah Range, southern Great Basin. In: J.D.Cooper (Ed.), Cavalcade of Carbonates. Pacific Section Society of Economic Paleontologists and Mineralogists, Book 61, p. 87-100.

Miller, J.M.G., 1982. Kingston Peak Formation in the southern Panamint Range: A glacial interpretation. In: J. D. Cooper, Geology of selected areas in the San Bernardino Mountains, western Mojave Desert, and southern Great Basin, California. Shoshone, California, Death Valley Publishing Company, p. 155-164.

___, 1985. Glacial and syntectonic sedimentation: The Upper Proterozoic Kingston Peak Formation, Panamint Range, eastern California. [Ph.D. Thesis] University of California, Santa Barbara, CA, 355 p.

Miller, R.H., Sundberg, F.A., Harma, R.H., and Wright, J., 1981. Late Cambrian stratigraphy and conodonts of southern Nevada. Alcheringa, 5: 183-196.

Montañez, I.P., Banner, J.L., Osleger, D.A., Borg, L.E., and Bosserman, P.J., 1996. Integrated Sr isotope variations and sea-level history of Middle to Upper Cambrian platform carbonates: implications for the evolution of Cambrian seawater $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$. Geology, 24: 917-920.

Mount, J.F., Hunt, D.L., Greene, L.R., and Dienger, J., 1991. Depositional systems, biostratigraphy and sequence stratigraphy of Lower Cambrian Grand Cycles, southwestern Great Basin. In: J.D.Cooper and C.H. Stevens (Eds.), Paleozoic Paleogeography of the Western United States-II. Pacific Section, Society of Economic Paleontologists and Mineralogists, 67: 209-229.

Narbonne, G.M., Myrow, P.M., Landing, E., and Anderson, M.M., 1987. A candidate stratotype for the Precambrian-Cambrian boundary, Fortune Head, Burin Peninsula, southeastern Newfoundland. Canadian Journal of Earth Sciences, 24: 1277-1293.

Nolan, T., 1929. Notes on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada. American Journal of Science, 17: 461-472.

Palmer, A.R., 1960. Trilobites of the Upper Cambrian Dunderberg Shale, Eureka District, Nevada. U. S. Geological Survey Professional Paper 334-C, 109 p.

___, 1965. Trilobites of the Late Cambrian Pterocephaliid Biomere in the Great Basin, United States. U. S. Geological Survey Professional Paper 493, 105 p.

Palmer, A.R. and Hazzard, J.C., 1956. Age and correlation of the Cornfield Springs and Bonanza King formations in southeastern California and southern Nevada. American Association of Petroleum Geologists Bulletin, 40: 2494-2499.

Palmer, A.R. and Halley, R.B., 1979. Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin. U. S. Geological Survey Professional Paper 1047, 131 p.

Pierce, D.E. and Awramik, S.M., 1994. Age and significance of microfossils from the Meso-Neoproterozoic Pahrump Group, eastern California. Abstracts with Programs, Geological Society of America Cordilleran Section Meeting: 81.

Pierce, D. and Cloud, P., 1979. New microbial fossils from ~1.3 billion-year-old rocks of eastern California. Geomicrobiology Journal, 1: 295-309.

Prave, A.R., 1994. The Pahrump Group: alternative speculations on the Neoproterozoic geodynamic development of the Death Valley region. Geological Society of America, Abstracts with Programs, 26(2): 82.

___, 1999. Two diamictites, two cap carbonates, two delta^{13}C excursions, two rifts: The Neoproterozoic Kingston Peak Formation, Death Valley, California. Geology, 27: 339-342.

Riding, R., 1991. Classification of microbial carbonate. In: R.Riding (Ed.), Calcareous Algae and Stromatolites. Springer-Verlag, Berlin, p. 21-51.

Roberts, M.T., 1976. Stratigraphy and depositional environments of the Crystal Spring Formation, southern Death Valley region, California. In: B. W. Troxel and L. A. Wright (Eds.), Geologic Features, Death Valley, California. California Divisions of Mines and Geology, Special Report 106: 35-43.

Shapiro, R.S., 1998. Upper Cambrian-lowermost Ordovician stratigraphy and microbialites of the Great Basin, U.S.A. [Ph.D. Thesis] University of California, Santa Barbara, 446 p.

Shapiro, R.S. and Awramik, S.M., 2000. Microbialite morphostratigraphy as a tool for correlating Late Cambrian-early Ordovician sequences. Journal of Geology.

Stewart, J.H., 1966. Correlation of Lower Cambrian and some Precambrian strata in the southern Great Basin, California and Nevada. In: Geological Survey Research 1966. U. S. Geological Survey Professional Paper 550-C: C66-C72.

___, 1970. Upper Precambrian and Lower Cambrian strata in the southern Great Basin California and Nevada. U. S. Geological Survey Professional Paper 620: 205 p.

___, 1972. Initial deposition in the Cordilleran geosyncline: evidence of a Late Precambrian (>850 m.y.) continental separation. Geological Society of America Bulletin, 83: 1345-1360.

___, 1982. Regional relations of Proterozoic Z and Lower Cambrian rocks in the Western United States and northern Mexico. In: J.Cooper, B.Troxel, and L.Wright (Eds.), Geology of Selected Areas in the San Bernardino Mountains, Western Mojave Desert, and Southern Great Basin, California. Volume and Guidebook for the Geological Society of America Cordilleran Section Fieldtrip no. 9, p. 171-180.

Summa, C.L., 1993. Sedimentologic, stratigraphic, and tectonics controls of a mixed carbonate-siliciclastic succession: Neoproterozoic Johnnie Formation, southeastern California. [Ph.D. Thesis] Massachusetts Institute of Technology, Cambridge, MA, 616 p.

Tucker, M.E., 1983. Diagenesis, geochemistry, and origin of a Precambrian dolomite; the Beck Spring Dolomite of eastern California. Journal of Sedimentary Petrology, 53: 1097-1119.

Wertz, W. E., 1982. Stratigraphy and sedimentology of the Stirling Quartzite, Death Valley area, California and Nevada. In: J.D.Cooper, B.W.Troxel, and L.A.Wright (Eds.), Geology of Selected Areas in the San Bernardino Mountains, Western Mojave Desert, and Southern Great Basin, California. Geological Society of America Annual Meeting, Cordilleran Section Field Trip, No. 9, p. 165-170.

Wright, L.A. and Troxel, B.W., 1954. Western Mojave Desert and Death Valley region. In: R.H.Jahns (Ed.), Geology of Southern California. Geologic Guide No. 1, Division of Mines, California, Bulletin 170, 50 p.

Wright, L.A., Troxel, B.W., Williams, E.G., Roberts, M.T., and Diehl, P.E., 1974. Precambrian sedimentary environments of the Death Valley region, eastern California. In: Guidebook, Geological Society of America, Cordilleran Section Field Trip No. 1: 27-35.

___, 1974. Precambrian sedimentary environments of the Death Valley region, eastern California. In: B.W.Troxel and L.A.Wright (Eds.), Geologic Features Death Valley, California. California Division of Mines and Geology, Special Report 106, p. 7- 15.

Wright, L.A., Williams, E.G., and Cloud, P.E., 1978. Algal and cryptalgal structures and platform environments of late pre-Phanerozoic Noonday Dolomite, eastern California. Geological Society of America Bulletin, 89: 321-333.

Wrucke, C.T., 1972. Correlation of Precambrian diabase in Arizona and California. Geological Society of America Cordilleran Section Meeting, Abstracts with Programs, p. 265.

Young, G. M., 1976. Iron-formation and glaciogenic rocks of the Rapitan Group, Northwest Territories, Canada. Precambrian Research, 3: 137-158.

Abstracts from the Year 2000 Desert Symposium

John C. Roos and the Flora of Inyo County

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John Roos was a physician at Loma Linda University Medical Center and an avid amateur botanist. He was a close associate and enthusiastic student of both Edmund Jaeger and Philip Munz. Between 1930 and the mid 1970s, he collected extensively throughout southern California, from Inyo and Kern counties south into the Baja California peninsula. His interest focused primarily on the grasses and herbaceous plants, but his preferred collecting sites ranged from urban lots and suburban gardens to some of the most remote wilderness areas in the state. Dr. Roos eventually donated his private herbarium to several institutions, a significant portion coming to the Clark Herbarium at the Riverside Municipal Museum.

During the middle of the century, John Roos made a series of field trips to sites in the northern Mojave Desert, including many in Inyo County. Often accompanied by his wife Lucille, his father Alfred, Jaeger or Munz, Roos succeeded in collecting a wide sample of the region's flora, many specimens going on to be described in the literature as new types and first records for the state of California.

Thermoluminescence Sediment Dating of Two Nested, Inset Alluvial Units at the Calico Site, San Bernardino County, California

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The exposure of sediment grains to sunlight at the time of deposition is sufficient to greatly reduce (bleach) a thermoluminescence (TL) signal and thereby provide the basis for age determination. TL sediment dating is useful for assessing aeolian and low energy fluvial and lacustrine deposits; rapidly deposited sediments are often problematical. TL determinations on sediment samples taken from two different artifact-bearing alluvial units at the Calico Site have yielded middle and late Pleistocene ages. Fluvial sediments at a depth of 4.25 m in the site's Master Pit I dated to 135,000+infinity/-30,000 b.p. (the upper limit for the method is approximately 150,000 b.p.). This date is congruous with assessments of the soil profile as approximately 100,000 years old and uranium-thorium dates averaging approximately 200,000 years from calcium carbonate rinds found encrusting artifacts in the basal mudflow of the alluvial deposit. Sediments from a depth of 52 cm (stratigraphically equivalent to the base of a well-formed chalcedony biface) in the side of a drainage channel in a younger, nested inset alluvial unit dated to 14,400±2,200 years b.p. Three cultural components are now identified at the Calico Site: the newly-identified late Pleistocene sub-surface Rock Wren locality artifactual assemblage dating to about 14,400 years ago; the late Pleistocene surface and shallow sub-surface artifacts of the Lake Manix Lithic Industry (inferred to be >18,000 yr b.p. given dated pollen profiles and artifact occurrence above the 543 m elevation, the shoreline elevation of Pleistocene Lake Manix which drained 18,000 years ago); and the middle Pleistocene sub-surface artifacts of the Calico Lithic Industry.

Current Issues in the Management of Cultural Resources at Death Valley National Park

Tim Canaday, *Archeologist, Death Valley National Park, P. O. Box 579, Death Valley, CA 92328*

Death Valley National Park encompasses some 3.3 million acres in the northern Mojave Desert. To date, less than 3% of the Park has been systematically inspected for cultural resources. Current archeological work in the park includes both research and compliance-driven projects. Present research includes rock art and rock alignment studies conducted through the park's VIP program, as well as Masters Thesis research on obsidian sources in the park. Compliance projects include site improvement plans for Eureka Dunes.

The Joshua Tree as a Water Source for Woodrats

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Animals must have water to survive. Many animals obtain water directly by drinking from streams, springs or potholes. Food resources are another important source of water, particularly for carnivores. Most animals are at least two-thirds water by weight and therefore provide an excellent source of free water for predators (Schmidt-Nielsen, 1964). Plant parts including leaves, stems and fruit can also contain much free water—sometimes approaching animals in the amount of moisture they contain (Cornett, 1987).

Desert animals require as much, and in some cases more, water than animals living in humid environments. Yet obtaining water in a desert environment is obviously difficult. In the desert regions of California, the prevailing aridity has been intensified by an unusually severe drought beginning in the fall of 1998 and winter of 1999 and continuing into the winter of 2000. Precipitation records at Twentynine Palms, adjacent to Joshua Tree National Park, indicate that in 1999, precipitation was 21% below the long-term average (Joshua Tree National Park records). The drought became even more severe in early 2000.

Beginning in 1998 I noticed unusually intense browsing on Joshua tree (*Yucca brevifolia*) leaves at seven study sites in the Mojave Desert of California and Nevada. In most cases browsing was not distributed evenly through the crown of adult trees but confined to one or two branches. Browsing was noted as high as 5 meters above the ground. In a few instances browsing resulted in the death of trees under 0.5 meters in height.

In every instance in which Joshua tree leaf browsing was evident at least one woodrat nest was found within 15 meters of the tree. An examination of each nest revealed dozens of both old (gray to brown in color) and new (yellow-green in color) Joshua tree leaves. Woodrat habits and diets can generally be determined by the kinds of plant parts left in and around the nest (Miller and Stebbins, 1964). It is therefore assumed that at least some, if not all, of the browsing was done by woodrats. In support of the idea that browsing of adult trees was done by woodrats is the fact that the most severely browsed Joshua trees were those with woodrat nests at their bases. The species of woodrat present on each of the seven study sites was the desert woodrat, *Neotoma lepida.*

Unlike some other desert rodent groups (such as Heteromyids and some Cricetids), known to survive on seeds alone, woodrats are dependent upon the free water found in cacti, agave, and other succulent desert plants (Finley, 1990). Over broad areas of the Mojave Desert Joshua trees are the only succulent plant present that could provide a reliable, year-round supply of moisture. Thus the woodrat's existence in many areas seems permitted by the local presence of Joshua trees. This dependency may be particularly critical in years of unusually low precipitation.

Literature Cited

Cornett, J. W. 1987. *Wildlife of the North American deserts.* Nature Trails Press, Palm Springs, California.

Finley, R. B., Jr. 1990. Woodrat ecology and behavior and the interpretation of Paleomiddens, in *Packrat middens, the last 40,000 years of biotic change.* University of Arizona Press, Tucson, Arizona.

Miller, A. H. and R. C. Stebbins. 1964. *The lives of desert animals in Joshua Tree National Monument.* University of California Press, Berkeley, California.

Schmidt-Nielsen, K. 1964. *Desert animals, physiological problems of heat and water.* Oxford University Press, Oxford, England.

Rehabilitation/Restoration of a 1903 Structure in Willow Canyon near Amargosa Gorge

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CA-INy-2371 is a standing, single room structure built in 1903 of locally obtained cut blocks of tuff. The building may have been used as an assay house, a wagon stop and supply store and railroad house. Local lore also suggests it was used as a saloon. The structure was occupied until the 1930s. The structure complex includes evidence of two additions and a "dug-out". The BLM acquired these lands in Willow Canyon in November 1997 and the structure's state of disrepair became a concern. Emergency stabilization measures were initiated in 1998 and a restoration program began in 1999. This involved subsurface testing of an associated cultural component during excavation for footings to stabilize the existing foundation. The stabilization includes straightening the walls, repointing, replacement of original head beams and replication of the original roofing material. The site is being nominated to the National Register of Historic Places.

Museum Collections Management at Death Valley National Park

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Death Valley National Park has a museum collection of some 600,000 objects, specimens, and archival materials. The collection is diverse and valuable and represents Death Valley's rich natural and cultural resources. The lack of nearby museums of any size and expertise requires park museum staff to be self-sufficient in its collection management program, although museum staff continues to seek partnerships with outside agencies and institutions where beneficial. Current issues in museum collection management include storage and preservation of collections, acquisition of collections, and use and access to the collections.

Synoptic Mojave: Full Resolution Landsat Mosaic of Southern California

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A full-resolution Landsat Thematic Mapper mosaic has been assembled for that portion of southern California south of Bishop and east of Bakersfield and for all of east-central and southern Nevada. This 15-scene digital mosaic, composed primarily of data acquired during April 1996, provides a regionally consistent synoptic view of the Mojave Desert, the central and southern Great Basin, and adjacent areas. The first of a series of regional mosaics that will eventually include most western states, this mosaic was generated using newly-developed algorithms that enhance nearly all land cover-land use categories, ranging from unvegetated to relatively densely vegetated terrains. Thus, it constitutes an ideal regional base map (at 1:100,000-scale or smaller) for a variety of resource management applications including biologic, hydrologic, surficial geologic/geomorphic mapping and analyses. A preliminary version of this mosaic was used to produce a series of 21 1:100-000-scale image maps for much of southern Nevada and southeastern California. These maps are being utilized by the US Geological Survey for surficial and bedrock geologic mapping of this region.

Facies Analysis of Neogene Syntectonic Strata in the Soda Mountains, San Bernardino County, California: Implications for Constraint on Faulting on the Soda-Avawatz Fault Zone

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The Soda-Avawatz fault zone (S-AFZ) is a dextral shear zone in the Soda Mountains, northwest of Baker, California. The fault lies between the Mojave Desert and Basin and Range structural provinces. This study constrains slip along the S-AFZ and results are compared to previously proposed structural models. Tertiary fanglomerates of the Avawatz Formation are exposed along the S-AFZ and were analyzed to determine provenace, paleocurrent directions, depositional environments and faulting history.

Results indicate that the lower member of the Avawatz Formation was derived from a source area to the south and east of the S-AFZ. Right-lateral slip along the S-AFZ displaced the source to the south, creating a more distal source, resulting in the deposition of the middle member. The upper member was derived from a western source. Transpression within the S-AFZ uplifted bedrock through the Avawatz Formation. Offset along the S-AFZ is estimated to at least 20 km.

The Last of the Death Valley Prospectors

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In this presentation, based on my book, *These Canyons are Full of Ghosts*, I will relate my personal adventures with some of the Death Valley old-timers and things that took place when we were still prospecting for, and mining, gold. My subjects will be Mr. Harry Briggs and his gold mines, and Assa Russell and his lost ledge. Both of these men were good friends and fellow miners in the badlands of America's most famous valley. Mr. Briggs was a corporate tycoon back east. In 1929, during the great depression, he was wiped out.

With determination and gold fever, he ended up with several claims in the Panamint Mountains. One of his gold mines is still a going affair, now a multi-million dollar high-tech operation. Assa Russell was a would-be, latter-day Death Valley Scotty: a colorful miner, con man and story teller. His camp in Stripped Butte Valley is still habitable and often staffed by Park Service Rangers.

A Shore Bird in a Desert Oasis: Habitat Preferences of Large-billed Savannah Sparrows Wintering at Salton Sea, California

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The large-billed savannah sparrow (*Passerculus sandwichensis rostratus*), which some authorities now treat as a distinct species, is recognized as a species of special concern in California. Although large numbers formerly wintered in the littoral zone of the southern California coast, nest habitat loss in the Gulf of California has lead to a dramatic decline and only rarely are they now encountered along the coast. In recent decades a population of undetermined size has begun to winter in the desert at the Salton Sea. During the winter months of 1997-1999, we conducted extensive surveys to assess habitat preferences of typical (*P. sandwichensis* ssp.) and large-billed savannah sparrows in the Salton Sea vicinity. We found a significant difference in habitat preferences of these two taxa. Only large-billed savannahs were found along rocky primary shoreline (N=17; 5.52 birds/km). Equal numbers of typical (N=39; 3.20/km) and large-billed savannahs (N=43; 3.52/km) were found in close proximity to the emergent vegetation (iodine bush, saltbush and/or tamarisk) of primary and secondary shoreline where there was a secondary body of water adjacent to the Sea. Similar vegetation along the primary shoreline where there was no adjacent body of water supported fewer typical (N=1; 0.14/km) and large-billed savannahs (N=7; 0.98/km). No sparrows were encountered along primary shoreline bordered by desert scrub, along primary shoreline lacking rocks and vegetation, within vegetation more than 30 m inland from any shoreline, or along tertiary shoreline (streams, impoundments) several hundred meters or more inland from the Sea. Typical savannah sparrows were abundant in agricultural fields (N=147) where no large-billed savannahs were found. Although large-billed savannahs are occasionally reported from the north end of the Sea, nearly all of the wintering population occurs south of the line between Salton City (W shore) and Bombay Beach (E shore). Our surveys reveal the importance of littoral habitats to wintering large-billed savannah sparrows—particularly rocky shorelines and emergent vegetation associated with secondary bodies of water adjacent to the Sea—and provide baseline data for monitoring future population fluctuations.

Digitizing Paleontological Sensitivity Maps

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The initial, manually-developed version of the Riverside County paleontologic sensitivity map was developed fifteen years ago from records at the San Bernardino County Museum. This ground truth data is being used to evaluate the paleontological sensitivity of sedimentary formations. LSA Associates, Inc. (LSA) transferred data from 1:250,000 scale USGS maps to 1:100,000 scale maps to identify major geologic formations that pertained to the paleontological sensitivity map. Using USGS geologic maps as a base proved to be an efficient way to transfer information to a digital format. Specific map features such as corners and crossroads were identified and used as digitizing reference points. In this manner, all information drawn on the USGS base maps could be entered into the GIS and be compared against other existing data, such as township and range information. In order to ensure accuracy, the identified paleontological sensitivity map was printed with the township and range information on top. Corrections were made on the map itself and entered back into the GIS. This format allows further refinement of the map as more levels or accuracy become available. The unique advantage of using GIS is that a myriad of data can be layered, providing the user with the ability to look not only at paleontological sensitivity but examine slope, aerial photos, and other data that might have an influence on the final sensitivity map.

The Mud Hills Quarry History

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The first record of fossils from the Mud Hills occurred in 1911, when J. C. Merriam, a biologist from the University of California at Berkeley, obtained vertebrate fossils from John R. Suman. Suman had received the specimens from H. S. Mourning, who mined in the Mud Hills area. Later that year, C. L. Baker accompanied Suman and Mourning to gather more fossils. Baker subsequently published the definitive stratigraphic study and geologic maps of the day. Later, when type specimens were recovered, several were named after these men, including the horses *Archaeohippus mourningi* and *Merychippus sumani*.

J. P. Buwalda and Chester Stock of the California Institute of Technology explored the area in 1913. John C. Merriam did not visit in person until 1915, when he studied prehistoric faunas of both the Mud Hills and of Red Rock Canyon, to the west near Mojave, California. From these studies Merriam published *Tertiary Mammalian Faunas of the Mojave Desert* in 1919. This publication generated great interest in fossils from the Mud Hills within the academic community.

In the early 1920s, when scientists from the American Museum of Natural History (AMNH), the University of California and other institutions began actively collecting in the Mud Hills, it is likely potential fossil sites were discussed with workers of the Fullers Earth Mining Company. The AMNH began collecting extensively in the area from 1923 to 1940, starting again in the 1950s after World War II. Barstow provided a favorable winter field area in contrast to the museum's colder field locales in South Dakota, Nebraska and other areas. The Mud Hills sites proved to be rich in both quantity and quality for the museum's vertebrate collections. During the period from 1923 to 1940, 458 crates of specimens were sent to New York. The institution opened 16 major quarries and numerous minor localities. The main portion of what is known as the Barstovian Land Mammal Age fossil assemblage was collected and identified during this time.

Childs Frick, who operated the Frick Paleo Labs in conjunction with the AMNH preparation staff, oversaw the museum's operations in the Mud Hills. Frick visited the quarry sites rarely, preferring to oversee operations in New York. Frick managed field logistics, processed field information, and ultimately the fossil specimens shipped to New York.

The AMNH's field work can be divided into three intervals represented by three different field leaders and their assistants. Joseph Rak supervised from 1923 to 1930 with assistance from Charles Falkenbach and Jack Wilson. Rak was the first to identify the "Wolf stratum" (later called the *Hemicyon* stratum) and attempted to resolve inconsistencies with earlier stratigraphic studies. Jack Wilson succeeded Rak in 1931 and was probably the most productive, shipping 242 crates of fossils. Before leaving for the Navy in 1940, Wilson also did the most accurate measurement of the area's stratigraphy. Ted Galusha, an assistant under Wilson from 1935 to 1940, restarted quarrying in 1951. Galusha emphasized well-written and accurate field reports utilizing aerial photos and, in 1966, wrote the AMNH's formal report representing 30 years of field work.

Interest in the Mud Hills fossil locales continued in the 1960s, even though collecting by major museums and universities slowed considerably. Raymond Alf and students of the Webb School in Claremont collected specimens. The University of California at Riverside with Dr. Richard H. Tedford, Dr. Michael O. Woodburne and George T. Jefferson did field work with graduate and undergraduate students in the area. Local interest in the Mud Hills sites increased when Art Robbins, a Hinkley schoolteacher, discovered new sites near the older quarries. Among these sites, Robbins, Robert Reynolds and others developed Robbins Quarry. This site has proven to be very fruitful, yielding type specimens of herbivores and carnivores. Working with the Bureau of Land Management, museums and universities are able to coordinate continued collection and research in the Mud Hills area.

The Geology and Ore Deposits of the Yellow Pine Mining District, Goodsprings, Clark County, Nevada

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The Yellow Pine Mining District, more commonly known as Goodsprings, is located in the southern Spring Mountains, Clark County, Nevada, about 30 miles south of Las Vegas. Stratified rocks in the district are dominantly Paleozoic limestone and dolomite and Triassic to Jurassic sandstone and shale. The Late Cretaceous Lavina Wash Sequence unconformably overlies these older units. Intrusive rocks are concentrated in the central part of the district where a series of dikes and sills of granite porphyry (180 MA, 189 MA, 190 MA) are exposed. South of the Cottonwood Fault that marks the northern boundary of the district, a sequence of three prominent northerly-striking and westerly-dipping thrusts (Contact, Keystone, and Green Monster-Sultan) ramp across lower plate rocks. Numerous secondary thrusts, associated tear faults and folds occur within each thrust block. These secondary structures appear to be the conduits for the intrusions and the later metal-bearing hydrothermal fluids. The most dramatic structural change lies in the central part of the district where the northerly-striking Keystone Thrust bends sharply to the east, resulting in a distinct easterly-trending reentrant in the thrust pattern. Carr (1983) believes the reentrant developed from the wrapping of the Keystone Thrust around a structural block uplifted along the Ruth Fault.

The Early Jurassic age for the intrusions indicates that some of the thrusting occurred perhaps as early as Late Triassic. In the area of the reentrant, the Late Cretaceous Lavina Wash Sequence occurs in the lower plate of the Keystone Thrust and is indicative of a later episode of thrusting. Detailed mapping of mine geology (Hewett, 1931 and Albritton et al., 1956) demonstrates that the ores are post-intrusion and therefore at least post-Early Jurassic. A pre-Late Cretaceous age for mineralization is supported by the copper-bearing, Iron Gold skarn and the adjacent Lavina Mine porphyry. Both of these units are incorporated in a fault slice within the Ruth Fault zone. Displacement along the Ruth Fault is almost entirely pre-Keystone Thrust. Oxidation of the primary sulfide ores probably occurred either beneath the sub-Miocene unconformity or later during the elevation of the southern Spring Mountains and the erosional removal of the Miocene deposits.

The dikes, sills and the later hydrothermal mineralization may represent the higher portions of a deeply buried porphyry system. A relationship between the Early Jurassic intrusive event and the emplacement of the ores is reflected in the zoning of the metals and the distribution of the porphyry relative to the reentrant block in the central part of the district.

Remnants of the primary ores indicate a complex assemblage of sulfides and sulfosalts subsequently thoroughly oxidized to form an extensive suite of secondary base metal minerals. Studies conducted by Jedwab (1999) on Boss Mine samples resulted in the recognition of the platinum and palladium bearing mineral potarite and a host of additional sulfides encapsulated in a bituminous matrix. Cinnabar may be an important indicator in the Pt/Pd mineral assemblage.

The Lower Mojave Valley, Mojave Desert, California: A Destabilizing Aeolian Environment

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One of the most notable aspects of ecosystem deterioration in arid regions is sand movement subsequent to the loss of plant cover owing to human mismanagement. In most cases, the loss of vegetation stems from cultivation, overgrazing, disturbance of the surface by vehicular traffic and economic development. The lower Mojave Valley in southeastern California is undergoing geologically rapid environmental change as a result of human activity that has decreased groundwater levels, caused the death of riparian vegetation, and the reactivation of aeolian sand. The study area lies east of Barstow, along the Mojave River, in a zone approximately bounded by Minneola and Harvard Roads. The environment includes: a) vegetation-anchored dunes (nebkhas and sand shadows) within the Mojave River or on adjacent fluvial terraces; b) extensive nebkha dunes on the open plains; c) a small field of barchans west of Harvard Road; d) sand streaks with clearly defined margins, aligned parallel with the prevailing wind; and e) blowing dust, both along the river and from exposed silty surfaces on the open plain. The exposed bed of the Mojave River is the main source of sand supply for sand transport and ultimate dune formation.

In the study area, wind direction and fluvial transport are generally in alignment. Aeolian transport increases following flood events, which reactivate alluvium from upstream areas, scour lag deposits in the channel, and erode riverine dunes as the channel system shifts position. In some places along the channel, sand movement is impeded by thick riparian vegetation or by scattered mesquite plants. Although vegetation is eroded from the channel during flood events, high water tables allow seedlings to quickly germinate, with the channel rapidly recolonizing. Both within the channel, on terraces adjacent to the channel, and on the open plain, large vegetation-anchored dunes (nebkhas or coppice dunes) accumulate wherever the water table is high. The principal dune-forming plant, mesquite (*Prosopis glandulosa*), often attains large stature.

The natural balance between winds, sand supply, and vegetation began to change in the middle- to late-twentieth century, as increasing demand for groundwater caused a precipitous drop in the water table. For example, along the Calico-Newberry fault, water tables were near the surface in 1919, had declined to 6 m below the surface by 1960, to 15 m by the mid-1980s, and to 24 m by the mid-1990s. Mesquite shows stress if the water table falls below 4.5 m, and it is not observed to grow where the depth to water is more than 7.5 - 9 m. The groundwater decline caused the loss of mature riparian vegetation and prevented the establishment of seedlings, leaving extensive areas of the channel exposed to wind erosion. In addition, vegetation-anchoring dunes on river terraces and on the open plain declined, increasing aeolian erosion. Subsequently, sand released from degrading nebkhas and sand eroded from the devegetated channel has reaccumulated downwind in migrating sand streaks and barchanoid dunes that are impinging on human settlement. Today, residents are experiencing problems of dune encroachment and blowing dust. Such encroachment has buried equipment, rendered buildings and homes unusable, blocked entrances to property and destroyed pasture areas. Dust emissions are also a problem in the region and have been blamed for fatal highway accidents. The nebkha dunes are representative of a "wet aeolian system," where the water table lies at or close to the surface. Various stabilizing agents, such as vegetation, allow accumulation while the system remains active. The development of sand streaks and barchans over the past few decades represents the transition to a "dry aeolian system," where neither the water table nor vegetation exerts any significant influence, and surface behavior is largely controlled by local aerodynamics. Changes to the aeolian environment of the Lower Mojave Valley in recent decades reflect complex interactions between the wind regime, river channel morphology and sediments, surface and subsurface hydrology, geology, vegetation, and human influence. Clearly, the significance of such changes has broad implications for the future well-being of this fragile environment.

Aspects of the Ecology of the Western Pond Turtle in the Mojave River

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We studied aspects of the ecology of relict populations of the western pond turtle (*C. marmorata*) in the Mojave River of the central Mojave Desert, California. Both populations occurred in habitats that were severely degraded as a result of ground water depletion from human activities along the river (especially Camp Cady), and one, Afton Canyon, was infested with the exotic shrub saltcedar (*Tamarix ramosissima*). We collected data on demography, reproductive and nesting ecology, and habitat use of the western pond turtle and compared our findings with data from other parts of its range.

Thirty-seven individuals were captured or observed 193 times from May 1998–September 1999. Mean female carapace length (CL) was significantly greater (14.4 cm) than that of males (13.7 cm). Mean female weight was 523 g (SD = 80.1, n = 18) and ranged from 400–750 g. Mean male weight was 406 g (SD = 78.9, n = 18) and ranged from 265–533 g. The overall adult sex ratio was 18 males:19 females. Shelled eggs were visible in x-radiographs from May 26–July 14. Mean clutch size was 4.46 and ranged from 3–6 eggs. Clutch size did not vary between 1998 and 1999 and was significantly correlated with CL for both years combined. Gravid females ranged from 13.3–16.0 cm. Some females may lay two clutches per year and some nested in both years. Mean X/REW was 21.8 mm (SD = 0.82, n = 55) and ranged from 19.0–23.0 mm. XREW was not significantly correlated with CL (r2 = 0.01, P = 0.51, df = 1, 53) or clutch size (r2 = 0.01, P = 0.43, df = 1, 53). XREW differed more among clutches than within whether using CL as a co-variate (P = 0.001), or not (P = 0.001).

Eight females made 13 known and putative nesting migrations between 6 June and 8 July. Most nesting migrations were oriented toward the dry channel of the river. Minimum round trip distances ranged from 17.5–585 m (n=12) with a mean of 195 m (SD = 187 m). Mean estimated time of departure from the drift fence as calculated by circular statistics, was 1813 hours. Most females returned to the ponds in the early morning. Nesting migrations required females to be out of the water for estimated periods of 0.83–83 hours. The destination of nesting females was typically fluvial sand bars in the channel of the dry riverbed.

Overall, the ecology of *C. marmorata* in the Mojave River was very similar to that reported for populations in less xeric habitats along the western coast of the United States. Notable exceptions included long nesting migrations, and an apparent lack of terrestrial overwintering behavior in Mojave River populations. The general similarity of desert and coastal populations is likely a reflection of the recency of their genetic and physical separation. Overall, populations in the Mojave River exhibited few obvious adaptations to living in the desert and are considered to be tenuous relicts of the Pleistocene. The small size and tenuous status of these populations calls for immediate conservation action that should include establishment of satellite populations as a hedge against extirpation.

A Geochemical Model for Saline Waters

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The hydrologic balance and salinity of waters in deserts have important implications for human habitability, dryland agriculture, reclamation, and biodiversity. Chemical equilibrium models are becoming increasingly important tools in understanding complex chemical systems. The FREZCHEM model is a phase equilibrium model for electrolyte solutions in the temperature range from -60° to 25°C. Activity and osmotic coefficients are calculated with the Pitzer equations, which allows accurate calculation of salinity and mineral precipitation from dilute solutions to concentrated brines. The model presently includes 35 potential solid phases including ice, and Na, K, Mg, and Ca salts of chloride (9 phases), sulfate (11 phases), and carbonate (14 phases). Two reaction pathways are built into the model allowing chemical equilibrium calculations across (1) a range of temperatures, which can simulate freezing at low temperatures, and (2) a range of water contents, which simulates evaporation. Other features of the model include a choice between equilibrium versus fractional crystallization and the calculation of pH in open, complex carbonate systems. Carbonate chemistry in the model is partially validated by comparing measured and calculated pHs of western saline, alkaline waters. The model has been used to clarify cold chemical equilibria in the Arctic, Antarctic, Mars, and Europa. We plan to apply the model to warm deserts (T>25° C) by extending the temperature range for Pitzer-equation parameters and mineral solubility products and by incorporating new minerals into the model that are important at higher temperatures (e.g., thermonatrite).

The Hyoid Bones of *Mammuthus meridionalis* from the Mid-Pleistocene of Anza-Borrego Desert State Park®

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The bones of the hyoid apparatus are located between the rami of the mandible, and attach to the skull at two points on each side. They are joined together and to the skull by cartilage, forming a sling to support the tongue and permit vocalization. The hyoid apparatus or hyoids consist of five bones: the right and left stylohyoids, the right and left thyrohyoids, and the basihyoid (Figure 1). These bones are very fragile, and usually become disarticulated soon after death and seldom are preserved. There is a wide variation in the morphology of the hyoids between individuals and between the two sides in the same individual.

In most mammals, the skull is antero-posteriorly elongated and the hyoids are oriented horizontally. The skull of the Elephantidae is short, and the hyoids are vertical in orientation (Figure 1).

The stylohyoid is the longest of the hyoids, and consists of a corpus and the superior, inferior, and posterior rami. The lateral surface of the corpus is convex anteroposteriorly and dorsoventrally. Orientation and identification of a fragmentary specimen can be determined by this characteristic.

Systems for measuring the stylohyoid have been proposed by Inuzuka *et al.* (1975), Kubiak (1980), and modified by Graham (1986). The system of Graham (1986) will be followed herein (Figure 2). The most important measurement of the stylohyoid is the *angle of divergence* (angles x and y) (Figure 2). Angle x is the angle between the anterior margin of the inferior-superior rami and the ventral margin of the posterior ramus. Angle y is the angle between the posterior margin of the inferior ramus and the ventral margin of the posterior ramus.

Table 1. Measurements, in mm, of the stylohyoids of *Mammuthus meridianalis*, ABDSP(IVCM) V5126.

Measurement	Left	Right
1. IR-PR (a-b)	-	146.7
2. SR-PR (b'-c)	92.3	88.6
3. SR-IR (a-c)	-	159.6
4. e	-	8.8x10.4
5. f	-	10.8x12.6
6. g	-	13.4x13.6
7. h	32.8x8.2	31.0x14.2
8. i	33.8x12.4	35.7x15.0
9. angle x	-	47.5
10. angle y	-	52.0

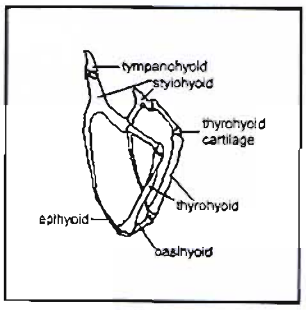

Figure 1. Hyoid bone of *Elephas* (modified from Inuzuku *et al.*, 1975).

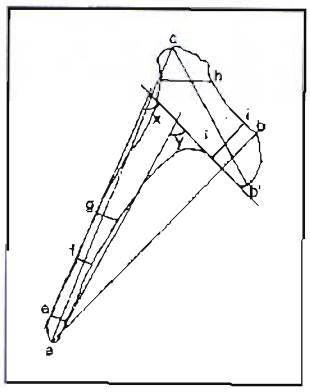

Figure 2. Measurements of the stylohyoids, in mm (after Graham, 1986), of *Mammuthus meridianalis*, ABDSP(IVCM) V5126. Explanation: IR = inferior ramus; PR = posterior ramus; SR = superior ramus.

The thyrohyoid extends dorsally and slightly posteriorly from the basihyoid (Figure 1). The ventral extremity fuses medially with the basihyoid when the animal reaches full maturity. Anteriorly, the distal extremity connects with the epihyoid cartilage of the inferior ramus of the stylohyoid. Dorsally, the thyrohyoid is connected to the posterior ramus of the stylohyoid via cartilage, and to the larynx via the thyrohyoid cartilage. The thyrohyoids twist from dorsal to ventral, the right counterclockwise, and the left clockwise.

The "bowtie-shaped" (Agenbroad, 1994) basihyoid lies transversely between the ventral extremities of the thyrohyoids and connects to the epihyoid cartilage of the inferior rami of the stylohyoids anteriorly.

Included in the skeletal elements recovered from the southern mammoth, *Mammuthus meridionalis* partial skeleton ABDSP(IVCM) V5126 (McDaniel and Jefferson, 1999), are a nearly complete right stylohyoid, the corpus of the left stylohyoid, most of the right thyrohyoid, and the basihyoid.

The short, thick superior ramus of the right stylohyoid attached to the styloid process of the temporal bone through the cartilagenous tympanohyoid. The posterior ramus is longer than the superior ramus, and the distal extremity is roughened for muscle attachments. The long slender inferior ramus tapers ventrally, and curves medially and posteriorly. The distal 2-3 cm of the distal end of the right stylohyoid is missing. Measurements of the stylohyoids are in Table 1.

The inferior ramus of the left stylohyoid is missing. The antero-ventral portion of the superior ramus and a small postero-dorsal piece of the posterior ramus also are missing. The corpus is thinner than that of the right stylohyoid. The left stylohyoid is thinner than the right, and the posterior ramus is longer than that of the right stylohyoid.

The right thyrohyoid of ABDSP(IVCM) V5126 twists counterclockwise nearly 60° from dorsal to ventral. It curves outward ventrally and becomes bulbous. It has not fused with the basihyoid ventrally although the animal was approximately 50-55 years old at the time of death (McDaniel and Jefferson, 1999).

The *angle of divergence* has been used to compare species of elephantids. Inuzuku *et al.* (1975) feel that this angle becomes more acute as the animal matures and the tongue becomes bigger.

Kubiak (1980) suggests that this angle is a specifically diagnostic character, but Graham (1986) disagrees. In comparing the *angle of divergence* published by various authors, this measurement does not seem to be specifically diagnostic. There are, however, recognizable differences between genera. This angle is most acute in *Loxodonta* (Agenbroad, 1994). It is not as acute in *Elephas* (6 specimens) as it is in *Mammuthus* (18 specimens), but there is too much overlap to separate these two genera by this character alone. The angle in *Mammut* is obtuse.

There is no significant difference between the measurements of the thyrohyoids (8) and basihyoids (2) of *M. columbi* from Hot Springs (Agenbroad, 1994) and those of *Mammuthus meridianalis*, ABDSP(IVCM) V5126.

References Cited

Agenbroad, L.D. 1994. Taxonomy of North American *Mammuthus* and biometrics of the Hot Springs Mammoth Site of South Dakota. *In* The Hot Springs Mammoth Site of South Dakota, Hot Springs, South Dakota, L. Agenbroad and J. I. Mead eds., Hot Springs, South Dakota p. 158-207.

Graham, R. 1986. Descriptions of the dentitions and stylohyoids of *Mammuthus columbi* from the Colby site. *In* The Colby mammoth site, G. Frison and L. C. Todd eds., University of New Mexico Press, Albuquerque, Appendix 2, part 2 p. 171-190.

Inuzuka, N., Y. Hasagawa, H. Hogariga, and T. Kamei 1975. On the stylohyoid bone of Naumann's elephant (*Elephas naumanni*, Makiyama) from Lake Nojiri. Memoirs of the Faculty of Science, Kyoto University, Series of Geology and Minerology vol. 41 no. 1 p. 49-65.

Kubiak, H. 1980. The hyoid bone in the mammoth Mammuthus primigenius (Blumenbach). Folia Quaternaria vol. 51 p. 47-56.

McDaniel, G.E. Jr., and G.T. Jefferson 1999. *Mammuthus meridionalis* from the Borrego Badlands, Anza-Borrego Desert State Park®, California. On file at the Colorado Desert District, Stout Research Center, State of California Department of Parks and Recreation, Borrego Springs, California 74 p.

Developing a Paleontological Sensitivity Map and GIS Database for the Mojave Desert

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In February 1997, the Mojave Desert Ecosystem Program (MDEP) under the U.S. Department of Defense's Legacy Program entered into a partnership with the State of California, Office of Historic Preservation to create the Mojave Desert Historical Resources Geographic Information System (MDHRGIS), an integrated database within the California Historical Resources Information System (CHRIS). The project involves the integration of archaeological site, historic property, and paleontological resource information into a common and secure database for enabling better cultural resource and database management. The paleontological resource sensitivity map and Geographic Information System (GIS) database, although a minor part of the MDHRGIS project, has brought about the need to further develop an information framework for locational data linked to thematic data already collected. This paper is about the cooperation between the San Bernardino County Museum, providing the local paleontology knowledge base, the University of Redlands, providing the GIS and data synthesis, and the Paleontology and Cultural Resource Action Team (PACRAT), providing the oversight and overall direction of the group. Over the last thirty years, the San Bernardino County Museum has compiled a large database of paleontological resource localities from the south half of California, southern Nevada and western Arizona. This ground truth data can be used to evaluate the paleontological sensitivity of a given sedimentary formation. PACRAT, representing the Desert Managers Group (DMG), was instrumental in working with MDHRGIS to develop the first digitized paleontologic sensitivity map of a portion of California.

Source of Clay and Temper for Southern Paiute Brown Ware

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This paper discusses the working hypothesis that workable clay and temper sources in the Virgin Mountains were more desirable to the Southern Paiute of the Moapa Valley than locally available clay and temper sources. Many archaeologists agree that Great Basin Brown Ware vessels are crude in form due to their expedient production and function. It is further assumed that brown ware vessels were crafted at or near habitation sites. If so, one would expect to find workable clay and temper sources nearby. These local materials would then be predicted to match inclusions within the clay bodies. However, recent studies of Moapa Valley ceramic assemblages suggest the geologic source is located in the Virgin Mountains. This finding suggests that Moapa brown ware was not made in or around habitation sites. Instead, it is likely that travel to and from production areas in the Virgin Mountains occurred. Transportation from these areas may have also affected the form of brown ware vessels.

Fort Irwin Cultural Resources Program

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Fort Irwin is the site of the U. S. Army's National Training Center. Ten times a year, armored and mechanized infantry forces train in this 1,000 square mile installation with large-scale war games and realistic live fire training. In the midst of this mission, the Fort Irwin Cultural Resources Program has the responsibility of inventorying and protecting the archaeological and historic sites on the installation. Since the early 1980s, the program has conducted extensive surveys and established a curation facility. This presentation summarizes the program's status and goals.

A Model for Control of a Unique Drainage Pattern: A Double Water Gap east of Yucaipa, California

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Wind and water gaps are commonly associated with the eastern United States, but here in the west, they often express not only stream incision due to uplift, but also the effects of shifts in local base level due to strike-slip motion. In the course of examination of the foothill zone south of the San Andreas Fault between Wrightwood and Banning, a new twist in the theme of water gaps, stream capture and tectonics was observed. It appears a large landslide block is creating a double water gap, with the stream morphology predominantly controlled by the location of the headscarp and lateral tear faults around the slipping block.

The community of Oak Glen is in a trough south of Yucaipa Ridge, with the San Andreas Fault just to the north. Drainage of this area is bi-directional, split by a small saddle. The western part of the community drains west towards Mill Creek, while the eastern part drains along youthful channels southeasterly into Little San Gorgonio Creek. This creek trends to the south and heads towards the city of Banning. It passes through a water gap in the ridge situated east of Yucaipa, and is for several hundred feet leveed on the west by Oak Glen Road. At this exact location, a second stream passes through the same water gap, leveed on the east by the same road segment, resulting in the road appearing as an elevated causeway between the two streams. This westerly stream trends southerly, then makes a near right angle turn to the west, and drains into Yucaipa Creek through Wildwood Canyon towards the city of Yucaipa. This very straight, east-west drainage is subparallel to the Banning Fault, and may be inferred as fault-controlled.

Several lines of evidence suggest this is not a simple stream capture that had been subsequently rechanneled by road construction. Gradients of the two stream profiles are virtually identical, but are displaced in elevation relative to each other at the only point capture could have occurred, suggesting they were never interconnected. Further, the material under the county road appears to be natural, rather than fill, suggesting there was no historical connection. Finally, because the floor of the channel west of the road is about 30 feet lower in elevation than the channel of Little San Gorgonio Creek, had a connection previously existed at this point, this elevation differential should have forced rapid incision of the Little San Gorgonio Creek, and a jump in the stream profile should have been quickly created, precluding the smooth stream profiles seen in the field.

From examination of satellite imagery and digital elevation data, the stream and geomorphic evidence suggests that the two streams are and have been separate, and it appears probable that the control of Yucaipa Creek is probably by erosion along a fault. The morphology suggests a headscarp of an incipient landslide. The youthful appearance of the drainage east of Oak Glen may reflect an earlier similar event, when extension created a break in the ridge and allowed headward erosion of Little San Gorgonio Creek to suddenly lower local base level and incise the drainage east of Oak Glen. It therefore seems probable that this failure is recurrent, and that the headscarp and Wildwood Canyon are just the most recent manifestations of an ongoing landslide.

Comparison of a Miocene Puente Formation Flora from the Flint-Ridge Development, Southeastern Chino Hills, to Other Puente Formation Floras.

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Collections from several sites in the Puente Formation from the Eastern Chino Hills, Riverside County, show a variety of fossil taxa including marine mammals, fish, invertebrates, algae and terrestrial plants. This study cataloged more than 270 terrestrial plant fossil specimens including 22 genera from the Flint Ridge Development site (E1/2, NW1/4, NW1/4, Sec. 35, T2S, R8W, SBBM). During the past 25 years, several other floras from the Chino Hills have been collected. Analysis of the combined data allows a paleoecological interpretation of the terrestrial source area for the Puente Formation in the Chino Hills area.

Thirty-eight genera have been reported from this study and four previous reports. These are tabulated below. Identification of individual members in the Puente Formation is sometimes problematical, so all of the taxa have been reported together from each site. Individual leaf fossils at the Flint Ridge site are moderately well to poorly preserved. The sedimentary rocks are generally massive to poorly bedded and most of the leaves are not in a single plane. Impressions of entire leaves were never observed. Along with individual leaves were two examples of leaves attached to small branches, fragments of leaves and wood, and charcoal.

The identified flora is compatible with a lowland valley to streamside community. *Platanus* (sycamore), *Palmae* (palm), *Salix* (willow), *Betula* (birch), *Magnolia*, *Sassafras*, *Persea* (avocado), *Cercis* (redbud) and *Umbellularia* (bay) all require significant moisture and warm to temperate climates. *Quercus* (oak) species are adapted to a wide range of habitats. *Rhus* (sumac), *Arbutus* (madrone), *Ceanothus* (coffeeberry), *Pinus* (pine) and *Cupressus* (cypress) tolerate drier conditions and are components of oak woodland and coastal scrub communities often associated with riparian floras in southern California assemblages from the Tertiary. *Sequoiadendron* (redwood) is reported from a single site and is present with many of the other genera reported in modern communities. However, the range in taxa from those preferring cooler microclimates (redwood) to those inhabiting warmer microclimates (avacado) suggests that the drainage system delivering these fossils covered several biomes.

Table Comparing Terrestrial Plant Fossil Genera from the Chino Hills

Genus / Reference	Flint Ridge 1999	Green Valley 1989	Soquel Canyon 1989	Townsend School 1985	Kinoshita Thesis 1998
Sequoiadendron					●
Pinus	●		●		
Juniperus					●
Cupressus	●				
Sabal	●		●	●	
Smilacena			●	●	
Poaceae	●				●
Phragmites		●	●	●	
Bumelia			●		
Ribes			●		
Platanus	●		●	●	●
Amalanchier				●	
Ficus			●		
Acer	●	●	●		●
Populus	●		●	●	●
Salix	●	●	●	●	●
Juglans	●				
Alnus	●		●	●	
Betula	●	●		●	
Cercis	●		●		
Robinia	●		●		
Magnolia	●	●	●	●	
Sassafras		●	●	●	
Umbellularia	●	●	●	●	●
Persea	●	●	●	●	●
Quercus	●	●	●	●	●
Malva				●	
Ceanothus	●				●
Rhus	●	●			
Arbutus	●				
Rhamnus					●
Arctostaphylos					●
Ocotea					●
Brahea					●
Oreomunnea					●
Psychotria					●
Rhododendron					●
Cercocarpus					●

Track Site Conservation through Track Replication and *In Situ* Management of Late Miocene Vertebrate Tracks in Death Valley National Park, California

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Late Miocene lacustrine deposits in Death Valley National Park preserve an abundant and diverse assemblage of fossil vertebrate tracks. These lacustrine deposits are susceptible to a variety of natural and human-related threats, leading to the loss of these non-renewable paleontological resources. Anecdotal conservation techniques have been implemented upon the tracks by park staff since the site discovery in 1937. *In situ* management has included: public closure of the site, application of consolidants, a photo-documentation program and periodic field collection. In 1998, a Global Positioning data acquisition system was utilized to develop a detailed paleontological resource locality map to reinforce the long-term *in situ* management strategies of Death Valley. This comprehensive field inventory relocated previously recorded track sites and identified new track sites.

Four fossil vertebrate track localities have been reported within Death Valley National Park (Bauer, 1942; Curry, 1939, 1941; Nyborg, 1998; Santucci and Nyborg, 1999; Scolnick, 1987; Scrivner, 1984; Scrivner and Bottjer, 1986), where over sixty vertebrate track sites have been recorded, utilizing photo-points and global positioning data. The most significant ichnotaxa (trace fossils, including tracks) of morphological quality and quantity is contained within the lacustrine (lake) deposits of Copper Canyon. During the summer of 1998 Torrey G. Nyborg was assigned the task of producing a global positioning map of the track sites contained within the Copper Canyon Track Locality. During the mapping of this site and investigations into the other three smaller sites, Nyborg assessed a number of trackways (a rock face that contains more then one track). These trackways were either too large and/or fragile to successfully remove from the field. These trackways are managed *in situ* (found in their original position of formation) at Death Valley National Park. Management of these trackways can be accomplished in many ways, including: collection of easily transportable track material, replication of trackways or significant tracks that are too large or fragile for collection, and blueprinting of those tracks that are inaccessible to collection or replication. To meet part of these management goals, lightweight, high resolution silicon mold casts of the significant tracks and trackways in Death Valley National Park was initiated in April 1999. This grant was funded through the Natural History Association of Death Valley.

Because of the unusual nature of the lacustrine deposits in Death Valley, special materials were used in the replication process. These materials had previously been used at four other track localities with different sedimentary substrates and are the standard used in the mold-making process (Reynolds, pers. comm., 1999). The materials and methods used during this project are as follows (figure 1):

- **Mold release** - is applied to the rock surface to reduce impregnation by the replicating agent. A thin layer of mold release (wax paste) was applied to the track and surrounding area where the mold medium would be applied. The mold release was the only substance to actually come in contact with the track. The mold release that was used was chosen for its ability to evaporate in sunlight, thusly leaving no damage to the track itself.

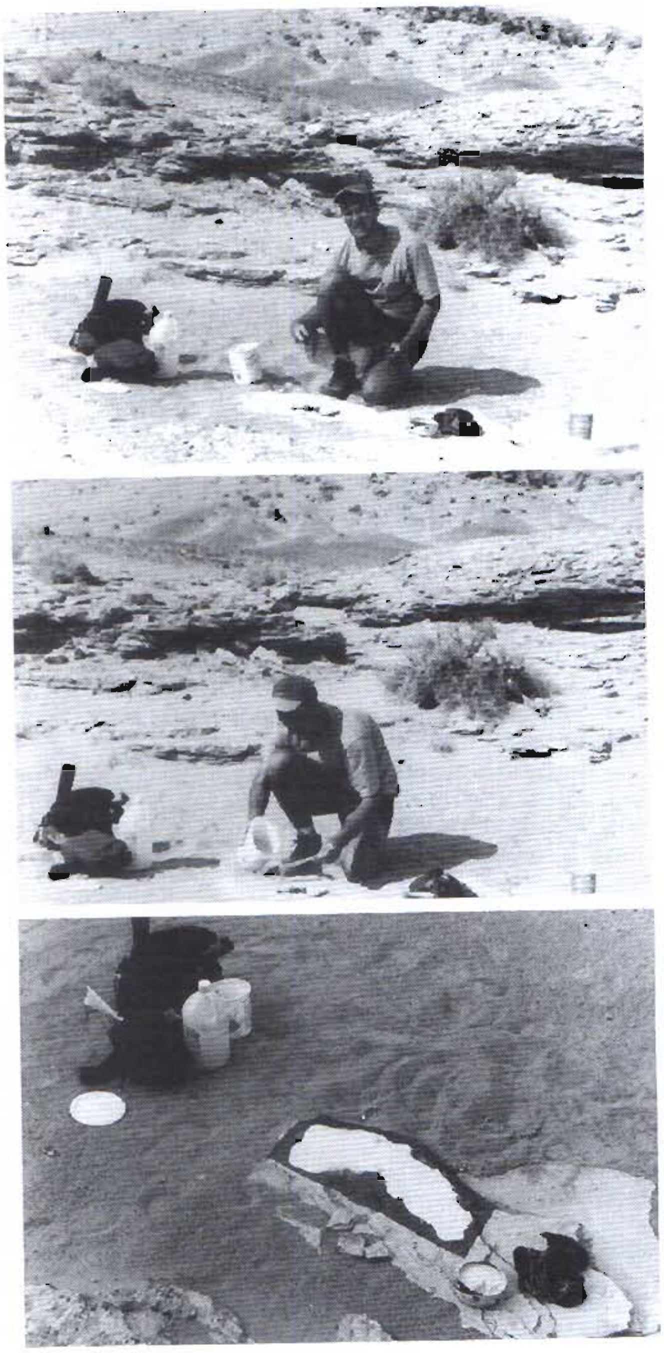

Figure 1: Three photographs depicting the track replication process of a bird trackway at the Salt Creek Track Locality. Top, application of silicon. Middle, after first application, the wire mesh is applied to give flexibility to the mold. Bottom, a second and possibly third coat of silicon mold medium is applied to the track and surrounding area. After this dries, the silicone is peeled from the rock and the replication is complete.

- **Mold medium** - The silicone rubber, GI 1000, was used as the replication medium. This product has the advantage of low adherence to the rock surface, and high preservation of detail. It was applied in several thin coats to minimize flow. A nylon mesh was applied to the back of the silicone to increase flexibility of the replication and reduce tearing of the silicone. Silicone caulk added further reinforcement, being applied to the silicone to thicken the mold. The silicone caulking procedure proved challenging in the heat of Death Valley and took several days to set. The application of the silicone caulk is best performed in the field, but can be supplemented in the museum. It is applied to the back of the silicone and mesh to thicken the mold further.

- **Curation** - After the silicon had dried, the mold was carefully peeled away from the rock. In most cases, the molds came off clean and the cast was a success. There were a few tears and sometimes erosion had begun on the track, which yielded sediment flakes on the mold. With the removal of the replica, the mold was labeled using the global positioning points set forth in Nyborg (1998).

Conclusion

Fossil vertebrate tracks can be found outside of the boundaries of Death Valley National Park, but the abundance, diversity and most importantly, the quality of preservation of these tracks surpass most other track localities in North America. Through *in situ* management by means of replication of these tracks, preservation for future use is guaranteed. The value of placing emphasis on the research of these vertebrate tracks is to understand Death Valley's past, some ten million years ago, and also to have available replicas of these tracks for scientific research and utilization in interpretive themes without damaging the original track, which remains in the field.

Thirty-five trackways were replicated within the Copper Canyon Track Locality. An additional three trackways were also replicated at the other track localities contained within the park. These replicas represent the known ichnofossil types in Death Valley National Park. Plaster casts of these molds will produce many trackways that were previously only known from photographs. These casts can be utilized for further scientific research and interpretive themes. Continuing to produce molds of the tracks and trackways, along with the associated management plans, can further the preservation of these unique and non-renewable resources.

References

Bauer, C. M. 1942. Memorandum on mammal and bird tracks, Copper Canyon, Death Valley National Monument. Unpubl. Report, Death Valley National Park library, 6 p., 1 map.

Curry, H. D. 1939. Tertiary and Pleistocene mammal and bird tracks in Death Valley. Bulletin of the Geological Society of America, 50(12): 1971-1972.

Curry, H. D. 1941. Mammalian and avian ichnites in Death Valley. Bulletin of the Geological Society of America, 52: 1979.

Nyborg, T. G. 1998. Paleontological resource management: Systematic recording and preservation of vertebrate tracks within Copper Canyon, Death Valley National Park, California. Unpubl. Death Valley National Park library, 37p.

Santucci, V. L., and Nyborg, T. G. 1999. Paleontological resource management, systematic recording, and preservation of vertebrate tracks within Death Valley National Park, California. Desert Research Symposium, 1999. San Bernardino County Museum Press, California.

Scolnick, R. 1987. Fossil tracks in Copper Canyon site locations. Unpubl. Report, Death Valley National Park library, 8 p., 16 plates.

Scrivner, P. J. 1984. Stratigraphy, sedimentology, and vertebrate ichnology of the Copper Canyon Formation (Neogene), Death Valley National Monument. Unpubl. M.S. Thesis, University of California, Los Angeles, California, 334 p.

Scrivner, P. J., and D. J. Bottjer. 1986. Neogene avian and mammalian tracks from Death Valley National Monument, California: their context, classification, and preservation. Paleogeography, Paleoclimantology, Paleoecology. 56:285-331.

Minimization of Impacts to Wildlife Species During Mine Closures at Old Borate

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Abandoned mines are an issue in both the public and private sectors. Historic mines are considered for closure for hazard abatement, reclamation, or renewed mining. At the same time, these manmade structures provide habitat for a number of wildlife species, including bats and desert tortoises (*Gopherus agassizii*). U.S. Borax Inc. (formerly Pacific Coast Borax) operated underground colemanite (calcium borate) mines in the Calico region of San Bernardino County from approximately 1890 until 1907. Because they pose substantial safety and liability concerns, U.S. Borax evaluated 149 mine openings for possible closure. The underground surveys revealed that the mine workings were collapsing due to poor ground conditions in the highly faulted shales. Mine openings were prioritized into five categories for closure, based on sign of wildlife and human use, safety hazards to humans, and accessibility. Openings were surveyed for wildlife in the spring of 1999 and again during the summer of 1999 with a focus on bats and the state- and federal-listed desert tortoise. Surveys included daytime, internal examination, as well as nighttime surveys with night scopes, night vision goggles, and Anabat detectors. Tortoise sign was located in the vicinity, but not in any of the openings. Bats or bat sign were observed in 33 of the openings. Known and suspected use of the openings was by California myotis (*Myotis californicus*), western pipistrel (*Pipistrellus hesperus*), Townsend's big-eared bat (*Corynorhinus townsendii*), pallid bat (*Antrozous pallidus*), and at least one other unidentified *Myotis* species. Biologists conducted a final round of internal examinations just prior to closure. All openings subject to closure were completely covered with chicken wire fencing within two weeks prior to actual closure. The chicken wire prevented species such as desert tortoise from entering, but still allowed bats the opportunity to leave the openings. U.S. Borax closed 129 mine openings during November and December 1999. The mine openings were excavated to solid bedrock and then the openings were backfilled with boulders. Final reclamation will include closure of the mine access roads and contouring of the disturbed areas to prevent erosion and to encourage revegetation.

Desert Lands Restoration Task Force

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The California Desert Managers' Group (DMG) was formed in 1994 to implement the congressional mandates of the California Desert Protection Act: to provide desert-wide operational collaboration for ecosystem management, customer service and organizational efficiency (data-sharing) amongst such organizations as BLM, NPS, USFWS, DoD, USGS, USDA (NRCS), California Fish and Game, Department of Parks and Recreation, and interested groups such as the California Native Plant Society, Cal EPCC, and others.

Their charter includes resource conservation and habitat restoration, visitor services, public education and safety, and applied science and monitoring. This presentation will introduce DMG and focus on one of its sub-groups, the Desert Lands Restoration Task Force (DLRTF).

The Kiss of Death: How Southern Pacific Rattlesnakes (*Crotalus viridis helleri*) Allocate Venom Resources during Predatory and Defensive Bites.

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Until recently, little has been known about the quantity of venom expended by pitvipers when biting prey or when biting to defend themselves. Several studies have shown that western rattlesnakes (*Crotalus viridis*) are able to intrinsically meter the amount of venom they inject into different sizes and types of prey, and in defensive bites as well. In this study three experiments were conducted to determine the amount of venom expended by the rattlesnake *Crotalus viridis helleri* during multiple predatory and defensive bites in quick succession, and to ascertain the effects of snake size and duration of fang contact upon venom expenditure. In experiment 1, models of mice were used to elicit multiple predatory bites. In experiments 2 and 3, defensive bites of two threat levels to the snake were elicited, one by use of a human limb model, and the other by voluntary venom extraction. The models were assayed for venom content by whole protein assay, and videotapes of all bites were analyzed to determine duration of fang contact. Venom expenditure was well correlated with snout-vent length, and rattlesnakes injected significantly more venom in defensive bites than in predatory bites with a similar duration of fang contact. Additionally, more venom was expended in the first bite than in subsequent bites.

Tracks through Time: A Learning Experience

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The Desert Discovery Center, the Mojave River Valley Museum and the Barstow Bureau of Land Management have partnered to preserve fossil trackways and involve visitors and students by offering instruction in making replicas of fossil tracks and traces and by developing an interactive exhibits program. The objectives of the program are: to preserve fragile fossil footprints, trackways, and traces of past life and activities in the Mojave Desert; to teach preservation and replication techniques to students and volunteers; to develop outreach education programs with specimens and exhibits that travel to classrooms and learning centers; and to develop all-weather exhibits at several interpretive centers at key points in the Mojave Desert.

The Desert Discovery Center offers instruction in fossil recognition, preservation, curation and interpretation. The "Tracks through Time" project will preserve representative Mojave Desert tracks and traces of Proterozoic and Paleozoic invertebrates; of Mesozoic dinosaurs and quadrupeds; and of birds, reptiles and mammals from Miocene and Pleistocene times. By directly involving the public, the project will encourage understanding and respect for the preservation of irreplaceable prehistoric resources.

The Forgotten Gold Rush

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The Forgotten Gold Rush is a museum display at seven locations in Southern California. The display focuses on the Gold Rush in Southern California and its effects on land and people. It is "forgotten" in the sense that it is seldom covered in depth in presentations of the California Gold Rush, which tend to focus on central and northern California. Images are included of the very first California Gold Rush, which did not originate at Sutter's Mill, but rather six years earlier in 1842. Ranchero Francisco Lopez stopped for lunch in Placerita Canyon, near Newhall, and accidently discovered gold particles clinging to the roots of some wild onions. The Placerita Canyon rush, which saw 6000 Sonoran miners invade the canyons of Southern California, ended with the Mexican-American War, when most of the Sonoran miners returned to Mexico.

Southern California's role in the Gold Rush of 1849-1852 was primarily to supply cattle and sheep to the north to feed 300,000 miners newly arrived from all over the world. Many of the rancheros of Southern California became wealthy with the flow of gold from the north to purchase their supplies. When the main Gold Rush ended, and the easy pickings played out, the miners started south and spread through the deserts and mountains of Southern California. Due to the absence of good transportation and the lack of water, mining activity in the south proceeded at a slow pace. However, when the railroads arrived in the late 1870s activity increased substantially. It was now possible for miners to travel to distant wilderness locations, and more importantly, they were now able to get heavy and more efficient equipment near to the mines.

The story of the Forgotten Gold Rush includes descriptions of Lucky Baldwin, William Wolfskill and others who helped to make Southern California a dynamic and freewheeling culture. Aggressive and dynamic people arrived and thrived in an atmosphere with a new and little tested legal system, and a cultural climate that encouraged people to try new things — and if you failed, to try again. But it wasn't all pleasant, and the huge influx of people to Southern California also had its victims.

The Forgotten Gold Rush created many problems for the Indians of Southern California. They lost their traditional lands and faced an onslaught of deadly diseases which decimated their populations. The land was also affected. The huge herds of cattle and sheep destroyed much of the native grasslands of Southern California, particularly in what we know as the desert regions. In addition, hunting for sport and for provisions reduced the native wildlife. The grizzly bear and the pronghorn antelope became extinct in Southern California, and the bighorn sheep almost disappeared.

In the 1980s a new Gold Rush developed when the price of gold increased and large mining companies opened up a number of very large open pit gold mines. These new mines have produced more gold in just a few years than all of the historic hard rock and placer gold mining of the past 150 years. Serious environmental issues are raised by these huge new open pit mines. In addition, their impacts on Native American cultural sites have caused fierce opposition in Imperial County to a proposed new open pit mine. The long range future of this type of mining is in question.

Archaeology in the Cronese Basin: A History

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East and West Cronese Lakes are overflow basins at the terminus of the Mojave River. Today, they fill sporadically when precipitation in the San Bernardino Mountains, supplemented by local runoff from the Mojave River drainage, causes flooding of the river. In the past, the basins filled more often and lakestands were probably higher, but written records of flood episodes earlier than those of the 19th century are not available. A rich archaeological record exists in the area. From the work of Malcolm J. Rogers in the early part of the 20th century to very recent work in anticipation of the extension of Fort Irwin, archaeologists have attempted to unravel the story of human activities here. This paper presents the history of archaeological investigations in the Cronese Basin: the archaeologists, the foci of their investigations, what they found, and what they said; the indigenous populations that frequented the shorelines and why they were there; and the implications of both the archaeology and cultural history for better understanding the regional prehistoric chronology, paleoecology, economic patterns, and lifeways.

The Mojave Validity Program: What it Is and What it Ain't

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The Validity Program, for the National Park Service at the Mojave National Preserve, is a means to determine which mining claims have valid existing rights. The California Desert Protection Act and the Mining in the Parks Act only allow mining to occur on claims that are valid. The determination of validity is a complex process that requires an extensive knowledge of mining law, geology, mining engineering, mineral processing, and mineral economics. The process must be impartial and not controlled by local or national politics.

A New Goat-like Camel from the Latest Blancan of the Tecopa Lake Beds, California

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A diversity of fossil vertebrates, including microvertebrates and at least four camels, were recovered from gypsiferous mudstones within the Tecopa Lake Basin of southern California. Most abundant in the fossil assemblage is a peculiar new camelid that appears to represent a late survival of the common Miocene subfamily Miolabinae. The fossils were recovered 2–3 m below a distinctive volcanic tuff that has been chemically correlated with the Huckleberry Ridge Ash bed, radiometrically dated at about 2 Ma.

This new camel displays an interesting combination both primitive and derived (specialized) characteristics. Notable among the primitive characters is retention of unfused metapodials (foot and hand bones) and retention of powerful upper incisors, morphological characteristics that can be found only in camelid lineages more than 20 million years old. Specialized characters include highly shortened feet and rapidly increasing size and hypsodonty from first to last molars. This combination of characters further suggest a long separate history for this new taxon. The short, powerful limb articulations, especially the goat-like proportions of the feet, represent adaptations for low-gear locomotion unique among camelids. Evidently this camel lineage lived undetected for more than 20 million years in mountainous terrain of western North America.

Carbonate-endemic Plants of the San Bernardino Mountains: Biology, Economic Conflict, and Conservation Efforts

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Five plants endemic or nearly endemic to carbonate soils of the northern San Bernardino Mountains are listed as threatened or endangered under the federal Endangered Species Act. Ranges of four of these (*Astragalus albens, Erigeron parishii, Eriogonum ovalifolium* var. *vineum*, and *Oxytheca parishii* var. *goodmaniana*) include commercially valuable limestone deposits north of Big Bear Lake, extending to the mountain foothills above Lucerne Valley and eastward. They generally occur in the pinyon and juniper belt on the desert-facing slope of the mountains. All four have some tendency to occur on naturally disturbed sites and two (*Erigeron parishii* and *Eriogonum ovalifolium* var. *vineum*) have been successfully introduced onto a road cut where they continue to propagate without intervention. Land use conflicts between conservation and mining have seemed likely to eventually force a legal confrontation involving the 1872 Mining Act and the Endangered Species Act. Instead, the mining industry, conservation advocates, and public agencies are attempting to resolve conflicts cooperatively. An eventual conservation strategy will likely involve land set-asides and listed plant reintroductions onto disturbed sites. The regular occurrence of the listed species on non-commercial carbonate substrates and their ecological tolerance of disturbed sites suggests that this strategy is viable.

Nuclear Dynamite — The Plowshare Program

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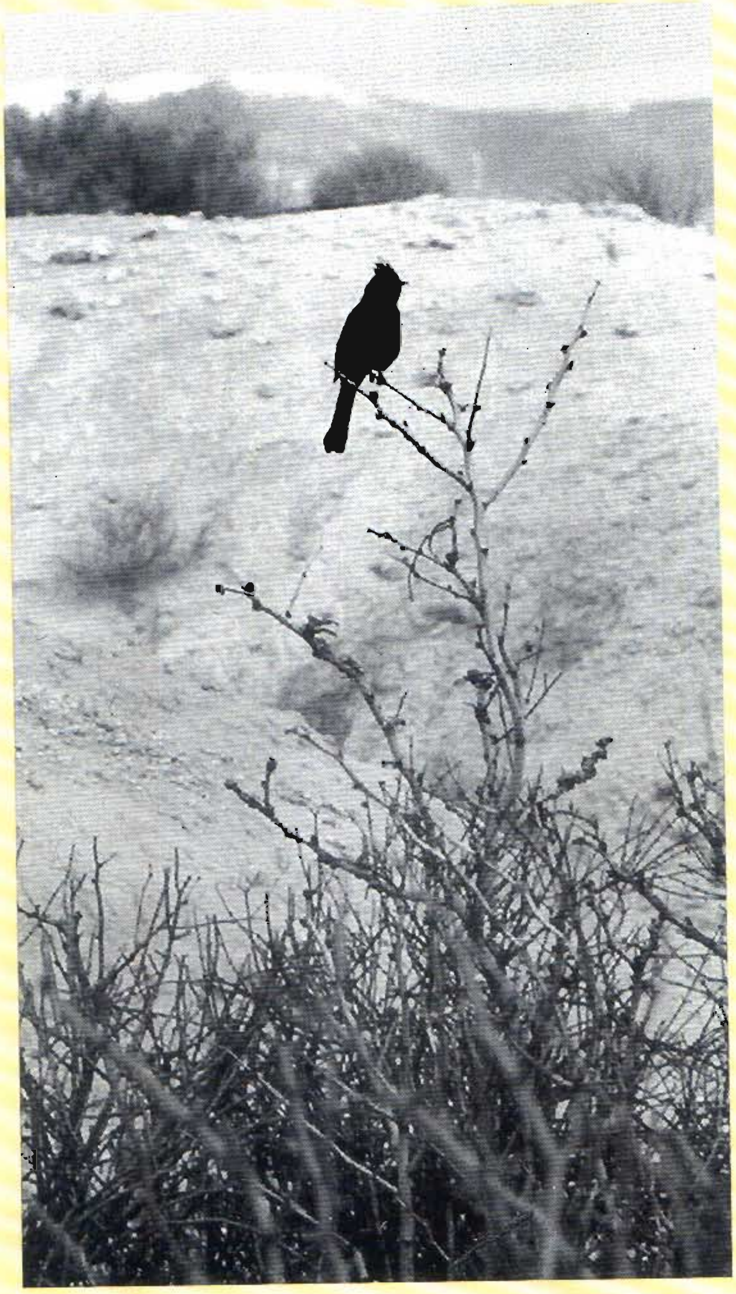
The most bizarre episode (so far) in the nation's nuclear history is the Plowshare Program conducted by the Atomic Energy Commission (AEC) between 1957 and 1973. The idea was to put weapons of mass destruction to work for peaceful purposes. Peaceful uses of atomic energy received impetus from the successful test of an H-bomb at Enewetak Atoll in the Pacific Ocean, which obliterated the island of Elugelab. The devastation lent perverse credence to Soviet claims of using nuclear dynamite for "razing mountains, irrigating deserts, cutting through the jungle, and spreading life, happiness, prosperity, and welfare." The so-called and highly-touted "clean bomb" seemed to provide a limitless supply of safe nuclear dynamite. Enewetak dramatically demonstrated that nuclear fusion explosions were powerful enough to excavate land, stimulating grand ideas among nuclear cheerleaders.

Plowshare program objectives including building a sea level canal across Nicaragua to replace the Panama Canal, and constructing harbors, dams, highways, and underground storage cavities. Other proposed projects were explosives development, producing heavy (transuranic) elements, and improving oil and gas production. Proponents of the program, principally Edward Teller and Glenn Seaborg, head of the AEC, waxed as poetic as the Soviets had in their claims of the possible accomplishments of peaceful nuclear explosions (PNE): projecting control of weather and earthquakes, defending the earth against comets and meteors, creating vast reservoirs of water in the desert, producing diamonds, and diverting rivers.

The Plowshare Program initiated 27 nuclear tests in all: six excavation projects, three natural gas stimulation projects, ten PNE explosives design tests, four heavy-element production tests, two emplacement-technique tests, one steam-power generating experiment, and one to test effects in carbonate rocks. Most of the Plowshare experiments were conducted on the Nevada Test Site, but six took place elsewhere in the continental U.S.

The Plowshare Program failed on many fronts. One after another the projects failed technically, and "clean detonations" were never achieved. Tests failed politically because they violated the conditions of the Partial Test Ban Treaty then in effect (which required containment of radioactive debris within the nation's boundaries) and the nascent environmental movement of the late 1960s helped to block AEC efforts to run roughshod over people living on and using the land to be blown up. Plowshare finally died when industry withdrew participation because of costs.

The Plowshare Program provides lessons about the need for involvement of an informed public in policy decisions that affect our everyday lives, and the lives of future generations. We and future Americans will both be limited by the radioactive residues of these experiments that will poison the ground and the water for thousands of years.



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San Bernardino County Museum Association Information for Authors

The San Bernardino County Museum Association publishes articles and monographs on subjects pertaining to the cultural and natural history of San Bernardino County and surrounding regions. We welcome submissions of such manuscripts.

Subject Matter: articles and monographs pertaining to San Bernardino County, inland southern California, and surrounding regions, in history, anthropology, archaeology, paleontology, mineralogy, zoology, botany, ornithology, and related disciplines. Manuscripts considered for *Quarterly* publication should be written toward the well-educated non-specialist. Technical research will also be considered for publication. All manuscripts should reflect original work which furthers knowledge in their fields.

Format: Two clear copies of the manuscript must be submitted to the Editorial Board with a letter of transmittal requesting that the manuscript be considered for publication and that it is not presently under consideration elsewhere. Manuscripts should be typewritten, double-spaced, on one side only of 8.5 x 11" paper. Ample margins should be allowed for editing comments. The first page should contain the title and author(s) name, address, telephone number and E-mail address, if applicable. The author's last name and page number should appear at the top of each following page. Include COPIES of figures, tables, and photographs. Do not send original photographs or figures with your initial submission.

Style: Authors should follow the standards for footnotes, citations, headings, and other conventions as applicable to their discipline. The Editorial Board suggests the following:

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History: American Historical Association *(American Historical Review)*
Geology: Geological Society of America *(Bulletin)*
Paleontology: Society of Vertebrate Paleontology *(Journal)*
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