Land of Lost Lakes
the 2003 Desert Symposium Field Trip

Robert E. Reynolds, Editor
LSA Associates, Inc.

with

Abstracts from the
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Front Cover. View southeast across Soda Lake playa toward the Cow Hole and Old Dad Mountains.

Back Cover. View northeast across Soda Lake playa toward the LIttle Cowhole Mountains and the Lava Beds district. Streams from springs incise the efflorescent saline crust that covers the playa. Brush and grasses are salt tolerant; mesquite trees have deep roots to reach fresh water.

Land of Lost Lakes:
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Robert E. Reynolds, *LSA Associates, Riverside, CA*
David Miller, *U.S. Geological Survey, Menlo Park CA*
Kim Bishop, *Department of Geological Sciences, California State University, Los Angeles, CA*

Introduction

With the expansion of urban areas in southern California and southern Nevada and the increased utilization of areas between for recreation, major hydrological studies have focused on the southwestern states, where Pleistocene drainage systems and the subsurface aquifer flow between basins are being examined. The literature over the past 30 years discussing Pleistocene basins refers to "green sediments" as the result of lacustrine deposition and as associated with intermittent playa deposits. Recent studies also recognize the presence of other water- and moisture-related deposition along fault scarps, at spring mounds, where bedrock causes aquifers to rise along water courses, in marshlands, and most importantly, in areas separate from those systems where evaporative discharge occurs.

Recent studies in the Mojave and Colorado deserts and the Basin and Range Province, also with scarce rainfall, have recognized that these are lands that may not have been filled with Pleistocene lakes. Instead, deposition provides evidence of seasonal, fluctuating, structurally controlled drainage systems that were not a direct result of pluvial rainfall creating lacustrine deposits in every internally drained southwestern basin.

This guidebook will examine different characteristics that represent lacustrine deposition, deposition around marsh lands and springs and deposition that is a result of evaporative groundwater discharge (E-GWD). The desert we will explore was thought of as a "Land that Lost Lakes," but since this guide reviews the presence of many deposits that occur as a direct result of hydrological discharge, this volume is called " The Land of Lost Lakes."

DAY 1

The route of Day 1 will introduce us to sedimentary features that are clearly lacustrine, deposited by Lake Manix. Our route will travel through Afton Canyon, a gorge that could only have been cut by a release of a large volume of water that eroded sedimentary dams. We will pass playas that suggest ephemeral lacustrine deposition. The day will end at West Cronese Lake, where we will see the contrast between a groundwater discharge platform and the playa surface of West Cronese Lake. We will see lacustrine features of Lake Manix (green, lamellar lacustrine siltstones, transgressive shoreline sand, tufa on conglomerate, flat pebble (shingle) beach bar, ponded back bay, terraces developed on the Mojave River Formation); fluvial features (incised meander, meander terraces, stream channels, fluvial sand and gravel); groundwater discharge platform (unbedded silts, carbonate cemented silts, efflorescent salts); playa features (tan, laminated silts, mud cracks and rip-up clasts, cross-playa channels). Discussion will attempt to determine why the deposits are separate and distinct.

0.0 (0.0) Convene in central Baker at the intersection of Highway 127. Start with a full tank of gas for the 100-mile day. Enter I-15 and proceed west to the Basin Road offramp.

6.1 (6.1) Pass Zzyzx Road.

11.9 (5.8) Pass Razor Road.

15.6 (3.7) Exit the freeway.

15.8 (0.2) Stop, TURN LEFT (south).

16.1 (0.3) PARK on the open area at the Basin Road offramp.

Stop 1.1. Ventifact Hill. Lake Manix breached 18.1 ka, approximately the glacial maximum (17.8 ka) (Meek, 1999). The sudden availability of sand from the Mojave River delta caused granitic ventifacts to be carved by the wind (Laity, 2000). HIKE EAST, uphill, to view granitic ventifacts. East Cronese Lake lies to the north, and West Cronese Lake is further north through the pass. These "twin lakes" were on an alternate route used by emigrants (Lyman and Walker, 1999) traveling south from 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, 2000). Return to vehicles and proceed south to the sand fields of the Mojave River Sink.

16.8 (0.7) Pass a BLM kiosk.

18.0 (1.2) Take the left fork in the road.

20.4 (2.4) Bear right.

20.9 (0.5) TURN LEFT (south) at the intersection on the north side of the tracks. The road bends south and then west, parallel to the tracks.

21.3 (0.4) Enter "Afton Canyon Natural Area" (BLM sign).

21.4 (0.1) Cross the river and TURN LEFT (west) on the north side of the river parallel to the railroad tracks.

22.0 (0.6) Pass the site of the box car (Reynolds et al., 2000) buried in place by the railroad. The boxcar does not sit on buried tracks. The railroad bridges have 1926 and 1928 dates, and are similar to the 1905 grade. Photographs of the 1938 flood do not show a box car in the river channel. The rate of decomposition since 1985 suggests that the box car could not have been in the channel for many years.

22.9 (0.9) PARK at Bridge No. 194.65, dated 1928.

STOP 1.2. Slot Canyon. This slot canyon suggests that rapid incision has occurred during the formation of Afton Canyon. The topography (Cave Mtn 15' quad) suggests that overflow from Lake Manix could have occurred at locations below 1800' both north and south of the present Afton Canyon. This tributary has incised in response to the rapidly lowered base level of Afton Canyon. The vertical incision of antecedent streams draining Lake Manix 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. Look east to the termination of the cliffs with gravel dipping 15º. The gravels have a silty component near the cliff base; higher cliffs are solid gravel. Look southwest to colorful, fault-disrupted Miocene volcanics and the contact with overlying indurated gravels that may be equivalent to the Mojave River Fm. These gravels were incised rapidly, perhaps along fault-generated fractures.

24.5 (1.6) Drop down to the road at river level. Take the lower road, dropping away from the tracks but staying parallel to them on the south side. On the south channel wall are two openings — the historic "caves" — just above the modern channel floor. Excavation of the caves has revealed evidence of historic occupation, including square nails. "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 Formation abutted by the Manix/Afton Fault against red and black Tertiary volcanics (Meek and Battles, 1991).

25.2 (0.7) At Trestle 3 (192.227), drop into a wet river crossing without stopping, BEAR RIGHT under trestle, and climb up the hill.

25.4 (0.2) PARK at the wide pullout of top of a small hilltop that offers a good, easily accessible view of the upper end of Afton Canyon.

STOP 1.3. Incised Bedrock Meander. North of this stop is a contact of Miocene rocks overlain by the Mojave River Formation (Bortugno and Spitler, 1986), in turn overlain by sediments of Lake Manix. Eastward, you can see the mouth of a tributary canyon incised into dark reddish-brown and gray crystalline bedrock. This canyon leads into the bay behind North Afton Beach Ridge and Shoreline Hill. Its deep incision into solid bedrock has occurred since Lake Manix drained about 18 ka (Meek, 1999).

Notice how the Mojave River forms a large incised meander as it passes beneath the trestle and then travels to the south around the large bedrock ridge blocking its path. Incised meanders are an unusual landform; another meander occurs at the "Big Bend" of the Mojave River twelve miles upstream. An incised meander indicates that the course of the river was predetermined by subsurface structures. The cause of this meander may be related to positions of beach ridges that no longer exists (Blackwelder and Ellsworth, 1936). When the lake basin was breached, the initial outflows were diverted around the beach ridge, and the subsequent incision trapped the river in a meandering channel. Although the beach ridge has completely eroded away, the river platform indicates it once formed a local topographic barrier.

The crest of the meander ridge is capped with Mojave River gravels, showing that the river once flowed above the ridge. A series of terraces atop the bedrock ridge show how the river meander gradually increased in size as the canyon was incised.Return to vehicles and PROCEED west.

25.8 (0.4) Pass site of Afton Station, 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 only foundations. A small cemetery is just north of the main cliffs. 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).

South of the trestle is habitat for the western pond turtle, *Clemmys marmorata*, protected by the State of California. Recent surveys (Lovich and Meyer, 2000) confirm that many populations have been extirpated or are declining. 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 is infested with the exotic pest plant saltcedar, *Tamarix ramosissima,* replacing an estimated 70 percent of the native riparian vegetation, although the BLM has done an excellent job of removal. The changes in channel morphology and hydrology associated with saltcedar invasion 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.

26.2 (0.8) TURN RIGHT diagonally off the berm and go through a water crossing. Proceed slowly but steadily; if you go too fast or if you stop, your engine may drown.

26.4 (0.2) Pass the entrance to Afton campground.

26.8 (0.4) The terrace holds the Afton Canyon group camp site. The road climbs through the Mojave River Formation (Jefferson, 1999; Nagy and Murray, 1990, 1991). Note the thick caliche and tan silts.

27.4 (0.6) PARK on the lower terrace.

STOP 1-4. Structural terraces. The lower terrace is heavily cemented with pedogenic carbonates of the Mojave River Formation (Nagy and Murray, 1990). 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 its south side. The Cady Mountains 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 tufa is believed to be from the initial rise of an OIS 6 lake (~190 ka). Thick green clays (ahead) 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, Jefferson, 1999; Reynolds et al., 2000). 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. PROCEED NORTH.

27.9 (0.5) Note the patch of green Lake Manix silts on the middle terrace (elevation 1720')

28.3 (0.4) Pass under power lines. Red Pliocene gravels crop out to the north.

29.4 (1.1) Stop before I-15 intersection at frontage road.

STOP 1.5. Beach Ridge. We are at the 1780' shoreline of Lake Manix. Walk east to see the imbricated flat pebble 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 at the Wisconsinan glacial maximum, 18,000 ypb (Meek, 1999), 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 (1781'), although the maximum lake stage was normally 2 to 3 m lower. Storm overwash built 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. Return to vehicles, PROCEED NORTH across the overpass.

Fig. 1. Three layers of limonite-stained tufa suggest sub-aerial weathering episodes during Lake Manix low stands. R.E. Reynolds photo.

Fig. 2. Hematite-stained tufa caps on beach cobbles. R.E. Reynolds photo.

Fig. 4. A small population of crucifixion thorn bush grows with creosote on and around a playa. R.E. Reynolds photo.

29.8 (0.2) Cross over I-15 at Afton Road. The Old Spanish Trail ran 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.

30.0 (0.1) TURN LEFT on Frontage Road.

30.3 (03) PARK.

STOP1.6. Tufa-Coated Cobbles. Walk south (left). The road cut on the south side of the road contains brown, degraded tufa on cobbles. The tufa stiff effervesces with application of acid, but has been stained brown by limo-

nite, suggesting exposure and weathering during one of the low stands of Manix Lake. PROCEED WEST, upsection, through the lake sediments.

30.8 (0.4) LOOK SOUTH at youngest cobbles capped by white tufa.This outcrop exhibits the contact between silty distal conglomerates and overlying lacustrine sediments (Awramik et al., 2000). This contact increases in elevation to the east as the sediments from Lake Manix moved upslope over time. Some of the large cobbles that were exposed in shallow water at the top of the conglomerate are coated with white tufa, a biological carbonate precipitate.

In certain cases wave action apparently rolled these cobbles because the tufa entirely surrounds them, although generally one side of the cobble has a thicker rind indicating it was up for a greater length of time. Return to vehicles, PROCEED WEST.

31.2 (0.4) Slow, TURN NORTH (right) at the end of Frontage Road. The pavement gives way to graded dirt.

32.0 (0.6) Pass a ridge of "Pliocene" gravel. (Jennings et al., 1967).

33.1 (1.1) Enter "Crucifixion Basin." Its central playa has a surface elevation of 1860.'

33.4 (0.3) Pass a right turn to the playa.

33.7 (0.3) Pass a right turn to

Fig. 3. White tufa caps on beach cobbles mark the most recent transgression of Lake Manix. R.E. Reynolds photo.

the Green Stone commercial and decorative aggregate mine.

34.0 (0.4) Stay left around the playas. These small playas sit at elevation 1857.' It is interesting to speculate whether they developed along a north-northwest trending fault or are a product of overflow from the wash (ahead) that fills West Cronese Lake.

34.8 (0.8) Pull out on right and PARK.

STOP 1.7. Crucifixion Thorn. Walk east into the playa to the crucifixion thorn bush site (Lum, this volume).

35.3 (0.7) Cross the wash that drains the northeastern Alvord Mountains and runs east to West Cronese Lake.

36.1 (0.8) The road bears northwest.

37.0 (0.9) TURN RIGHT onto the power line road.

37.7 (0.7) Pass through tan Miocene sediments.

38.3 (0.6) View at 10:00 (north) of tan Miocene silty sands and gravels overlain by gravity slide blocks of Paleozoic carbonates and Proterozoic metamorphic rocks.

38.5 (0.2) Pass outcrops (left and right) of chaotic meta-

morphic rocks overlying Miocene sediments.

39.4 (0.2) Cross the wash that drains east to West Cronese Lake.

39.6 (0.9) Leave the tan Miocene playa sediments. Cross a northwest-trending fault and enter the "Pliocene basalts" (Jennings et al, 1962) that overlie Miocene sediments.

40.3 (0.7) 10:00 view north of a domed basalt flow nicknamed "The Whale." This view of its southwest side shows steeply tilted blocks along a linear structure, possibly a fault. This structure is north along strike from the mapped fault that we just crossed. The "domed" appearance could be caused by compression between that fault and the left-lateral strike slip Bicycle Lake - Bitter Spring Fault Zone (Byers, 1960).

40.7 (0.4) Leave the Pliocene basalts.

42.4 (1.7) Bitter Springs (Dill) Wash. TURN RIGHT (southeast) off the powerline road and follow the wash to the corral.

46.7 (4.3) BEAR LEFT (east) to the corral.

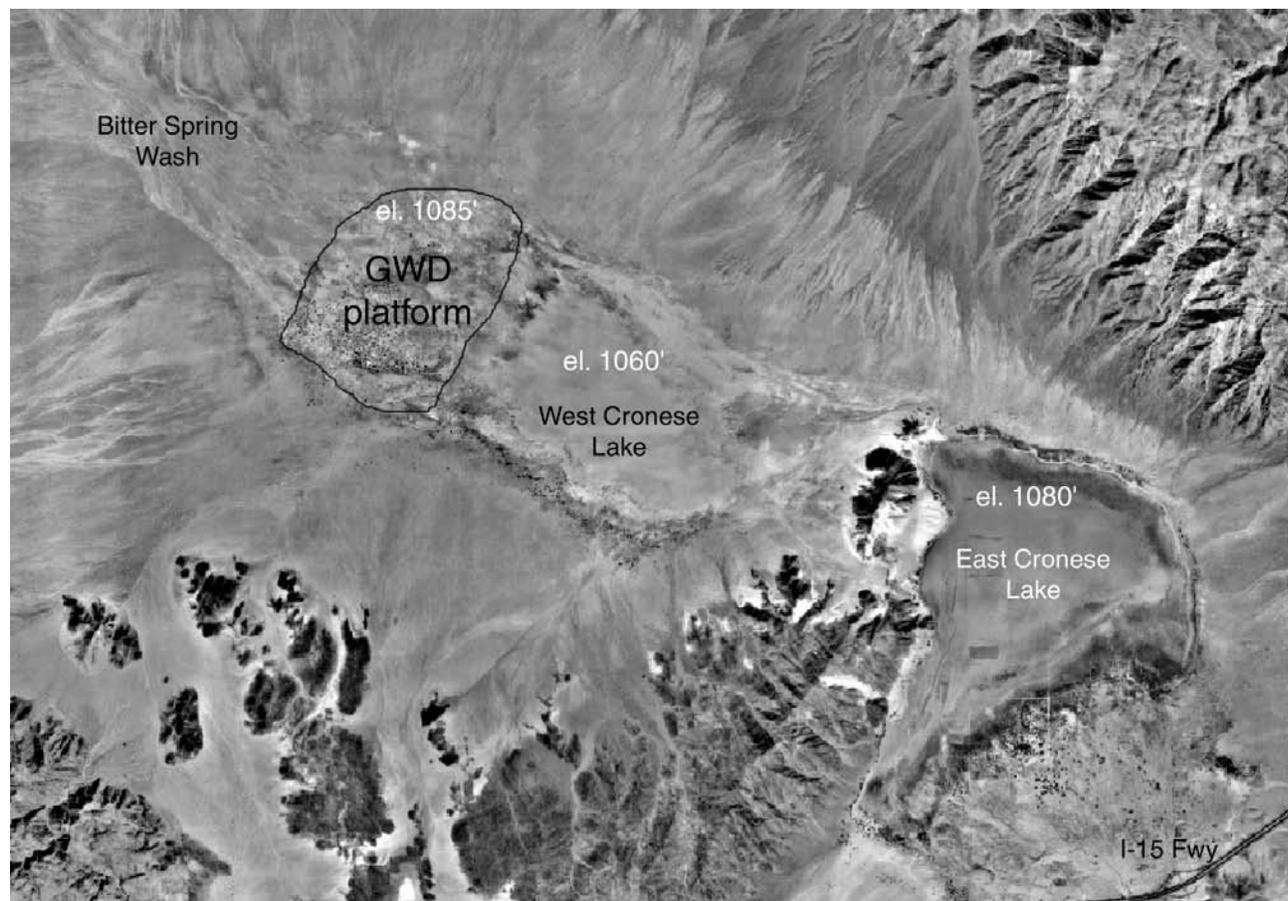46.9 (0.2) Proceed south on east side of the corral.

Fig. 5. Cronese Basin and west and east lakes are an alternate terminus of the Mojave River. The West Cronese GWD platfrorm is located at the confluence of three drainages from the west and north, and stands above the West Cronese playa surface. Image courtesy D. Miller.

Feature	Lacustrine	Marsh	GWD	Soil Profile

Stop 1-8 worksheet.

47.1 (0.3) PARK before reaching the mesquite trees.

STOP 1.8. West Cronese Platform. We are on a ground-water discharge (GWD) platform where ground water carrying salts and calcium carbonate evaporate, leaving deposits of precipitant in silt that is captured from atmospheric deposition by abundant vegetation. West Cronese Lake is to the south and East Cronese Lake is further southeast through the pass. Why is this GWD platform located at a point north of West Cronese Lake? Our route crossed three major drainages, including Bitter Spring Wash, that were directed toward this point. The outwash from the drainages are three commingling sandy deltas that merg with the GWD. Groundwater discharge probably enhances vegetation and reduces stream gradient, both of which effectively terminate fluvial systems. Ground water will percolate vertically and evaporate on a daily basis, leaving cemented sand and silt at elevations 20' to 30' above the 1060' playa of West Cronese Lake. Note the steep scarp between us and the lake, a common feature in springs and wetlands, and a feature easily confused with fault scarps. Use the following chart to note features that contrast the GWD platform with the playa. Return to vehicles; RETRACE to the powerline road.

52.4 (5.3) TURN LEFT (west) at the power line road.

57.8 (5.4) TURN LEFT (south) at "Afton" Road

63.5 (5.7) TURN LEFT (east) before you reach the freeway and meet the pavement at Frontage Road.

64.9 (1.4) Enter I-15 heading east.

83.0 (18.1) Continue past Zzyzx Road.

89.2 (6.2) Central Baker offframp. Be sure to refuel your vehicle. End Day 1.

DAY 2

What We Will See

The routes of Day 2 and Day 3 will cross terrain and topography that is a result of Miocene extensional tectonics and the development of the right-lateral Southern Death Valley–Avawatz–Soda–Bristol Fault Zone. A stop at the Iron King Mine east of Red Pass will suggest the pre-Miocene structural setting.

Our search for cool, clear water that once spread across the burning sands will start near the gate to Zzyzx, as we look at fault-controlled springs adjacent to the vast, shimmering playa of Soda Lake. We will examine examples of groundwater discharge and evaporative discharge at Halloran Summit and Valley Wells, the latter showing characteristics of both ponding and spring activity. We will pass the playas of Silver and Silurian Lakes and discuss stratigraphy and topographic features at Salt Spring Playa. The trip will end in Tecopa Basin, where we can see and discuss greenish silts with planar bedding, mud cracks

Fig. 6. View south of western Soda Lake playa and spring-fed ponds. Old Dad Mountain, along the Day 3 route, is in the distance. R.E. Reynolds photo.

and rip-up clasts, and ripple marks, contrasting these with featureless siltstones that may represent groundwater discharge "platforms."

0.0 (0.0) Convene at Zzyzx with a full tank of gas for the 280 mile trip.

0.1 (0.1) Pass through swinging pole gate.

1.2 (1.1) **STOP 2.1. Soda Lake Playa.** We are at the west margin of Soda Lake Playa, known to be filled with water in the latest Pleistocene (Wells and Reynolds 1990; Wells, Anderson, et al, 1990; Wells, Miossec et al, 1990). The road marks the contact between the Soda Lake Playa and conglomerates of granitic, volcanic and marble clasts. The desert varnish on blocks of rock upslope has been degraded by salt weathering and wind erosion. The flat playa to the east contains tan silts with white concentrations of salts and carbonates. Local springs keep the distal fan-glomerates and playa silts wet, to the point where streams trickle across the playa. Not only does water leave the area by spring flow, but evaporates directly from open sources, from vegetation, and from the silts. This evaporation produces some of the white precipitants that effloresce on the silts, and produce a "puffy" surface on the playa.

Several plant communities are encountered. On the east side of the road (western shore of Pleistocene Lake Mojave) are several "islands" of salt marsh vegetation associated with ground water seeps produced by the interaction of the Soda Mountain watershed and the relatively high ground water table under Soda Lake Playa. These marsh communities exhibit some zonation of salt tolerant (halophytic) vegetation, with salt grass (*Distichlis spicata stricta*) forming the outer-most band, intermixed with alkali weed (*Cressa tuxillensis minima*), Nitrophilia (*Nitrophila occidentalis*), and locally lowland purslane (*Trianthema portulacastrum*). Working inward on these vegetation islands (wetter and less saline soils), the following can be encountered: the broad-leaved yerba mansa (*Anemopsis californica*), rushes (*Juncus balticus* and *cooperi*), and sedge (*Scirpus americanus*). Some of the seeps also support stands of common reed (*Phragmites australis*) and narrow leaved cat-tail (*Typha domingensis*). From late November through mid-May, some of these seeps support shallow pools, which act as breeding habitat for Pacific tree frogs (*Hyla regilla*), and attract migratory waterfowl.

Also associated with these sites are marsh wrens (*Cistothorus palustris*), the hawk-like northern harrier (*Circus cyaneus*), desert cottontail rabbits (*Sylvilagus aududoni*), and larger predators such as coyote (*Canis latrans*), bobcat (*Lynx rufus*) and gray fox (*Urocyon cinereoargenteus*) seeking prey and water. On the distal ends of the alluvial fans bordering the west side of Zzyzx Road, additional salt and alkaline tolerant plants are found, including inkweed (*Suaeda moquinii*), alkali goldenbush (*Isocoma acredenia ermophilia*), and the salt-bushes desert holly (*Atriplex hymenelytra*) and allscale (*Atriplex polycarpa*). Father up the alluvial fans, and the bajada slope ascending to I-15, are classic Creosote Bush (*Larrea tridentate*)–White Bursage (*Ambrosia dumosa*) plant communities common on well drained soils at moderate elevations in the Mojave Desert (Rob Fulton, site manager, Desert Studies Center, p.c. 2003).

Look slightly south of west from this stop up the canyon in the Soda Mountains to see the Paleozoic/Mesozoic stratigraphy. Near the top of the ridge is a large light colored outcrop Paleozoic carbonate. Below the carbonate is dark colored Mesozoic metavolcanic rock. Most of the Soda Mountain area exposes more of the metavolcanic rocks. The carbonate is a klippe (erosional remnant) of an allochthonous sheet that Grose (1959) proposed once covered the entire Soda Mountains area along a major low-angle fault. An important question in understanding the geology of this region is whether or not Grose's (1959) hypothesis is correct. The next two stops will further investigate this question. As a note of interest, the carbonate seen at ZZYZX behind the kitchen area is also a part of the proposed allochthon.

4.7 (3.5) Enter I-15.

11.0 (6.3) Pass Kelbaker Road, central Baker. Proceed east on I-15.

24.4 (13.4) Pass the Halloran Spring offramp.

29.9 (5.5) Exit I-15 at Halloran Summit.

30.2 (0.3) Stop, TURN LEFT (north) over I-15.

30.7 (0.4) TURN RIGHT (east) at fiber optic road (marked with red-orange signs).

31.2 (0.5) Pass a left turn (north) near a dated basalt (4.25 Ma, Turrin and others, 1985).

Feature	Lacustrine	Marsh	GWD	Soil Profile

Stop 2.2 worksheet.

Fig. 7. View north of Valley Wells sediments showing units C, D, E and G. R.E. Reynolds photo.

Groundwater Discharge Sediments. Previous work on vertebrate fossils (Reynolds and Jefferson, 1971, 1988; Reynolds et al, 1991) indicates the sediments range in age from late Pliocene (2.2 Ma) to Late Pleistocene (<300,000 ka). Erosional unconformities and soil profiles are present which account for a period of 2 million years and three land Mammal Ages in just 28 feet of section. The sediments have been divided into seven units (Reynolds et al, 1991) (Table 1).

Characteristics of the prominent caliche cap indicate that it may have taken more than 300,000 years to form (Reynolds, 2001). This cap is hard, cemented, and contains abundant nodules. Recent review suggests that some of the units contain features originally referred to as lacustrine that may actually be GWD features. WALK NORTH through the units and discuss what the features indicate. Return to vehicles, RETRACE to Excelsior Mine Road. An active spring mound can be found adjacent to the large cottonwood tree at the Valley Wells copper smelter site about a mile north of here. The mound is a gently convex-upward feature composed of white to brown silt and find sand, covered by sparse grasses requiring perennial ground water. The cottonwood and mesquite trees suggest fresh ground water at depth.

32.4 (1.2) **STOP 2.2. Windmill Station**. PARK at a shallow wash cut into white carbonate and tan siltstone. The carbonate is probably of both groundwater origin and pedogenic. At this location, underlying Miocene sediments and glassy ash are exposed along the east side of a north-striking fault. This fault may influence groundwater, causing damming of water and past discharge here. Lack of phreatophytic plants indicates the GWD are old. Discuss characteristics of this outcrop that indicate GWD and how to differentiate the probably pedogenic overprint on the GWD. Continue east on power line access road.

33.2 (0.8) Pass through a gate, closing it if found closed.

36.3 (3.1) Cross a sand wash without stopping.

36.5 (0.2) Pass through a second gate; close it if found closed.

37.6 (1.1) Stop at the pavement of Excelsior Mine (Cima) Road. Look for traffic and proceed across.

37.8 (0.2) **STOP 2.3. Valley Wells Lacustrine and**

37.9 (0.1) Stop at Excelsior Mine Road. TURN RIGHT.

38.2 (0.3) Pass under the transmission line.

Table 1. Valley Wells soil profiles.

Unit	Description	Age
Unit G	Pink, gypsiferous playa siltstones	Rancholabrean LMA (late Pleistocene)
Unit F	Pale siltstone	
	Local unconformity	
Unit E	Pedogenic carbonate	Irvingtonian LMA (mid Pleistocene)
Unit D	Greenish siltstone, efflorescent toward top	
Unit C	Pinkish siltstone, sandstone, and limestone gravel	
	Unconformity	
Unit B	Silty peat	Late Blancan (Pliocene)
Unit A	Green and brown siltstone and claystone	

Fig. 8. A black layer sits above green siltstone and below thick pedogenic carbonate at Valley Wells. R.E. Reynolds photo.

Feature	Lacustrine	Wash	GWD	Soil Profile

Stop 2.3 worksheet.

38.4 (0.2) Slow for a bend.

38.9 (0.5) Pass a right turn to the Valley Wells copper smelter. Look for a pile of gravel on the left (west).

39.3 (0.4) TURN LEFT on the water line road just past the gravel pile. A 50 mph sign is on the right.

39.9 (0.6) **STOP 2.4. Transverse Pan Surface**. Stop at crossroads and terraced desert pavement with "transverse pans." This example of transverse pans overlying well-developed pedogenic carbonate is typical of what can be seen at several places in the Halloran Hills and may indicate a marker horizon developed above and since the development of the circa 0.3 Ma. pedogenic carbonate. RETRACE to Excelsior Mine Road.

40.6 (0.7) TURN NORTH on Excelsior Mine Road. Pass Valley Wells (Rosalie) cemetery.

41.9 (1.3) Pass through a saddle in Miocene conglomerate consisting of Paleozoic rocks from Clark Mountain and the Mescal Range.

43.7 (2.8) The road bends left. Pass a right (east) turn to Pachalka Spring.

44.2 (0.5) Pass a right turn to the Colosseum mine.

45.1 (1.9) TURN LEFT (west) onto the power line access road.

48.7 (3.6) Pass right turn (north) to Shadow Mountain.

49.6 (0.9) Pass a right turn (north) to Shadow Mountain.

50.4 (0.8) Pass a left (southwest) turn to Francis Spring and Halloran Spring.

53.1 (2.7) View north at 2:30 of beige, fine-grained sediments in Shadow Valley Basin. They are overlain by coarse basin fill and avalanche breccia and then by slide blocks such as Shadow Mountain.

54.8 (1.7) The road bears left at the crest.

55.1 (0.3) Caution: slow. We are in an area where the road has many sharp bends, tight curves, and poor visibility.

55.4 (0.3) Slow for sharp bend.

55.8 (0.4) Pass through a saddle in Paleozoic landslide breccia. These Paleozoic rocks sit on east-dipping Miocene sediments that have produced fossil rodents and fossil fish.

Pyroxene andesite exposed one-quarter mile south in Willow Wash is located below these lacustrine sediments.

56.1 (0.3) PARK at Willow Wash.

STOP 2.5. Willow Wash. Hike north to examine pedogenic carbonate.

56.4 (0.3). The hill at 9:00 (south) is the same lithology as Squaw Mountain, with bleached carbonate that may be the equivalent of the Riggs carbonate.

56.6 (0.2) Prepare for dips.

57.9 (1.3) Cross Beudantite Wash. Sediments to the south in this wash have produced fossil fish. There is a pipeline metering station on the right. Were we to go a mile north and downstream in this wash, we would encountered a northern exposure of the mid-Tertiary erosional surface on granite covered by pyroxene andesite and lacustrine sediments.

58.1 (0.2) Pass a north-striking contact. We are between the mid-Tertiary erosional surface and the pyroxene andesite and lacustrine sediments. Here the mid-Tertiary erosional surface trends north and is overlain by pyroxene andesite and lacustrine sediments.

61.6 (3.5) Powerline road.

62.2 (0.6) Caution; slow for left bend.

62.9 (0.7) Pass a right turn to Riggs Wash.

63.6 (0.7) Look north at talc mines, and northwest (2:00) to fans emanating from the Avawatz Mountains.

64.2 (0.6) Pass a left turn to Cree Camp.

65.7 (1.5) Pass a left turn to Hayten's Well. Note the carbonate kernals in the road berm and well-developed desert pavement to west at 1:30. View north-northwest along the north-dipping surface of Valjean Valley supported by pedogenic carbonate.

66.3 (0.6) Pull into the pipeline clearing on the right and PARK.

STOP 2.6. Riggs Wash. WALK 300 feet west to pedogenic carbonate. This carbonate is at the same elevation as the low, concordant summits planed by erosion on the quartz monzonite ahead.

Fig. 9. Valjean pediment, panoramic view. Pedogenic carbonate on the north flank of the Halloran Hills is overlain by well-developed desert pavement and controls the surficial drainage system. R.E. Reynolds photo.

69.0 (2.7) Leave Riggs Wash.

70.5 (1.5) Top of rise. TURN LEFT toward the site of Silver Lake.

72.1 (1.6) Reach the pavement of Highway 127. This is the site of the second community of Silver Lake, along the grade of the Tonopah and Tidewater (T&T) railroad, completed in 1907 as part of F.M. "Borax" Smith's development of borate mines in Death Valley. It operated between Ludlow and Beatty, Nevada, by way of Silver Lake, Tecopa, and Death Valley Junction. Tracks for the T&T were laid here in 1906; the line was abandoned in 1939.

Fig. 10. Gravel pit at shoreline on the west side of Silver Lake contains a 15–14 ka sequence of *Anodonta* shells in lacustrine sands interfingering with tufa-coated cobbles. R.E. Reynolds photo.

The grade has been flooded at this location several times since its construction (Wells and Reynolds, 1990). Watch for traffic and PROCEED across pavement; follow the dirt road across Silver Lake.

73.5 (1.4) View northwest of a dark butte incised by shorelines of Pleistocene Lake Mojave. The shorelines date between 18 Ka and 11 Ka (Brown et al, 1990; Orr and Warren, 1971).

73.9 (0.4) Pass a gravel pit on the right. The principal source of the gravel was from a wave-built gravel bar. In the walls of the pit, shoreline features can be observed in cross-section. Tufa deposited on cobbles by blue-green algae is present as are articulated and disarticulated shells of the clam, *Anodonta californica* (Schneider, 1994; Warren and Schneider, 2000). These shells provided initial dates of Lake Mojave shorelines in a regular progression from 13,670±550 BP to 8,350±300 and 9,160±400 BP (Orr and Warren, 1971; Brown and others, 1990).

74.5 (0.6) Continue through the junction with the LADWP power line road.

75.1 (0.6) Crest of saddle.

75.4 (0.3) PARK at base of hill.

STOP 2.7. Iron Mountain Road. Look west-southwest across the wide valley to the high peak at the north end of the Soda Mountains known as Spectre Spur. The lighter colored rock comprising the main mass of Spectre Spur is Paleozoic carbonate. This carbonate is bounded to the south and north by outcrops of dark colored Mesozoic metavolcanic rock. The contacts between the carbonate and the metavolcanic rock on both sides are

Feature	Lacustrine	Wash	GWD	Soil Profile

Stop 2.8 worksheet.

high angle faults. There have been two interpretations for the structural configuration of the carbonate and metavolcanics. Grose (1959) suggests that the carbonate is another klippe of the allochthon seen at Stop 2.1. According to Grose (1959), the carbonate block has been downdropped along the two faults so that the basal fault is not exposed.

Walker and Wardlaw (1989), on the other hand, do not believe the carbonate is a klippe. They propose that the carbonate is part of a fault block that has been uplifted from below the metavolcanic rocks. If they are correct, then Grose's (1959) proposal of a major allochthon across the entire Soda Mountains is in doubt.

76.0 (0.6) Cross the wash.

76.4 (0.4) Pass a right turn to the southern Avawatz Mountains and outcrops of the Avawatz Formation (Spencer, 1990; Whistler and Reynolds 1991).

80.7 (4.3) The small knob on the road side is a gravity slide block of Mesozoic volcanics over Miocene silts.

80.9 (0.2) The Iron King mine entrance is to the left.

81.0 (0.1) **STOP 2.8. Iron King Mine** (Wright and others, 1953). Exit vehicle and walk a few hundred feet around the southeast end of the hill to an open pit – the Iron King

Fig. 11. Gravity slide of Jurassic volcanic rocks emplaced on siltstones of the Avawatz Formation. R.E. Reynolds photo.

Mine. The hill exposes megabreccia of a large-runout landslide in the Miocene Avawatz Basin. The pit is excavated in megabreccia comprised of hydrothermally altered metavolcanic clasts. Upslope is megabreccia comprised of Paleozoic carbonate clasts. The contact within the megabreccia separating the zones of the two types of clast lithogies is well-exposed in a dozer cut above the pit. Note that the contact is distinct and that it dips northerly. The dip of sedimentary strata within the Avawatz Basin at this locality is also toward the north. Thus, if the basin strata were restored to horizontal, the contact between the two breccia types would also restore to horizontal with the carbonate megabreccia on top of the metavolcanic megabreccia.

The only possible source for the metavolcanic type megabreccia is the surrounding hills to the south and east. The carbonate megabreccia on top of the metavolcanics was carried into the basin as part of the same landslide. This outcrop provides evidence that the nearby Mesozoic metavolcanic basement rock outcrops were once structurally overlain by Paleozoic carbonate. This, in turn, supports Grose's (1959) hypothesis that a regional-scale allochthon consisting of Paleozoic carbonate once covered the entire Soda Mountains. It is inferred that the carbonate block exposed at Spectre Spur (Stop 2) is a part of the allochthon. RETRACE to the left turn to Silver Lake, a terminal dry playa (Forester et al, this volume).

81.3 (0.3) Right bend in road; proceed east.

86.4 (5.1) Pass the road leading to the southern Avawatz Mountains.

87.7 (1.3) Pass through a saddle.

88.2 (0.5) Pass through the power line junction.

88.9 (0.7) The west shoreline of Silver Lake. Proceed east.

90.7 (1.8) Highway 127. Watch for traffic; TURN LEFT (north) onto the highway.

91.9 (1.2) Pass a power line.

92.4 (0.5) From top of this rise is a good view of fanglomerates on the east margin of the Avawatz Mountains. The older fans vis-

ible from here appear to be over-steepened, perhaps by thrusting. Transpressional uplift at the intersection of the Garlock and Death Valley fault zones resulted in young uplift of the Avawatz Mountains, largely composed of Mesozoic diorite. On the eastern range front the diorite is faulted over Quaternary alluvial fan deposits at the head of the impressive Avawatz bajada. Note the steepness of the alluvial fans.

Highway 127 leaves the Silver Lake Basin and descends into Silurian Valley, marking the present divide between the Mojave River and Salt Creek drainages. Salt Creek flows northward through Silurian Valley and joins with the Amargosa River just north of the Dumont Basin. Late Pleistocene overflow from Lake Mojave would have flowed through Silurian Valley, supplying water to Lake Dumont or flowed through the basin to join with the Amargosa River. Present data suggest there was no overflow from the Silver Lake Basin prior to Lake Mojave I high stands (about 22 Ka) and none after the latest Mojave II high stand (about 8.7 Ka).

The low distant hills north of the Silurian Hills to the northeast are the Shadow Mountains. The range on the skyline is the Kingston Range, with a central massif composed of late Miocene granite. The lower hills at the base of the range are the Valjean Hills. Several northwest-trending faults that cut through the Valjean Hills exhibit evidence of right-lateral displacement. They juxtapose late Proterozoic rocks of the Valjean Hills against Miocene granite (12.1 Ma, Calzia, 1997) on the west side of the Kingston Range (McMackin, 1977).

To the north, the broad range of low hills on the skyline is the Sperry Hills (also known as the "Tecopa Hump." McMackin (1997) suggests that the Tecopa Hump formed as a transpressional uplift at the intersection of the Valjean Hills shear zone and the Crystal Spring fault zone which enters the Sperry Hills from northeast of the Kingston Range. The Silurian Valley in the foreground is interpreted to be a transpressional depression. Much of the floor of the Silurian Valley depression is overlain by the Valjean sand sheet which may be of early Pleistocene age. In the western part of the valley, the well-developed calcrete layer beneath the sand is cut by the most recent movements on the Valjean Hills shear zone.

97.0 (4.6) Cross the channel of Salt Creek near the bend in the road. Note that the channel is only slightly inset into fans.

99.9 (2.9) Continue past the turnoff to Riggs (Duffield-Stoll, 1996). Silurian Lake ahead on the right is an example of a dry playa, one that has no groundwater discharge and probably receives some water percolation in response to inundation by floodwaters. It is also interesting in that it is not in a terminal valley position, like many plays; water flows in at the south via Salt Creek and exits on the north also by Salt Creek. In essence, it is a flat spot in the creek bed where the creek spreads widely, reduces in velocity to almost nil, and drops both bed load and suspended load (Forester et al, this volume).

110.4 (10.5) TURN LEFT across traffic into lake sediments. PARK.

STOP 2.9. "Lake Dumont." The pale olive green, white, and brown sediments are latest Pleistocene lake, evaporite, and associated deposits with radiocarbon ages ranging from 27,500 to 14, 910 BP. These dates differ from the time of basin filling of the Soda/Silver Lake system studied extensively by Ore and Warren (1971) and S.G. Wells and his colleagues (e.g., Wells et al., 1989; Enzel and Wells, 1997). The sediments overlie older playa and alluvial fan deposits exposed across the basin and are largely preserved along the margins of Dumont Basin (Anderson and Wells, 1996, 1997; Ritter, 1990). Two15-m deep cores contain stratigraphic and paleoecological evidence for perennial lakes estimated to range between 30,00 and 18,000 BP. To the north, and inset into the older lake deposits, is young brown valley-fill alluvium that has been radiocarbon dated from 9,300 to 2,500 BP. To the left (southwest), a prominent shoreline-like bench is cut into the quartzite-cobble colluvial deposits of the Salt Spring

Fig. 12. Fanglomerates low on the slopes of the Avawatz Mountains show differential colors due to age and maturity of desert pavement and desert varnish. R.E. Reynolds photo.

Fig. 13. Groundwater discharge deposits below a prominent linear bench cut into granite, Mesquite Spring, Fort Irwin (similar to benches at Salt Springs). View to west, photographed March 2003. Note the oversteepened slope left of bench, caused by sapping of material on slope. Bench is underlain by carbonate-rich silt and fine sand, with scattered pebbles and cobbles of granite. Note the vegetation (grasses and trees) dependent on consistent supply of water, indicating spring is active. D. Miller photo.

Highway 127.

111.6 (1.2) Pass a turn to the Salt Springs Hills (BLM kiosk).

112.5 (0.9) Pass the Harry Wade exit monument and the road west to the Owl Head Mountains.

113.5 (1.0) Pass a BLM kiosk.

114.6 (1.1) Cross the Amargosa River.

116.5 (1.9) Pass a right turn to the Dumont Dunes OHV area.

119.3 (2.8) Low hills immediately west alongside the road contain abundant clasts of light-colored Noonday Dolomite. The source of the clasts is to the west in the Saddle Peak Hills. The gravels in the low hills are remnants of an older fan.

121.4 (2.1) Prior to a left bend in the road, look to the right at 2:00 at a light gray limestone megabreccia sheet and dark volcanic rocks interbedded with the China Ranch beds (Wright, 1974). This is a western extension of the basin formed by Tertiary extensional tectonics.

Hills. This feature was interpreted as a shoreline associated with the 30,000 to 18,000 BP lake stands (Anderson and Wells, 1996). Notice that the late Pleistocene shoreline is buried by Holocene fan gravels. However, difficulties with the lake interpretation include: (1) timing at adds with the Mojave River spillover from Lake Mojave, (2) lack of a closed basin in which waters could be impounded, and (3) ambiguous invertebrate fossils that can be interpreted as either lacustrine or groundwater discharge origin (R. Forester, personal commun. 2002). An alternative interpretation to consider is that the deposits are chiefly or entirely GWD in origin (similar to the modern GWD at Salt Spring but more widespread during cooler climate intervals) and the bench cut into colluvium was formed by sapping, as is observed in active springs such as Mesquite Springs. This is an Area of Critical Environmental Concern (ACEC)) and we are prohibited from digging or collecting in this area. Return to vehicles and CONTINUE NORTH on

122.3 (0.9) TURN LEFT and PARK along the road to the microwave station.

STOP 2.10. Microwave Station. The Saddle Peak Hills on the west contain a well-exposed section of Kingston Peak Formation, the Noonday Dolomite, and the Ibex Formation. Unpublished mapping by Troxel shows that this is an important section in documenting the Proterozoic Basin. The Kingston Peak section is repeated in Fatzinger Ridge east of the road. Note the erosional channels on top of the buff Noonday Dolomite. The channels are filled by the lower Johnnie Formation.

A few hundred meters east of the road, late Miocene volcanic rocks with large taffoni (weathered pockets) crop out through the alluvial fan deposits. In one-half mile, the road makes a 40° turn to the west as it turns parallel to the Meteor Rocks fault zone. This northwest-trending fault (McMackin, 1997) exhibits evidence of right-lateral

Feature	Lacustrine	Marsh	GWD	Soil Profile

Stop 2.10 worksheet.

oblique reverse displacement. The reverse displacement has uplifted the granitic rocks of the Sperry Hills over the Late Proterozoic rocks and Tertiary volcanic rocks on this southern flank of the range. Topping (1996) has suggested that these rocks are part of a huge late Tertiary landslide. Troxel and Wright (unpublished mapping) have interpreted these rocks as granite bedrock uplifted along high-angle reverse faults. Intense fracturing is common, as one would expect in a fault zone, but the fractures are locally systematic and generally close-fitting. Other outcrops provide better exposures of these fractures and in general support the interpretations of Troxel and Wright. Isotopic data provides evidence that the granite here is closely related to the Miocene granite of Kingston Range (Calzia, 1997). McMackin (1997) suggests that the two granite bodies have been offset by the complex intersection faults that also formed the Tecopa Hump. RETRACE and TURN LEFT (north) onto Highway 127.

125.0 (1.7) Enter Inyo County at Ibex Pass. We are passing from faulted bedrock granite on the south-facing slope to an overlying granite boulder conglomerate, dipping 15º to 25º north, on the north slope of the Sperry Hills. At outcrops a few miles east, the granite is overlain by an 8.4 Ma tuff which in turn is unconformably overlain by the boulder conglomerate.

125.4 (0.4) Continue past a road that goes left to the Mammoth Talc Mine.

125.7 (0.3) Encounter the first outcrops of Lake Tecopa sediments dipping very gently eastward. In 0.2 mile we will see the Lava Creek B ash, dated at 0.62 Ma (Hillhouse, 1987).

126.4 (0.7) Continue past a left turn to Greenwater Valley.

126.9 (0.5) As we approach the Old Spanish Trail Highway, Spanish Trail Mesa is on the right side of the road. There is a clean planar fracture in the well-cemented tuff that caps the mesa. McMackin (1997) discusses the possible origin of these fractures.

127.3 (0.4) Pass a right turn to Tecopa near the talc ore bins.

128.3 (1.0) Zabriskie.

129.2 (0.9) Pass a second right turn (southeast) to Tecopa. Prepare to stop.

129.7 (0.5) Pull to the right shoulder of road and PARK.

STOP 2.11. Amargosa River. WALK east one-quarter mile to a steep cliff cut by the Amargosa River. This locality shows planar bedding of green siltstones. Elsewhere in the Tecopa Basin are siltstones and volcanic ash with ripple marks, mud cracks and rip-up clasts (Whistler and Webb, 2000; Woodburne and Whistler, 1991), features generally but not exclusively associated with lacustrine

deposition. However, many deposits are massive mud. Deposits within the muds that form large lenses of both hard carbonate and friable carbonate were interpreted by Nelson et al. (2001) as spring tufa deposits. Springs currently discharge in the valley bottom in many places, as well as in several locations near the margin of the Tecopa deposits. The commonly massive character of the Tecopa muds and known GWD within the basin raise questions about the interpretation of the deposits as largely lacustrine in origin (Larsen, 2000), but resolving this question will require much more field research. A start on answering the question has been undertaken by Rick Forester, who has examined ostracodes collected at several positions in the basin. All have indicated paleoenvironments corresponding to modern spring and wetland settings of the region, rather than lacustrine environments. More comprehensive study of fossils is needed, but preliminary suggestions are that Tecopa Lake sediments are mainly GWD environments. Return to vehicles. PROCEED NORTH to Shoshone.

133.8 (4.1) Slow entering Shoshone.

134.3 (0.5) Pass the right (east) turn to Pahrump via Highway 178.

134.5 (0.2) STOP at the Shoshone Museum. End Day 2.

DAY 3

What We Will See

The route of Day 3 will also cross topography and terrain that is a result of Miocene extensional tectonics and the development of the right-lateral Southern Death Valley–Avawatz–Soda–Bristol Fault Zone. A stop at central Old Dad Mountain will illustrate magnitudes of offset resulting from the interplay of these forces. From the Cima terrain to the Granite Mountains there will be a noticeable absence of pedogenic carbonate, and the trace outcrops that we do see will be nowhere near as well developed as the examples in the Halloran Hills.

Our search for cool, clear water that once spread across the burning sands continues as we look for evaporating signs of lacustrine deposits across the white shimmering sands of the Devil's Playground. We will examine exposures of groundwater discharge and evaporative discharge at Sands and at Glasgow Siding, both along Kelso Wash. We will travel past Kelso and through Granite Pass to the Bristol Lake Playa in Cadiz Valley. Bristol Lake is divided, perhaps by structures connecting faults in the Bristol Mountain and faults in the Iron Mountains. The western half of Bristol Lake is saline, and the eastern half of the basin contains fresh water that flows along Fenner Wash from the 7000 foot peaks of the New York Mountains. At Cadiz, we will see three lobes of the Fenner Wash delta. The northern lobe is a GWD platform that was deposited into a topographic depression, the southern lobe was de-

posited by GWD over a near-bedrock source of fanglomerates, and the central lobe retains deltaic configuration at the mouth of Fenner Wash. The trip will end at Chambliss, on Historic Route 66, 80 miles from the nearest services and supplies, so come prepared!

CONVENE at central Baker. Fill your vehicle with gas and check fluids and tire pressure. Cross I-15 on the overpass and proceed easterly on Kelbaker Road.

0.0 (0.0) Cross the first cattle guard, and continue easterly on Kelbaker Road.

0.2 (0.2) Notice the "Mojave National Preserve" sign on the right; it is located approximately at the elevation (935') of the high stand of pluvial Lake Mojave.

1.6 (1.4) Cross a second cattle guard. On the right skyline, Old Dad Mountain at 1:30 and the Cowhole Mountains at 2:30 flank the northern edge of Devils Playground. Climbing dunes bury the north flank of Little Cowhole Mountain at 3:00. The Little Cowhole Mountains contain Goodsprings Dolomite above a contact with quartz monzonite.

For the next several miles the road crosses Holocene and modern distal fan deposits from the Cima volcanic field, approximately 15 miles east. Well-varnished basaltic boulders and cobbles are scattered across this arkosic surface. These clasts have been transported six miles across slopes of 1.5º and another six miles across slopes of 2º to 4º.

4.0 (3.4) The outcrop ahead is Teutonia Quartz Monzonite. Beyond at 10:30 and at 2:00 are granitic domes (Reynolds et al, 1996) below elevated late Miocene through Pleistocene basalt flows. To the right are young basalt flows roughly coincident with the modern drainage and topography; erosion of the surrounding surface has left the flows slightly elevated.

Kelbaker Road is surrounded by granitic alluvial fan products. These granites provide favorable conditions for biologic soil crusts (Hereford and Webb, 2001). Basalt cobbles armor the fan, slowing the rate of erosion on pediment surfaces.

5.5 (1.6) The road bends to the right and ascends the southern Cima volcanic field. The next nine miles provide views of prominent pediment domes. These granitic domes were tilted east by listric-normal faults, and now sit with the retreating scarp facing west and the original surface tilted east.

10.0 (4.5) Slow for an abrupt 90º curve to the right (south). Large inselbergs of granitic gneiss block the view on the left. The road crosses an active piedmont northwest of the Cima volcanic field. Alluvial debris from floods are regularly plowed from the next two miles of road. No pedogenic carbonate is visible in wash exposures. Old Dad Mountain is ahead.

13.1 (3.1) Pass 17-Mile Point (named because it was midway along the 35-mile stretch between Marl Spring on the east and Fort Soda on the west). The Old Government Road crosses here, at a point between Marl Spring and Fort Rock Spring to the east and Fort Soda at Soda Spring (Zzyzx) to the west (Casebier, 1975) .

Kelbaker Road crosses a 0.17±0.06 Ma basalt flow (at road level) over reddened sediments and passes the western end of higher flows that range in age from 0.17 to 0.58 Ma. Sources of these flows are vents located 2 miles east (Wells and Reynolds, 1990) . The 0.58 Ma flow buries early to middle Pleistocene fan systems and younger flows have partly buried the 0.58 Ma flow. The basalt flow temporarily dammed all drainage from the southern part of the Cima volcanic field. The road passes through a shallow notch cut across the distal end of these flows where basalt ponded against the east flank of Old Dad Mountain, driving the wash farther west where it eventually cut down through the Proterozoic carbonate rocks to "avoid" the basalt.

15.2 (2.4) On the left is the Black Tank flow, the youngest in the Cima field, tentatively dated at less than 0.02 Ma (Renault and Wells 1990). On the right skyline at 12:00 to 6:00 are the Kelso Mountains, Radar Ridge, and Old Dad Mountain. This region is underlain by 10–12 Ma eastward-tilted fanglomerates faulted by the eastern California shear zone (ECSZ) against Tertiary through Precambrian rocks (Barca, 1966). Neogene faults are predominantly northwest-trending, right-lateral strike-slip shear zones (Skirvin and Wells, 1990).

16.7 (1.5) Pass through a dip. On the right is a ridge of Miocene granitic boulders shed from the Teutonia Quartz Monzonite (TQM) terrane to the east.

19.2 (2.5) Pass the junction on the left with the Aiken Cinder Mine Road, marked by a dirt pile with a sign. Note your mileage for the next turn that leads to the microwave station access road on the right in 0.4 mi.

19.6 (0.4) TURN RIGHT and proceed south toward the transmission towers and microwave complex on the ridge.

21.6 (0.3) TURN RIGHT before reaching a complex intersection with the power line road. Continue past a left turn down a steep power line grade.

21.9 (1.3) Continue past a left turn.

23.2 (1.3) Continue past a right turn.

23.3 (0.1) The road bends southerly.

24.8 (1.5) At 3:00, note the well-developed desert pavement on a dip slope ridge.

25.1 (0.3) 3-way intersection. Proceed south on the right branch. Do not go left, up the switchbacks.

26.0 (0.9) Pass an intersection on the right.

26.3 (0.3) Pass a second turn to the right.

26.5 (0.2) The road bears right at willows.

26.7 (0.2) Pass pistachio-green outcrops of epidote-rich gneiss in the wash.

27.3 (0.6) View south down Marble Canyon. Notice the falling dunes on the lee side of the ridge. Sand is blown from Devil's Playground, to the west.

27.7 (0.4) Dip.

28.0 (0.3) Pass through the railroad tie fence.

STOP 3.1. Carbonate Chaos. On the south face of Old Dad Mtn (north), the metamorphosed Monte Cristo Limestone sits on reddish granitic rocks. These granitic rocks have leisingang weathering rings between joint sets, indicating that they were deeply weathered below an erosional surface. The contact between the granitics and the carbonates was originally mapped by Barca (1966) as a thrust fault. It is possible that this was a carbonate gravity slide block from the Soda or the Avawatz Mts area where similar Paleozoic carbonate rocks occur. It was emplaced on a mid-Tertiary erosional surface developed on granitic rocks. This suggests a minimum of 20 miles of right lateral movement on the ECSZ to allow for the present relationship. The relationship between rock types and the chaotic structure of the carbonates is similar to that in the Silurian Hills (Reynolds, 2001; Reynolds and Calzia, 2001).

29.6 (1.6) Pull to right shoulder

STOP 3.2. Old Dad Wash. Exposures on south side of the transmission line road contain alternating fanglomerates and climbing dunes suggesting the possibility of climate-controlled cyclic deposition. Note the absence of thick pedogenic carbonate. Proceed west.

30.2 (0.6) Do not stop as we drive through the dunes.

32.2 (2.0) Take the left fork (southwest) toward Sands.

32.9 (0.7) Pass a granitic bedrock outcrop on right. We are passing through a series of crescent dunes deposited by winds from the west. Some of the dunes climb over and

Fig. 14. Old Dad Wash, view east of interfingering sand and gravel deposits. Dark gravels derived from the Old Dad Mountains are shed westward and interfinger with climbing dunes from Devils Playground. There is an absence of well-developed pedoogenic carbonates in this section. R.E. Reynolds photo.

obscure bedrock outcrops.

34.4 (1.5) Pass to the left of an outcrop of black Jurassic porphyritic volcanic rock. Note the old grading alignment on the east side of the road. Since this road was built, creosote on the east side of the road has recovered well.

34.8 (0.4) BEAR RIGHT at "Y" west-southwest intersection.

35.9 (1.1) "T" intersection marked with tires. Take the right fork (northwest) toward the white carbonate platform. DO NOT PARK in dune sand. PARK on top of carbonate platform.

36.4 (0.5) **STOP 3.3. Sands Carbonate Platform**. We are at the distal Kelso Wash (elevation 1,100') at a point where water must pass through the crescent dunes of the Devil's Playground and bedrock narrows between the Bristol and Cowhole Mountains to reach the Mojave River and southern Soda Lake (920'). The Mojave River, which drains to Soda Lake west of here, sources at elevations of 11,000' in the San Bernardino Mountains. The source of the Kelso Wash is in the southern New York Mountains,

Feature	Lacustrine	Wash	GMD	Soil Profile

Stop 3.3 worksheet.

Mid Hills, and Providence Mountains(elev. 5000 – 7525'). The Providence Mountains are to the east, the Kelso Dunes and the Granite Mountains to the southeast, and the Bristol Mountains to the south-southwest. West-southwest are the Mesquite Hills and remains of the railroad town Crucero. Cave Mountain is west-northwest and the Soda Mountains are northwest. Portions of the Avawatz Mountains can be seen to the north-northwest. The Cowhole Mountains are immediately north-northeast.

We are south of the trace of the Soda Lake lineaments (Brady, 1992; Brady and others, 1989) marked by mesquite trees that have tap roots penetrating a possible fault zone in search of fresh water. This possible fault zone is part of the trace of the Soda–Avawatz Fault Zone that strikes southeast toward the Bristol–Granite Fault Zone (Brady, 1992; Dokka and Travis, 1990). All of these right-lateral strike-slip faults form the eastern margin of the Eastern California Shear Zone (ECSZ). Linear scarps cutting late Pleistocene gravels in a canyon to the southwest may mark a trace of one of the Bristol Mountain faults (Brady, 1992).

We are standing on sediments referred to as lacustrine (Reynolds and Jefferson, 1971). Fossils of horse and camel suggest a late Pleistocene age for the sediments as do unpublished IRSL ages of ~13 ka (S. Mahan, written commun. 1999). The deposit therefore formed while Lake Mojave was extant. Walk east along carbonate bluffs and discuss indicators that will help determine if these are paleosols with pedogenic carbonate, lacustrine deposits, or evaporative groundwater discharge deposits that have been dissected by Kelso Wash. Note the carbonate cap, which contains nodular carbonate and other indicators for a pedogenic influence, and sand-dominated sediments beneath. These deposits extend west for a few miles but not to the level of ancient Lake Mojave, which was tens of meters lower at its highstand. Note the lack of a means of impounding lake waters; transitory dunes are the only possibility, but most of the sand in the Devils Playground system postdates the deposits. The deposits, probably GWD, may be located by GW damming by the immediately adjacent bedrock or by damming by the possible faults west of here. In either case, lack of modern GWD indicates lowered GW levels since the late Pleistocene, no doubt as a result of climate variability. RETRACE to the "T" intersection at the railroad.

36.8 (0.4) "T" intersection. BEAR RIGHT (south) to the railroad.

36.9 (0.1) TURN LEFT (east) before reaching the tracks.

37.7 (0.8) Pass the Sands Siding water tower. Our route eastward takes us from Sands Siding past Glasgow Siding, Kerens Siding, and Flynn Siding to Kelso Depot. Mendenhall (1909) reported available water at a well south of

Epsom Station (east of Crucero, west of Balch) at the north end of the Old Dad Mountains. (On later maps, the Old Dad Mountains are shown as a northern part of the Bristol Mountains, south of Soda Lake, and Old Dad Mountain is to the northeast, east of Soda Lake). Water was also convenient at Balch Station on the Los Angeles and Salt Lake Railroad (LA&SLRR). Water was available in a cistern at the Balch crew house, but "It is practically impossible for automobiles to reach this place on account of sand." Sands Siding had water available at the LA&SLRR pumping plant, and cisterns with water were present at crew houses at Glasgow and Flynn. By 1929, Sands was the major pumping plant for the section of the LA&SLRR west of Kelso Station. At that time, Kelso Station was a "town" with groceries and petroleum available (Thompson, 1929). However, all roads west ended at Kelso, as the road parallel to the railroad " is so sandy that it is impassable for automobiles, but it could probably be traversed by wagons" (Thompson, 1929). The preferred route was north, via Cima, or south to Fenner and National Trails Highway.

37.9 (2.0) Watch for oncoming trains and vehicles. BEAR RIGHT and cross to the south side of tracks at double railroad signal.

38.1 (0.2) Drop down to the road at tamarisk tree level. The tamarisk tree was introduced to the Southwest from southern Eurasia late in the 19th century to create windbreaks along railroads and roads. Its phenomenal reproductive output and tolerance to drought and flood compared to native species has led to rapid and persistent establishment in riparian communities (Warren and Turner, 1975).

40.4 (2.1) Sign for Sands Siding. Proceed southeast along the tracks. Stay on the gravel road adjacent to the tracks.

41.2 (0.8) Pump station.

42.9 (1.7) Pass a railroad crossing at the pump station near Glasgow Siding.

43.5 (0.6) Pass a granite outcrop. We are leaving Devil's Playground (west) and entering the Kelso Dunes to the east-southeast. Kelso Wash is joined by Devil's Playground Wash from the south side of the Kelso Dunes and by Budweiser Wash from the south side of the Granite Mountains. Miocene volcanic rocks of "Old Dad Mountain" in the Bristol Mountains are due south at 2:00.

43.8 (0.3) PARK past the granite knob east of Glasgow Siding.

STOP 3.4. Glasgow Siding. Walk to the north side of the railroad tracks to discuss buried carbonate layers. We are at the southern toe of fans from the Kelso Mountains that exhibit interbedded west-derived eolian sand and sand-enriched gravel worked down the piedmont. Within this section are east-dipping carbonate layers that appear to be duplicated by faulting. The carbonate layers may be

Fig. 15. Groudwater discharge carbonate sheets on north side of railroad east of Glasgow Siding are buried by aeolian sands from Devils Playground. R.E. Reynolds photo.

the south. The dunes have been stabilized by vegetation and a mixture of aeolian and fluvial silt.

51.2 (1.1) Flynn Trestle. Winston Wash from the southern Providence Mountains joins Kelso Wash here.

55.5 (4.3) Stop at Kelbaker Road. Kelso Depot is to the north, being renovated by the National Park Service. The small settlement around this important railroad station and yard provided water, gasoline and food for travelers, who, if traveling by automobile, had reached the "end of the line" in 1917. No reasonably passable road went west along the LA&SLRR. The only exit from Kelso Valley was north, via Cima and Valley Wells, or east to Fenner and then south to National Trails Highway (Thompson, 1921, 1929). TURN RIGHT and proceed south.

56.1 (0.6) Cattle guard. Slow to 45 MPH around curve.

58.9 (2.8) Watch for a yellow sign at the bend ahead.

59.1 (0.2) TURN LEFT (southeast) 1/10-mile before the right bend sign on the road to the Vulcan Iron Mine in the Providence Mountains.

60.3 (1.2) Rough wash crossings.

60.7 (0.4) **STOP 3.5. Vulcan Mine Road**. PARK on the right side of road. The Bishop Ash, dating to 765,000 years is found in very coarse conglomerate exposed in stream channels to the north-northeast. The Providence Mountains are to the east, Cima Dome is north-northeast, Cimacito

located here because the bedrock forms a groundwater barrier that forces water to the surface where it evaporates and carbonates precipitate. Alternatively, the carbonate may be entirely pedogenic in origin. By this interpretation, upper parts of the soil profile that match the relatively old calcic horizon should be present, but they appear to have been eroded and then the lower calcic horizon part was covered by younger sediment that lacks soil development. PROCEED EASTWARD.

45.6 (1.9) Kerens Siding.

46.1 (0.4) Pump station.

48.1 (2.0) Drop into Kelso Wash and pass a Burlington Northern & Santa Fe Railroad trestle. Stay on the south side of the tracks.

50.0 (1.9) We are at the southern end of the Kelso Mountains separated by Kelson Wash from the Kelso Dunes to

Feature	Lacustrine	Wash	GWD	Soil Profile

Stop 3.4 worksheet.

(Dome) is north, the Kelso Mountains northwest, the Kelso Dunes and Bristol Mountains to the west, and the Granite Mountains are southwest. From here you can see sand plumes along the Mojave River produced by high winds. RETRACE to Kelbaker Road.

62.4 (1.7) TURN LEFT (south) on Kelbaker Road.

62.5 (0.1) Kelbaker Road bears west.

66.3 (3.8) Proceed past the junction to the Kelso Dunes.

66.8 (0.5) Proceed through a junction with a power line/gas line road.

67.3 (0.5) Kelbaker Road bears left (south).

70.4 (3.1) Pass a junction on the left with Arrowweed Spring Road.

71.0 (0.6) Pass a right turn to Cottonwood Spring.

71.4 (0.4) Note the reddish-brown soil with carbonate root casts in a cut on the east side of the road. This may be the most well-developed soil profile that we pass on today's route.

72.9 (1.5) Pass a right turn towards Snake Springs, Granite Cove, and Dorner's Camp.

73.0 (0.1) Microwave station at Granite Pass.

73.1 (0.1) Slow for 30 mph curve.

74.3 (1.2) Pass the intersection east with Hidden Hills Road. The Van Winkle Mts are at 10:00.

76.7 (2.4) Pass a right turn to the microwave station; continue on Kelbaker Road.

79.0 (2.3) View at 10:00 of the flat surface of the granitic pediment at the south base of the Granite Mountains. The pediment was produced by mid-Tertiary erosion (Reynolds et al, 1995).

80.7 (1.7) Proceed under I-40. Miocene volcaniclastic flows and pyroclastic rocks of the Brown Buttes to the west and of the northern Marble Mountains to the east.

83.0 (2.3) South along Kelbaker Road the pediment cut on granitic rock gives way to a Late Pleistocene–Holocene soil profile. For two-tenths of a mile, pedogenic carbonates and reddish arkosic sands are exposed in a low road cut.

85.5 (2.5) Well-developed desert pavements are visible in the saddle to the west at 10:00.

87.4 (1.9) Continue past a road to the right to the microwave station.

87.9 (0.5) Cross Orange Blossom Wash, which drains the Bristol Mountains and the western Granite Mountains.

88.3 (0.4) The Hope/New Method mine is located to the west (Jenkins, 1995).

90.2 (1.9) At the bend in road, the Blackjack iron mine and Snowcap limestone mine are two miles west (Wright and others, 1953; Brown, this volume).

91.9 (1.7) STOP at Route 66 (National Old Trails Highway). Bristol Lake to the south is divided by a groundwater barrier. The western half of the lake is saline, and the eastern half of the basin contains fresh water that flows along Fenner Wash from the 7000 foot peaks of the New York Mountains. The saline portion of the lake produces commercial salt (NaCl) and calcium chloride (CaCl) as well as the minerals celestine ($SrSO_4$) and temperature-sensitive antarcticite ($CaCl_2.6H_2O$). The fresh water portion supports commercial citrus and grapes. The GW barrier might be an un-mapped portion of the Bristol–Granite Fault Zone (Brady, 1992) that trends southeast toward the northwest-trending faults in the Iron Mountains (Bishop, 1963). The trend of such a fault trace would project near to Bolo Hill.

At the turn of the last century (Mendenhall, 1909), water in the Bristol Basin was unavailable along the Santa Fe Railway, except as dispensed from water tenders at Amboy, a stage stop on the route to the Dale Mining District to the south. East of Cadiz, along Fenner Wash at the north end of the Ship Mountains, water of excellent quality and abundance was available for travelers from railroad pumping stations at Siam and Danby. By 1921 (Thompson), Amboy was important enough to boast of "Water, gasoline, general supplies, and a hotel and garage accommodations." An oiled road crossed east over the southern Marble Mountains to Danby (gasoline and food) and Fenner (meals, gasoline and groceries). Travelers could take the southern route —"Parker cutoff"—through Cadiz Valley, or take a better road south from Danby to the Parker Cutoff. Water was generously available at section houses along the AT&SFRR. Many travelers still preferred the longer but quicker and smoother route east to Needles, then south to Parker. Although Cadiz was the major junction of the two routes, it never boasted having supplies or accommodations other than emergency water (Thompson, 1929). The route south of Amboy was very sandy on the south side of Bristol Lake and at Dale Lake, and automobiles had to "...cross it on deflated tires." The mines at Dale closed in 1918, and the road fell into disuse. TURN LEFT (east) past Bolo Hill on south (Lerch, 1992).

97.1 (5.2) Pass left turn to Iron Hat Mine in southern Marble Mountains.

97.4 (0.3) TURN RIGHT at Chambliss (now called Cadiz) onto Cadiz Road.

100.6 (3.2) Slow. The road bears left (east) as we pass historic railroad station of Cadiz. We are in a groundwater discharge at the end of Fenner Wash.

101.4 (0.8) View northeast of Marble Mountains trilobite localities (Mount, 1980).

Feature	Lacustrine	Marsh	GWD	Soil Profile

Stop 3.6 worksheet.

101.6 (0.2) Road bears right (south) and crosses Burlington Northern/Santa Fe tracks.

101.8 (0.2) Pass south through an intersection on the south side of the tracks.

103.9 (2.1) Cross the railroad tracks and BEAR LEFT (southeast).

104.2 (0.3) Cross the All American gas transmission line east of the two heat station tanks. We will be crossing braided channels of Fenner Wash for the next several miles.

107.9 (3.7) **STOP 3.6. Archer sediments**. The white Archer sediments are in the southern lobe of three fluvial and groundwater discharge sediment lobes created by Fenner Wash. Fenner Wash drains the New York and Providence Mountains, as well as part of the Old Woman Mountains, and therefore has a precipitation similar source as Kelso Wash. The deposits here lie on granite-clast
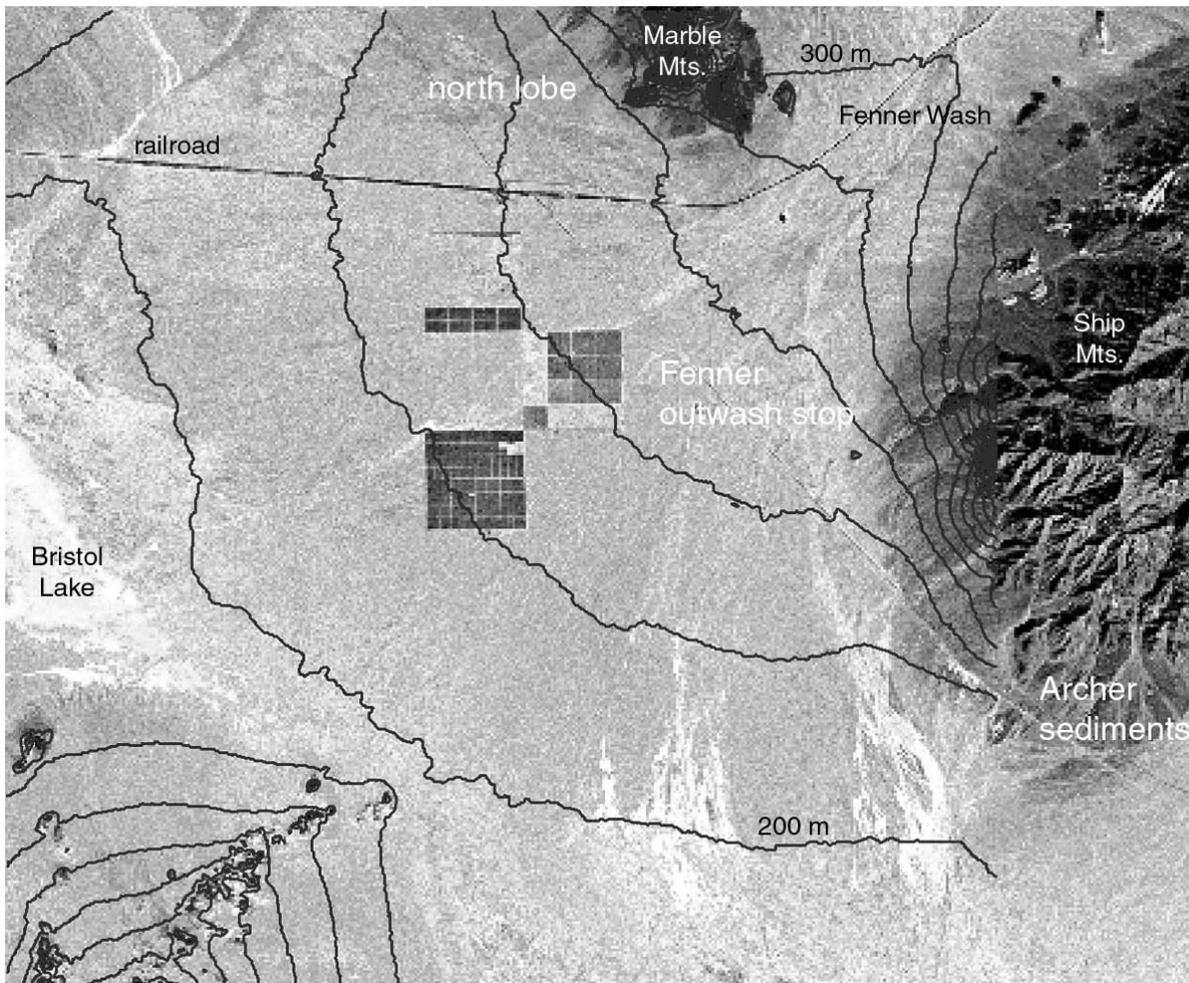

Fig. 16. Landsat 7 image of distal Fenner Wash with 20 m contours added. Fenner Wash drains as a confined wash system between Marble and Ship Mountains, and forms a large fan between that construction and the Bristol Lake valley floor. White colors in many places are GWD. Agricultural fields form rectangular anomalies on the fan. Image courtesy D. Miller.

Feature	Lacustrine	Marsh	GWD	Soil Profile

Stop 3.7 worksheet.

fanglomerate derived from the southern Ship Mountains at an elevation of 750 feet. Walk south and discuss features that indicate whether this deposit is the result of lacustrine, marsh–spring, or evaporative groundwater discharge. These sediments have produced a Pleistocene fauna consisting of xeric small mammals, birds, lizards, and snakes including a boa, and one species of gastropod, *Succinea*, a land snail (Reynolds and Reynolds, 1992). RETRACE to gas line.

111.7 (3.8) Pass All American gas line and heating tanks; prepare for a left turn.

111.9 (0.2) TURN SHARP LEFT before reaching the tracks; prepare for a right turn.

112.0 (0.1) TURN RIGHT on the El Paso gas line.

112.5 (0.5) **STOP 3.7. Fenner Wash.** PARK at orange gas sign #215. WALK to the right (northeast) to look at inter-

Fig. 17. Stratified silts and carbonate deposits south of Cadiz. R.E. Reynolds photo.

Fig. 18. Pedogenic carbonate, carbonate kernels, and root casts exposed in pit wall at Fenner Wash. K.S. Rivera photo.

bedded tan silts and white carbonates. Distinctive detrital spherolitic opal indicates that the source of sediment is from Lanfair Valley via Hackberry Wash to Fenner Wash. We are in the middle lobe of the Fenner Wash drainage. Outcrops of low relief contain alternating brown silts and white calcareous silts. The sediments have produced a mid- Pleistocene fauna consisting of xeric small mammals, birds, lizards, and snakes. Horses and proboscideans are absent, but camel and medium and small pronghorn are present. The two antelope, along with the giant tortoise, *Geochelone,* suggest the mid-Pleistocene Irvingtonian age of the fauna, perhaps older than 300,000 years (Reynolds and Reynolds, 1992). Also present are the fossil remains of a toad, the clam *Pisidium casertanum*, and the land snails *Physa* sp., ?*Succinea*, and ?*Planorbula*. Recently located are aquatic snails *Fossaria* sp., *Gyraulus* sp., and a pupillid (?*Vertigo* sp.) (Rivera and Pedone, this volume).

Fenner Wash drains more than 1200 square miles, including Lanfair Valley, which is surrounded by peaks up to 7,000 feet. We are in the distal part of that drain-
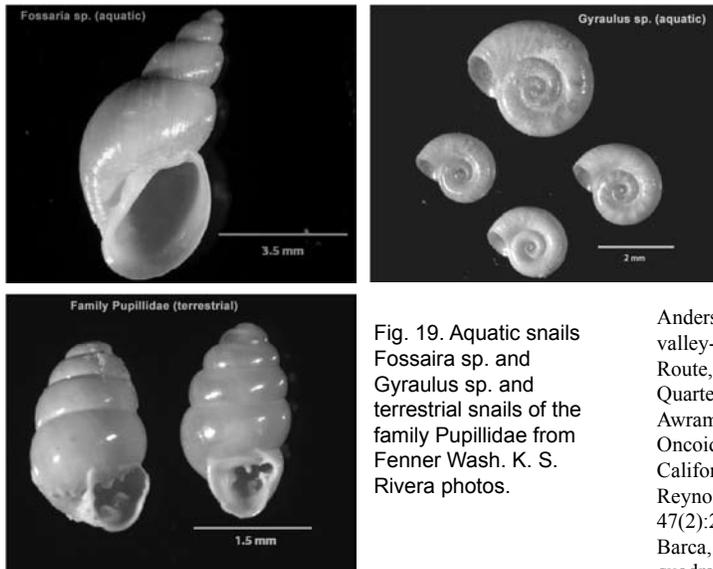
23

Fig. 19. Aquatic snails Fossaira sp. and Gyraulus sp. and terrestrial snails of the family Pupillidae from Fenner Wash. K. S. Rivera photos.

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age system, and the outwash has developed a tri-lobed pattern. The northern lobe is in a topographic depression west of the Marble Mountains, between the distal sediments of Orange Blossom Wash and the central part of the Fenner Wash delta. The northern lobe (elevation 740') may receive subsurface and surface overflow from both those drainages, and will discharge water by evaporation, leaving carbonate precipitates. The southern lobe at Archer (elevation 750') receives both subsurface and surface overflow from Fenner Wash and discharge (including evaporation) is at the groundwater barrier of the southern Ship Mountains. The central lobe (elevation 820') was probably deposited as a deltaic marshland during the late middle Pleistocene (Illinoian interglacial). Dates on deposits in the different lobes might distinguish the sequence of depositional events and groundwater levels through time.

We are east of the groundwater barrier of Iron Mountain/Bolo Hill where water is fresh and plentiful enough to support citrus and grapes. RETRACE to Chambliss.

113.1 (0.6) Stop; cross the railroad tracks.

115.2 (2.1) Cross the tracks at Cadiz.

116.3 (1.1) BEAR RIGHT (north). Note a white GWD platform 0.2 miles north of the bend in the first gully on the right, north of the mobile housing.

117.5 (1.2) Pass a right turn to the northern GWD lobe.

119.6 (2.1) **End of trip.** We are on historic Route 66. Access to Route 40 is via Amboy to Ludlow and Barstow. Needles is to the east. The nearest gas is (sometimes) at Amboy.

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Ground water and ground-water discharge carbonate deposits in warm deserts

Richard M. Forester, *MS 980 DFC USGS Denver CO, 80227*
David M. Miller, *MS 975 USGS, 345 Middlefield Road, Menlo Park CA 94025*
Vicki A. Pedone, *Geological Sciences, CA State Univ. Northridge, Northridge, CA 91330*

Abstract

Carbonates are common in warm deserts and are produced by a complex set of processes, including the processes related to ground water and ground-water discharge. The importance of ground water and ground-water discharge to the desert aquatic environment has only recently been appreciated. Consequently, many carbonate deposits are thought to have formed in other environments. Therefore, we review the general physical characteristics, the fossil content, isotope properties, and field relations of carbonates formed in ground water supported environments to provide a basis for their utilization in paleoenvironmental reconstructions.

Introduction

Continental carbonate deposits are common in warm deserts and generally are thought to have originated from one of three processes: 1) pedogenesis (caliches, calcrete; Goudie, 1983), 2) physical/chemical and biologic activity in lakes (epilimnetic carbonates, shoreline tufa, biogenic/bioinduced carbonates; Jones and Bowser, 1978; Kelts and Hsu, 1978), and 3) efflorescent/capillary fringe/evaporation on wet-playas (calcrete in part, salt crusts; Eugster and Hardie, 1978).

Recent studies (e.g. Quade and others, 1995, Quade and others, 2003) have identified the importance of ground-water discharge in wetlands and springs in producing carbonate . Other studies (Forester and others, 1999, Whelan and others, 2002, Winograd and others, 1985, Winograd and others, 1992) have identified carbonates filling fractures and voids that precipitated from ground water in the saturated zone (SZ) or from percolation in the unsaturated zone (UZ). Hydrologic settings in warm deserts generally fall into the ground water, including perched ground water, and ground-water discharge categories, because surface waters are commonly lost to the high levels of evaporation. We suggest a need to reevaluate many desert carbonate deposits and define a new class of carbonates termed ground water and ground-water discharge deposits (GWD). Many deposits previously called "playa" and "lake" are now interpreted as GWD. This interpretation carries considerable significance for understanding past hydrologic conditions, from which paleoclimate may be inferred.

Subsurface water (ground water and percolation) originates from meteoric water that has penetrated below the root zone (infiltration), where it percolates through the unsaturated zone (UZ) and if it reaches the water table (recharge) it becomes ground water. Percolation is important in deserts, because the dry climates commonly result in a thick UZ and long infiltration times before recharge occurs.

Surface water also originates from meteoric water, but remains at the earth surface as overland flow, rock pools, wetlands, playas, and lakes, or near-surface soil moisture. Surface water in warm deserts is often seasonal, owing to intense evaporation, but may also be persistent because of, for example, high elevation snowmelt or episodic, but intense, convective summer storms.

When water is evaporated, degassed, mixed with other waters, or solutes are added (water-rock interactions), then carbonate, (especially calcite) may precipitate. Carbonates may also be precipitated as the skeletons of aquatic organisms, such as charophytes (calcareous green algae), ostracodes (microscopic crustaceans), and mollusks (snails and clams). Biologic activity may also induce carbonate mineral precipitation as in the case of microbialites (stromatolites), as endogenic carbonates (whitings) in lakes, and pedogenic root casts. In a desert environment, the pedogenic and ground-water settings are likely to produce extensive carbonate deposits, because those waters contain moderate to high concentration of Ca and alk (HCO_3 and CO_3 comprising total carbonate alkalinity), resulting in carbonate mineral over-saturation and mineral precipitation. In contrast, desert surface water settings are often derived from local or regional storms and owing to the dilute nature of the water may be undersaturated with respect to calcite and thus may not precipitate large quantities of calcite or other carbonate minerals.

We describe general characteristics of GWD carbonates with an aim to identifying features that aid field recognition of particular hydrologic settings. We will compare and contrast the ground water and ground-water discharge carbonates with their pedogenic cousins and to a lesser degree with strictly surface-water derived carbonates.

Definitions of hydrologic settings

The following hydrologic settings are considered here: subsurface waters comprising ground water (SZ) and percolating water (UZ), springs, wetlands, wet-playas, and lakes. Each is defined below in general hydrologic terms,

followed by a description of common faunal and flora associations and then the isotopic characteristics for each setting. Finally a section describing the macroscopic and microscopic characteristics of the carbonates associated with each setting, including field identifying characteristics. Table 1 summarizes these characteristics and compares the carbonate deposits to some less common types such as cave and hot spring deposits.

Subsurface waters: The subsurface environment comprises two distinct hydrologic settings. The first and typical setting is shallow through deep ground water, where water fills all available voids in the saturated zone (SZ). The second setting incorporates the rock and sediments above the SZ, but below the soil zone that may contain substantial amounts of water, but where that water does not fill all available voids (UZ). Caves represent a special situation that may involve saturated or unsaturated settings.

Springs: Springs are point sources of ground-water discharge, sometimes referred to as ground water outcroppings. The discharge may range from seepage to high volume flow from deep to shallow aquifers. The outlet may be a few cm to a few meters wide. Spring discharge may form open pools, small to moderately large streams, or just local seepage. Spring discharge may be sustained for hundreds of thousands of years as is implied by the antiquity of the Devils Hole ground-water-carbonate record (Winograd et al. 1992) or only discharge on a seasonal and geologically short-lived basis. Spring discharge may be isolated or associated with other hydrologic settings such as wetlands or streams.

Wetlands: Wetlands result when the water table intersects the ground surface, in low-lying areas. In contrast with springs, wetlands have dispersed ground-water discharge, thus forming a shallow water body across a broad, low-relief area. Dependent on local conditions, such as topography and structure, wetlands may be supported by simple to complex hydrologic conditions. Examples of simple conditions are those sustained by just shallow ground-water discharge, whereas complex conditions would be a mixture of deep and shallow springs in addition to the local water table discharge. Wetlands typically contain fresh to slightly saline waters, because source ground waters are usually dilute and fluid outflow from the wetland minimizes solute accumulation. Because of ground water sapping (water saturated sediments that collapse into the wetland), wetlands typically do not have well defined margins.

Playa: Playas were recently reviewed by Briere (2000), who proposed restricting the term to discharging continental basins with negative water balance (inflow < evaporation). In contrast, we consider playas to be flat, fine-grained deposits in and near valley axes that fall into two distinct hydrologic settings. Playas, because of hydrol-

ogy and geomorphology, often have well defined margins, but generally do not have complex shore-zone features. Dry-playas, are playas that have ephemeral water bodies supported by only surface water, because ground water is deep below ground surface. Wet-playas are basins that receive ground-water discharge, whether as liquid or vapor in addition to surface water (see Mifflin, 1988; Eakin and others, 1976). Wet playas are often places where ground-water flow terminates, so fluid through flow is minimal and outflow to vapor is large. In contrast, wetlands are settings where the water table is only open to the atmosphere along the ground water flow path. Thus, wet playas, owing to solute storage from high water loss to evaporation, often contain saline waters, which precipitate evaporate minerals including di and monovalent carbonates, while wetlands tend to contain fresh to only slightly saline (a few grams per liter total dissolved solids) waters, which precipitate calcite and aragonite.

Lakes: A lake is any standing body of water, in that sense, wetlands and playas are lakes. However, for this discussion, we prefer a more restricted hydrologic definition of lakes. The term lake, as used herein, is restricted to those standing water bodies supported by a mix of surface and ground waters. In this context, wetlands and wet playas are distinguished from lakes by being standing water bodies supported by predominantly ground-water discharge. Lakes may be hydrologically open or closed (surface or subsurface) as well as permanent or ephemeral, due to many factors including climate, topography, and porosity/permeability of catchment rocks. In addition, desert lakes may be very sensitive to climate variability and undergo rapid and extreme changes in volume, which creates highly variable sediment records.

Lake waters are chemically diverse, both because of solute sources derived from catchment water-rock interactions and hydrochemical processes within a lake's water column (Eugster and Jones, 1979, Kelts and Hsu, 1978). In most warm deserts, lakes are uncommon, but they do exist, especially if supported by river flow from nearby large mountains, such as Mono Lake, California and Great Salt Lake, Utah. Lakes commonly have complex shore zones composed of sand and gravel beaches associated with shoreline deposition and erosion processes. Stream flow into lakes may create deltas. As ground water often enters a lake along its margin, solute mixing and bioactivity may result in carbonate precipitation ranging from prominent tufa deposits to cemented sand and gravel (beach rock).

Faunal and floral characteristics of the hydrologic settings

Subsurface water—Oxygenated ground waters support a variety of aerobic microbes and protozoans to complex metazoans. Anoxic ground waters often contain a variety

of anaerobic microbes. Ostracodes and mollusks are the only common ground water organisms that make a shell (calcite and aragonite respectively) and so leave a fossil record of a ground water setting. Population of ground water by complex organisms is dependent on there being adequate dissolved oxygen, moderate water temperatures, and food. Oxygen is not produced in ground water, so infiltrating flow must bring oxygen from the surface. The water temperature must be relatively low because most metazoans can't survive at higher temperature (> 50°C) and warmer water doesn't contain as much oxygen. Food must be adequate to support the base of the metazoan food chain, but not so abundant that oxidation of organic carbon consumes available oxygen.

Biologic activity in ground water derives its energy from organic materials originating from infiltration as well as a variety of chemogenic reactions. As all biologic activity in ground water involves relations that may change pH and add CO_2 to the water that activity has the potential to cause carbonates to precipitate in or dissolve from ground water.

Waters in the UZ whether oxygenated or anoxic may also support fauna such as microbes and protozoans. Perched ground water in the UZ may support metazoans in addition to microbes and protozoans.

Springs—Springs support an array of plants and animals. The kinds of plants and animals are dependent on the hydrologic characteristics of the spring, so important factors include discharge, temperature, permanence, total dissolved solids (TDS), dissolved ions, and biologic factors such as aquatic predators or density of emergent vegetation. Forester (1991) suggested ostracode occurrences in springs were partly related to temperature and solute composition. Because springs often are the only source of permanent water in the desert they attract and support a wide number of terrestrial vertebrates and invertebrates. Because desert springs are commonly isolated water bodies, they often support endemic plants and animals (see Smith et al, 2002; Hershler and Sada, 2002).

Wetlands—Wetlands also support an array of plants and animals that are dependent on the hydrologic properties of the wetlands. Their diversity is controlled by the depth and volume of water, seasonal/annual water temperature profile, dissolved ion composition (solutes) and concentration (TDS), seasonal/annual permanence of the setting, and hydrologic heterogeneity or homogeneity, e.g. spring as well as ground-water discharge versus only ground water discharge from the water table. Wetland communities may have complex biofacies, especially in hydrologically complex situations. The plant community may include various emergents (e.g. cattail, bulrush), subaquatic macrophytes (e.g. Myriophylum, Potomogetan), and planktic (diatoms), and benthic (diatoms, charophytes) algae. The animal community will include representatives of

most invertebrates including ostracodes, and mollusks that leave a fossil record and so produce biogenic carbonates. Biologic activity in general, and photosynthetic activity in particular can result in the precipitation of carbonates from wetland waters.

Playas—Plant and animal diversity is typically lower in playas than in other settings due to their episodic and unpredictable nature (dry playa) and high salinity (wet playa). Dry-playas with their sporadic flooding events commonly only sustain aquatic organisms that can hatch, reach maturity, and produce resting eggs or seeds in a short time. The Branchiopoda (fairy shrimp, clam shrimp, and tadpole shrimp) are found in many dry playa settings, where cyanobacteria is the primary food. Because photosynthesis is often limited and the water dilute, dry playa waters may produce little or no carbonates.

Wet playas commonly support taxa that are tolerant of brines. Specialized animals such as brine shrimp (related to fairy shrimp) may be common in wet playas. Some ostracodes and other crustaceans, as well as some charophytes also live in saline wet-playa settings having a TDS below about 100 g/L or as high as 400 g/L in many Australian wet playas. In addition to charophytes various algae, such as *Duneliella* spp, and cyanobacteria live in salt-water. Microbes are also common in the sediment and their activities, such as sulfate reduction of organic carbon producing bicarbonate are important for understanding the fate of organic matter in sediments and carbonate production in the water column.

Lakes—Lakes, as defined here, defy easy categorization the faunal and floral characteristics. Whether the lake is permanent or ephemeral, deep or shallow fresh or saline, and so on, will determine the abundance and diversity of the fauna and flora. Diversity may be high in geologically long-lived lakes such as Baikal, with thousands of species of plants and animals or low as in the case of ephemeral saline lakes. Conversely, species abundance may be high in the ephemeral saline lake, but low in long-lived lakes. For example, the ostracode species diversity in Lake Mannix during much of the late Pleistocene was low composed of a single abundant species *Limnocythere ceriotuberosa* indicating lake characterized by strong seasonal variability in surface water input.

Characteristics of carbonate deposits in different hydrologic settings.

Subsurface waters—Ground-water carbonates commonly take on two forms. The first is a clear, milky or colored sparry calcite that precipitates in the fractures of regional aquifers. The calcite veins at Travertine Point above Death Valley and the vein filling at Devils Hole are examples. The Devils Hole calcite vein grew very slowly, on average 1800 years for 1.27 mm of calcite growth (Landwehr and others, 1997). The driver of deep ground

Table 1.

Mojave Desert carbonate paleo-environments

	spring mound	wetland	saline wet playa	pedogenic	cave	hot spring	lake
geomorphology							
shape	mound; convex upward surface	gentle dip to flat	nearly flat	occurs within alluvial fan, eolian, and other deposits, generally 20–100 cm deep	cave, karst structures	platform or mound	drapes topography
position	mountain front to valley bottom	along apprx btm third of alluvial fan, base of fan valley floor	valley axis, terminal playa, beach zone common contrast with valley fan	mountain front to valley bottom	mountains; rarely, valley bottoms	mountain or valley	generally low areas
other	forms perched benches	may have "puffy" salt crusts					
sediment	fine sand to silt and clay; mostly eolian material; may have enriched organics	well bedded to massive, sand silt and clay, green, blocky; "black mats"	gray muds, salt minerals, carbonate crusts	may have gravel and sand fragments in carbonate	flowstone and speleothems; pure $CaCO_3$	tufa, flowstone, sinter, opaline materials	marl to limestone; gravel accumulations that are well sorted
carbonate	minor to dispersed calcite, loose white chalky material	nodular calcite in matrix or popcorn texture common	calcite, aragonite, dolomite, Na carbonates	calcite dispersed (stage 3) to layered and dense (stage 4 and greater); may form kernels, vertical pipes as root casts	aragonite, calcite	aragonite	aragonite or calcite as tufa, microbialites, endogenic, authigenic, biogenic
isotopes							
Sr 87/86	value of ground water	gw rock water interaction	ground water	dust, local rock	ground water rock interaction	ground water rock interaction	surface and ground water rock interaction
C 13/12	DIC ground water	DIC gw, photosynt fractionation	biofractionated	C_4, C_3, cams	soil carbonate, ls, biofract	soil, atmospheric, ls	DIC
O 18/16	recharge or higher value	recharge, evaporative enrichment	meteoric	meteoric	meteoric	meteoric	water, water temperature
paleontology	abundant phreatophyte plant impressions		brine shrimp pellets		crustaceans other invertebrates		
ostracode	large cyprids, others	certain candonids, limnocytherids, small cyprids, darwinulids	certain limnocytherids, candonids, cyprids to none	none	gw candonids	Select cyprids, darwinulids	particular candonids, limnocytherids, Cytherissa lacustris
mollusk	hydrobiids, terrestrial gpods	physids, stagnicolids, planorbiids, terrestrial gpods	none	none	gw snails	none	Anadonta, sphaerids, pisidiids
diatom	benthics	benthics	benthics	wetground	none	benthics	plantics and benthics
vertebrate	rodents??	wide variety	small animals	none	fish	fish	fish
bioturbation	extreme	moderate	none	wide burrows common	none	none	variable
other features		pedogenic overprint common		micro-piping		sulfides and sulfates; Fe/Mn oxides	
examples	Valley Wells, Jack Spring	lower Kelso Wash, Blind Spring-Cronese Lake platform, Valley Wells, Las Vegas Valley	upper Soda Lake, Bristol Lake, Searles Lake	widespread in alluvial fan deposits	Devils Hole, Mitchell Caverns	Coso??	Manix Lake beds, Lake Mojave shoreline gravels, Searles Lake beds

water carbonate growth likely involves factors that cause loss of $CO_{2(aq)}$ following the general relation

$$Ca + 2HCO_3 \rightarrow CO_2 + CaCO_3 + H_2O$$

Thus gains in water-temperature, decreases in pressure, addition of solutes from water rock reactions and mixing of ground waters drive the above reaction.

The second form of ground water carbonate precipitates near the water table, typically in unconfined aquifers. This carbonate is commonly a fine-grained white chalky or sugary carbonate that may or may not have root casts and clastic grains floating in a carbonate matrix, so may be similar to soil carbonates. However, unlike soil carbonates, it may contain aquatic fossils, commonly ostracodes, and may or may not have distinctive $d^{13}C$ values. Soil carbonates tend to take on a $d^{13}C$ value of either C_3 or C_4 plant CO_2, whereas water table carbonates will take on the value of the dissolved inorganic carbon (DIC), which is generally a higher value than soil carbon in carbonates. Root casts tend to be very common in soil carbonates, but less common in water-table carbonates, although depending on the setting water table carbonates might grade into soil carbonates. In warm deserts water-table carbonates may form extensive carbonate cemented deposits that might be classified as calcrete (Goudie, 1983). Water-table carbonates may precipitate due to degassing noted above, evaporation, or even biologic activity. In the desert, water-table carbonates may be found in alluvial fans, as well as in association with springs, wetlands, and playas. They are exposed in hectorite pits in the Amargosa Desert, often being expressed as thin carbonate layers in clay. Any calcrete that is suspected of being a ground-water carbonate would require study in the field and lab to distinguish it from a pedogenic carbonate.

Springs—Spring carbonates are associated with regional (deep) ground water discharge, but can also precipitate from shallow ground-water discharge from unconfined aquifers. Quade and others (1995) described the factors associated with the precipitation of carbonates from spring discharge from regional ground water. The primary factor involves CO_2 degassing near the spring orifice as the ground water equilibrates with the atmosphere. Regional spring discharge is often characterized by extensive carbonate mounds as well as tabular carbonate (calcrete-like) deposits. The tabular deposits form as the spring migrates across the landscape, where flow from spring discharge erodes the sediments in the outflow direction and precipitates "pseudo-bedded" carbonates along the trailing edge of the migration. Over time, the tabular carbonates can form extensive and widespread pavements. Because terrestrial and aquatic vegetation grows around the spring, the spring mounds and tabular carbonate deposits may contain root casts as well as the bulbous or tuberous rooting structures of bulrush and cattail. The CO_2 equilibration with the atmosphere continues to occur along flow from the orifice,

resulting in carbonate precipitating in the flow channel and around the ever present emergent vegetation, such that extensive emergent vegetation carbonate stem casts can develop. Large springs commonly support subaquatic macrophytes and beds of charophytes as well as abundant mollusks and ostracodes. Shells from organisms can be found in the carbonate mounds, flow channel carbonates, and sometimes in the tabular trailing flow carbonate beds.

Shallow ground water spring discharge may also produce inorganic, bioinduced, and biogenic carbonates. However, because shallow ground water generally is not charged with CO_2, its discharge does not produce the massive quantities of carbonates common to regional ground water spring discharge. Warming of shallow discharge, solute mixing, and photosynthetic activity may result in local carbonate encrusting of plants and rocks.

Wetlands—Wetlands contain fine grained carbonates dispersed in (usually mud-size) silica-clastic sediments; the muds may be so calcareous they could be classified as a marl. The deposit is commonly composed of a green to greenish grey calcareous mudstone with fine, blocky bedding. The carbonates are likely produced by photosynthesis, solute mixing of ground waters with surface waters, warming of the waters, and evaporation (particularly in wetlands with limited through flow), as well as the accumulation of airborne dust.

When a wetland dries out it often produces a terminal deposit known as a-"black mat"-, which is a black to dark-brown organic-rich sediment derived largely from emergent vegetation and algae that populate the final aquatic phase of the wetland (Quade and others, 1998). Black mats are more common in the northern Mojave Desert and the Great Basin than they are in the southern Mojave Desert. The blackmat deposit is often capped by a calcrete deposit with what is called "popcorn" tufa; likely related to carbonates produced from evaporating ground water in the capillary fringe and (or) pedogenesis.

Biogenic carbonates, mollusks, ostracodes, and charophytes are common in wetland sediments (Quade and others, 2003). Biogenic and bioinduced carbonates may dominate the sediments in a wetland. For example, sediment cores from the southern Pahranogat Lake near Alamo Nevada are dominated by the calcareous stems of charophytes and by ostracode shells.

Playas –Dry playas, commonly only produce minor amounts of carbonate owing to their dilute waters. The resulting carbonate may accumulate or be lost to deflation. Most dry playa sediment is pale brown, green, and red fine sand, silt, and clay from clastic overland flow sources. The deposits are generally thin-bedded and may show mud cracks.

Wet playas, by contrast, with their connection to ground water and a continuous input of solutes containing Ca and alk in various proportions will produce carbonates. Calcite

saturation typically occurs at TDS values of about 250 to 300 mg/L and wet playas commonly have TDS values of 10's to 100's grams per L, so calcite and other carbonates are very insoluble in most wet playa waters. Consequently, inflow will typically precipitate carbonates on the margin as discrete units and fine-grained carbonates in the water column. Photosynthesis, evaporation, and temperature changes may also result in carbonate production. Owing to the typically high TDS values mollusks are usually not found in wet playas, but may live on the margin, where ground water enters the system. Ostracodes and charophytes are common in wet playas having an average TDS value below about 100 g/L, so their skeletal carbonates may be present in wet playa sediments. Wet playa sediment is pale green and brown to white fine sediment, may be dense or "fluffy", and may include salt crusts and other evidence of salt deposition. Bedded salt is relatively rare, but is present in some locations such as Death Valley and Searles Lake. Brine mineralogy can be quite variable depending on water chemistry, and in many cases the playas are mined for commercial purposes, such as at Bristol, Cadiz, and Searles playas.

Lakes—Lakes contain a variety of carbonates forming in the shore zone, within the water column, and within the sediments(Jones and Bowser, 1978). Further, many types of carbonates (di and mono valent) are associated with brine lakes (Eugster and Hardie, 1978).

Shore-zone carbonates commonly originate from biologic or ground-water activity along the margin of the lake. Biologic activity often involves microbial mats of various types with different redox preferences whose metabolic, respiratory, and or photosynthetic life processes result in the formation of microbialites (often referred to as stromatolites). Microbialites may be near the shore zone or in the littoral to sublittoral zone of the lake. Ground-water activity commonly involves carbonate-saturated ground waters entering the lake along the shore zone, where they mix with lake water and precipitate carbonate minerals. The later process is often facilitated by ground water being enriched in either the carbonate cation or anion, while the lake water has the opposite enrichment. Ground water mixing with lake water can result in cemented beach sands or gravels, tufa mounds, and carbonate encrusted rock.

Littoral to sublittoral zone carbonates are derived from biologic and or ground water activity. In small lakes, extensive growths of subaquatic macrophytes and *Chara* spp often induce calcite precipitation as a byproduct of photosynthesis. When such carbonate production is extensive the resulting carbonate-mud mix is referred to as marl. Similarly, fresh or saline lakes with low energy littoral zones may support algal mat growth that also promotes carbonate-mineral precipitation. The later commonly takes on a laminated or varved appearance, but unlike open lake laminated sediments, these laminae are algal

bound. Inflowing ground water can result in solute mixing and carbonate precipitation. Solar-insolated, shallow lake waters may both evaporate more readily than open lakes or warm up resulting in CO_2 out-gassing and carbonate precipitation.

Open water in deep lakes with a well-developed epilimnion and hypolimnion often precipitate endogenic carbonates due to heating of the atmospheric-lake boundary layer or to algal photosynthetic activity. Both of the latter processes are dominant in the warm season. The resulting clay- and silt-sized, commonly calcite or aragonite, carbonate minerals then settle into the hypolimnion. If those crystals are not dissolved in the hypolimnion and the hypolimnion is anoxic, and unable to support benthic life, the carbonate crystals may form a discrete layer. Cold or wet season fine-grained clastics then settle out on the carbonate layer forming open-lake carbonate laminated sediment. These carbonate-laminated sediments differ from the shallow water forms by having sharp boundaries between the layers.

Lake sediments, owing to biologic activity, solute type and concentration variability, redox setting and reactions may produce many kinds of carbonate minerals. Sulfate reduction in anoxic sediment is a simple example. The reaction products are variously H_2S or HS^- and HCO_3 from CO2 hydration. If the pore fluids or the overlying waters are rich in Ca, calcite or aragonite will precipitate.

Lake sediments may also contain a significant amount of biogenic carbonate, commonly as ostracode shells, mollusk shells in the shallow water, charophyte stems and gyrogonites (calcareous material surrounding oogonia), and in fresher water lakes planktic algae such as *Phacotus* spp (see Kelts and Hsu, 1978, fig. 3). Fecal pellets, such as those from brine shrimp, may also calcify and can form a calcified pellet coquina or serve as nuclei for ooids.

$d^{13}C$, $d^{18}O$, $^{87/86}Sr$ characteristics of carbonate deposits in different hydrologic settings

Because all of the hydrologic systems considered in this study are supplied by meteoric water, isotopic distinctions between them result from water-rock, water-atmosphere, and water-biosphere interactions within the specific system. This section discusses factors that affect carbon, oxygen, and strontium isotopes systems in such settings and the isotopic differences that might help distinguish them.

Although isotopes are chemically similar, they are not chemically identical. An important manifestation of this is fractionation of low-atomic-number isotopes, such as carbon and oxygen, that is influenced most by temperature and by state of matter. Minerals formed at lower temperatures are isotopically heavier than those formed at higher temperatures from a fluid of the same isotopic composition. In liquid-solid and gas-liquid reactions, the heaviest isotope is preferentially incorporated into the denser phase.

Isotope data are often reported in the so-called "del-notation," which is shown by the following equation, using oxygen isotopes as an example:

$$\delta\, ^{8}O = \frac{^{8}O/^{6}O_{sample} - ^{8}O/^{6}O_{s\tan dard}}{^{8}O/^{6}O_{s\tan dard}} X1000$$

Note that because the differences in d[18]O between substances are usually small, d[18]O is reported as permil (hence X1000) instead of as percent. If a substance has a d[18]O = -10‰, the substance is depleted relative to a standard by 1%.

Carbon isotopes. The carbon isotope composition of carbonate minerals is the result of: 1) the type and extent of water-rock and water-biosphere interactions that alter the isotopic composition of dissolved inorganic carbon (DIC) in meteoric water, and 2) the fractionation between the DIC and mineral.

Dissolution of carbonate minerals along the flow path (water-rock interaction) affects d[13]C of DIC. This is particularly true where the catchment area contains marine carbonate rocks, which, when unaltered, commonly have an average d[13]C = 0 ‰. Meteoric water that has undergone depletion via water-biosphere interaction, particularly with soil gases, will become isotopically enriched by such water-rock interaction. The final d[13]C value of DIC, and therefore of carbonate minerals precipitated from it, depends on the d[13]C values of the organic matter and carbonate minerals in the hydrologic system and on the extent of water-rock and water-biosphere interactions. Even water-volcanic rock interaction results in a distinctive d[13]C value for DIC. Atmospheric and soil gas CO_2 is hydrated producing H^+ and HCO_3^-. The H^+ reacts with a volcanic mineral resulting in the precipitation of a clay mineral and the release of a cation, commonly Na^+, leaving HCO_3^- as an anion(Eugster and Jones, 1979). Thus the d[13]C value will variously trend towards an atmospheric or soil gas value.

Water-biosphere interactions act to enrich d[13]C of DIC in a fluid in equilibrium with the atmosphere, because the photosynthetic production of organic matter is isotopically depleted in ^{13}C compared to atmospheric CO_2. If that organic matter is deposited in the sediment, then the resulting DIC d[13]C values increase. The d[13]C value of soil gas and of soil organic matter are also depleted with the degree of depletion being dependent on the photosynthetic pathway used by the plant. C_3 plants(~90% of modern plants), such as trees, shrubs, and many grasses, have d[13]C values between –23 and –34 ‰; whereas C_4 plants, such as many warm temperate and tropical grasses and several kinds of shrubs, have d[13]C values between –6 and –14 ‰ (Quade and others, 1989). Decomposition of soil organic matter and production of soil gas may saturate infiltration with d[13]C depleted CO_2 that then produces d[13]C depleted DIC and carbonate.

Carbon isotopes are fractionated during gas-liquid and liquid-solid reactions, such that the heavier isotope becomes enriched in the denser phase. The amount of fractionation is temperature dependent and differs between minerals. For example, calcite precipitated from water at low temperatures will be enriched in the heavier isotope by about 0.5 to 0.9 ‰ relative to the d[13]C of DIC, whereas aragonite will be enriched 2.4 to 2.7 ‰ (Rubinson and Clayton, 1969; Grossman, 1984). The amount of fractionation in biotically formed $CaCO_3$ may differ between types of organisms, often down to the genus level, and this "vital effect" can be as great as several permil, particularly when metabolic carbon is added to the shell (Hoefs, 1997). The dissolved inorganic bicarbonate (DIC) in water in equilibrium with atmospheric CO_2 (d[13]C = -7 to -8 ‰) will be enriched at about 25º C by 7.7 ‰ and have a d[13]C H•+0.5 ‰ (Deines et al, 1974).

Ground-water, spring, and wetland settings supported by high flow will have d[13]C values close to DIC in equilibrium variously with the atmosphere, soil gas, or with carbonate rocks when they are in the flow path. Lakes, wet playas, and some wetlands, however, may be sites of high organic productivity. The d[13]C of water in those settings will likely have high, often very high, d[13]C values when the organic matter is deposited and isolated from the water. The d[13]C DIC becomes enriched compared to water in equilibrium with atmosphere. Similarly, if carbon is lost via methane production the resulting d[13]C values of DIC can become very high, e.g. +14 PDB, (Curry and others, 1997). By contrast, a very low value is also possible if CO_2 from decaying organic matter is oxidized. Hence, carbonate minerals formed in these hydrologic settings are likely to have more negative or more positive d[13]C than those precipitated from ground water, springs, and or other through flowing setting.

O isotopes. The d[18]O value of a carbonate mineral depends on the temperature at which the mineral formed and the isotopic composition of the fluid. Colder water temperatures result in greater fractionation, so higher d[18]O values in the carbonate mineral. The fractionation between water and calcite decreases ~0.26 ‰/°C. Evaporation of water also causes enrichment of the heavy isotope in the water, because the light isotope is preferentially removed in the vapor phase. The d[18]O value of meteoric water is dependent on the d[18]O of the initial water source, Raleigh fractionation (continuous isotopic equilibrium between vapor and water), and the temperature of condensation of the precipitation.

The d[18]O of ground water, spring, wetland, and lake having high flow will be close to that of the source meteoric water. As evaporation becomes more important and approaches inflow isotopic enrichment will occur. Wetlands, wet playas, and many lakes have large area to volume ratios. Hence, the balance between input and evaporation

could result in large seasonal swings in $d^{18}O$ of the water that results in high variability of the $d^{18}O$ values carbonate minerals precipitated in those settings.

Sr isotopes. The $^{87/86}Sr$ ratio in carbonates formed in all of the hydrologic settings in this study result from water-rock interaction between meteoric water and rock material in the system. Rain water contributes only a minor amount to the Sr budget. Therefore, both the Sr concentration and $^{87/86}Sr$ value of surface and groundwater is the result of mixing between rainwater and Sr derived from minerals along the flow path. The $^{87/86}Sr$ ratio of a fluid represents the sum total of the $^{87/86}Sr$ of each source mineral, weighted by its Sr abundance, that was contributed to the fluid from all surface and ground water catchments. Sr is a minor element in the Earth's crust and it readily substitutes for Ca in minerals. Radiogenic ^{87}Sr is derived from beta-decay of ^{87}Rb, which substitutes for K in minerals. Therefore, chemical reactions between water and Ca- and K-bearing minerals will determine the $^{87/86}Sr$ ratio of the fluid. High-atomic-number elements like Sr are not fractionated in liquid-solid reactions; and therefore, the $^{87/86}Sr$ of the carbonate is the same as the water from which it formed. The ratio measured in the carbonate will reflect two controls: 1) the type of minerals encountered by the water, and 2) the rate and chemical conditions of flow, i.e., duration of water-rock interaction.

Secular variation in $^{87/86}Sr$ in a carbonate deposit or core can provide important information about hydrologic change, such as rate of flow, which affects extent of water-rock interaction, and changes in contributions from different water sources. Ground water, spring, wetland, wet playa, and lake all involve ground water as either a major or minor component of its water source. The Sr isotopic signature of the fluid is derived from water-rock interaction along its entire flow path. In contrast, the Sr isotopic signature of pedogenic carbonates is derived from water-rock interaction in the host sediment only. It might, therefore, be possible to identify a pedogenic carbonate by measuring a similar $^{87/86}Sr$ in the carbonate and leachate from carbonate-free host sediment.

Contrast with pedogenic carbonates

Pedogenic carbonate accumulates by deposition of fine-grained, loose to dense, calcite in the near-surface UZ by soil forming processes. Evaporation and infiltration events repeatedly dry and wet the sediment creating an environment where carbonate minerals can precipitate. Plants also extract water and precipitate Ca oxalate minerals, which can be altered to carbonates by pedogenic processes. Gile and others (1966) and Machette (1985), among others, found that pedogenic carbonate is progressively accumulated in soils in warm deserts. This accumulation of carbonate (see Gile and others, 1966) serves as an age-diagnostic criteria for soil development in a deposit. The

first stage of pedogenic carbonate accumulation typically consist of thin, white $CaCO_3$ rinds on pebbles, a characteristic common in early to mid-Holocene alluvial fan deposits. In contrast, advanced stages are characterized by massive to laminated and even brecciated carbonate commonly referred to as "petrocalcic soil" or "calcrete" that may be 500 ka or older.

Pedogenic carbonate deposits (B_k horizons) commonly forms in association with other soil horizons , such as the B_t (clay-rich) horizon. Erosion could remove the overlying parts of the soil horizon, exposing the B_k horizon, so they could be confused with GWD and surface-water carbonates. Distinguishing features between pedogenic and ground-water carbonates include decreased grain to grain contact in Stage III and older pedogenic carbonates, a lack of ostracodes and mollusks in pedogenic carbonates and distinctive $d^{13}C$ characteristic of plant photosynthetic pathways (e.g., C3 and C4 plants). Because of the large gas to water volume in the soil zone, the $d^{13}C$ values of pedogenic carbonates should be significantly more negative than those associated with GWD and surface water. Most precipitation of the carbonate minerals in soil probably forms during the drying stages of the wet-dry century to millennial climate cycles. The $d^{18}O$ should be slightly to significantly heavier than that of the source meteoric water. Therefore, pedogenic should have characteristic light $d^{13}C$ and heavy $d^{18}O$. Presence of clastic fluvial material in the carbonate, thick calcic rinds on those clasts, and abundant root casts are typical of pedogenic carbonates, but are not necessarily unique to them.

Pedogenic carbonates may overprint other carbonate deposits with ground water origins, and ground-water deposits may be superposed on pedogenic soils, creating complex carbonate deposits. For example, tabular capping carbonates typical of spring settings probably form as a consequence of drying as the spring migrates, but also as infiltrating meteoric water evaporates; the two processes in combination, along with plant-water interactions, create a hybrid dense carbonate layer. Association of hybrid carbonate deposits with other sediments, whether parts of a soil profile or parts of a GWD system, is key to interpreting their origins.

Summary

Warm deserts are dry places due to the seasonal dominance of the subtropical highs. Because surface water is uncommon or seasonal and there is often a large depth to ground water in warm deserts carbonate deposits are often attributed to pedogenic processes. Warm deserts can be relatively wet in some places, even though they usually do not sustain permanent surface water bodies. Carbonate minerals and carbonate deposits of many kinds provide the evidence for the complex hydrology of warm deserts. The hydrologic processes that result in the precipitation of

carbonates, ranging from small particles to massive bedded deposits, are complex and diverse in nature. The physical characteristics of those carbonates are often process dependent; they provide direct insight into past hydrology and allow inferences to be made about climate and hydrologic history. Because many of these carbonate characteristics can be observed in the field, they offer an important tool for the regional assessment of hydrologic change on a geologic time scale. In addition to the field characteristics the majority of the carbonates have particular isotopic and fossil characteristics that allow recognition of their hydrologic setting. The inferred water properties allows for paleohydrologic reconstructions and when the linkage between climate and hydrology is understood, paleoclimate reconstructions can be attempted.

Warm deserts are also situated at latitudes where climate change (interglacial to glacial) result in a semi-arid to arid climates changing to climates dominated by winter precipitation. Lake Manix in the Mojave is an example of climate driven hydrologic change resulting in the appearance of surface water bodies on the once desert landscape. During the wet phases, lakes and wetlands become common, producing their own forms of carbonates and other deposits on the landscape. Reconstructing the paleohydrologic setting from the carbonates provides a means of understanding and recognizing climate change. Similarly, examination of the isotope and fossils found in such carbonates as well as wetland and lake sediments provide ways of recognizing the climate characteristics that produced the surface water settings.

Acknowledgements

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The evolution of Fort Irwin

Neil C. Morrison, *Museum Director, NTC & 11th ACR Museum, Ft. Irwin, CA 92310*

First Inhabitants

This region is rich with anthropological history dating back, according to some archaeologists, over 15,000 years ago, when Indians inhabited this area around Ice Age (Pleistocene) lakes and river areas. Vegetation and animal life was in abundance. Stone flakes caused by percussion produced cores that littered the camps. Atlatl points (throwing spear tips), arrowheads, stone tools, sleeping circles, split-twig animal figures and rock art (mostly petroglyphs) still remain as evidences of their existence. The meanings behind the rock art remain unclear.

The mystery remains as to what happened to these early people, who like the Anasazi (the ancient ones), disappeared. As water sources dried up and rivers became seasonal, Ice Age mammoths, ground sloths, camels and horses became extinct, and pines, oaks and elderberries retreated to the higher mountains.

Nomadic tribes continued to pass through the Mojave River region with some Uto-Aztecans settling around the waterholes of the desert like Aqua de Tomaso (Bitter Springs).

The Uto-Aztecan language group of Native Americans lived in the middle of the Mojave Desert. They were referred to by European travelers as Beneme, Vanyume, Paiute (Pah-Utah, Pai-Ute, Piute) and Serrano. They lived along the Mojave River from the San Bernardino Mountains to Afton Canyon. North of the Mojave River were the Numic Branches of the Uto-Aztecan language group called Paiute, Northern Paiute, Owens Valley Paiute, Koso, Panamints and Shoshoni. Most European Americans called all these groups of people "Paiute" and did not distinguish between bands.

First foreigners

The first recorded contact with the local Indians was through Father Francisco Garces, a Spaniard, as he traveled the Mojave Indian Trail in 1796 while exploring what was being called New Spain. Father Graces noted current campsites and several older abandoned camps belonging to the Anasazi. He followed the migration/trade routes of the Paiuti of the Uto-Azetcan language group in the Vanyume region. He noted on his map, Aqua de Tomoso "Water of Thomas" for Thomas was one of his guides. Father Garces made no indication to its taste. Today we call the site, Bitter Springs.

NOTE: A walking path made by man would generally be 12-14" wide and would travel the path of least resistance as possible from water source to water source.

First American
Jedediah Smith, mountain man

Jedediah Smith was a mountain man who traveled in search of new fur trapping sources. He was an early explorer in search of "what might be on the other side of the mountain". After Smith's return from what was known as Mexico (California) back into what was known as New Mexico (Nevada), more pioneers passed through this region traveling the Old Spanish Trail between Santa Fe (New Mexico) and Pueblo de los Angeles (Los Angles, California). They stopped at Aqua de Tomoso (Bitter Springs) because it was a necessary water source in spite of its bitter taste.

First military presence
"Chaining the Region"

Brevet Captain John C. Fremont of the Corps of Topographical Engineers and his guide and friend Kit Carson traveled this region from 1843-44. They were sent by the American Government to survey the migration/trade routes of the local Indians. Also they were to make scientific explorations of geological and horticultural resources of this region. In addition, they were also sent to determine an access route for covered wagons and supply trains for future immigrates coming into this region. They traveled in civilian attire to avoid alarming the local Indians and Spanish-Mexican settlers who had large haciendas (ranches). The Rancheros (ranchers) were very protective of their lands and would have been concerned seeing U.S. military uniformed personnel surveying their property. Captain Fremont's surveying expedition traveled quickly to minimize detection and only indicated the most direct routes, easiest access paths and water resources. They spent a short time at Aqua de Tomaso (Bitter Springs) and noted it on their map.

Note: Fremont did not know that Father Francisco Garces had named the spring for one of the Indian guides, but merely noted what was related to him as the name of this site on his map as Aqua de Tomaso (Bitter Springs). He also wrote the name Mohahva (Mojave) River as it was pronounced to him.

Captain Fremont would have Carson's men stretch out the 66-foot chain and hold the rod while he noted the angle. Carson would mark that length by placing a metal pin into the ground. After noting the location on the map, the men would pull up the back pin from the last point and re-stretch the chain 66 feet. They would repeat this pinning and re-stretching 80 times to equal 1 mile. This was called "chaining".

Rod & Chaining

5280 feet = 1 mile • The rod is 16' 6" tall

The chain is 66' long • 320 rods = 1 mile

80 chain lengths = 1 mile

The men's attire is based on a pen and ink drawing of Fremont and an oil painting of Carson. Size and build is based on accounts at time of their deaths.

Mormon Battalion

Bitter Springs (Aqua de Thomoso), April 1848

The Mormon Battalion left Council Bluffs, Iowa to fight in the Mexican War. Their first stop was Fort Leavenworth, Kansas to be outfitted with some military equipment. From there they marched 2,000 miles to San Diego. They arrived just as the war moved back into Mexico and was no longer a direct threat to the U.S. The Mormon soldiers were discharged in July 1847 and began traveling to their new homes in Salt Lake City. A small group commanded by Captain Daniel C. Davis re-enlisted for 8 months. The newly formed Mormon Volunteers were responsible for patrolling Cuidad (City) de los Angeles, San Diego, San Luis Rey Mission, and the surrounding areas. They were to protect the citizens from Indians raids and the Mexicans until both governments could sign a treaty.

By 1848 approximately 35 Mormon soldiers headed to Salt Lake City accompanied by Captain Davis, his wife Susan, and her son. They made camp at Bitter Springs (Aqua de Tomoso) in April 1848. Jefferson Hunt, a member of the party and a former Captain in the Mormon Battalion, named this spring "Bitter Spring" because of the alkali in the water that gave it the bitter taste. He noted the name on his map and the name remains.

The importance of the Mormon Volunteers passing through this region is that they were the first U.S. military forces on what is known today as Fort Irwin. Captain Davis brought the first military covered wagon drawn by mules into this area. The Indians had never seen a "white" man, woman or boy before. It is reported that one Indian tried to spit on a soldier's hand to remove the coloring to see what his natural color was.

The Mormon Battalion is unique because it represents the only U.S. military battalion to have been raised based solely on religion. The flag has five orange bars representing the 5-infantry companies and 28 stars representing each state in the Union as of 1846. The migration of Mormons to and from Salt Lake City through San Bernardino to San Diego re-established the Old Spanish Trail from Santa Fe to Pueblo de los Angeles in part by developing a branch trail that quickly became known as the Mormon Trail.

Camel expedition 1857–58

The Secretary of War, Jefferson Davis, wanted to test the use of camels as desert transportation for military equipment and supplies. He assisted in acquiring $30,000 for an expedition to go to Egypt and bring back 70 camels for the test trek. The camels fared the sea crossing well and arrived at Indianola, Texas on 14 May 1856.

Navy Lieutenant Edward F. Beale was tasked to conduct a survey for a wagon/camel route from Fort Defiance, New Mexico Territory (today's north-eastern Arizona) to the Colorado River and from Fort Mohave (western Arizona) along the 35th Parallel to Fort Tejon, California. He was also to test the fitness and service of the camels for the Army as a replacement of the horses and mules in the desert.

Lt. Beale began with 70 camels and 150 sheep. Most of the soldiers rode their horses and used the camels for transports. They did not believe that camels would be as reliable as horses. The sheep were for fresh meat so that the soldiers would not need to hunt.

Try to picture what it must have been like for the native Americans who had not seen many white men. There was an olive-brown Arab in traditional clothing along with strange looking "desert devils": dromedary (one hump) camels used for riding; bactrain (two humps) camels for carrying the cargo; and sheep. This must have been a sight to behold.

The Camel Expedition did not set foot directly on today's Fort Irwin. Lt. Beale and Hi-Jolly (Hadji Ali), the camel driver, rode horses up to Bitter Springs as a possible route into other parts of the country. They determined that the water was too bitter for animals and man alike.

Lt. Beale sent out five men on horseback to find water. When they did not return, he sent Hi-Jolly on his camel to locate them. Hi-Jolly saw the five men being attacked by a band of Indians. Once Hi-Jolly realized he did not have time to go for help, he drew his Arabian sword and charged them yelling "Bismiallah" (God is Great). The Indians had never seen a camel or such a rider and fled the area in a state of terror. They said that they saw "desert demons flying out of the sky".

After reaching Fort Tejon, Lt. Beale decided that the camels' performance far exceeded that of the horses for desert transportation but were not compatible with soldiers. The camels had a nasty personality, bit, spat and made lots of noise when they walked. These were not the types of things the military would tolerate and the camels were released into the desert.

Comparison: horses vs. camels

Could camels swim the Colorado River? Lt. Beale could not get them to set foot into the water. Hi-Jolly led the oldest camel to the water's edge for a drink. With little effort, Hi-Jolly led the camel into the water and all 70

crossed without incident. Unfortunately, 8 horses and 14 mules drowned during the crossing.

How did the camels compare in cold weather? In January, Lt. Beale pitched his camp within a few hundred yards of the summit of the Sierra Nevada mountains. His camels thrived happily and grew fat in two to three feet of snow. During a snowstorm camels were sent to rescue stranded wagons, people and mules. The camels brought the load through ice and snow back to camp. A strong six-mule team was unable to extricate the empty wagons. Yet the camels seemed to pull them out with little effort. The camels were sent back to retrieve the mules, which were freezing to death. The mules were tied up on the sides of the camels and carried out of the snow and mountains.

Would the leathery, hoofless feet of the camel carry them across the stony southwest? The camel has no shuffle in its gait, but lifts its foot perpendicularly from the ground and replaces it without sliding. The camel's coarsely granulated foot enables it to travel continuously in a region where other beasts could not last a week. They survived in both deserts and snow-bound areas with equal agility.

How often do the camel and the horse need water? A horse needs 8-12 gallons of water 2-3 times a day in the desert. A camel can go 10-12 days without water. Horses need special foods whereas camels eat almost any desert vegetation. Horses do not perform well under extreme heat or cold. Neither seems to effect camels. Camels gained weight in snow-bound areas because they could eat the abundant dead vegetation and get water from eating snow.

How much of a load can a camel carry? A horse can carry 170-250 lbs. and walk 30-40 miles in a day with stops and watering. A camel was tested over several days with increasing load. The camel carried up to 1,256 pounds 40-45 miles in a day at one continuous speed.

How do camels compare for riding? On a special trip away from camp, Lt. Beale rode his camel, Sid, eight miles an hour with "least effort" and traveled twenty-seven miles in three hours. The dromedary was used for riding and the bactrain carried the cargo.

Why did the camels fail the experiments? They scared the horses, mules and all animals in general. The soldiers could bond with a horse, but no one was able to bond with a camel. The camel's bit, spat, made noises when they walked, and had a nasty personality worse than any mule.

1ST Dragoons, Co. K
Redoubt, 1860-66

In the spring of 1860, Major James H. Carleton led a military campaign against the Pah-Utah Indians of the Mojave River area. On 18 March 1860, Thomas S. Williams and his brother-in-law, Jehu Jackman, who were scouting for a Mormon wagon train from Salt Lake City, were killed in an Indian attack at Bitter Springs. The local ranchers petitioned the government for military protection to keep the Indians away from the watering holes.

Major Carleton and eighty men built a series of redoubts and camps. The first, Camp Cady, was a fortified sand and adobe walled structure. A second Camp Cady was built as buildings and a parade field on the Mojave River. Soda Springs redoubt, first called Hancock redoubt (today called Zzyzx, pronounced: "ziz-eck") and Bitter Springs redoubts, were constructed between 1860-61. The two redoubts were built as overnight camps to protect both soldiers and civilians in case of Indian attack. The Bitter Springs redoubt was built on 19 April 1860 (in what is now Fort Irwin). The sand and adobe structure stood approximately 5' in an 80-foot circle. Inside, around the base of the slopped walls, were stepping-stones used by soldiers to rise up over the summit of the wall and fire their rifles. Inside the redoubt the soldiers would sleep and cook their meals out of harms (and winds) way. Wagon train travelers rested, filled their water barrels and watered their animals. The soldiers would return to Camp Cady after the wagon train departed.

In July 1866, a new mail service was inaugurated connecting San Bernardino to Prescott, Arizona over the Mojave Road (formerly the Spanish Trail-Mormon Trail). The Battle of Camp Cady on 29 July 1866 helped convince the Army and the mail contractors that the Mojave Road was not safe and military escorts would be needed for each mail crossing. The Rock Springs redoubt was built ninety miles to the east and additional outposts were established at other springs along the road. These camps and redoubts represent the first permanent U.S. Army presence in this area. Bitter Spring redoubt was used until 1866. Camp Cady remained in service until 1871.

Gold and silver in them thar' hills!

Captain Jefferson Hunt, from the Mormon Battalion, explored a route back to Salt Lake City over a giant dried salt lakebed. One of his party members died from starvation and lack of water and was buried there. As the party crested over the rim on its way out of the valley, Juliet Brier, one of the women, noted the following in her diary. "Goodbye death valley." Hence the name today, Death Valley.

The 1849 California gold rush began at Sutter's Mill (now Sutter's Fort) bringing massive amounts of immigrants into California. During one of the 1849 crossings, a member of the Hunt's party noted the rock formations and mineral contents along the way. Gold was found on the northern end of today's Fort Irwin and silver was found shortly thereafter. In addition, copper and turquoise was discovered in the area.

After the military pulled out of Camp Cady in 1866,

there was no significant military presence in this region. Therefore, law enforcement and protection for miners was under the local sheriffs. Several stories about shooting claim jumpers and run-ins with the law heavily reflect the history of the Bitter Springs region. There are old graves and ruins of buildings still baking in the sun as a reminder of the early history.

As in all mining endeavors, when the veins ran out prospectors began looking for another "Mother Lode" waiting just around the next bend. With mines opening and closing, the miners could only live a very basic lifestyle of one room shacks or tents. Many dug caves into the mountainside to get out of the heat of the day or worked in the mines during the day and came out during the cool of the night. "Grub runs" into town were often the miners' only contact with other people for long periods. While in town, they would need a "mine watch" to keep an eye on their property. One famous "mine watch" was Louis L'amour, the author, who referred to his time in this region as a "mine watch" in his novel, *Education of a Wandering Man.*

In the late 1930's the U.S. government began to develop the Mojave Anti-Aircraft Range and active mining began to decline. Most mines are privately owned and some were abandoned. The Army is serving as a caretaker and all mines are restricted areas.

Borax at Death Valley, 1880s

A booming economy flourished as Borax was discovered at Death Valley and miners poured into the region hoping for the mother lode. Soon, mining related businesses, railroads, and workers marked new growth within this region. The nearby town of Newberry Springs was the railroad's first choice for a crossroads but the townspeople raised the prices of property far too high and the Santa Fe Railroad moved over to the sleepy town of Barstow.

First water

Water is always an issue of concern in the desert. Bitter Springs could not produce enough nor did the taste meet the needs of the military inspectors. A water specialist with a water witch and a divining rod located the first well. He dug the well with his own equipment to prove to the military that doubted the location. It did not produce enough water and more wells were needed. However, good, clear water was available on the military reservation.

Mojave Anti-Aircraft Range 1940

In 1940 President Franklin Delano Roosevelt established the Mojave Anti-Aircraft Range (MAAR), a military reservation of approximately 1000 square miles in the area of present Fort Irwin. The purpose of this range was as a training ground for the Anti-Aircraft Batteries at Camp Haan stationed on March Army Air Corps Field in San Bernardino who provided air defense for the airfield against possible Japanese attacks. The new recruits first came out to the MAAR wearing a shoulder patch of a black circle with red "AA" for Anti-Aircraft. When they returned to their units, they changed the patch to AAA, Anti-Aircraft-Artillery. The recruits lived in "tent city" and trained on M-1 and M-2 90mm anti-aircraft guns as well as the 40mm Bofors anti-aircraft gun and the 50 cal water-cooled machine gun. The recruits fired against drone aircraft for in-flight firing. The Army Air Corps flew many training missions and provided training bombs with flour for smoke to indicate explosions.

In 1942 the MAAR was renamed Camp Irwin, in honor of MG George LeRoy Irwin from the 57th Field Artillery Brigade during World War I. Two years later Camp Irwin was deactivated and placed on surplus status.

Rocket testing at Gold Stone
14 July 1943

The U.S. lagged far behind the enemy, Germany, in weapons technology at the start of WWII. The Navy worked with California Technical College (CalTech) to develop forward firing rockets. The CalTech scientists needed plenty of open, uninhabited space to conduct rocket testing. The Navy used Camp Haan's sub-post, Camp Irwin, to test fire their prototype rockets.

It was well known that in Europe, the German Air Force had a plane-to-plane rocket in operational use. The concern was that the Germans might also be well along the way with a proximity fuse. The combination of rockets and proximity fuses would pose a serious threat to the Allied air offensive.

The day of the first air launch of a forward-fired rocket was a big day for the West Coast rocketeers. This meant firing while flying level or in a dive. Since the CalTech rocket had not been checked for reliability, the first air tests were made with one British rocket ("Test One") on each wing of a TBF-1 "Avenger" aircraft. The overall length of the rocket was 61 inches and its weight was 140 pounds. The rockets reached a velocity of 1,175 feet per second. Two "Test Two" models were eventually developed. One had a base fuse and a semi-armor piercing head. The other had both base and nose fuses

The testing was so successful that Dr. Renard of CalTech said, " . . . if we hit anything with that we're going to blow it up. The others didn't have the firepower. With the forward-firing rocket we saw firepower. This baby - wham - every time - and they were exciting to see. Now we have a lead."

Armored Combat Training Area 1951

Camp Irwin reopened its gates in 1951 as the Armored Combat Training Area. The camp served as a training center for combat units during the Korean War. Regimental

tank companies of the 43d Infantry Division from Camp Pickett, Virginia was the first to train at the new facility. Armor units continued to train here throughout the war.

Renamed Fort Irwin
January 1961

Camp Irwin was designated a permanent installation on 1 August 1961 and renamed Fort Irwin. During the Vietnam buildup many units, primarily artillery and engineer, trained and deployed from Fort Irwin.

In January 1971 the post was deactivated again and placed in maintenance status under the control of Fort MacArthur (Los Angeles Harbor), California. The California National Guard assumed full responsibility for the post in 1972. From 1972 to 1979 Fort Irwin was used primarily as a training area by National Guard and Reserve units.

On 9 August 1979 the Department of the Army announced that Fort Irwin had been selected as the site for the National Training Center (NTC). With over 1000 square miles for maneuver and ranges, an uncluttered electromagnetic spectrum, restricted military airspace, and its isolation, Fort Irwin was an ideal site for the NTC. The NTC was officially activated 16 October 1980 and Fort Irwin returned to active status on 1 July 1981.

Since its activation, the NTC has witnessed many firsts. The first unit to train against the newly established Opposing Force (OPFOR) was from 1st Brigade, 1st Infantry Division in January 1982. Infantry and engineer units first augmented the OPFOR in 1984. June 1984 saw the first use of M1 Abrams tanks and M2 Bradley fighting vehicles on the NTC battlefield. The first armored cavalry squadron rotation occurred in November 1984. Units from the 101st Airborne Division participated in the first light force rotation in March 1985. The first urban terrain mission was conducted at the NTC Pioneer Training Facility in December 1993.

The NTC and Fort Irwin continue to serve as the Army's premier training center. Officials from many countries have visited the NTC and use it as a model to build their own training centers. As in the past, Fort Irwin pits soldiers against a harsh environment, but now adds a determined and formidable OPFOR.

As during World War II, Korea, Vietnam, and Desert Storm, the National Training Center and Fort Irwin continue to train units to fight and win on the world's battlefields.

Miocene landslides within Avawatz Basin support hypothesis of a Paleozoic allochthon above Mesozoic metavolcanic rocks in the Soda and Avawatz Mountains, southeastern California

Kim M. Bishop, *Department of Geological Sciences, California State University, Los Angeles*

The Soda and Avawatz Mountains in the northeastern Mojave Desert (Fig. 1) expose structurally complex and multiply-deformed Precambrian to Tertiary rocks. Because of the complex and protracted deformation that has affected this area, the geologic history of the area is not well-understood. The western part of the Soda and Avawatz Mountains exposes Triassic and Jurassic metamorphosed volcanic and volcaniclastic strata intruded by younger Mesozoic plutons. Within the Soda Mountains, these rocks are structurally intermingled with smaller fault blocks of Paleozoic miogeoclinal carbonates (Grose, 1959; Walker and Wardlaw, 1989) (Fig. 2).

An important controversy regarding the geology of the Soda Mountains is the nature of the structural relationship between the miogeoclinal carbonates and the lower Mesozoic metavolcanic rocks. According to Grose (1959), the carbonate blocks throughout the area rest on top of the metavolcanic rocks along a regional-scale, low-angle fault

of Mesozoic age. However, another hypothesis, espoused by Walker and Wardlaw (1989), suggests that the carbonate blocks have been uplifted from beneath the metavolcanic rocks. The purpose of this paper is to present evidence found in Miocene landslide deposits supporting Grose's (1959) hypothesis for a regional-scale allochthon.

Summary of pertinent stratigraphy and structure in the Soda and Avawatz Mountains

For the purposes of this paper, the Soda and Avawatz Mountains are structurally divided into eastern and western belts. In the Avawatz Mountains, the Arrastre Spring fault divides the two belts, whereas in the Soda Mountains, the Avawatz-Soda fault divides the belts (Fig. 2). The eastern belt contains basement rocks consisting of Precambrian gneissic rocks, late Protereozoic to Paleozoic miogeoclinal rocks, and Mesozoic plutonic rocks. In marked contrast,

Figure 1. Location map.
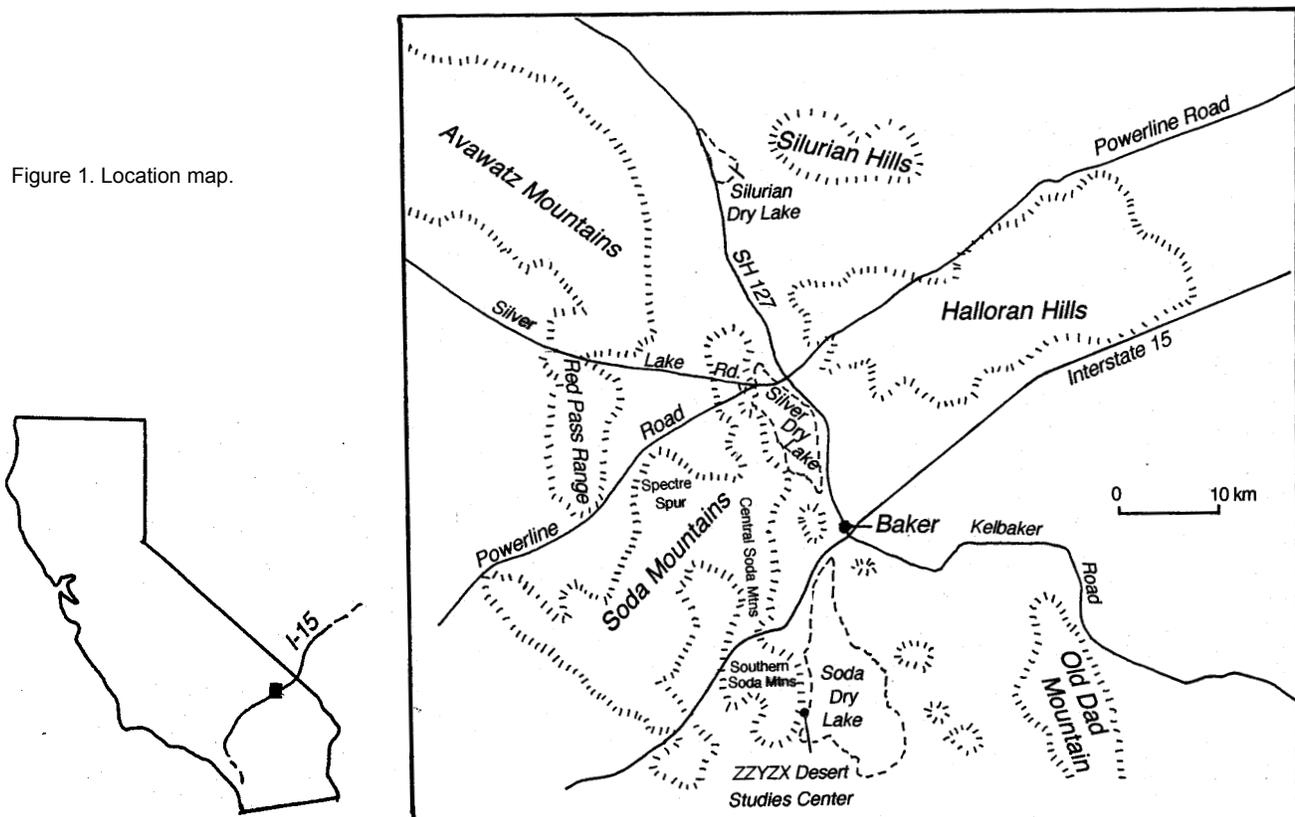
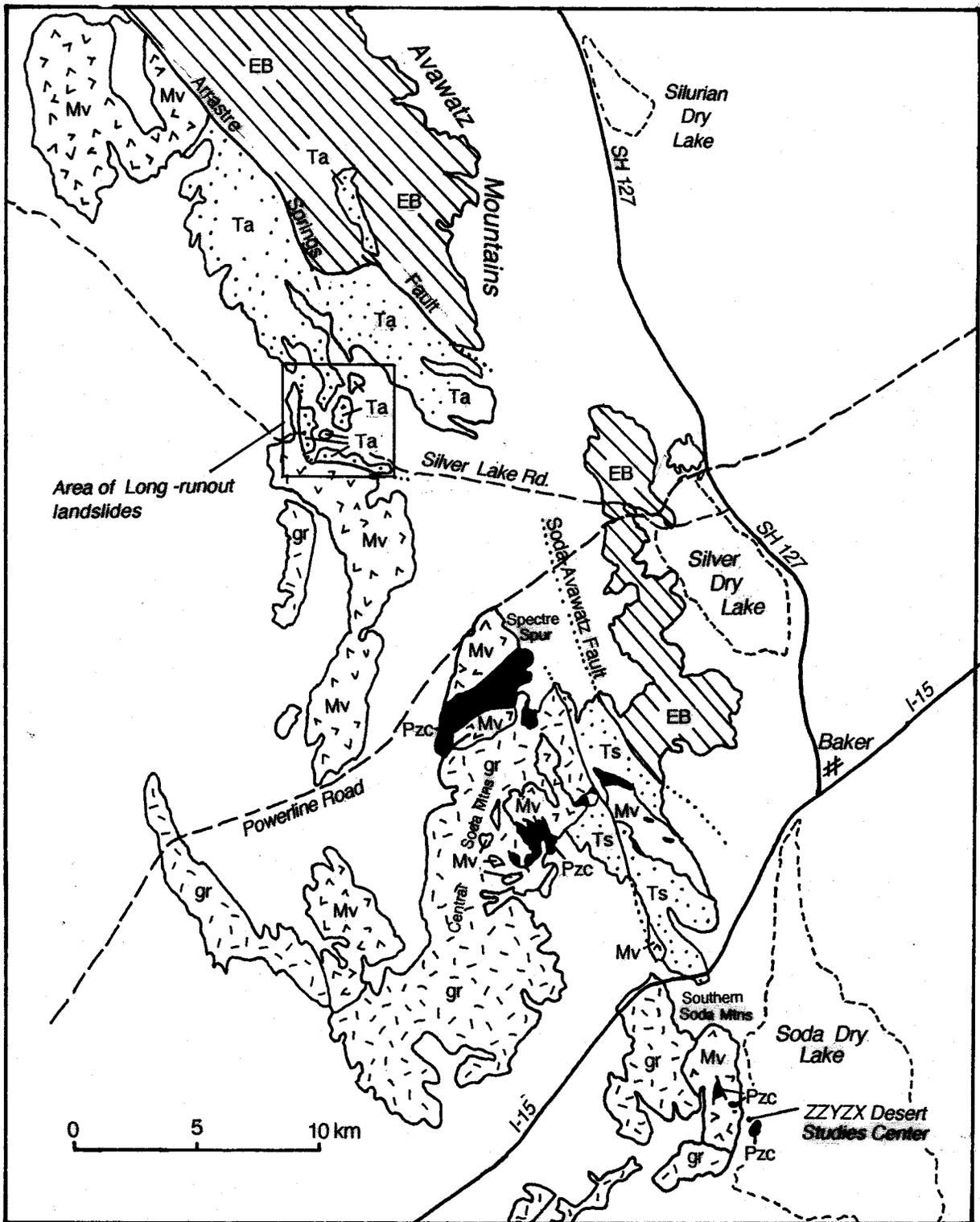Figure 2. Simplified geologic map of the study area. **EB**: Eastern Belt rocks; **Pzc**: Paleozoic carbonate; **Mv**: Mesozoic metavolcanic rock; **gr**: Mesozoic granitoid intrusive rocks; **Ta**: Tertiary sedimentary rock of the Avawatz Basin; **TS**: Tertiary sedimentary rocks in the Soda Mountains. Note that Paleozoic carbonate outcrops are shown in black. (Modified from Jennings et al., 1962).

the western belt consists of Paleozoic carbonates, lower Mesozoic metavolcanic rocks, and Cretaceous granitoid intrusive rocks (Grose, 1959; Spencer, 1981). Within the western belt, the Paleozoic rocks are sparse compared to the metavolcanic rocks (Fig. 2). Also, the Paleozoic rocks are in fault contact with the metavolcanic rocks and both types are intruded by the granitoids. Only the western belt rocks are the concern of this paper. The eastern belt rocks will not be considered further.

Outcrops of Paleozoic carbonates in the western block are restricted to the Soda Mountains. These rocks have been identified as belonging to the Cambrian Nopah, Devonian Sultan, Mississippian Monte Cristo, and Pennsylvanian/Permian Bird Springs Formations (Grose, 1959; walker and Wardlaw, 1989). In addition, Pennsylvanian carbonate and siliciclastic strata above the Bird Spring Formation form an unnamed sequence (Walker and Wardlaw, 1989).

The Mesozoic metavolcanic strata in the western belt consist of andesite flows and flow breccias, pyroclastic deposits, welded tuff, volcanic sandstone, and nearly pure quartzite (Grose, 1959). Locally, maroon, fissile shale and light pale green to dark gray laminated and indurated argillite are present (Spencer, 1981). A minimum thickness of 2000 meters has been estimated for the sequence in the soda Mountains, although faulting and stratigraphic complexity precludes and accurate measurement (Grose, 1959). Age of the unit is interpreted to be Triassic to Jurassic based on correlation of sandstones in the sequence to the Jurassic Aztec sandstone exposed in areas to the east (Grose, 1959).

Cretaceous intrusive granitoids range from quartz monzonite, granodiorite, diorite, quartz diorite, to granite (Grose, 1959). These units intrude both the metavolcanic rocks and the Paleozoic carbonates of the western belt.

Contrasting interpretations of the structural relationship between Paleozoic carbonate and Mesozoic metavolcanic rocks

Grose (1959) constructed a detailed geologic map of the Soda Mountains and concluded that the isolated blocks of upper Paleozoic carbonates in the western block represent erosional remnants of an allochthon that structurally overlies the Triassic-Jurassic Mesozoic metavolcanic rocks along a low-angle fault. These blocks are present in the southern Soda Mountains south of Interstate 15, in the central soda Mountains west of Baker, and at an area known as Spectre Spur in the northern Soda Mountains (Figs. 1 and 2). Such widespread exposures indicate that the allochthon proposed by Grose (1959) was a regional-scale feature. Although remnants of the proposed allochthon are not present in the Avawatz Mountains and the Red Pass Range between the Soda and Avawatz Mountains (Fig. 1), the allochthon likely would have been present over the

metavolcanic rocks exposed in these mountains, too.

Walker and Wardlaw (1989) mapped the Spectre Spur area in detail and came to a different interpretation that Grose (1959) regarding the structural relationship between the Paleozoic carbonate and Mesozoic metavolcanic rocks. At Spectre Spur, a large central block of Paleozoic carbonate is in contact with metavolcanic rocks to the north and south (Fig. 2) along two northeast-trending faults. Walker and Wardlaw 91989) concluded that the carbonate fault block came into contact with the younger metavolcanic rocks by being uplifted from a deeper stratigraphic level. If correct, then the Paleozoic carbonate at Spectre Spur cannot be part of Grose's (1959) allochthon, which in turn casts doubts on Grose's (1959) proposed regional-scale allochthon across the western belt. Indeed, Walker and Wardlaw (1989) discount the notion of significant low-angle faulting in the western Soda Mountains. Instead they propose that any low-angle faulting in the area was the result of roof deformation above rising Mesozoic granitoid plutons.

Regarding the carbonate masses mapped by Grose (1959) in the central part of the Soda Mountains, I have looked at the area in reconnaissance. I found that some areas of carbonate are erroneously mapped. For example, some of the areas indicated to be carbonate by Grose (1959) actually expose metavolcanic rocks. I also could not find any areas where Paleozoic carbonate unequivocally rests on metavolcanic rocks along a significant fault contact. In most places where carbonate is in contact with metavolcanic rocks, the contacts are high-angle faults. This relationship does not preclude the carbonates from being on top of the carbonates because the bases of the carbonate are not exposed. Grose (1959) interprets that the carbonate is on top of the metavolcanic rock along a low-angle contact and that the contact has been down-dropped along high-angle faults since the time of low-angle faulting. Thus, the low-angle fault in this area is buried in the subsurface according to Grose's (1959) model.

In the southern part of the Soda Mountains are several outcrop of Paleozoic carbonate rock adjacent to the larger outcrop area of Mesozoic metavolcanic rocks outcrops. The largest of the carbonate outcrops occurs along the crest of the southern Soda Mountains about 1.5 km northwest of ZZYZC Desert studies Center (Soda Springs). This location is the only one that I have found in the Soda Mountains that clearly supports Grose's (1959) notion that the Paleozoic carbonates are situated structurally on top of the Mesozoic metavolcanic rocks along a significant low-angle fault. At this outcrop located on the crest of the Soda Mountain ridge, the carbonate is seen to be a klippe resting in structural contact on top of the metavolcanic rock.

Because the presence of a low-angle fault separating Paleozoic carbonates on top of Mesozoic metavolcanic rock is obvious at only one location (in the southern Soda

Mountains), Grose's (1959) hypothesis of a regional-scale allochthon is not well-established. Supporting data would be helpful. I propose that supporting evidence is indeed present in Miocene landslide deposits of the southern Avawatz Mountains.

Miocene landslide deposits in the Avawatz Basin

Within the southern Avawatz Mountains are subaerial and lacustrine sedimentary rocks of the Miocene Avawatz Basin (Spencer, 1990). These basinal strata are assigned to the Avawatz Formation (Henshaw, 1939). The strata straddle the Arrastre Spring fault, but most are found to the west of the fault. The Avawatz Formation is minimally 3600 meters thick (Spencer, 1990). Faulting and folding has affected these strata and they have been erosionally beveled

Intercalated within the formation are sheet-like mega-breccia deposits. These deposits range from 5 to 30 meters thick and extend laterally up to 3 km (Brady, 2002). Clast sizes range from less than a centimeter to tens of meters. The typical clast size is 5 to 30 cm (Brady, 2002). The megabreccia deposits are matrix-poor and have a clast sup-ported structure. Matrix material comprises 5 to 10 percent of the deposits.

Clasts within the megabreccia deposits consist of Paleo-zoic carbonate, Mesozoic metavolcanic rock, and granitic rocks (Spencer, 1981; 1990). Each of these lithologies is monolithologically partitioned within the slides. Approxi-mately 85% of the megabreccia material consists of Paleo-zoic carbonate. Mesozoic metavolcanic material comprises about 10% and granitoids about 5%. In addition to the lithologic partitioning, source rock layering is preserved throughout much of the deposits indicating clasts were not

mixed during sliding (Spencer, 1981). Fusulinid fossils have been recovered from some of the Paleozoic carbon-ates and indicate a Permian age, indicating that the fossil-bearing carbonates belong to the Bird Spring Formation (Brady, 2002). Metavolcanic megabreccia clasts contain lithologies similar to those of the metavolcanic basement rocks in the eastern belt basement rocks. The metamorphic grade is the same as well.

The megabreccia deposits are interpreted to represent long-runout rock avalanche landslides, similar to the well-known Blackhawk rock avalanche of the southern Mojave Desert (Shreve, 1968). The most important characteristics of the megabreccia deposits leading to their interpretation as long-runout rock avalanches are the following: position within the basin far from basin edges, pervasive brec-ciation, sheet-like geometry, preservation of source rock stratigraphy, and matrix-poor composition.

In four areas, metavolcanic-clast megabreccia is in contact with carbonate-clast megabreccia. I all of these ar-eas, the metavolcanic rocks lie stratigraphically below the carbonate megabreccia. Three possibilities could explain the origin of the contact between the carbonate-clast and metavolcanic-clast megabreccia. One possibility is that the contact is preserved from the source area. A second is that the contact represents an internal, discrete slip plane that formed during landslide emplacement. The third possibil-ity is that the metavolcanic-clast and carbonate-clast mega-breccia masses represent separate landslides that came to rest in contact with one another by deposition in the basin.

Of these three possibilities, three lines of evidence indi-cate that the contact between the Paleozoic carbonate-clast materials and the metavolcanic-clast materials is preserved from the source area. First, there is no change in size of breccia clasts at the contact; second, there are stringers of secondary carbonate extending from the contact into the metavolcanic-clast megabreccia; and third, iron mineralization is locally found both in the carbonate-clast and metavol-canic-clast breccia.

The first line of evidence is the lack of any significant contrast between the breccia along the contact and that of the main body of the metavolcanic-clast and carbonate-clast megabreccias. Long-runout rock avalanches generally have strongly comminuted breccia at the base caused by sliding across their substrate (Yarnold and Lombard, 1989). If the carbonate megabreccia, which overlies the metavolcanic megabreccia, represents a separate landslide from the metavol-canic breccia, then one would expect to find comminuted carbonate breccia at the contact, but such is not the case.
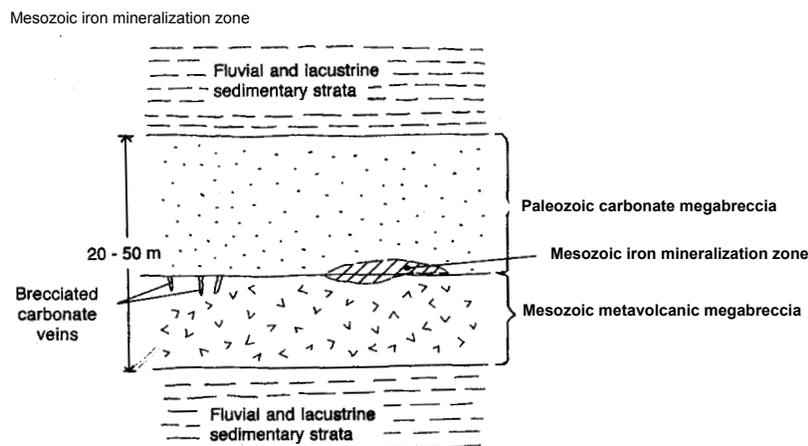

Figure 3. Conceptual diagram of megabreccia containing Paleozoic carbonate and Mesozoic metavolcanic clasts. Diagram depicts the stratigraphic relationship of carbonate megabreccia to metavolcanic megabreccia and the location of carbonate veins and iron mineralization.

The second line of evidence that supports the concept that the contact between carbonate and metavolcanic megabreccia is preserved from the source area is the presence of veins of secondary carbonate extending from the contact into the metavolcanic zone. These secondary deposits are approximately 10 to 20 cm wide and extend up to 3 to 5 meters into the metavolcanic rocks from the metavolcanic-carbonate breccia contact. The deposits must have formed before the landsliding because they are brecciated similar to that of the surrounding metavolcanic materials. These deposits are interpreted to have been secondary fracture fillings in the metavolcanic rocks derived from the adjacent carbonate while the rocks were in the source area.

Finally, the third line of evidence is the presence of iron mineralization found in the metavolcanic and carbonate megabreccias along the contact between the two breccia types. The iron mineralization mainly consists of magnetite with lesser amounts of hematite and limonite (Limey, 1948) and occurs along the contact in four different megabreccia deposits. In each area, at least some mining activity has been performed. In one of these areas is a significant mine known as the Iron Mountain Mine, which is presently in production. The Iron Mountain Mine is in the southwestern part of the Avawatz Basin along Silver Lake road. Another area in which some production apparently took place is the Iron King Mine, about 3 km east of the Iron Mountain Mine and also along Silver lake Road. The iron mineralization occurs as a replacement mineral in both carbonate and metavolcanic rocks along the carbonate-metavolcanic megabreccia contact, although the majority of the replacement occurred in the carbonates.

Iron mineralization is common in carbonates throughout the volcano-plutonic circum-Pacific arc systems (Hutchinson, 1983). A model for their formation has been proposed by Dugster and Chou (1979). In their model, iron from iron-rich rocks is dissolved in hydrothermal fluids by reaction with hydrochloric acid to form FeCl in solution. Movement of the fluid into contact with carbonate rocks leads to precipitation of iron oxide. The precipitation of iron oxide occurs because the iron in solution is replaced by calcium form the carbonate to from CaCl in solution. This model appears consistent with the deposits in the Avawatz Mountains because the iron mineralization is restricted to the contact area between the carbonate and metavolcanic rocks and because the metavolcanic rock would be a good source for the iron.

Regardless of the validity of the model as applied to the Avawatz Basin iron deposits, it is clear that the iron mineralization formed in the source rock areas of the landslides and was carried into the basin as part of the landslides. There are two observations supporting this conclusion. First, Spencer (1990) used the K-Ar method to date coarse white mica formed with the iron in the mineralization zone and obtained a minimum probable age of 147 Ma, much older that the Miocene age of the landslides. Second, the ore material is brecciated in the same manner as the carbonate and metavolcanic host rocks in the landslides. Brecciation, in turn, is interpreted to have occurred during landslide emplacement. Thus, it is strongly indicated that carbonate and metavolcanic rocks were in contact within the source area.

A conceptual illustration of the important features for the carbonate-metavolcanic-clast megabreccia deposits is shown in Figure 3. An important observation to again point out is that in all four areas where carbonate and metavolcanic megabreccia occur in the same sheet, the carbonate-clast megabreccia overlies the metavolcanic-clast megabreccia (Fig. 3).

Interpretation of the landslide source areas

The only known source for the metavolcanic rocks within the landslides are the metavolcanic rocks of the western belt in the soda and Avawatz Mountains, which includes the Red pass Range to the southeast of the Avawatz Basin (Fig. 1). Because the metavolcanic megabreccia clasts are lithologically identical to the western belt metavolcanic basement rock, it seems apparent that the metavolcanic landslide materials must have been derived from the western belt rocks along the west and southwest margin of the basin. No appropriate source rocks occur to the east of the Arrastre Springs or Soda Mountains faults in the eastern belt rocks, nor is there evidence that such rocks may have been exposed in that area during the time of Avawatz Basin deposition.

Circumstantial evidence that the metavolcanic landslide materials were derived from the surrounding metavolcanic basement to the southwest or west comes from the distribution of the landslides in the Avawatz Basin. Many rock avalanche deposits are found throughout the basin and total approximately 30 (based on Spencer, 1981). The landslide deposits containing metavolcanic clasts are concentrated in the southwestern part of the basin. In the northeastern part of the basin, most of the landslides consist of granitic materials. A simple explanation for these distributions is that the granitic-bearing landslides were derived from areas of granitic exposures to the east and northeast of the basin in the eastern belt of basement rocks and the metavolcanic-bearing landslides were derived from the metavolcanic exposures in the western belt.

Because the carbonate-bearing landslides are associated with the metavolcanic bearing landslides and the evidence is that the contact is preserved from the source area rocks, the carbonate megabreccia is indicated as having been derived from the west or southwest, just as the metavolcanic megabreccia was. The carbonate breccia overlies the metavolcanic breccia and this relationship then, must have been present in the source area. This geometry, in turn,

indicates that the metavolcanic basement bordering the Miocene Avawatz Basin was capped by Paleozoic carbonate. The cap is interpreted here to be part of the carbonate allochthon proposed by Grose (1959).

Summary and discussion

There are single landslide megabreccia deposits in the Miocene Avawatz Basin that contain clasts both of Paleozoic carbonate and Mesozoic metavolcanic rocks. The carbonate megabreccias overlie the metavolcanic megabreccias along a contact that was preserved from the source area. Because the metavolcanic rocks are indicated as having been derived from bedrock to the east or southeast of the basin, the carbonate megabreccia must also have been derived from those areas. This previous presence of Paleozoic carbonate on top of Mesozoic metavolcanic rock in the Avawatz and Red Pass Range supports the hypothesis by Grose (1959) that the metavolcanic rocks were overlain by a regional-scale Paleozoic carbonate allochthon.

Movement of the carbonate allochthon over the Mesozoic metavolcanic rocks is a poorly-understood orogenic event. Many questions are unanswered such as, when did the allochthon move, what was the direction of movement, and is the allochthon associated with crustal contraction (thrust faulting) or extension (low-angle normal faulting)? Also, could the allochthon be associated with other cryptic low-angle faults in the area? For example, the Silurian Hills to the northeast (Fig. 1) expose the Riggs fault, which carries a large allochthon of Paleozoic carbonate in the hanging wall (Kupfer, 1960) similar to the Soda Mountains allochthon. Also, to the southeast is the Playground thrust(?) fault at Old Dad Mountain (Dunne, 1977), which also carries a large allochthon of carbonate in the hanging wall. If, indeed, the carbonate allochothons from these various areas are related, then a unifying picture of Mesozoic low-angle faulting in the region may be emerging.

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Crucifixion thorn
(Simaroubaceae *Castela emoryi (*Gray) Moran and Felger)

Maria A. Lum, *LSA Associates, Inc., Riverside, Ca 92507 (maria.lum@lsa-assoc.com)*

Crucifixion thorn (*Castela emoryi*) is an endemic species of the Sonoran Desert and southern Mojave Desert. It is common is Arizona, but not widespread in California. There are several small populations in eastern San Bernardino County.   A small population occurs in the lava bed area approximately 25 northeast of Dagget. The largest population in the world exists at the Crucifixion Thorn Natural Area in Imperial County, California.

The crucifixion thorn is the only native member of the tropical family Simaroubaceae in California. The weedy, non-native tree-of-heaven (*Ailanthus altissima*) is a member of the same plant family. Most of the species in the Simaroubaceae occur in tropical, warm-temperate climates, such as rain forests.

The scattered populations of the crucifixion thorn may be "refugees" from a moister and warmer historic climate. In the contemporary drier and colder climate conditions, the plant occurs in fine-textured soils of plains and bottomlands, dunes, and basalt flows. Specifically, it occurs in low hot areas at moist sites where frost is rare.

Crucifixion thorn is a unique dioecious shrub, meaning the male and female reproductive structures occur on separate plants. The shrub grows 3-6 feet tall in San Bernardino County. The plants can flower from April through May. The green-yellow flowers are inconspicuous. The fruit is shaped like a wheel or star–like structure formed by 6 to 8 spreading carpels, similar to sections of an orange. Stems are rigid with spine-tipped branches. The bark is covered with a short dense pubescence and is light green. Since there are no leaves on the mature plant, the stem is photosynthetic.

The fruit can persist on the plant for several years in California. The thick carpel wall must be scarified in order for the seed to germinate. Since the fruits occur in large clusters at the end of the branches, Andrew Sanders, UCR botanist, conjectures that the seeds were dispersed by large herbivores. The fruits could have been eaten by the now extinct Pleistocene megafauna, such as camel, sloth, and horse.

Crucifixion thorn has been used medicinally for the treatment of internal parasites and intestinal protozoa making it useful for amoebic dysentery and giardia.

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Geology, genesis and mining of pharmaceutical and food grade calcium carbonate at the Amboy Limestone Quarry

Howard Brown, *Geologist, Omya (California) Inc., P.O. Box 825, Lucerne Valley CA 92356 (howard.brown@omya.com)*

Introduction

Omya (California) Inc. operates the Amboy Limestone quarry, near Amboy California, in the central Mojave Desert area of Southern California. The quarry is the premier producer of USP pharmaceutical and Food Grade limestone in western North America. The quarry is located 6 miles north east of Amboy California, in the southern Bristol Mountains (Figure 1).

This report will summarize the regional and local geologic setting, the genesis of the limestone deposit, the mine operation, and the various consumer products which are manufactured from the limestone mined at the quarry.

High purity high brightness limestone resources

Omya (California) Inc. has developed the Amboy Limestone deposit, a very high purity, high brightness (white) crystalline limestone deposit. Detailed mapping and core drilling have proven a large reserve. Assay data have shown that the rock is of such high purity it is suitable for pharmaceutical and food grade limestone applications, and can be utilized in products for human consumption.

The existing Omya quarries in the Lucerne Valley area, and the Amboy deposit are one of the few available existing sources of high purity limestone in the western United States that can be used for whiting. Whiting is used in the form of naturally occurring nontoxic fillers and extenders in a very large number of consumer products ranging from toothpaste, carpet backing, plastics, PVC, paint, paper stucco, many home building products, and many other common pharmaceutical and consumer products. Within the United States, productive deposits of white high purity limestone suitable for human consumption are restricted to only a few areas, and the Amboy deposit is one the purest limestone deposits in the world.

Products made from limestone mined by Omya (California) Inc.

Some of the most common consumer products which are made from limestone mined by OMYA include (actually hundreds and hundreds of consumer products are made utilizing limestone) are shown on Table 1, and Figure 2.

Because of the complexity of geological processes, limestone deposits of this type are unique and restricted to only a few areas in the United States.

The socio-economic impacts of the limestone mining allow us (you and me) to live the life we live. Our life-style and civilization as we know it would not be possible without limestone.

Summary of the geologic setting of the Amboy region

The Amboy region lies in the central Mojave Desert, a large area bounded on the north by the Garlock fault, the southwest by the San Andreas fault and to the east by the Colorado River. The area has undergone a long and complex geologic history which ranges from PreCambrian to recent geological time. Mountain ranges in the western portion of the Amboy area trend northwest. Mountains in
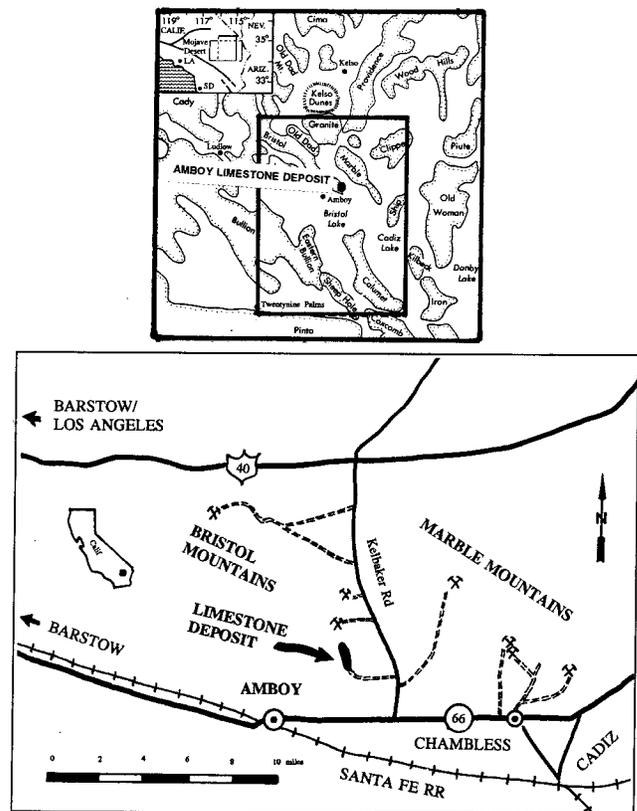

Figure 1. Index map showing location of the Amboy limestone deposit in the central Mojave Desert area.

Figure 2. Products using calcium carbonate.

ous and Permian age. Paleozoic strata unconformably overlie the PreCambrian crystalline rocks. In some places a bedding plane fault separates the Paleozoic rocks from the underlying basement terrain. Although highly deformed and disrupted in most ranges, the Paleozoic section can be pieced together, and a composite section assembled.

Cambrian strata consists of the Tapeats Sandstone, the Latham Shale, Chambless Limestone and Cadiz Formation of Hazzard (1933), which have been correlated with the Carrara Formation terminology, the Bonanza King Formation, and the Nopah Formation including the Dunderberg Shale Member. These rocks are deformed by bedding plane faults and are metamorphosed in the Marble Mountains and the Ship Mountains. The same Cambrian strata are also present in the Bristol Mountains, but are even more strongly metamorphosed and deformed than in other areas.

Metamorphosed Paleozoic strata in the Bristol Mountains are highly deformed but a nearly complete section can be pieced together which includes the Cambrian Tapeats, Carrara Formation including the Chambless Limestone and Cadiz Formation, Bonanza King Formation and Nopah Formation. Unconformably overlying the Cambrian rocks is the Devonian Sultan Limestone including three Members, the Upper, Crystal Pass Member, middle dolomite member, and a lower stromatoporoid bearing marker bed, the Mississippian Monte Cristo Limestone including the Dawn, Anchor and Bullion Members, and the lower part of the Pennsylvanian and Permian Bird Spring Formation. The presence of a sub-Devonian unconformity in the Paleozoic strata of the Amboy region indicates that they are cratonal as defined by Burchfiel and Davis (1981).

The Paleozoic strata were intruded in the

the southern and northern part of the region trend northerly. The Bristol Mountains, in which the Amboy limestone deposit is located trend northwest. This discussion of the geology of the Amboy area is mostly summarized from the published work of Brown (1981, 1995), and Miller and others (1982), and unpublished work of Brown (1980-2002). Figure 3 is a regional geologic map of the area, and Figure 4 is a stratigraphic correlation chart of the Amboy region.

PreCambrian granite and gneiss in the Amboy region form a basement terrain on which were deposited cratonal Paleozoic sediments of Cambrian, Devonian, Carbonifer-

Table 1. Some common consumer products made from limestone mined by OMYA (California) Inc.

Environmental	Construction	Consumer products	Human or animal uses	Some other uses
Water filtration	Dry wall mud	Crayons	Pharmaceutical products	Athletic field line marker
Acid water neutralization	Paint	Glue	Antacids	Wire coating insulation
Acid sewage neutralization	Plastics	Fabrics	Buffered aspirin	Carpet backing
	Stucco	Polyester	Calcium supplements	Sugar refining
Acid rain neutralization	Roofing paper	Latex compounds	Toothpaste	Floor tile
Air emission control	Synthetic marble	Household cleanser	Calcium additive in breakfast cereal and baked goods	Glass
Acid soil treatment	Calking compound	PVC pipe		Fiberglass
	Tile grout	Shoe polish	Disinfectants	
	Roofing shingles		Chewing gum	
	Highway paint		Animal nutrients	

TABLE 2. Table showing quarry development phases and projected production

QUARRY DEVELOPMENT PHASE	PRODUCTION TONS/YEAR	DURATION (YEARS)	YEARS
PHASE 1	25,000 tons/yr	15 years	1995-2010
PHASE 2	100,000 tons/yr	20 years	2011-2030
PHASE 3	200,000 tons/yr	20 years	2031-2050
PHASED RECLAMATION		15 years include reclaiming	2051-2066

Early to Middle Jurassic by epizonal plutons, synchronous with or closely following folding and thrust faulting. In the Bristol mountains the strata were folded into a large overturned to possibly recumbent synform. Folding was accompanied by complex and compound multiphase thrust faulting and bedding plane faulting. Deformation predates the Jurassic intrusive activity. Plutons assigned to the Jurassic suite range widely from diorite to monzogranite and quartz syenite. In the Bristol mountains, Jurassic rocks are represented by a syenite pluton. Large plutons of a younger Cretaceous suite composed of granodiorite, monzogranite, and two mica monzogranite are common in the area. Diabase dikes and sills have also intruded the Paleozoic rocks in the Bristol Mountains area.

Metamorphism of the Paleozoic and Mesozoic strata was related to widespread emplacement of the plutonic rocks during Mesozoic time. Skarns developed along some contacts of Jurassic plutons. Several skarns are present in the Bristol Mountains, Marble Mountains, and Ship Mountains. Some of the skarns have been prospected for iron ore, and garnets. Diabase sills in the Bristol Mountains have also formed Wollastonite and serpentine by contact metamorphism of the adjacent strata.

Tertiary strata, largely volcanic, unconformably overly the older rocks in the region. The lower part of the sequence is dominated by clastic rocks and rhylolitic tuffs and breccias, and is overlain by andesitic, dacitic, and basaltic rocks, and welded rhyolite tuff. The welded tuff is correlated with the Peach Springs Tuff, a wide spread unit in the eastern Mojave area, and western Arizona.

Tertiary rocks are tilted southwesterly over much of the area, and may have been rotated in blocks above detachment faults similar to those recognized to the west and southeast. A Tertiary dike swarm suggests more than 5 miles of northeast-southwest extension. Similar dikes, as well as lamprophyric and diabase dikes commonly dip steeply and strike northeast in the Bristol Mountains.

Alkali olivine basalt and basanite of latest Tertiary and Quaternary age form composite cinder cones and flows west and northwest of Amboy. Most flows are covered by Pleistocene alluvium, but the youngest Amboy Crater flow is covered only by Holocene deposits of Bristol Lake. The volcanic rocks are located in or near the axis of the regional trough that runs northwest through the region.

Lower Pleistocene gravels are cut by northwest trending right separation faults in the western portion of the Amboy region. The west-northwest trending Barstow-Bristol structural trough obliquely transects the physiographic and structural grain of northwest trending mountain ranges. This major crustal structure is marked by thick accumulations of playa sediments, latest Pliocene and Quaternary alkali basalt extrusion and divergent trends of the mountain blocks north and south of the trough.

Playa sediments in Bristol and Cadiz Lakes extend below sea level in the subsurface. At Bristol Lake the sediments are dominated by clay and salt, and extend to a depth of over 1000 feet. Sodium chloride and calcium chloride brines are being extracted commercially from both Bristol and Cadiz Lake beds. Large tracts of wind blown sand lie in the basins and are banked against the northwest sides of mountains in the region.

Geology of the Amboy limestone deposit

The Amboy limestone deposit forms an extensive dip slope of Mississippian age Monte Cristo Limestone, Bullion Member, up to 300 feet thick, and 1500 feet long (Brown 1995). The deposit trends nearly north-south and dips about 45 degrees to the east. Footwall rocks include the lower Members of the Monte Cristo Limestone and the Sultan Limestone of Devonian age (Figure 5).

The deposit is truncated to the north and to the west by Jurassic syenite. Small skarn deposits are located along some of the contacts. Several thin diabase dikes also cut through the deposit. Where the diabase dikes have cut the footwall Anchor Member, the cherty limestone has been metamorphosed to high grade wollastonite marble.

Several high angle faults have cut the limestone and shifted contacts a few tens of feet. None of the high angle faults is of large displacement. A compound west dipping low angle normal fault is present near the top of the limestone ridge, and has placed what is now an erosional remnant (klippe) of Bird Spring Formation strata on top of the Monte Cristo Limestone (Brown 1981).

Economic geology of limestone deposits and formation of white high purity limestone deposits

Carbonate rocks are common on all continents, but high purity, high brightness (white) limestone deposits are uncommon in nature because their formation is dependant on the superposition of several independent geologic processes, acting over a long period of time (Brown, 1987).

Among the processes are:

1) Deposition of originally pure limestone in high energy agitated, shallow marine environment to winnow out fines and silt impurities.

2) Metamorphism and/or magmatic processes to bleach and recrystallize the rock and disperse any impurities which may have been present.

3) Folding, faulting and orogenic processes to place the

GENERALIZED GEOLOGIC MAP OF THE AMBOY REGION

MODIFIED FROM MAPPING BY:
H.J. BROWN (1981, 1995, and unpub.mapping 1980-2002
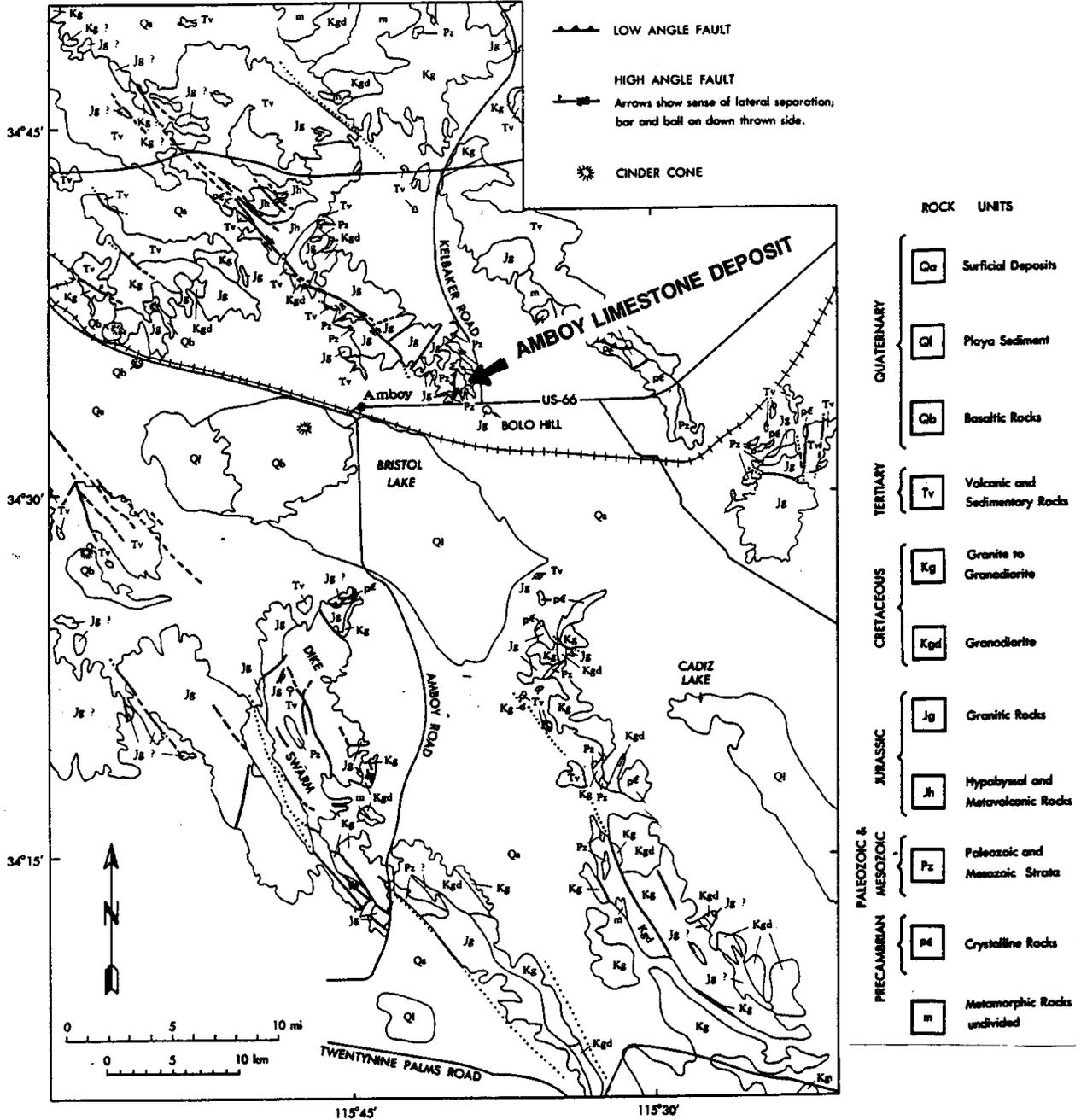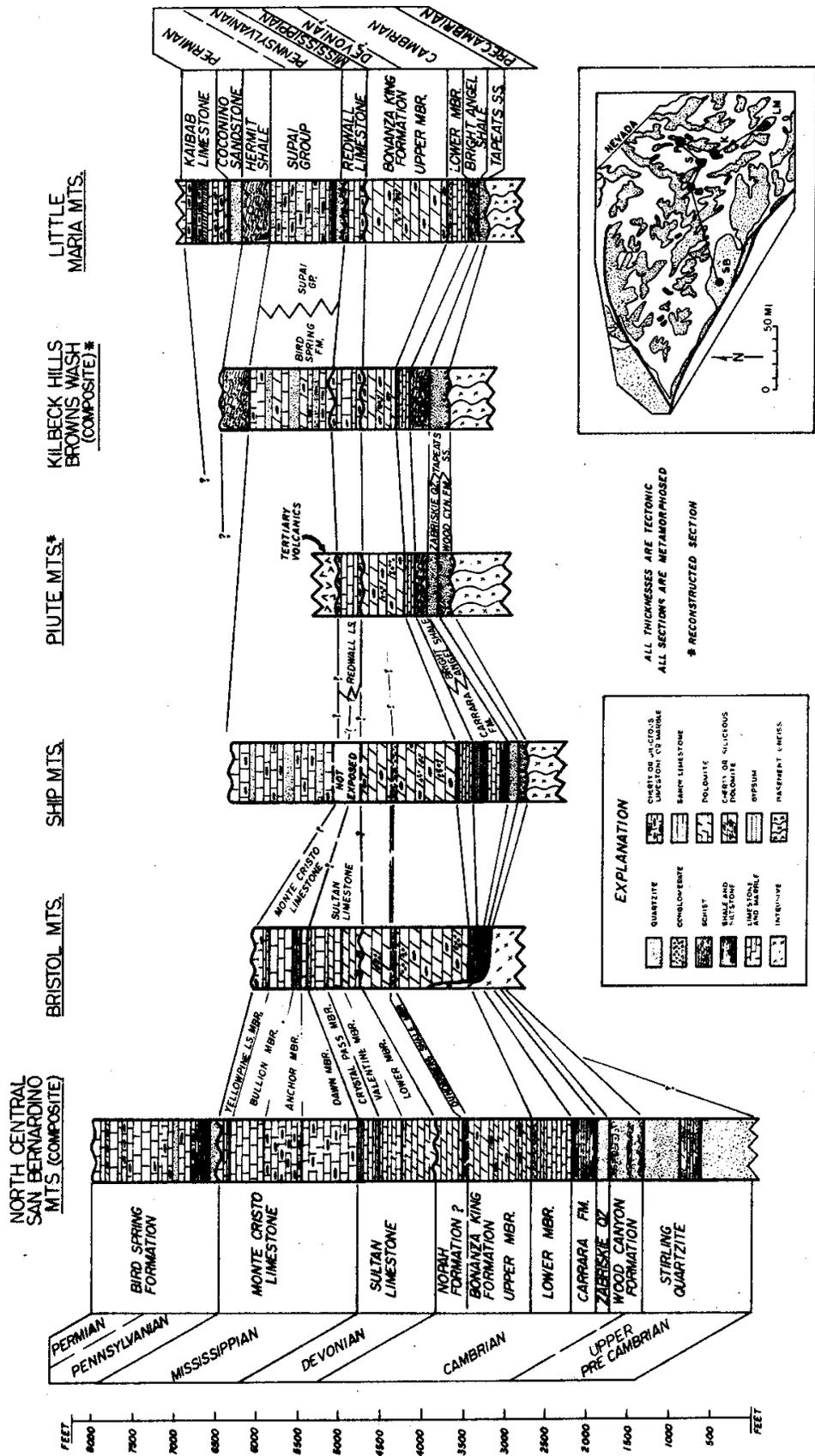### MILLER AND OTHERS (1982)

Figure 3. Generalized regional geologic map of the Amboy area.

Figure 4. Correlation chart of Paleozoic rocks in the Amboy area.

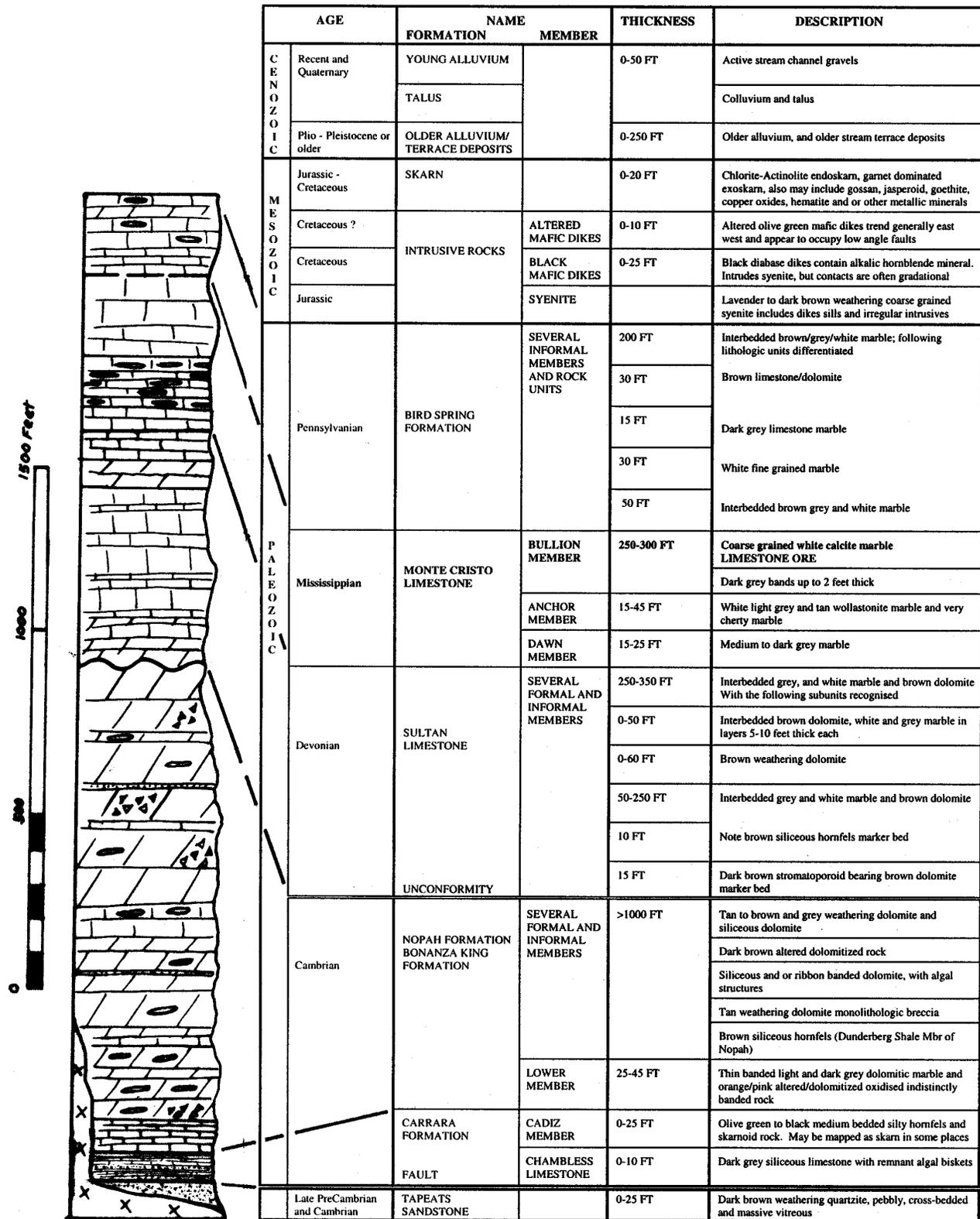| AGE		NAME		THICKNESS	DESCRIPTION
		FORMATION	MEMBER		
C E N O Z O I C	Recent and Quaternary	YOUNG ALLUVIUM		0-50 FT	Active stream channel gravels
		TALUS			Colluvium and talus
	Plio - Pleistocene or older	OLDER ALLUVIUM/ TERRACE DEPOSITS		0-250 FT	Older alluvium, and older stream terrace deposits
M E S O Z O I C	Jurassic - Cretaceous	SKARN		0-20 FT	Chlorite-Actinolite endoskarn, garnet dominated exoskarn, also may include gossan, jasperoid, goethite, copper oxides, hematite and or other metallic minerals
	Cretaceous ?	INTRUSIVE ROCKS	ALTERED MAFIC DIKES	0-10 FT	Altered olive green mafic dikes trend generally east west and appear to occupy low angle faults
	Cretaceous		BLACK MAFIC DIKES	0-25 FT	Black diabase dikes contain alkalic hornblende mineral. Intrudes syenite, but contacts are often gradational
	Jurassic		SYENITE		Lavender to dark brown weathering coarse grained syenite includes dikes sills and irregular intrusives
P A L E O Z O I C	Pennsylvanian	BIRD SPRING FORMATION	SEVERAL INFORMAL MEMBERS AND ROCK UNITS	200 FT	Interbedded brown/grey/white marble; following lithologic units differentiated
				30 FT	Brown limestone/dolomite
				15 FT	Dark grey limestone marble
				30 FT	White fine grained marble
				50 FT	Interbedded brown grey and white marble
	Mississippian	MONTE CRISTO LIMESTONE	BULLION MEMBER	250-300 FT	Coarse grained white calcite marble LIMESTONE ORE
					Dark grey bands up to 2 feet thick
			ANCHOR MEMBER	15-45 FT	White light grey and tan wollastonite marble and very cherty marble
			DAWN MEMBER	15-25 FT	Medium to dark grey marble
	Devonian	SULTAN LIMESTONE	SEVERAL FORMAL AND INFORMAL MEMBERS	250-350 FT	Interbedded grey, and white marble and brown dolomite With the following subunits recognised
				0-50 FT	Interbedded brown dolomite, white and grey marble in layers 5-10 feet thick each
				0-60 FT	Brown weathering dolomite
				50-250 FT	Interbedded grey and white marble and brown dolomite
				10 FT	Note brown siliceous hornfels marker bed
		UNCONFORMITY		15 FT	Dark brown stromatoporoid bearing brown dolomite marker bed
	Cambrian	NOPAH FORMATION BONANZA KING FORMATION	SEVERAL FORMAL AND INFORMAL MEMBERS	>1000 FT	Tan to brown and grey weathering dolomite and siliceous dolomite
					Dark brown altered dolomitized rock
					Siliceous and or ribbon banded dolomite, with algal structures
					Tan weathering dolomite monolithologic breccia
					Brown siliceous hornfels (Dunderberg Shale Mbr of Nopah)
			LOWER MEMBER	25-45 FT	Thin banded light and dark grey dolomitic marble and orange/pink altered/dolomitized oxidised indistinctly banded rock
		CARRARA FORMATION	CADIZ MEMBER	0-25 FT	Olive green to black medium bedded silty hornfels and skarnoid rock. May be mapped as skarn in some places
		FAULT	CHAMBLESS LIMESTONE	0-10 FT	Dark grey siliceous limestone with remnant algal biskets
	Late PreCambrian and Cambrian	TAPEATS SANDSTONE		0-25 FT	Dark brown weathering quartzite, pebbly, cross-bedded and massive vitreous

Figure 5. Rock units and Paleozoic stratigraphy, Amboy limestone deposit area.

Figure 6. Amboy limestone quarry. Upper photo: haul truck being loaded with pharmaceutical grade limestone ore, 1240 bench, blas hold drill working on bench above. Lower photo: crusher and crushed ore stockpile.

Amboy limestone quarry from the Bullion Member of the Monte Cristo Limestone. Rocks of the Bullion Member of the Monte Cristo Limestone formed in a high energy shallow marine environment which winnowed out fines and silt, resulting in chemically pure bioclastic limestone. Mesozoic metamorphism recrystallized and bleached the rock to form white, high purity calcium carbonate marble. Superimposed folding and faulting have resulted in a major deposit of high purity, high brightness calcium carbonate marble, which is suitable for all high quality USP and Food Grade applications. Uplift during Tertiary time has allowed erosion to remove most of the hanging wall overburden, leaving an extensive dip slope white limestone deposit well suited for open pit mining, with very little overburden (Brown 1995).

Extensive core drilling and lab testing of samples has shown that the rock is exceptionally pure calcium carbonate. The assay data have shown that the rock is of such high purity it is suitable as pharmaceutical and food grade limestone, and can be utilized in products for human consumption.

Quality specifications for USP and food grade limestone

To be suitable for pharmaceutical grade and human consumption requires very pure calcium carbonate which meets strict FDA (Federal Drug Administration) and various pharmaceutical manufacturer purity requirements. Minimum requirements include: Pb <0.25 ppm, acid insoluble content <0.20%, carbonate content (including Ca and Mg combined (>99.0%). Other important components which must meet FDA requirement include arsenic, chromium, nickel, manganese, and fluorine among others. In addition the ground product must be white (brightness >92.5). In short, to meet USP pharmaceutical requirements the rock must be exceedingly pure and white.

Extensive testing of the raw material including assay of all blast holes prior to mining, for a variety of components, as well as continual testing of the crushed rock, and quality control testing of the ground products during plant production. All packaged ground material is tracked from the original quarry blast to the finished consumer product.

Phased quarry development

Phased quarry development is in progress at the Amboy quarry. Current mine life is 55 years plus reclamation

rocks in desirable structural settings.

4) Uplift and erosion.

5) Preservation thru geologic time.

Because all the geologic processes are required, deposits of pure, white premium quality limestone are relatively uncommon in nature, and are vastly different from common limestone. Economic deposits of high brightness, high purity limestone are restricted in their occurrence. Currently the major producing areas in the United States are located in Vermont, Alabama, Georgia, and Mojave Desert California, including Lucerne Valley, and the Amboy area. The Amboy deposit is the premier source of natural ground USP and Food grade calcium carbonate in North America.

Pure, white, calcium carbonate is produced at the

phases for a total operation life of 70 years. Quarry development includes four (4) phases of mining. The existing mine plan is based on existing proven reserves. During the life of the mine additional reserves may be located, and the mine plan modified and the life of the mine extended.

Rock from the Amboy quarry is currently utilized for pharmaceutical and food grade limestone products, but in the future it will also be blended with the existing currently mined high grade limestone resources in the Lucerne Valley area, in order to maximize the utilization of available raw materials resources over the long term.

Mining at the Amboy quarry is by conventional methods (Figure 6). The ore is drilled and blasted in benches 30-40 feet high. All blast holes are assayed for a variety of components, and the various grades of ore and waste are determined from blasthole assay data. Selective blasting and mining is utilized to separate the various grades of ore and waste. The blasted rock is loaded with a 988 loader (8-10 cy bucket) into 35-50 ton off highway trucks and hauled to the crusher, where it is crushed and separated into piles of the various quality grades. Ultimately more than 10 benches will be developed in the quarry over a vertical interval of 400 feet. The crushed ore is transported to the Omya processing plants in Lucerne Valley, California and Superior, Arizona for processing.

The current Phase 1 quarry development occurs in a area of about 10 acres. The ultimate quarry will cover approximately 50 acres. Of the total quarry acres, 48 acres are on private fee patented land, and approximately 2 acres are on BLM land. The quarry is being be developed in a phased and progressive manner that will insure adequate and responsible measures are taken to prevent unnecessary or undue degradation of the Federal and Private lands involved.

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A 20-kyr climatic and hydrological history of Salton Basin, California recorded by geochemical proxies in lacustrine deposits

Hong-Chun Li, *Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740 (hli@usc.edu)*

Located in the arid southeastern California, Salton Basin hydrologically belongs to the Colorado River drainage basin. Scanty knowledge on late Pleistocene climate in this region exists due to the dearth of climatic archives in the desert environment. A better understanding of the climatic variability is key to the planning and management of the ecological, biological, and hydrological systems in the region. Our recent study on a 60-cm thick tufa slice (LC-1) from an ancient shoreline (33o24' N, 116o3' W) of Lake Cahuilla (a.k.a. Lake Le Conte or Blake Sea) reveals hydrological history of Salton Basin between 1,310 and 19,500 yr BP (Fig. 1). The hydrological variability has been chiefly controlled by the changes in discharge and/or flood frequency of the Colorado River into the Salton Basin, which in turn is tied to climate change in the Colorado River drainage basin.

Seven AMS-14C dates from LC-1 were 1,310±30, 3,450±30, 5,250±40, 6,465±80, 9,530±60, 12,160±80 and 17,660±140 yr BP at 0.1, 5.4, 10.5, 14.6, 31.7, 49.2 and 57.9 cm depth, respectively. The dates strongly support previous seven radiocarbon dates (ranging from 7,205 to 17,590 yr BP) on a tufa slice collected from Travel Point of Salton Basin by Turner and Reynolds (1977). An AMS-14C date of 160±25 yr BP on a modern barnacle shell from Salton Sea indicates that the reservoir effect on the radiocarbon dates is minor despite the saline condition of the modern lake. Furthermore, we collected three gastropod samples encased in a ~10-cm thick dendritic tufa from a highstand of Lake Cahuilla at Travertine Point. At this highstand, the lake should be quite fresh as to have a very small reservoir age. These gastropods were AMS-14C dated at 1,390±30, 1,405±30 and 1,660±30 yr BP, respectively, similar to the age of LC-1 top. The above data show that radiocarbon dating can provide reliable chronology for tufa deposits in Salton basin and the lake history in Salton Basin is much longer than previous thoughts.

As tufa deposits formed when past lakes filled Salton Basin, their geochemical and isotopic compositions reflect those of lake water in the past. A total of 192 pairs of d18O and d13C analyses was made on LC-1. The d13C values range from 0.8 to 3.76‰ and correlate with d18O which varies from −8.52‰ to −2.50‰ (PDB) with fluctuations often >3‰. From the calcite-water paleotemperature relationship, the d18O of water from which LC-1 precipitated under isotopic equilibrium should be 0 to −8‰ (SMOW),

much heavier than that of open lake water (-10‰). Thus, the d18O and d13C records and their covariance indicate that the tufa grew most of the time in a relatively saline and alkaline lake. This is because d18O and d13C in a closed lake are often much heavier than those in input waters due to evaporation. At present, d18O of the Salton Sea water is about –2.4‰, and d18O values of input waters are –12‰ from the Colorado River and –11‰ from local meteoric water. Fresh water discharge into the lake will reduce lake 13C and 18O when the total CO_2 concentration (or carbonate alkalinity) of the lake water is <~50 mol/m3. As such, d18O and d13C both decrease as the lake enlarges. If the lake shrinks as a result of reduced input and intense evaporation, its d18O and d13C both increase (Li and Ku, 1997). The d18O increase is because 16O preferentially enters vapor phase under isotopic fractionation during evaporation (Li et al., 1997). The d13C increase when the lake shrinks is due to: (1) a more concentrated nutrient level which favors lacustrine productivity and removal of 12C and (2) degassing of CO_2 as lake alkalinity increases (Li et al., 2000).

The hydrological history of Salton Basin can be reconstructed from the isotopic compositions in LC-1 as follows, which jibes well with observations made by previous studies. The last lake cycle of Lake Cahuilla started from a shallow lake ~2,000 yr BP (~50 BC), whose level continuously increased until 1,385 yr BP (560 AD) with a d18O depletion of 4‰ (Fig. 1). This scenario agrees with the earliest high lake interval of 100 BC–600 AD determined from archaeological sites along the shorelines (Wilke, 1978). After reaching the 12-m a.s.l. highstand ca. 700 AD, the lake overflowed most of the time until 1500 AD (Waters, 1983; McCown et al., 2001). Under this freshwater condition, tufa could not form in the lake, ending the growth of LC-1. The two low lake stands of Whistler et al. (1995) ca. 2,500 and 5,890 yr BP based on charcoal dates in sandstone layers can be identified in our d18O (heavy values) record of LC-1 (Fig. 1). Based on plant and vertebrate macrofossils in an packrat midden dated at 8640±100 14C yr BP in Salton Basin, Rinehart and McFarlane (1995) interpreted a high-standing, low-salinity Lake Le Conte (Cahuilla) and an increased flow of Salt Creek in Salton Basin during the early Holocene. This high lake stand can also be seen in the LC-1 d18O record (Fig. 1). Furthermore, six tufa layers deposited at the highstand at Traver-
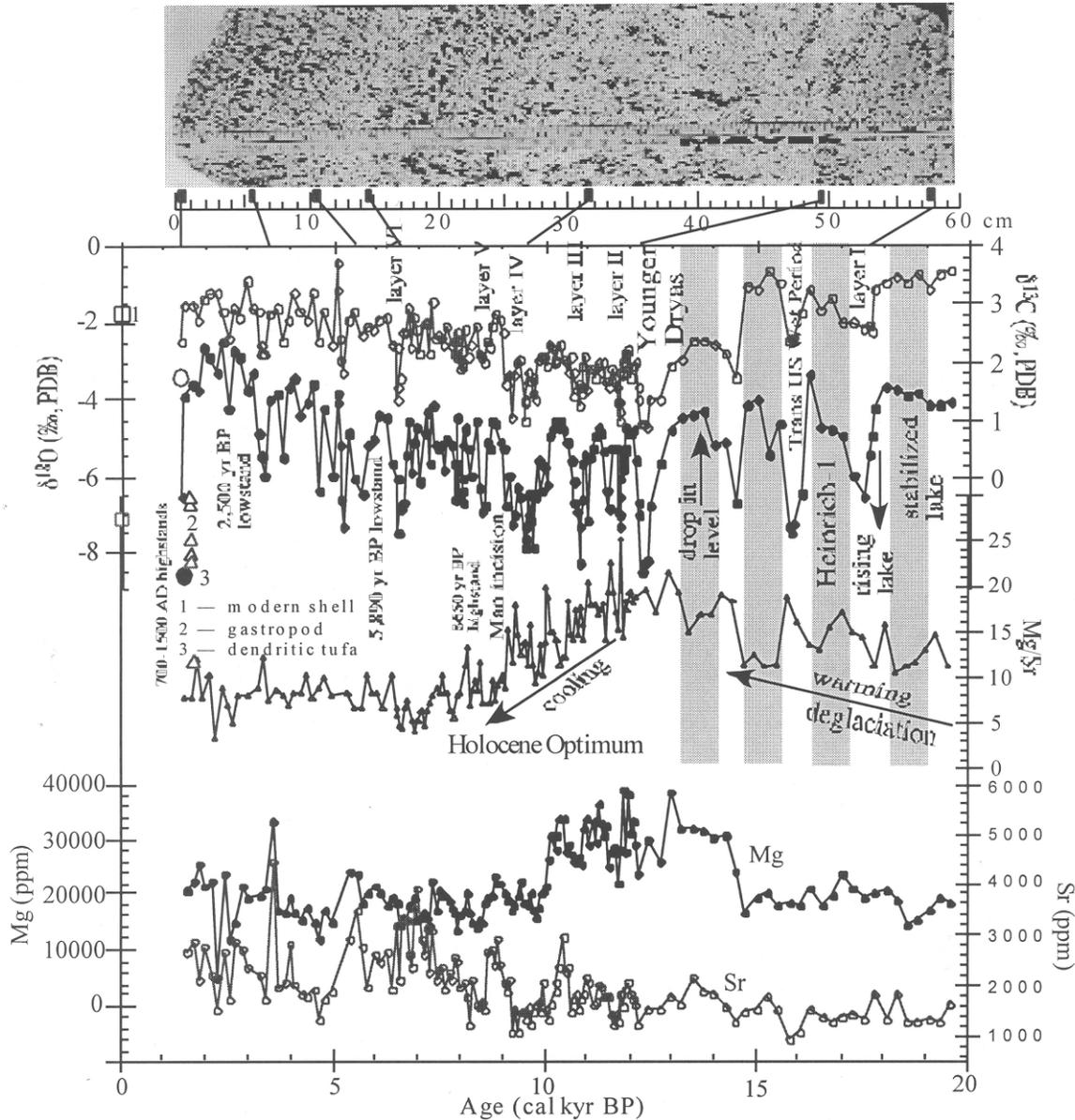
Figure 1. Isotope, Mg/Sr, Mg and Sr variations in tufa LC-1. Blue squares in the upper panel denote intervals for C-14 dating. Layers I to VI denote corresponding intervals of the Turner and Reynolds tufa. Previously reported high and low lakestands (with dates) and climatic events are consistent with the lake history deciphered by LC-1. On decadal-to-millennial scales Mg and Sr correlate positively with oxygen isotopes, implying that their variations are all influenced by salinity changes in the same direction. However, Mg/Sr ratio may reflect temperature of the water from which calcite precipitates. Light blue bands show alternate warm/wet and cold/dry climates determined by d18O and Mg/Sr variations.

tine Point (Turner and Reynolds, 1977) have found their equivalents in the d18O depletion peaks (except layer 1) shown in Fig. 1. The d18O was relatively constant between 18,000 and 19,500 yr BP, reflecting a stabilized and closed lake. Were the lake open, the d18O values would be much lighter and tufa would not form in the lake. In addition, during this period the lake was not high enough to reach the shoreline in which the tufa of (Turner and Reynolds,

1975) was found. The human incision on the fourth layer at ~9,000 yr BP in the Turner and Reynolds tufa matches the lake regression at this time shown in the d18O record of LC-1.

In tufa deposits, Mg and Sr concentrations are also good indicators of lake level fluctuations (Li et al., 2000; 2003). We have measured 152 pairs of Mg and Sr concentrations in LC-1 by ICP-AES (Fig. 1). Figure 1 shows that

correlations exist between d18O and concentrations of Mg and Sr in LC-1. A drop in lake level (indicated by enriched d18O) is seen to accompany an elevation in Mg and Sr levels. However, Mg co-precipitation into calcite is also temperature dependent. The distribution of Mg between calcite and water (DMg/Ca) has a positive temperature coefficient. To correct for any change of Mg/Ca in the source water, the use of Sr/Ca was suggested, as this ratio does not show a temperature dependence in calcite formation. Therefore, Mg/Sr ratio may reflect temperature of the water from which calcite precipitates if the weathering regimes in the drainage basin remain unchanged. The results show a warming trend before 11,500 yr BP that heralded the deglaciation, and that alternate wet/warm and cold/dry patterns occurred during the deglaciation.

The d18O, d13C and Mg/Sr results in LC-1 allow us to glean the following paleoclimate information on Salton Basin. Beginning ~20 kyr BP, the basin was filled by a stabilized lake to an elevation of at least –23 m a.s.l. Although previous studies indicate that climate during the Last Glacial Maximum in the region was the wettest over the past 20 ka (Lozano-Garcia et al., 2002; McAuliffe and Van Devender, 1998; Van Devender, 1990, 1994), whether the lake was overflowing before 20 ka so that there was no tufa formation is unknown. The lake level sharply increased from 18 to 17.5 ka probably due to snowmelt from Colorado Plateau following the post-LGM temperature rise and then retreating ~16.5 ka. This retreat corresponded to Heinrich-1 event when closed-basin lakes in the Great Basin all had relatively low levels (Broecker, 1994). High lake levels ca.15.5 ka might be linked to the "Trans US wet period" when the Great Basin and southeastern US were unusually wet (Broecker, 1994). Following this wet period, the lake stayed low for a long period during which no tufa was formed at Travertine Point and a major desiccation in the Great Basin occurred (Broecker, 1994). Around 12.3 kyr BP during the Younger Dryas, the d18O and d13C were at their minima in the record to reflect the lake's reaching the 12-m a.s.l. elevation where it probably overflowed. This lake rise synchronized with the lake transgression in Lake Lahontan, perhaps due to a southward shift of the westerly jet stream during the Younger Dryas (Benson et al., 1990; Benson, 1999). Between 12 and 9 kyr BP, the tufa had the fastest growth and lightest d18O and d13C (Fig. 1), indicating a very wet early Holocene corresponding to the Maximum Effective Moisture period observed elsewhere (Blinn et al., 1994; Thompson et al., 1993) and having been brought about by the strengthening of the monsoons. Toward 2,000 yr BP, the climate became dryer, apparently as the result of the weakening of the monsoons as summer insolation reduced progressively throughout the Holocene (COHMAP Members, 1988). In addition, before early Holocene heavy d18O (dryer) is seen to correlate with low Mg/Sr (colder),

indicating monsoonal climate prevailed on millennial or shorter time scales. The presence of an overflowing lake between 700 and 1500 AD and disappearance of the lake afterwards may signify a warm/wet condition during the Medieval Warm Period and a cold/dry condition during the Little Ice Age, thus it would stress the monsoonal influence.

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Abstracts from the 2003 Desert Symposium

Key subadult and juvenile *Mammuthus* specimens recovered from new site at the Anza-Borrego Desert State Park®, southeastern California, USA

Jessie Atterholt, *Colorado Desert District Stout Research Center, Anza Borrego Desert State Park®, Borrego Springs, CA 92004*

Specimens of proboscidean origin, basicranial and maxillary skull fragments and the protruding proximal ends of two tusks, were found *in situ* in the western Borrego Badlands of Anza Borrego Desert State Park® (ABDSP). The site was discovered in February, 2002, during a scheduled intensive prospecting survey conducted by the ABDSP Paleontology Society. Further scrutiny revealed additional cranial material, as well as cheek tooth fragments.

It has been determined that the tusks and premaxilla belong to a subadult specimen *of Mammuthus* sp. (ABDSP V6520). The longer of the two preserved tusks measures about 90 cm in length and is 12.5 cm in diameter at the base. Estimated age of the individual at the time of death is about 20-23 AEY (Craig Scale in Haynes, 1991), based on tooth wear comparisons and I2/ diameter in *M. columbi* (= *M. imperator*) ABDSP(IVCM) V4056. Examinations strongly suggest that the maxillar and basicranial fragments including a Dp3/ are from a juvenile *Mammuthus* sp. (ABDSP V6524). This younger animal is estimated to have been <3 AEY (Craig Scale in Haynes, 1991) at the time of death. No postcranial materials were found on or near the site.

Locality number ABDSP 2286 was assigned to the site labeled GTJ 988 and its location determined by GPS. The fossils were located on the north side of the wash about 9530 m above the base of the Ocotillo Conglomerate formation, a horizon thought to be approximately 1.25 Ma based on paleomagnetic analyses and estimated depositional rates (Remeika and Beske-Diehl, 1996). The site age of these specimens is estimated at about 900 ka BP or within the mid Irvingtonian NALMA.

The specimens were both recovered from near the base of a 1.3 m-thick, pale gray green, silty fine-grained, moderately well sorted sandstone. Because the sandstone fines upward into a carbonate-rich siltstone, it suggests probable burial in a paludal and/or lacustrine environment. A south-southeast water flow direction, 90 degrees from present west drainages, is indicated by the pebble imbrication measurements in braid stream deposits that underlie the fossiliferous horizon. A bone-bed map was prepared. The long axis of ABDSP V6520 trends north and the northeast end of the specimen lies about 2 m northwest of ABDSP V6524. Fish and reptile remains have been revealed by initial microfossil sampling and analyses.

The use of portable tools for the excavation was dictated by the inaccessibility of the site by land vehicles. Over 3 m³ of overburden was removed, employing gasoline-powered drills and pneumatic tools. Once exposed, the fossils were jacketed in two plaster casts weighing approximately 400 and 1300 kgs each. The jacketed specimens were airlifted by helicopter to the Stout Paleontology for preparation, analysis and curation. Additionally, a number of smaller fossil fragments and matrix were removed and transported out on foot.

An interesting taphonomic study is presented by these proboscidean fossils to determine the possible simultaneity and cause of death. Planned work on ABDSP V6520 includes ring analysis and tusk wear pattern analysis to determine the subadult's health. Also in progress is ancillary microfossil floral and faunal work.

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Archeological favorability characteristics in the north-central Mohave Desert: Trends in prehistoric site patterning and geomorphic factors affecting lifeways

Tad Britt, *RPA., ERDC-CERL, Land and Heritage Conservation Branch, P.O. Box 9005, Champaign, IL 61826-9005;* Marilyn Ruiz, Ph.D. and Tom McTighe, *University of Illinois, Urbana;* Eric McDonald, Ph.D. and Tom Bullard, PhD, *Desert Research Institute, Reno, (John.T.Britt@erdc-usace.army.mil; moruiz@ uiuc.edu; emcdonal@dri.edu)*

A multi-discipline team of researchers has developed an archeological predictive model for the north-central Mohave Desert. Integral to the model is an understanding of the geomorphic processes, environmental effects and Native American adaptation strategies diachronically. This paper focuses on modeling a variety of site types (i.e., habitation/food processing, rock shelters, and lithic procurement/reduction). It demonstrates that site selection was predicated on a strong correlation with specific geomorphic conditions and environmental factors.

Phoenix dactylifera, the tree of life

Brian Brown, *P.O. Box 61, Shoshone, CA 92384-0061*
The date palm is the oldest known cultivated tree crop, with written records going back over 6,000 years to early Mesopotamia. Introduced into the United States on a large scale just over 100 years ago, it has done very well in a limited area of the southwest. There are dozens of known varieties as well as countless seedling types, and the tree's ability to reproduce both sexually and asexually make it a real survivor, even in the severe Mojave climate. Ongoing experimentation at China Ranch suggests that this tough desert tree may be capable of growing in a much wider range than conventional practices suggest.

This talk will give information about the species, its range, reproductive habits, cultivation practices, and how the various cultivars differ. It will also include free samples of the various types of dates.

Edmund Jaeger and the poorwill mystery

James M. Bryant, *Curator of Natural History, Riverside Municipal Museum, 3580 Mission Inn Avenue, Riverside, California 92501*
Fifty years ago this past February, *National Geographic* magazine published a seven page, illustrated article describing the discovery of the world's first bird species proven to hibernate. Entitled "Poorwill sleeps away the winter", the article brought to the world a sample of the methods and philosophy Edmund C. Jaeger brought to his desert research. This article, plus professional publications in Condor and other ornithological journals, brought Dr. Jaeger worldwide fame as a naturalist and desert authority. During the latter part of his career, he was called on frequently to lecture on the poorwill discovery, and in doing so he used a short, silent film of the actual project. Produced jointly with Lloyd Mason Smith (at the time, director of the Palm Springs Desert Museum), it was unseen for many years until Mr. Smith donated a negative of the film to the Riverside Municipal Museum for use in completing its exhibition, *Edmund C. Jaeger: Desert Naturalist*. The film will be shown as part of this presentation.

Resurvey of the Calico Early Man Archaeological District

Fred E. Budinger, Jr., *Calico Project Director, Friends of Calico Early Man Site, Inc., San Bernardino County Museum, 2024 Orange Tree Lane, Redlands, CA 92374 (fbudinger@aol.com)*
Personnel involved with the Calico Archaeological Project (Yermo, California) are currently re-surveying the Calico Early Man Archaeological District Area of Critical Environmental Concern (ACEC) for the purposes of expanding the size of the Calico District's National Register of Historic Places (NRHP) listing from 100 acres to the full 906.25 acres of the BLM ACEC. A "multiple properties" listing is anticipated that shall include not only the BLM Calico District ACEC per se, but also the nearby (10 miles distant) BLM Manix Basin ACEC, an area that is yielding (late middle) Pleistocene-age artifacts in addition to a rich assemblage of Rancholabrean faunal fossils of the Camp Cady Local Fauna (as initially defined by George Jefferson). This presentation shall present a synoptic overview of these two areas and the status of their re-survey efforts.

Charophyte mounds in the Middle Miocene Barstow Formation, Mud Hills, California

Carmen Caceres and Vicki Pedone, *Department of Geological Sciences, California State University Northridge*
The formation of charophyte mounds at the base of the Middle Member of the Barstow Formation in the Mud Hills has been investigated using a combination of field, petrographic, and geochemical/isotopic studies. Although over- and underlain by coarse-grained sandstone and conglomerates, the carbonate rocks of the mound unit contain little siliciclastic material. The mounds formed by the extracellular calcification of the green alga *Chara* are 1 to 3m thick and 3 to 5 m in diameter. Primary calcification of the *Chara* consists of alternating bands of dull-orange luminescent prismatic calcite and bright-orange luminescent micrite. The calcite has moderate levels of Mn (mean 1400 ppm) and low levels of Fe (mean 470 ppm). The ^{18}O of the charophyte fabric ranges from –5 to –9 permil (VPDB), and the ^{13}C ranges from +1 to –2 permil (VPDB). Based on the calcite ^{18}O and an estimated precipitation temperature of ~20°C, the lake water ^{18}O ranged from –4.3 to –8.3 permil (SMOW). Synthesis of all data suggests that the charophyte mounds formed in a shallow, nearshore environment of a lake where synsedimentary faulting temporarily disrupted clastic input, allowing carbonate deposition to occur. Mn and Fe abundances in primary calcite indicate that lake water during mound formation was only weakly oxic, suggesting poor circulation, coupled with moderate oxygen consumption by organic decomposition. This latter interpretation is consistent with the slightly low values of calcite ^{13}C. Calcite formed from dissolved inorganic carbon in equilibrium with pre-industrial atmospheric CO_2 would have had ^{13}C = ~+1.7 ‰. Lower values indicate addition of organic carbon. Estimates of ^{18}O values of Miocene meteoric water in the Mojave range from –8 to –10 permil (SMOW). Therefore, lake water ranged from meteoric to significantly evaporated meteoric, suggesting that this area experienced periods when evaporation exceeded inflow.

Geographical and historical perspective on Superior Valley

Margaret Eby and **Tom Howe**, *Riverside Municipal Museum, Riverside, CA 92501*

With the development of borax, gold and silver mining in Death Valley and its associated wagon and rail shipping lines through the southern passes and valleys to Barstow, adjacent Superior Valley was an area that enjoyed increased settlement. Prior to the Borax boom, silver miners in the Panamint mining camp to the north developed a route through the Panamint Valley to Lone Willow Springs past Pilot Peak through Copper City in Superior Valley on to Daggett and Barstow.

Superior Valley is approximately 25 miles north of Barstow and covers roughly 250 square miles. On the north, west, and northwest boundary of the valley are several noted mountain peaks—Eagle Crags, Slocum Mountain and Pilot Knob—while at the southwest fringe of the valley is Opal Mountain with lower, less defined drainage flanking it. The valley floor's lowest point is approximately 3000' above sea level, higher in elevation than most surrounding valleys. Several small dry lakes occupy the valley floor and most available ground water is at least 100 feet below the surface.

Before the area's acquisition by the United States military in 1940, Superior Valley enjoyed a brief flurry of attempted settlement. A town site at Goldstone mining camp was laid out in the northeast corner of the valley in 1916; however, by late 1917 mining stopped and the camp was abandoned. Prior to 1920 after drilling nearly all of the Superior Valley's 20 or more wells, D.K. Crutts' ranch was a stop for water as well as an ad hoc post office for mail deliveries from Barstow. During this time several families attempted to develop fruit orchards and grain fields on land in which wells were drilled by Crutts. They were unable to get enough water and their efforts failed. While much of the blame was placed on questionable "land locator" deals, it was also probably affected partially by WWI-era economic problems. Some development and homesteading continued on until 1940.

In 1940 the Mojave Anti-Aircraft Range was established by President Franklin Roosevelt, setting aside 1000 square miles for federal military operations, and in 1942 the installation was renamed Fort Irwin. Much of the northern half of Superior Valley was taken in the initial land acquisition. The 1950s and 1960s saw more homesteading on land in and around the southern end of Superior Valley by veterans who knew of the area from being at Fort Irwin. Fort Irwin expansion plans include more Superior Valley land when approved.

Formation and loss of desert riparian habitat at Red Rock Canyon State Park, Kern County, California

Matthew C. Farris and Roland. H. Brady III, *Department of Earth and Environmental Sciences, California State University, Fresno, CA 93740 (mcfarris@yahoo.com; rbrady@csufresno.edu)*

On Wednesday, September 3, 1997, a severe thunderstorm hit Red Rock Canyon State Park, located approximately 20 miles north of Mojave in eastern Kern County, California. An estimated 4.5 inches of rain fell in a little over an hour's time. The resulting flash flood at 28,000 CFS flowed through the park, overtopped the Highway 14 bridge, and surged into Koehn Dry Lake. The park was extensively damaged: most of the buildings and several vehicles were destroyed. Flood waters undercut a large section of Abbott Drive—the access road from Highway 14—scouring the channel to depths as great as 10 feet below their former grade. The downcutting increased the channel's gradient, significantly altering the local hydrology and riparian habitat.

Downstream of Abbott Drive, erosion intercepted the groundwater table, producing a surface water seep and surficial flow. A new, riparian rush habitat approximately 700 feet long has vigorously developed there. But approximately one mile downstream at Sodium Spring, a 1/4-mile long strip of well-established, mesquite-willow habitat is drying up because subsurface water that formerly recharged Sodium Spring is now intercepted at Abbott Drive and lost to evaporation. Although the total area of exposed surface water in the channel has increased, Abbott Drive is extensively traveled making the adjacent habitat is much less desirable to wildlife, and the steepened gradient causes continued erosion, undermining the attempts to establish woody vegetation there.

The older habitat at Sodium Spring could be restored by installing an infiltration gallery at Abbott Drive to capture the groundwater, conveying it through a buried pipeline to a leech field of perforated pipe to recharge Sodium Spring. However, park management must weigh the ecological gain from restoring an established habitat against the project's cost, the potential for continued hydrological instability, and the resultant loss of the new habitat at Abbott Drive.

This desert Is a free country

Robin Flinchum, *Shoshone Museum Association, Shoshone, CA 92384*

For a long time the history of Death Valley has been largely an accounting of the exploits of men. Except for the book *A Mine Of Her Own* by Professor Sally Zanjani, efforts at historical research have done very little to bring into focus the details of the lives of women who inhabited this desert. From the Native American women who trav-

eled the land for generations to Abigail Arcan and Juliet Brier in the ill-fated expedition of 1849, to Rosie Winters and the discovery of colemanite in Death Valley in 1880, to Gertrude Fessler selling real estate in Rhyolite in 1907 and beyond, women were present at almost every noteworthy moment in Death Valley history. Often dutiful historians recorded the simple fact of their existence—the same as they would record the unbearable high temperatures or the absence of water—as background details. The aim of this paper, in conjunction with the ongoing Death Valley Women's History exhibit at the Shoshone Museum and my own attempts to put together a book on this same subject, is to move the stories of these women into the foreground and to provide those interested in the history of this captivating land with a new perspective on an old tale. Using diaries, letters, local newspaper accounts, and census and other official documents, I will present an overview of why emigrant women came to this harsh land, why they stayed, and how they survived. I'll also present a brief look at a few of the individual women, both emigrant and Native American, who lived here.

Spring ostracode paleoecology as a potential source of Mojave paleohydrologic information

Richard M. Forester, *MS 980, USGS DFC, Denver CO 80225*

Ostracodes are microscopic aquatic crustaceans having a bivalved shell made of calcite. Their life cycles depend, in part, on environmental parameters that link species occurrences to hydrology and climate. They often live in particular hydrologic settings such as lakes, wetlands, springs, streams, or ground water. Within such settings, species are further limited by physical and chemical parameters, including total dissolved solids, major dissolved-ion composition, and water temperature, as well as the variability and permanence of the environment.

Springs within the southwest, whether supported by perched or regional ground water, contain characteristic ostracodes associated with the environmental properties of the discharge. Fossil spring ostracodes commonly differ from the living taxa, providing information about climate-driven hydrologic change. Fossil spring ostracodes provide paleoenvironmental information such as source, temperature, relative volume, and permanence of flow. Ostracode shells also store the stable and Sr isotopic properties of the waters in which they were calcified, so providing another paleohydrologic proxy.

The morphology of *Nothrotheriops shastensis*

Jeff Gromney, *University of Nevada, Las Vegas*

The remains of the Devil Peak Shasta Ground Sloth (*Nothrotheriops shastensis*) is one of the most complete fossils of this species ever discovered. The study's objective is to use the dimensions of the Devil Peak sloth and Aden Cra-

ter sloth (the only other complete skeleton of this species known) to characterize the morphology of *Nothrotheriops shastensis*. Radiocarbon ages taken from eggshells located with the Devil Peak sloth determined it is approximately 32,000 years old.

I measured various dimensions of both humeri, one radius, both ulnae, the pelvis, both patellae, and one tibia. Most bones of the Devil Peak skeleton are smaller than those of La Brea specimens with which is was compared, but equal in size to the Aden Crater sloth. However, the Devil Peak sloth pelvis is much larger than the pelvis of the Aden Crater specimen. I conclude the Devil Peak sloth was possibly a female adult sloth.

Lithics for Quaternary paleontologists

Chris Hardaker, *2013 N. Forgeus Ave, Tucson, AZ 85716 (hardaker@flash.net)*

Given the current doubt regarding the temporal nature of the First Americans, a slide introduction to non-projectile point lithic technology is offered. What would kill/processing sites look like if we did not have arrowheads sticking into bones to help us? What do kill sites look like in the Old World before the advent of bifacial technology? What would cutmarks on bone look like when a bone knife is used?

Styles of rock art in the Mojave Desert, California

Robert F. Hilburn, *Mojave River Valley Museum, Barstow, CA 92311*

Rock art in the central Mojave Desert occurs as pit-and-groove, petroglyphs, and pictographs. The former two are produced by deep or shallow picking and scratching with a hard stone tool; the latter involves application of pigment, either by hand or with an applicator made of plant material. Symbols are formed on rock: volcanic, granitic, or sometimes sedimentary. This study examines different executions of rectilinear and curvilinear forms that are constrained by or across margins of boulder facets. The superposition of symbolic forms and their relationship to phases of desert varnish deposition is explored. Rock art panels illustrated in this presentation are located northwest of Barstow at Black Mountain, southeast of Barstow at Newberry Springs, and south-southeast of Barstow near Ord Mountain.

The Tracks Through Time program at the Mojave River Valley Museum

Robert F. Hilburn, *Mojave River Valley Museum, Barstow, CA 92311* and Robert E. Reynolds, *LSA Associates Inc, 1650 Spruce St., Riverside, CA 92507 (bob. reynolds@lsa-assoc.com)*

The Mojave River Valley Museum's "Tracks through Time" program has been active for three years. In that short period of time, the program has captured tracks

from animals living during the last 180 million years. The objectives of the program are (1) to replicate tracks from the prehistoric Mojave Desert so they will not be lost to erosion or unauthorized collecting; (2) to preserve track replicas in local museums for research and exhibition; and (3) to present tracks and trackways to visitors through educational and touchable exhibits.

Mojave Desert trackways occur on public land managed by the National Park system and the Bureau of Land Management, both of whom provide permits for replication activities. Rarely, tracks have been found on private land, and negotiations for replication were made with the land owners. Nondestructive and non-invasive techniques and materials are used to make track replicas. Replicas are produced in concrete or in plaster, resin, or plaster and resin mixes.

These tracks appear in a "tracks through time" concrete walkway at the Mojave River Valley Museum in Barstow and at several exhibit sites through the Mojave Desert as small, touchable replicas and wall hangings. They include California's only dinosaur tracks, prints of Jurassic bipeds and prey, and quadrupedal mammal-like reptiles. Tracks of camel, horse, elephant, cats, and canids are represented from the Miocene Period. Mid-Pleistocene tracks of mammoth, camel, horse, and wolves have been replicated from the ash beds of Lake Tecopa near Death Valley.

Why surficial geology explains spatial patterns in the abiotically-driven Mojave Desert ecosystem

D.M. Miller, D.R. Bedford, K.M Schmidt, G.A. Phelps, K.M. Ellett, A.L. Flint, L.E. Flint, L. Gass, S.L. Dudash, C.S. Menges

Accurately depicting "what is where" in the Mojave Desert ecosystem is essential for making wise land-use decisions, for evaluating the sensitivity of an area to impacts, and for evaluating the state and rate of recovery for disturbed areas. Perhaps more importantly, knowing "what is where" leads to a capability for understanding *processes* that govern the spatial patterns of vegetation, animals, and soil organisms. Past and present research on surficial geology (physical characteristics of desert soils and their related soil moisture characteristics) of the eastern Mojave Desert strongly suggests that surficial geology is a powerful predictor of vegetation cover and composition and biological soil crust cover and composition. When geology is combined with altitude as a proxy for effective moisture, even greater predictive power emerges. The data point to soil moisture as the key relation for predicting vegetation: how much moisture, where it is stored, and how long it is stored appear to be predictors of vegetation attributes. As the processes that drive the biotic-abiotic relationships are quantified, our ability to better understand the desert's ecology and predict its behavior will be greatly improved.

Recent basin tectonics in the San Bernardino Valley as reflected by basin morphology and sedimentation

Robert Mortimer, *Wyo. Prof. Geol. #1721*

The San Bernardino Valley is a topographic low, roughly bounded on the north by the San Bernardino Mountains, on the west by the Lytle Creek–Cajon drainage system, and to the southeast by the Santa Ana wash, forming a roughly triangular basin floor. This form is reflected in the greater overall shape of the valley, with overall drainage funneling into the Santa Ana wash and emptying southwesterly. Drainage from the front of the San Bernardinos flows outwards to the south, and then turns and converges towards an axis running from Waterman Canyon southwesterly toward the Lytle Creek–Santa Ana confluence, with several of these streams turning and running subparallel to the Santa Ana channel . The major controlling regional scale tectonic elements of this basin that create this form have long been recognized, with the San Andreas Fault separating the San Bernardino mountain front from the valley floor, and San Jacinto Fault controlling the orientation of the Lytle Creek Wash, which it levees between the Rialto bench on the west, and low thrust fault-formed levees to the east. The Santa Ana Wash lacks such an obvious related tectonic feature. By a correlation of basin floor drainage patterns with the larger scale structural features of the valley, a clear relationship between differential slip rates along the San Andreas and San Jacinto faults and the orientation of the Santa Ana Wash becomes obvious, resulting in the third side of an extensional basin.

On a larger scale, the differential motion between the San Andreas and the San Jacinto faults is forming the greater San Bernardino Valley around a pull-apart basin, reflecting an oblique trans-tensional force. This is manifest in a number of large scale structural elements, all resultant from the differential slip and subsidence of the basin floor. Some of the more obvious of these include the rotational slump blocks on the eastern San Gabrial Mountains, a large recent gravity slide near Yucaipa, Pelona Schist blocks isolated across the valley, and the grabens in the mouth of Cajon Pass. Besides these structural elements, the sedimentation patterns between these uplifted elements and the subsiding valley floor also express both the vertical and lateral motions of the basin. By creating a dynamic model of the trans-tensonal elements of the basin, a synoptic model of the structural and sedimentological system appears which greatly clarifies several inconsistent appearing fluvial aspects of the San Bernardino Valley. The lineament which trends from the mouth of Waterman Canyon and the basin low at the Interstate 10/215 junction is the current locus of maximum extensional flexure between the two major strike-slip elements of the basin.

Biostratigraphy and reconstruction of the depositional and tectonic history of fossil mammal track localities, Death Valley National Park

T. G. Nyborg and R. S. Spencer, *Department of Natural Sciences, Loma Linda University, Loma Linda, CA 92354;* R. Taylor, *Death Valley National Park;* V. L. Santucci, *Fossil Butte National Monument, Kemmerer, WY;* P. H. Buchheim, *Loma Linda University(tnyborg06g@ns.llu.edu)*

Death Valley National Park preserves one of the richest and most diverse Cenozoic vertebrate trace fossil assemblages in North America. Thirty-six ichnospecies of cat, camel, horse, mastodon, and bird tracks have been identified from the lacustrine facies of Death Valley. Lacustrine facies within the Copper Canyon basin preserve twelve *Avipeda,* five *Felipeda*, five *Ovipeda*, three *Hippipeda*, one tridactyl track "cf. ?*Tapirpeda* n. sp.," and one *Proboscipeda* ichnospecies. The other areas of Death Valley that preserve mammal tracks include a member of the Artist Drive Formation within the Twenty Mules Canyon; a shoreline lacustrine and fluvial sandstone member of the Funeral Formation; and an undescribed formation at Salt Creek, an isolated outcrop in the central Death Valley playa. These tracks are especially important because they represent a diverse fauna of large terrestial mammals, many of which have no body counterparts in the fossil record. Yet there is very little written on these deposits. What has been written has mainly focused on the fossil mammal tracks. The biostratigraphic position of these tracks is needed. The lack of understanding of where these tracks temporally and lithologically fit into the similar Cenozoic basin and fill deposits of Death Valley hinders the correlation of these localities. Through a permit, a formal description of these deposits will be undertaken over the next few years. By applying geologic dating techniques, systematics, and depositional paleoenvironment reconstructions for these track localities, the mammal tracks of Death Valley can be biostratigraphically applied, greatly enhancing our knowledge of Cenozoic mammal evolution in southern California and in the reconstruction of the depositional and tectonic history of these important playa-lake environments within the context of the other Cenozoic basin and fill deposits of Death Valley National Park.

Groundwater discharge deposits in the Mojave Desert, California

K.S. Rivera and V. Pedone, *California State University Northridge, Department of Geological Sciences, Northridge, CA 91330*

A number of laterally limited and stratigraphically thin carbonate deposits are exposed at the surface in the Mojave Desert. The deposits overlie and/or are interbedded with unconsolidated silty sand to gravel and are presumed to be Pleistocene in age. The origin of these deposits is uncertain, and the purpose of this study is to determine the hydrologic system from which they formed: 1) a lacustrine system dominated by surface runoff, 2) a pedogenic system dominated by meteoric infiltration, or 3) a wetland dominated by groundwater flow and discharge. The initial results of the overall study, which will synthesize field, petrographic, and isotopic characteristics of the carbonates and their associated clastic deposits, have defined the geomorphology, areal distribution, stratigraphy, and paleontology of one deposit located along a broad alluvial fan surface near the intersection to two major drainage areas defined by the Bristol, Old Dad, Granite, Marble, Old Woman, Providence, New York, and Piute Mountains. The study site contains an approximately 1-km-wide irregular band of poorly exposed carbonate deposits that form subtle, resistant topographic highs. Carbonates are white to light-brown, fine-grained, and porous, and contain about 20% clastic sand and silt. Beds range in thickness from 3 to 35 cm and grade vertically above and below into moderately resistant, fine-grained, calcareous sand. Carbonate beds locally contain abundant molluscan fauna and commonly exhibit root casts within their gradational contacts. The gastropod assemblage, *Fossaria* sp., *Gyraulus* sp., and Pupillidae, are typical of those found in wetlands dominated by groundwater flow and discharge.

The Park Place Fauna: a faunal assemblage from Irvine, Orange County, California

Robert E. Reynolds, *LSA Assoc. Inc., 1650 Spruce Street, Suite 500, Riverside, CA 92507;* Kevin Buffington, *LSA Associates Inc. 20 Executive Park, Suite 200, Irvine, CA 92614 (bob.reynolds@lsa-assoc.com)*

The Park Place Local Fauna (Irvine, Orange County, California) contains no less than 47 taxa so far identified among tens of thousands of recovered specimens. Park Place has yielded the largest assemblage of the 37 known paleontologic sites in Orange County, and the taxonomic count will grow with further identification. In comparison, the next most diverse assemblage in Orange County is Newport Bay Mesa (LACM 1066-1067, 1100, 1240, 3877) with 31 taxa. The tar pits at Rancho La Brea have yielded 63 taxa. Two Park Place samples (BRS-990813-03) have yielded radiocarbon dates of 14,713±71 and 15,853±81 ybp (both from University WAIKATO, New Zealand). These dates, and the presence of *Bison sp.*, place the fauna in the late Pleistocene, Rancholabrean Land Mammal Age.

Large herbivores include the extinct antelope *Capromeryx* sp. (common) and camel, *Camelops* sp. (uncommon). Small carnivores including the long-tailed weasel (*Mustela frenata*), fox (*Vulpes fulva*), and bobcat (*Lynx rufus*) are rare. Several taxa of large carnivores are represented, including saber-toothed cat (*Smilodon californicus*) and, less commonly, bear (*Euarctos americanus*),

jaguar (*Felis onca*), and dire wolf (*Canis dirus*). Meadow mice (*Microtus* sp.) and wood rats (*Neotoma* sp.) are abundant. Identified reptiles include the western pond turtle (*Clemmys marmorata*), iguanid lizards, and colubrid and crotalid snakes, with frequency ranging respectively from uncommon to common. Raptors and other avian taxa are particularly abundant. Bony fish and bat rays (Mylobatidae) are very rare and one species of gastropod is uncommon in the assemblage.

The sample was recovered during construction monitoring within sediments associated with Pleistocene beds deposited in the San Joaquin marsh, a habitat that still exists at nearby Newport Bay. A perennial marsh environment is conducive to accumulation and preservation of the extinct and extant fauna represented. The assemblage suggests that multiple habitats existed close to the faunal deposit, including Springside Riparian, Scrub Brush/Chaparral, Aeolian Sand Flats, and Estuarian Back Bay deposits. The presence of fish and gastropods may be interpreted as the introduction of marine taxa through raptor detritus or an influx of tidal waters into the marsh. Fossil shark teeth at the site have been reworked from older sedimentary deposits.

The fauna offers tremendous research potential. The Park Place fauna will provide baseline data critical for comparing habitats of coastal, inland, and desert faunas. Skeletal elements with gut polishing can be quantified, and may shed light on hunting and predation. Further identification of small mammals, reptiles, and amphibians will provide clues to local microhabitats. Frequencies of raptor to non-raptor avian species may provide keys to local habitat, vegetation, and seasonality. Study of taphonomic processes will offer insights into the accumulation and deposition of faunal material.

Methods of faunal accumulation may include sources such as carnivore dens, raptor roosts, and woodrat middens, with local secondary concentration at spring vents. The methods of accumulation are distinct from those at Rancho La Brea, and lack the selective bias of tar entrapment.

Taphonomic evidence for predation of *Capromeryx minor* (Artiodactyla, Antilocapridae) from Park Place, Irvine, California (Pleistocene: Rancholabrean)

Meredith A. Staley, *Department of Geology, California State Polytechnic University, Pomona, California 91768*

The dwarf pronghorn antelope *Capromeryx minor,* first identified in Rancho La Brea by Taylor, 1911, is known from at least six sites in California and Nevada which are interpreted to be Sagebrush Steppe-woodland and Steppe-woodland foothill environments. The recently discovered Park Place site in Irvine, California, put an abundance

of *C. minor* remains in a marsh environment. *C. minor* is exceptionally common in these deposits, which contain tens of thousands of fossil remains from at least 47 vertebrate taxa. More than seven hundred specimens have been recovered from the wash of sediments from Pit 1 at Park Place, and these represent the remains of at least 46 individuals.

The condition of the specimens led to the hypothesis that the *Capromeryx minor* were accumulated by a predator, possibly as a part of a den deposit. Evaluation of wear patterns and skeletal elements support this hypothesis. An abundance of small, dense bones and fragments show evidence of etching associated with gut polishing, and, more rarely, puncture marks and other signs of predation are observable. The concentration of elements from the lower legs and teeth indicate a deposit at or near the entrance to a carnivore den which is used by the carnivores as a "latrine." The absence of any recognizable fragments of the axial skeleton prevents the likelihood that these are kill sites. The extreme wear and small size of the specimens prevents easy identification of the predator, but possible candidates include saber-toothed cats (*Smilodon californicus)* and the dire wolf (*Canis dirus),* both of which are present in the Park Place assemblage.

Montane small mammal diversity and isolation in the Mojave National Preserve

Kelly J. Thomas, *Dept. of Organismic Biology, Ecology, and Evolution, University of California, Los Angeles*

Currently in the East Mojave, pinyon-juniper woodland habitat is found only on isolated mountain ranges and is restricted to elevations greater than 1400m. During the glacial periods of the Pleistocene, however, this woodland was also present in the valleys that separate the mountain ranges. Contiguous pinyon-juniper habitat between the mountain ranges occurred most recently during the Wisconsin glacial stage (15,000-21,000ybp) at which time species associated with this habitat were able to disperse to adjacent mountains. With the recession of the glaciers approximately 7800-9000ybp and corresponding increase in temperature and aridity, the pinyon-juniper woodland habitat receded to higher elevations and desert scrub moved into the valleys, causing the isolated fragments of montane habitat that are present today. Similarly, the mammal populations associated with these isolated habitat patches are relics of their previous continuous distribution. The pinyon-juniper woodland habitat supports a variety of small mammals, a small subset of which is likely to be restricted to high elevations using the woodland habitat more or less exclusively. Here, I present data from the Mojave National Preserve indicating that small mammal species restricted to the pinyon-juniper woodland habitat are isolated from other conspecific populations on nearby moun-

tains. Species richness data seem to follow predictions of the theory of island biogeography and simple morphologic measurements indicate that the desert basins are dispersal barriers to some small mammals. If the pinyon-juniper woodland species are in fact isolated, further conservation of this montane habitat is warranted.

Surface survey of agrarian subsistence system in the Superior Valley and initial discussion of structures near Inscription Canyon

Jan Walkup and Sam Hunter

This abstract introduces the theory that a thriving sedentary agrarian culture lived in the Superior Valley of California. We have found evidence of what we theorize are raised fields, water containment and control, and ruined structures of various descriptions. At this time we do not know the time line for this activity. We theorize that a complex irrigation system complete with water containment tanks and natural lakes supplied water to at least one village and the raised fields in the Superior Valley. This abstract will layout our theoretical position and present supporting evidence for those conclusions. This is not to be considered a complete piece of research; there is much to be done at the site.

This abstract presents the theory that a large and thriving agrarian culture lived in the Black Mountains and Superior Valley of California some time in the distant past. Their primary subsistence was agriculture, not hunting and gathering as has been previously asserted by other researchers. We believe hunting and gathering did contribute to their subsistence but was not their entire source of subsistence.

The raised fields are northeast of Inscription Canyon and run for miles up the Superior Valley eventually running into the dry lakes. They may have harvested fish from the canals between the raised fields. We theorize that there was much more vegetation and water in the area than there is now and that is how this was possible.

The village site is located to the southeast of Inscription Canyon near Opal Mountain. The site runs for at least a mile and is approximately a half mile in width. In that area we have found the ruins of water tanks, manipulated and maintained creek beds, work shop areas, artifacts, and structures of many sizes and shapes. We theorize that there are other outlying sites which we have not surveyed or simply missed because these sites are very difficult to locate.

We do not make any time line statements because we do not have enough evidence to support such a statement. However, Charley Howe and later Wilson Turner did mention in their journal entries for the San Bernardino Museum at Redlands a timeline for the general area as old as 9,000 years. Charley Howe's survey came up with many artifacts as well as an early discussion of the petroglyphs in the area. Wilson Turner did a complex and exhaustive inventory of the petroglyphs in the Black Mountains and reported his findings in journal reports to the San Bernardino Museum. Wilson Turner asserts a timeline as old as 9,000 years. We have a great deal of respect for these two researchers. Their work saved us many hours of field work.

This is an ongoing project and presently we have no clear conclusion of exactly what the pre-contact Native Americans were doing in the Superior Valley. We will provide a more detailed update as our project continues.

Population abundance and diversity of reptiles in the East Mojave, Soda Springs area

Jason M. Wallace, *California State University, Fullerton*

Few studies have examined the dynamics of a reptile community over an extended period of time. Limited quantitative data exists regarding the relative abundance and habitat associations of reptiles. The purpose of this research is to determine, over two seasons (24 consecutive months), the effects of seasonal changes and environmental conditions on the abundance and diversity of the desert reptiles residing in the East Mojave, Soda Springs area. This information was compared with two seasons (24 consecutive months) of similar data previously collected at the same study site (June 1991-May 1993 vs. January 2000-December 2001). Of the total 16 reptile species captured, 7 were abundant enough to conduct a habitat utilization analysis. *Uta stansburiana* was both the most abundant and most evenly distributed species captured overall. *Urasaurus graciosus, Callisaurus draconoides* and *Coleonyx variegatus* represent 40.1% of all captures occurring June 1991-May 1993 while representing only 4.5% of all captures occurring January 2000-December 2001. A lack of juvenile recruitment in the 2000 season compared to 2001 was a result of low precipitation levels. No significant difference was found between adult males, adult females or juveniles for either *Uta stansburiana* or *Cnemidophorus tigris*. A detailed analysis of trap success found a lack of evenness between the four habitat types. Evidence suggests, however, that this difference has more to do with the habitat utilization of the resident reptiles than it has to do with the performance of the traps themselves.