The Incredible Shrinking Pliocene

The 2011 Desert Symposium Field Guide and Proceedings

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The Incredible Shrinking Pliocene

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FRONT COVER:

The Spanish Canyon Formation at Alvord Mountain.
Photograph by D. M. Miller.

BACK COVER:

View west of the Oligocene Vaqueros Formation and Miocene Cajon Valley Beds on the slopes of the 11,000-ft San Gabriel Mountains. R. E. Reynolds photograph.

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The Spanish Canyon Formation at Alvord Mountain.
Photograph by D. M. Miller.

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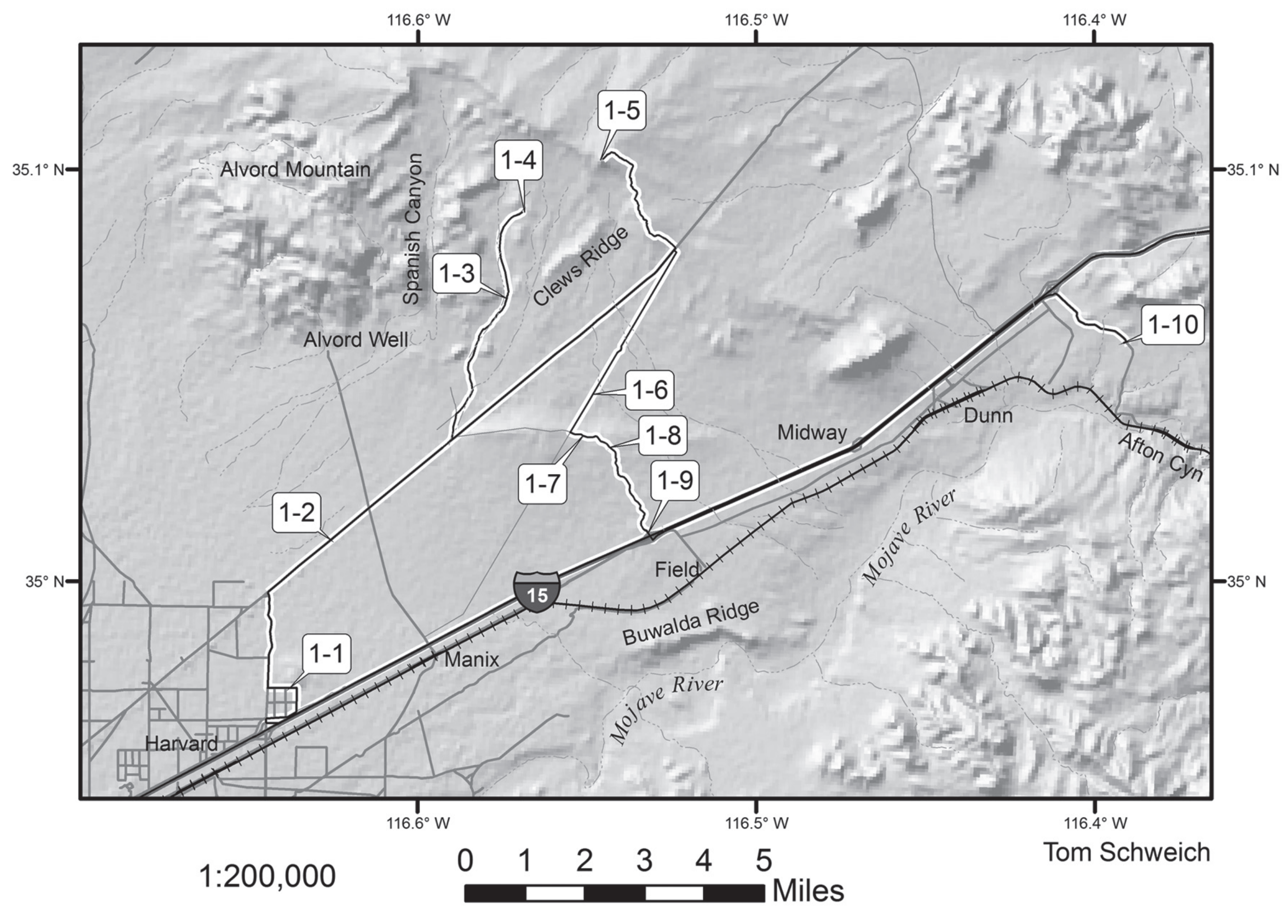

The incredible shrinking Pliocene: Field trip guide, Day 1

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Introduction

What's left of the Pliocene? Where is it in the Mojave Desert and what stories can it tell?

The middle Miocene marked the end of deep basin filling and large volcanic centers which left behind abundant records of geology, plants, and animals. After that time, meager records for the late Miocene and Pliocene have long puzzled desert workers. Yet, this period saw the inception of the Eastern California Shear Zone and development of strike-slip faults that plied most of the Mojave Desert. What records are available, why are they difficult to decipher, and what can be learned from them?

The very pliable Pliocene is now defined as between 5.3 and 2.6 Ma, (Finney, this vol.) but formerly started earlier and ended later. During the 1980s seven million years of Pliocene time were assigned to the late Miocene Epoch, greatly shortening the Pliocene. Recently, recognition that glacial cycles occupied the last 1 Ma of the Pliocene has led to a shift of the beginning of the Pleistocene Epoch back to 2.6 Ma. Even though short, the Pliocene was eventful. Global climatic events, such as gradual cooling and drying, the start of polar ice caps, and altered ocean currents from the closing of the Isthmus of Panama, are overprinted by regional events such as the rise of the Transverse Ranges and the resulting rain shadow that created the Mojave Desert climate. Across the Mojave, many coarse gravel deposits have been assigned to the Pliocene.

How can we recognize the "shrinking Pliocene" in the Mojave Desert? Are there sedimentary and volcanic rocks that fill the 5.3–2.6 Ma gap? Do volcanic rocks help date structural changes along major geologic province block boundaries? Do sedimentary deposits signal climatic change, tectonic uplift and denudation, or other factors? What animals and plants populated the desert and what do they tell of climate changes?

Early on Day 1, we will pass outcrops in three places along I-15, all presumed to be of Pliocene age (Miller unpubl mapping): at the Zzyzx on-ramp; southeast of the Basin exit; and just east of the Afton Road exit. We will call these deposits "Pliocene" to simplify the road log, despite the fact that many are only dated by older materials below them and younger Quaternary above. These three exposures have in common a coarse-grained and well-bedded set of gravel and sand, but some are low in the landscape and others high, some are faulted and others not.

Also on Day 1 (Stop 1-1) we will visit dated lacustrine deposits of the Miocene Barstow Formation unconformably overlain by Pliocene deposits, discuss the secrets that these relatively unstudied Pliocene gravels are yielding, and describe what the results imply for recent tectonics of the region. We will focus on chronology and depositional environments for the Miocene deposits as limits for the age of the overlying Pliocene gravels. Provenance of the gravels will be described, the limited age data revealed, and patterns of deposition across the region discussed. Lastly, we will evaluate the ages and environments of deposition for Quaternary units that overlap the Pliocene strata (Stops 1-10, 1-11).

Convene at Zzyzx Desert Studies Center;
proceed north to I-15.

0.0 (0.0) Enter I-15 westbound. Re-set odometer. Note the dipping beds of sand and gravel exposed in the road cuts on your right as you gain speed on the onramp. The locally derived gravels lie on Jurassic granites and metavolcanic rocks (Grose, 1959). Tilted beds indicate that the gravel has been deformed, and in places the map geometries require that it be faulted, but no faults are evident in this exposure.

5.9 (5.9) Pass the Rasor Road interchange. We have climbed well above the Zzyzx onramp, and yet just north of this interchange is another Pliocene gravel deposit that is similar to that near Zzyzx road.

9.7 (3.8) Continue past the Basin Road interchange. Gravel underlying the hills southeast of the interchange (Ventifact Hill, Laiety, 2000) is very coarse-grained, containing large granitic boulders suggesting nearby sources.

East Cronese playa, visible to the north, is fed by the Mojave River during floods. It has an extensive record of past lakes and human occupations (Schneider, 1989: Warren and Schneider, 2000). A recent paper (Miller and others, 2010) demonstrates late Holocene lakes present here during the Little Ice Age (~ AD 1650) and Medieval Warm Period (~AD 1290).

17.3 (7.6) Pass through faulted Pliocene sediments in the road cut. Note the mineralized faults in the western part of the cut. The faults stand in relief above the more rapidly eroding adjacent gravel. This gravel lies on Mesozoic intrusive and metamorphic rocks (Walker and others, 1990).

View west into Afton Basin, which was filled by Lake Manix in late Pleistocene time. Much of the hilly country south of the Mojave River is underlain by Pliocene and possibly Quaternary gravel. The badlands topography is caused primarily by the relatively recent, rapid downcutting of the basin through which the Mojave River currently flows.

18.3 (1.0) Continue past the Afton Road exit.

20.6 (2.3) The unnamed hill north of the freeway is composed of Mesozoic rocks against which, in the dissected foreground of the hill, are Pliocene gravels. The gravels are cut by several faults, considered by Miller to be part of the Cave Mountain fault zone. Pliocene gravels at the south base of the hill are of different lithologies than the hill. Strands of the (E-W) Cave Mountain Fault separate the gravels from the hill (Miller, pers. obsv.).

26.2 (5.6) Continue past the Field Road exit. We are on the crest of a broad dome or fold in Pliocene and Pleistocene gravel. Southward, the gravels appear to interfinger with beds of Lake Manix. Gravel in Buwalda Hill underlies the Mojave River Formation (Early Pleistocene) and contains Pliocene ash beds (Miller and others, this volume).

30.2 (4.0) Pass under Alvord Mountain Road.

31.9 (1.7) The highway cuts through eastern Lime Hill east of Harvard Road. The tilted (but unfaulted), medium- to thick-bedded gravels are well exposed in this cut and in quarries south of the road. We will discuss clast composition at Stop 1-1.

41.6 (1.0) Exit at Harvard Road.

41.9 (0.3) Stop, TURN RIGHT (north) and pass store.

TURN RIGHT (east) on Hacienda Road.

47.0 (0.5) TURN LEFT (north) on Pima Road.

47.4 (0.4) Park at the intersection of Pima Road and Temecula Street.

STOP 1-1: Lime Hill. Lime Hill is made up of Miocene Barstow Formation sediments overlain by a thick gravel sequence.

Walk up the hill to the top of prominently bedded deposits of the Barstow Formation. Here the Barstow consists of green sand and tuffaceous sand, with lesser green siltstone. Two prominent white silicified limestone beds, each thin but resistant, are located near the top of the exposure of the Barstow. Cut into the Barstow and crossing the limestone beds is a channel that contains white limestone-boulder conglomerate, presumed to be Pliocene. This deposit appears to have a local source of silicified Barstow limestone and only sparse clasts from other rock types. Above this white resistant deposit, which continues to the hill crest and beyond, is a brown-weathering sequence of gravels that is continuous with the Pliocene deposits viewed in the road cut just east of Harvard Road. Clasts in the brown gravels are derived from many sources north, south, and west of here. They are considered by Miller and others (this volume) to represent valley-axis deposits of east-flowing streams that drained several distant mountains during Pliocene time. Evidently, the future basin that Lake Manix would occupy during the middle and late Pleistocene did not exist. We will see more of these valley-axis deposits farther east of here later today, and discuss the terminus of the stream system at that location. All of the Miocene and Pliocene beds dip eastward in these hills, and only a few faults have been mapped.

Return to vehicles, proceed west to toward Harvard Road.

47.9 (0.5) Stop, TURN RIGHT (north) on Harvard Road.

48.4 (0.5) Pass Camelot Road. Slow through curves as we cross several Mojave River channel crests that are not dated at this location, but probably represent the fluvial top of a delta system that prograded into Lake Manix.

49.0 (0.6) TURN RIGHT (northeast) on the powerline road toward southern Alvord Mountain.

49.4 (0.4) We are crossing a small playa that formed at the junction of the alluvial fans shed from Alvord Mountain and the nearly flat Mojave River fluvial plain.

Figure 1-2. (a) and (b), furrows possibly left after using a Fresno scraper (c) cross-section illustrating relative size of scraper blade and width of feature.

49.7 (0.3) Cross a military vehicle road to Fort Irwin. Continue on powerline road.

Caution: the first of many dips is 300 feet ahead.

50.4 (0.7) **STOP 1-2: Harvard Maze**.Pull to the right and park to view Harvard Maze. N80ºW furrows on the north and south side of the power line road are three feet wide, and may have been made by Fresno scrapers (Lange, this volume) during an attempt at agriculture. Furrows farther southeast trend north, and furrows 0.3 miles north are concentric within the margins of a rectangle. The geographical extent of the furrows is constrained by section lines in certain cases, suggesting development after the date of Township & Range surveying in this area. Return to vehicles and proceed eastward.

51.2)(0.8) Cross a road to the left (north) heading toward Alvord Well (Thompson, 1929) and the route to Spanish Canyon, a canyon and pass ("Do Not Pass") on the Old Spanish Trail or Salt Lake Trail (Mendenhall, 1909; Lingenfelter, 1986; Lyman and Walker, 1997, 1999) between Bitter Springs and Fishponds (Daggett).

53.0 (1.8) TURN LEFT before entering the first major wash. Proceed north-northeast on the road parallel to the wash.

53.2 (0.2) Pass between yellow posts marking the gas line road.

53.4 (0.2) TURN RIGHT onto the northern transmission line road.

53.5 (0.1) TURN LEFT at the wash and proceed along it, staying to the left (west) side.

53.8 (0.3) Stay left (west) in the wash.

53.9 (0.1) Look for red tile and TURN LEFT out of the wash onto the terrace with existing tracks.

54.4) 9.8 (0.5) Continue past the south tip of the Clews Formation sandstone ridge.

54.9) 10.3 (0.5) Continue past the south end of an outcrop of the purple Alvord Peak Basalt (Byers, 1960) on the right.

55.3 (0.4) Pass the north end of the purple basalt outcrop.

55.7 (0.4) Park before reaching the narrows. Caution—do not enter the wash if the ground is wet.

Stop 1-3. Peach Spring Tuff. Stop near a prominent white ledge on the east side of the wash about 100 yards downstream from the narrows. This is one of two local marker units in the Spanish Canyon Formation—a white, pumaceous sandstone, commonly with spheroidal weathering. Under it in several places is a gray tuff that is somewhat altered, but distinctive

in being pumaceous and biotite-rich. This tuff can be found in several Spanish Canyon Formation sections and is the most important bed for correlating sections. Walk east along these beds until reaching a low, pale pink ridge that extends to the left (north). This is the Peach Spring Tuff, described by Hillhouse and others (2010). Although several outcrops of fine-grained andesite separate the tuff from beds of the Spanish Canyon Formation here, greatly complicating interpretations, it appears that the Peach Spring underlies olivine basalt exposed farther east. If this is the case, it lies about 15 m below the basalt. In other better exposed

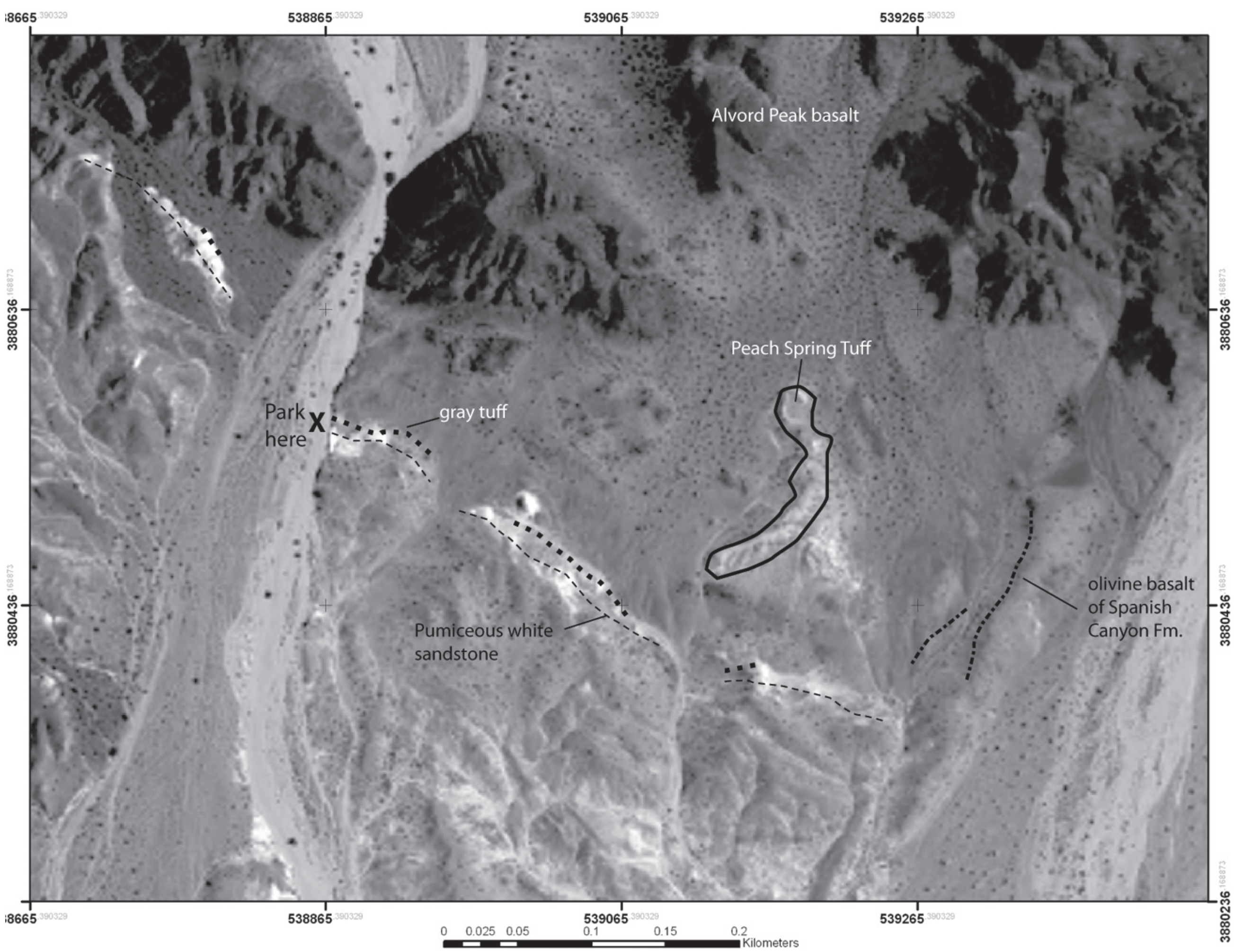

Figure 1-3. Map of the Peach Spring Tuff outcrop area, stop 1-3. The sandstone and gray tuff occur low in the Spanish Canyon Formation in other, more complete sections. The olivine basalts lie at the top of the section. The Peach Spring Tuff is structurally discordant to the gray tuff, suggesting that a fault separates the two. However, small outcrops of mafic volcanic rock similar to the Alvord Peak Basalt farther north are exposed between the two sections, and exact relations are unclear.

sections that lack the Peach Spring, the gray tuff lies 20 m or more below the lowest olivine basalt, so we think that this Peach Spring Tuff exposure indicates that it lies in the middle to upper part of the Spanish Canyon Formation. The Peach Spring Tuff is important regionally as a time marker and for its record of vertical-axis rotations of tectonic blocks. Here, it indicates about 55 degrees of clockwise rotation for this part of Alvord Mountain (Hillhouse and others, 2010).

Proceed north through the narrows.

55.9 (0.2) Keep right in the east branch of the wash.

56.6 (0.7) Keep right in the east branch of the wash.

57.0 (0.4) Bear right (east) into an east trending canyon.

57.2 (0.2) Pass between ridges of Clews Fanglomerate: granitic boulders in red sand matrix.

57.4 (0.2) Loop left and park, heading down-wash to prevent getting stuck when we leave.

Stop 1-4. Spanish Canyon Formation. Walk over a low ridge to the southeast to view the Spanish Canyon Formation section. This is probably the best exposed section in Alvord Mountain. The formation overlies reddish sandstone of the Clews Formation on the right, and is overlain by sandstones of the Barstow Formation on the left. The lower parts consist of a series of ridges of whitish sandstone, quite tuffaceous and in places pumaceous. The gray tuff lies low in the section. The upper part is composed of a pair of olivine basalts, the lower one normally magnetized and the upper one reversed (Hillhouse and Miller, this volume).

On the ridge crest to the northeast, we can see an unconformity with nearly white gravel on the crest overlying the Barstow Formation. The white gravel was considered to be Pliocene or Pleistocene by Byers (1960). Miller and others (this volume) consider it to be Pliocene and, because it is sourced from the Goldstone District, termed it the Goldstone gravel. Retrace to Power Line Road.

59.2 (1.8) Pass through the narrows, bearing right (southeast).

59.6 (0.4) Pass the north end of the Alvord Peak basalt.

60.4 (0.8) Pass the south end of the Clews Formation ridge.

61.0 (0.6) TURN RIGHT (south) and enter the main wash. Proceed south.

61.4 (0.4) TURN RIGHT (southwest) on northerly powerline road.

61.5 (0.1) TURN LEFT (south) onto the road on the west side of the main wash.

61.7 (0.2) Pass the yellow posts of the gas line road.

61.9 (0.2) Stop, TURN LEFT on the Alvord powerline road and proceed northeast. On the right and to the south is a linear ridge that apparently bounds the south splay of the Cave Mountain Fault. Several small faults have been mapped thus far but a major fault has not. If it exists, it must lie near the toe of the slope north of the ridge.

Figure 1-4. Spanish Canyon Formation in Alvord Mountain.

63.0 (1.1) Pass through the junction with the east-west power line; note the white K-rails. We will return to this junction. Continue northeast on the left fork.

64.3 (1.3) CAUTION: Dips. Pass through outcrops of the “Barstow Formation” of Alvord Mountain.

64.8 (0.4) Cross the lower of three basalt flows in the Barstow Formation. Miocene basalts within the Barstow Formation of Alvord Mountain are dated at 16.5±0.5 Ma (Woodburne and Reynolds, 2010). Vertebrate fossils recovered by Byers (1960) in this part of the Barstow and by subsequent workers verify the Barstovian NALMA age of the beds. Strata here are generally similar to those of the type Barstow Formation in the Mud Hills, but may represent a margin of the Barstow basin or perhaps a separate basin, since the distinctive sequence of three lake bed markers identified in many parts of the Barstow basin (Reynolds and others, 2010) have not been verified here.

65.1 (0.4) The powerline road crosses the Triple Basalt (Byers, 1960).

66.8 (1.7) TURN LEFT (northwest) onto a haphazardly paved road to the microwave station.

67.4 (0.6) The road bears right (northeast) and drops off the crest.

69.2 (1.8) Park on the north side of the microwave station complex.

Stop 1-5 Alvord Microwave Station. The view to the southwest shows exposures below the early Pliocene unconformity. Alvord Mountain rocks include Miocene sediments and volcanics overlying Mesozoic granitic rocks that intruded and metamorphosed Paleozoic clastic and carbonate sediments. The view northeast into Bitter Spring Basin shows a block of metamorphic rocks bounded by the Garlic Spring Fault and the Bicycle Lake Fault, the latter cutting basalts that date to 5.5 Ma.

The Goldstone gravel lies at our feet. It bears distinctive clasts of white muscovite granite and less common clasts of garnet-muscovite granite, sourced from a pluton east of the Goldstone district in Fort Irwin (Miller and others, this volume). Also present are metamorphic rocks from the same area and lesser clasts derived from Alvord Mountain. An ash bed in the gravel is 3.3 Ma, and the gravel is thus considered to be Pliocene in age. The Goldstone gravel lies on the Barstow Formation along an angular unconformity in places, and elsewhere appears to be conformable and gradational on the Barstow.

The Goldstone gravel deposit has been considerably deformed since it was deposited. We are at an elevation only slightly below its source area (50 to 600 ft higher), and 30 km distant. The deposits have been arched up here, and bowed down in the area north of Coyote Lake, since ~3 million years ago.

RETRACE to the Alvord powerline road.

71.6 (2.4) Stop, TURN RIGHT (west) and proceed southwest toward the junction with the east-west powerline road at the white K rails. Watch for dips.

75.4 (3.8) Stop just before reaching the K-rails and TURN LEFT (E) on the powerline road.

76.1 (0.7) Enter white conglomerate and interbedded arkosic sandstone. Large, well rounded cobbles of leucocratic biotite granite (quartz monzonite) and granitic pegmatite match a minor source area in Alvord Mountain; apparently at the time this deposit formed, a much larger area was exposed and eroding. This unit may be upper Miocene or Pliocene in age.

76.5 (0.4) Fractures in silty arkosic sediments are filled with white calcite. Ahead, note large blocks of 82 Ma, dark, porphyritic, hypabyssal dike rock that has limited aerial distribution.

76.8 (0.3) TURN LEFT (east) on the single-pole powerline road and park.

76.9 (0.1) **Stop 1-6. Granitic gravel above the Barstow Formation.** This small ridge of west-dipping, pale-colored conglomerate and sandstone contains abundant clasts of leucocratic biotite granite, probably derived from Alvord Mountain. This unit and another higher in the section here have been termed the South Alvord gravel by Miller and others (this volume). The unit is notably cemented and deformed by folds and faults, unlike most Pliocene and younger gravel units in the area. These beds may represent upper Barstow Formation or "supra-Barstow" gravel of Miocene age.

To the south, toward the ridge, the beds of this unit dip consistently southward and are interbedded with gravel of the overlying unit, which we will examine in stop 1-7.

Between this stop and the ridge crest, the south strand of the Cave Mountain Fault crosses the "supra Barstow" gravel unit, but its location is difficult to determine in the poorly exposed gravels. Topography and outcrops of small strands of left-lateral faults point to the fault lying near the toe of the slope.

77.0 (0.1) TURN RIGHT (southwest) at the junction with a single-pole powerline.. The pole line enters silty sandstone similar to the Barstow Formation. Farther ahead, darker colored hogbacks are conglomerate carrying increasing amounts of dacite volcanic clasts.

77.3 (0.3) Maintain speed as road ascends sandy slope of "Pliocene" gravels referred to as "Granitic Gravels" (Byers, 1960). Prepare to turn left (southerly) at ridge crest. Dark outcrops on left are upper beds of the

Figure 1-9. The Goldstone gravel.

"supra-Barstow" unit.

77.4 (0.1) TURN LEFT (east-southeast) onto the ridge-top road.

77.6 (0.2) **STOP 1-7. Volcanic gravel unit of Byers (1960).** This (dark purple) gravel lies conformably on the "supra Barstow" gravel of the last stop, and is of strikingly different composition. Dominant clasts are dacite and silicified limestone, and subordinate clasts are widely varying lithologies. The clast composition is similar to the upper sequence of gravels at Lime Hill, and suggests sources from several mountains lying to the west and north. We suggest that these gravels represent valley-axis deposition from east-flowing streams. An eastern depositional sink has not been found. The nearest basin deposits of Pliocene age are near Amboy, but many areas remain to be studied in the search for the depositional sink.

77.9 (0.3) The ridge-top road bends south. TURN LEFT (east) at crossroads.

78.1 (0.2) Take the right fork in the road.

78.3 (0.2) **Stop 1-8: Resistant limestone.** At this location, a thick bed of limestone lies in the upper part of the volcanic gravel unit of Stop 1-7. The carbonate, light in color, is much more resistant than the host sand and gravel, and forms ledges. The nodular fabric, with pebbles in the centers of big nodules, is similar to other groundwater-discharge deposits in the Mojave Desert. Down section and farther west are more beds of this type, suggesting that a long-lived spring persisted during deposition of the sand and gravel. The section above this bed records a transition upward to the overlying "Goldstone" gravel that we will look at in the next stop. Also, a bit upsection here one can find a small sinistral fault decorated by silica deposited in the fault. RETRACE to the ridge-top road.

78.7 (0.4) TURN LEFT (south) on the ridge-top road.

78.9 (0.2) **Stop 1-9. Goldstone gravel**. Lying conformably on the volcanic gravel is this white granite-dominated deposit bearing the distinctive clasts of the Goldstone gravel: white muscovite granite and metamorphic rocks. In addition, basalt clasts are fairly common and other less common rocks suggest a minor source from Alvord Mountain. Overall the unit is mostly sand, with the pebble and cobble beds typically bearing well-rounded clasts. If this is the same gravel unit that we stopped at the microwave station on Alvord Mountain, it is Pliocene in age. Alternatively, this could be a tongue of gravel from a Goldstone source after Alvord Mountain started tilting north, cutting off the Pliocene valley carrying Goldstone gravel north of Alvord Mountain. By this view, the streams crossed west of Alvord Mountain as the Coyote Lake area started to sag, and could be

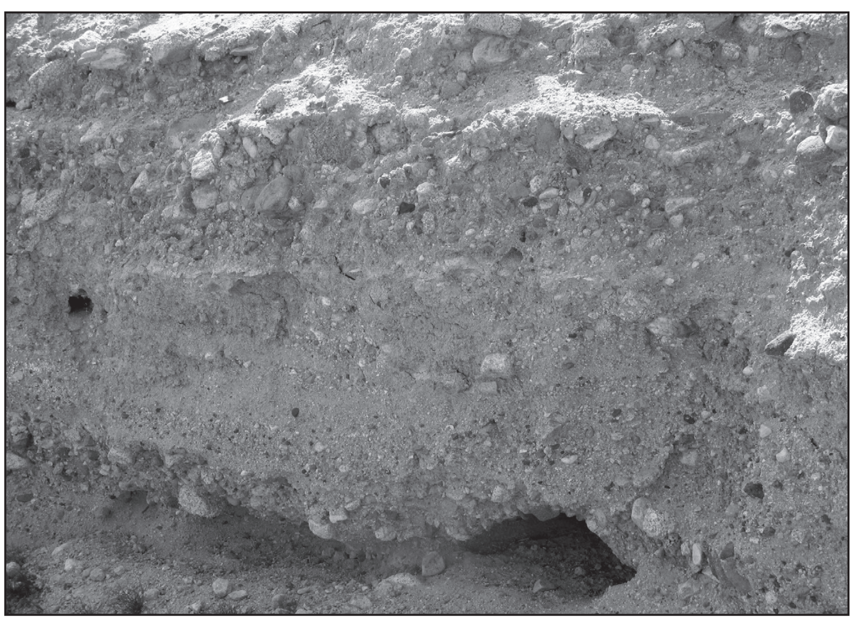

Figure 1-10 The Alvord gravel.

late Pliocene or early Quaternary in age. In either case, there was a depositional basin farther east of here, but presently not located. Proceed southeast on the ridge-top road.

79.3 (0.4) Cross the west-southwest-trending utility road and proceed southeast on the ridge-top road.

80.1 (0.8) Cross a buried cable route and proceed southeast on the ridge-top road.

80.7 (0.6) **Stop 1-10. Field Road exit.** Walk to the edge of the freeway cut to view SE-dipping beds of the south Alvord gravel. This unit lies on the Goldstone gravel, and at its toe the Alvord gravel grades into beds of the Mojave River Formation, and therefore is partly as young as early Pleistocene (2.4–1.0 Ma). It is deformed, dipping more steeply than is typical for deposits of this type, and up dip to the northwest it clearly is beheaded. Clasts are widely variable, reflecting sources from underlying gravel units and all bedrock types of Alvord Mountain. The Alvord gravel must represent alluvial fan sediment derived from deforming gravel deposits and an uplifting Alvord Mountain.

Apparently the valley axis shifted south with time as represented by (1) Pliocene valley-axis deposits of the volcanic Yermo(?) gravel at stop 1-7, followed by (2) a far-travelled stream in or near the axis a little farther south at Goldstone gravel time (Pliocene?), and (3) by early Pleistocene time the valley axis shifted to the Mojave River Formation playa, with the south Alvord gravel alluvial fan deposits leading south to that playa.

80.9 (0.2) Enter I-15 eastbound.

88.2 (7.3) Exit at Afton Road and drive south, over the freeway?

88.5 (0.3) Stop at Afton Road. TURN RIGHT and drive south on the graded dirt road.

89.0 (0.5) The graded road bears easterly.

90.2 (1.2) Pass under a power line.

90.3 (0.1) TURN LEFT (east) onto BLM route AC 9622.

Stop 1-11: Lake Manix. From here we can view the eastern basin of Lake Manix. It currently is incised by the Mojave River, leading to development of badlands visible along the south side of the valley. The badlands are cut into Miocene through Quaternary sediment, mainly gravel, but also tuff, basalt, and lake beds. Provenance of most gravel is from the Cady Mountains farther south of the valley. In contrast, gravel deposits on the north side of the valley (and in some places on the south) have mainly been derived from mountains to the north and northeast of here. This opposing provenance is evidence that the modern valley is inherited from similar predecessors, ancestral valleys that may have first formed in the Miocene. New discoveries by USGS mapping during the last few years include playas of middle Pleistocene in age between Buwalda Ridge and Afton (Miller and others, this volume). This is evidence that basin lows have persisted in this area for a long time.

SUMMARY: Pliocene in the Mojave Block. Enigmatic tectonic events probably have more to do with the types of deposits and their distribution in Pliocene time than does climate, but rapid changes in the climate caused by regional and global factors have to be considered as well. The primary earlier tectonic period was extension during the early Miocene, roughly 23–19 Ma. That event caused uplifts, volcanism, and filling of tectonic basins. Following that event was a period of relaxation, best exemplified by the Barstow basin of alluvial fan and lake deposits. The timing of this relaxation period is not well constrained, but lasted at least through 13 Ma, the age of the upper beds of the Barstow Formation. Between 13 Ma and the onset of the gravel deposition we have been studying today, little stratigraphic record apparently exists, and tectonic inferences are difficult to make. However, by the onset of Pliocene gravel deposition, perhaps 7 to 5 Ma, rocks had been newly uplifted and long-term depositional troughs had formed. Alignment of troughs with the major faults (Coyote Lake in the north and Manix in the south) suggests control on Pliocene physiography by strike-slip faults of the Eastern California shear zone. Topographic high areas may have been zones of compressional step-overs or corners of blocks undergoing vertical-axis rotations. The pictures that emerge from study of the Pliocene deposits will help us understand the duration of these compressive zones, eventually leading to a more complete view of strike-slip faulting in this region.

91.9 (1.6) Return to I-15 and enter the east bound lanes.

110.5 (18.6) Pass Zzyzx Road. Proceed to Baker to fill gas tanks for tomorrow's 350 mile trip.

116.4 (6.4) Refuel and obtain supplies for tomorrow's trip. Retrace to Zzyzx Road and drive south to the Desert Studies Center.

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The incredible shrinking Pliocene: Field trip guide, Day 2

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Convene at the Desert Studies Center with a full tank of gas, water, snacks, and protection from sun and wind. Drive north to I-15; enter I-15 eastbound toward Baker. Note: part of this day's route is within Death Valley National Park, where special use permits may be required for field trips with more than a certain number of visitors.

Continue past the first Baker exit; EXIT RIGHT at the second Baker exit and stop at Kelbaker Road. TURN LEFT (north) and cross over I-15.

0.0 (0.0) Stop at Main Street in Baker. Reset odometer to zero. Proceed north on Highway 127 toward Shoshone.

7.7 (7.7) Pass the ruins of historic Silver Lake, a town at the Tonopah and Tidewater railroad siding that served mines to the north and south (Myrick, 1991).

9.0 (1.3) Pass under the transmission lines at the north end of Silver Lake.

20.9 (11.9) Continue past a right turn to Valjean siding.

27.9 (7.0) Continue past a right turn to the BLM kiosk at Salt Springs.

28.7 (0.8) Continue past a left turn to the Harry Wade exit road. We are near the junction of the Salt Creek drainage system with the Amargosa River drainage system. During the last glacial, the Mojave River overflowed north of Silver Lake and flowed along the Salt Creek course to Death Valley.

32.7 (4.0) After crossing the Amargosa River, continue past the right turn east to the Dumont Dunes.

40.1 (7.4) At Ibex Pass, enter Inyo County.

46.4 (6.3) Continue past a right turn to Tecopa.

49.2 (2.8) Continue past a right turn to Tecopa Hot Springs.

54.3 (5.1) Continue past a right turn on Highway 178 to Pahrump, and enter Shoshone. Proceed north on Highway 127.

56.0 (1.7) Continue past a left turn to Highway 178 and the Jubilee Pass Road to southern Death Valley.

70.0 (14.0) **Eagle Mountain** is on the right. The hills here once closed off the valley bottom, isolating an upstream basin in which the Amargosa River terminated (Menges, 2008). During the middle to late Pleistocene, the river cut through this divide to integrate downstream with the Tecopa basin.

Eagle Mountain. J. Knott photo.

80.0 (10.0) Caution! Slow for a sharp right/left turn into Death Valley Junction.

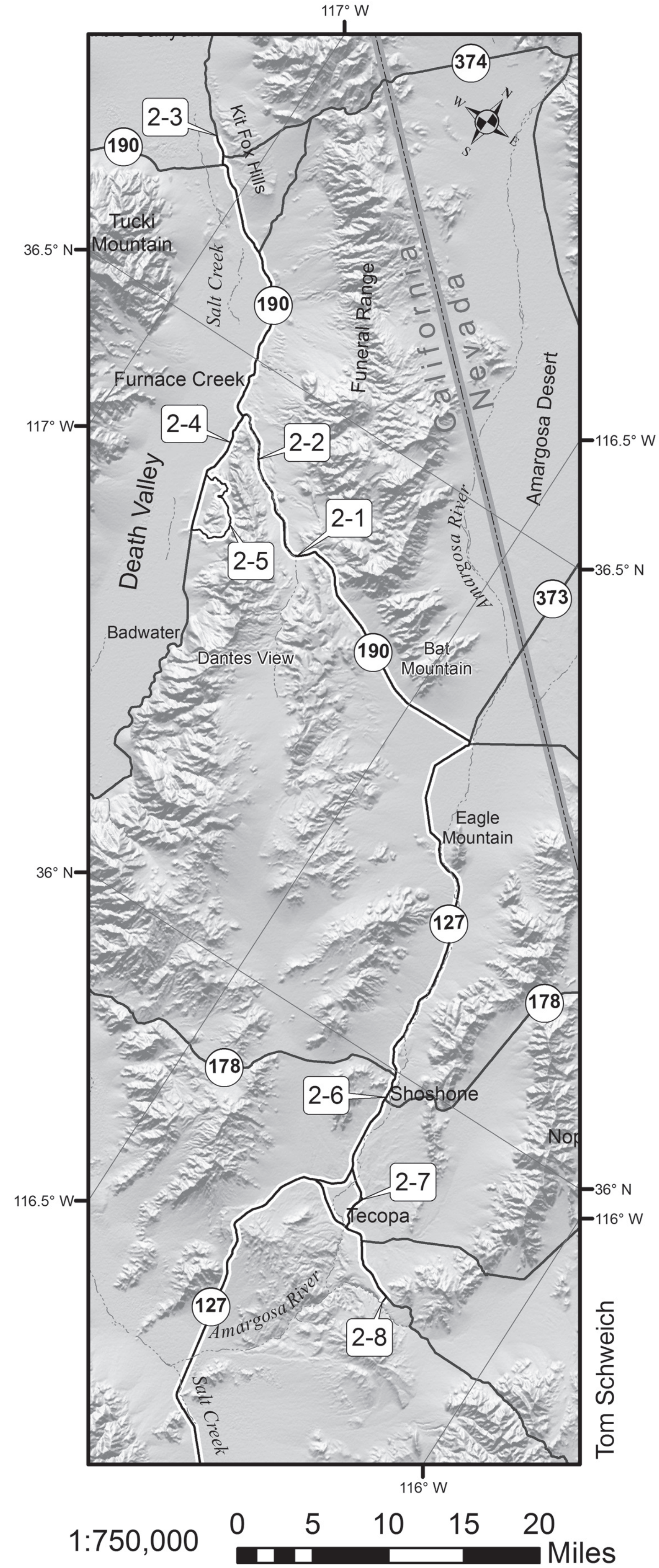
80.8 (0.8) Slow; enter Death Valley Junction.

81.0 (0.2) TURN LEFT (west) on Highway 190 toward Furnace Creek.

82.0 (1.0) **Bat Mountain**. Between 1 and 2 o'clock is the east end of the Funeral Range. The peak that forms the terminus is named Bat Mountain for the white feature that looks like a bat in flight on the left side of the mountain. The prominent canyon that is just to the right of the "bat" has a tongue of rock spilling out of it onto the alluvial fans. This is a large landslide deposit. Bat

Bat Mountain. J. Knott photo.

Day 2 Overview



Mountain is geologically important because this is where Charles Denny (1965) made many of his ground-breaking observations about alluvial fans. The rocks that make up Bat Mountain are the Conglomerate Member of the Bat Mountain Formation (Cemen et al., 1999). The Bat Mountain Formation is not directly dated, but is known to be younger than 19.8 Ma.

86.0 (4.0) **Furnace Creek Fault**. On the left is the north end of the Greenwater Range, which is composed of Miocene and younger sedimentary, volcanic, and plutonic rocks. Prominent, dark colored basalts make up most of the range.

The Funeral Range continues on the right with the west side of Bat Mountain. The red-brown Bat Mountain Conglomerate is seen in cross section. The Bat Mountain Formation overlies the gray Paleozoic rocks, beginning with the Mississippian Perdido Formation and progressing to the Cambrian Bonanza King Formation. The Bonanza King is easily recognized by its prominent black, gray, and white beds (Cemen et al., 1999).

The road here is parallel to the southeasterly extension of the right-lateral, strike-slip Furnace Creek fault. The Furnace Creek fault is considered a major crustal-scale fault by Wright et al. (1999). This seems logical because it juxtaposes rocks that differ in age by hundreds of millions of years. The Furnace Creek fault is considered inactive in the late Quaternary (Machette et al, 2001a).

91.6 (5.6) **Trailer Park**. Continue past pads for the abandoned trailer park at the former Monument boundary. The northern Greenwater Range on the left is composed of Pliocene Funeral Formation basalt flows with some cones on the skyline that were the source of some of the flows (McAllister, 1970). At the base of the slope you can see a horizontal cut—this is the old railroad grade for the narrow gauge railroad that serviced the mining town of Ryan.

94.7 (3.1) **Back Road to Ryan**. On the left is a dirt road that leads up and over the hill to the mining town of Ryan. From here we enter the sedimentary portion of the Pliocene Funeral Formation exposed on both sides of the road. On the right are large blocks (landslides?) of the Paleozoic rocks interbedded with the conglomerate (McAllister, 1970).

95.4 (0.7) **Excavation into Carbonate**. On your right is a 3-foot-wide backhoe trench cut into a carbonate-filled fracture in the Pliocene Funeral Formation conglomerate. While the conglomerate is Pliocene, the carbonate that fills the fractures is Quaternary (Winograd et al., 1985). Layers of carbonate that fill these fractures are like the rings of a tree. Analysis of rings for isotopes of oxygen and hydrogen allows reconstruction of the climatic history of the region for the last 2 Ma years.

95.7 (0.3) **Travertine Point**. Slow for sharp left turn. The Pliocene Funeral Formation (right) has numerous carbonate-filled fractures. The northern terminus of the Black Mountains is due south (12 o'clock after the turn). On the alluvial fans along the base of the Black Mountains are nearly horizontal yellowish deposits. These are reclaimed tailings from the Billie Mine that blend well into the landscape.

98.3 (2.6) **Stop 2-1: Introduction**. Kiosk This is a comfort stop; additional facilities are at Zabriskie Point. Looking to the left (10 o'clock) you can see the lift tower for the underground workings of the Billie Mine. The shaft and tunnels penetrate the Miocene Artist Drive Formation and the Pliocene Furnace Creek Formation. Billie borate deposits are in the Furnace Creek Formation (McAllister, 1970, 1973), and include sodium and calcium borates such as proberite ($NaCaB_6O_9 \bullet 5H_2O$), ulexite ($NaCaB_5O_9 \bullet 8H_2O$), and colemanite ($Ca_2B_6O_{11} \bullet 5H_2O$). Celestine ($SrSO_4$) is also present. The mine dumps visible to the south southwest are from the 1980 open pit excavations of the Thompson Mine. This mine produced euhedral colemanite crystals over twelve inches in diameter.

Introduction. The Pliocene of Death Valley, California, draws interest for several reasons. First, the economically significant borate deposits are found within the Pliocene Furnace Creek Formation (McAllister, 1970). Second, during the early Pliocene, a northwest–southeast flowing river system occupied north and central Death Valley (Wright et al., 1999). This river system was terminated by uplift of the Black Mountains beginning in the middle to late Pliocene (Knott et al., 1999; Machette et al., 2001a). Finally, the Pliocene marks a transition from a relatively warm to relatively cool global climate (Karas et al., 2011; Ravelo et al., 2004). Thus, reconstruction of the Pliocene paleogeography and paleoclimate may allow insight into the local distribution of mineral deposits, regional tectonics of the North American-Pacific plate boundary, and Pliocene climate conditions.

Presumed Pliocene-age deposits (Figure 1)are found throughout Death Valley (e.g., Hunt and Mabey, 1966; Knott et al., 2005). To understand Pliocene Death Valley, several studies were undertaken (e.g., Klinger, 2001; Knott et al., 2008; Sarna-Wojcicki et al., 2001). These generally involved determining that the deposits were Pliocene in age via tephrochronology, paleomagnetics and 40Ar/39Ar dating. Age determination was followed by descriptions of the sedimentary deposits to infer past depositional environment. Compilation of these various studies provides a better understanding of Pliocene Death Valley. For the Death Valley portion of the field trip, we will visit three Pliocene-age outcrops: Zabriskie Wash, Golden Canyon, and the Kit Fox Hills.

Stop 2-1. Pliocene Funeral Formation conglomerates of eastern Furnace Creek basin. J. Knott photo.

Proceed past left turn (south) toward Ryan and Greenwater Valley.

98.9 (0.6) Intersection with the road to Dante's View.

102.3 (3.4) On the left are the first good exposures of the Pliocene Furnace Creek Formation. The Furnace Creek Formation consists of yellow to tan, well-bedded mudstone, sandstone, and conglomerate representing an ancient lake and fan-delta depositional environment. Gypsiferous portions of the formation indicate lake drying (Blair and Raynolds, 1999; McAllister, 1970; Wright et al., 1999).

In many places, the Furnace Creek beds dip ~30°. This is due to northwest–southeast trending folds and faults related to compression of the ancient Furnace Creek basin as the Black Mountains uplifted during the Pleistocene.

103.0 (0.7) Continue past the 20 Mule Team Canyon exit.

104.6 (1.6) Continue past the entrance to 20 Mule Team Canyon with good exposures of the Pliocene Furnace Creek Formation.

105.0 (0.4) Angular Unconformity. On the right you will see steeply dipping beds of the Furnace Creek Formation overlain in angular unconformity by Quaternary alluvial fan deposits. These alluvial fan deposits are relatively thin (<10 m), but cover a great length (>10 km) of the piedmont. This relation fits the definition of a pediment: "a rock cut surface."

105.7 (0.7) TURN LEFT. **Zabriskie Point**. Hike southeast across the road up Zabriskie Wash. Bring water and sturdy shoes.

Stop 2-2. Pliocene Deposits at Zabriskie Wash, Death Valley. There are a number of locations in Death Valley where Pliocene-age deposits may be found: Copper Canyon, Artists Drive, Nova basin, Cottonwood Mountains, and Furnace Creek Wash, to name a few. Most recently, determination that deposits are Pliocene in age (5.332–2.588 Ma) is largely dependent on tephrochronology (volcanic ash bed correlation). The key tephra layers are the Mesquite Spring family (3.35–3.1 Ma), Nomlaki Tuff Member of the Tehama and Tuscan Formations (3.28 Ma), the tuff of Curry Canyon (<3.58–>3.35 Ma) and the tuff of Artists Drive (>3.58 Ma).

The most easily accessed Pliocene stratigraphic section is exposed at Zabriskie Wash. The age of this section of sediments is known from a combination of tephrochronology, 40Ar/39Ar dating of several tephra beds, and paleomagnetic correlation. From the Zabriskie Point parking area, walk east across Highway 190 up Zabriskie Wash. In this direction, we are walking up section (younger) with the best exposures on the

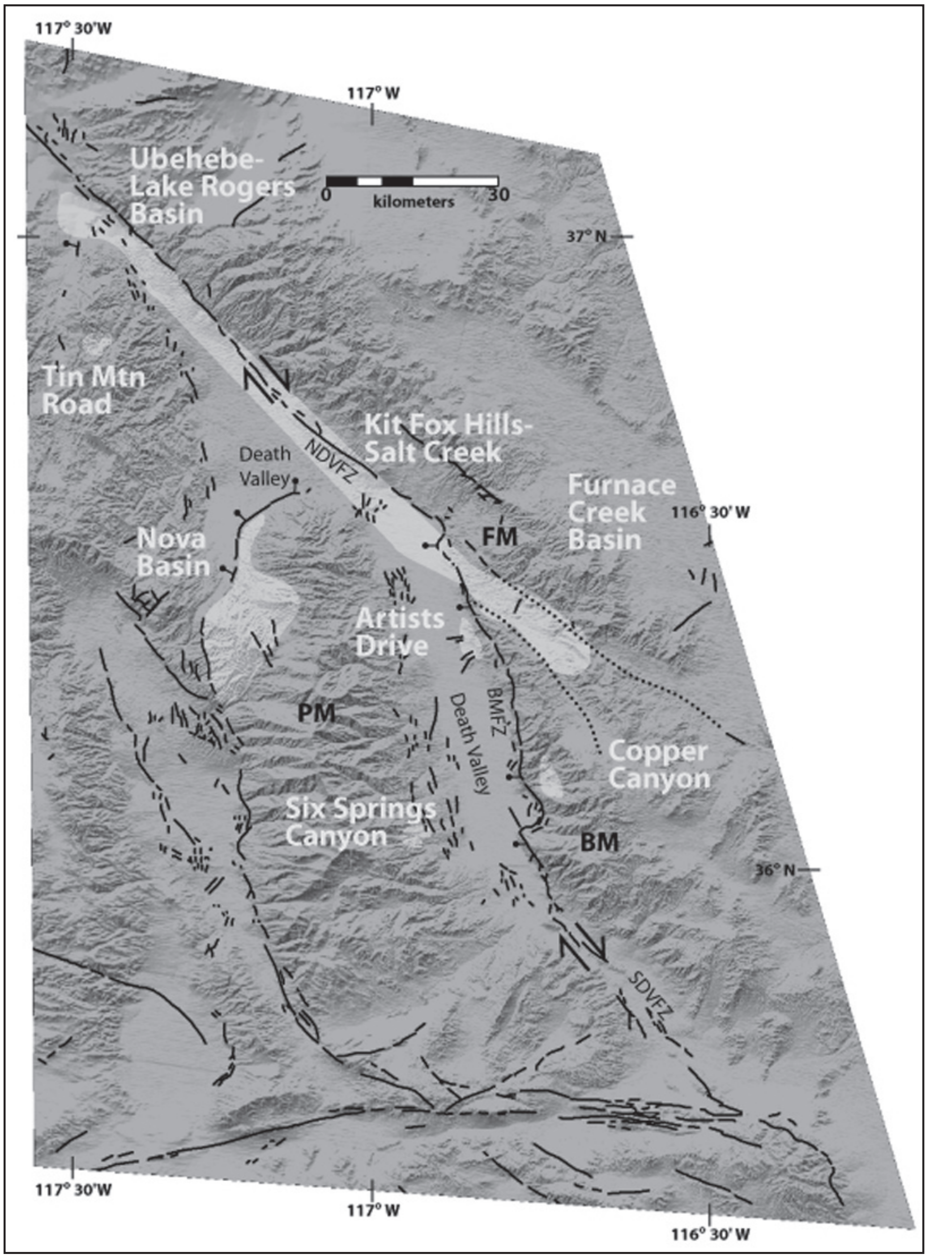


Figure 1: Shaded relief map of the Death Valley area showing major faults (black lines) and known Pliocene deposits (light shading). Faults of the Death Valley fault system are the Northern Death Valley fault zone (NDVFZ), Black Mountains fault zone (BMFZ) and Southern Death Valley fault zone (SDVFZ). Major mountain ranges surrounding Death Valley are the Panamint Mountains (PM), Funeral Mountains (FM) and Black Mountains (BM).

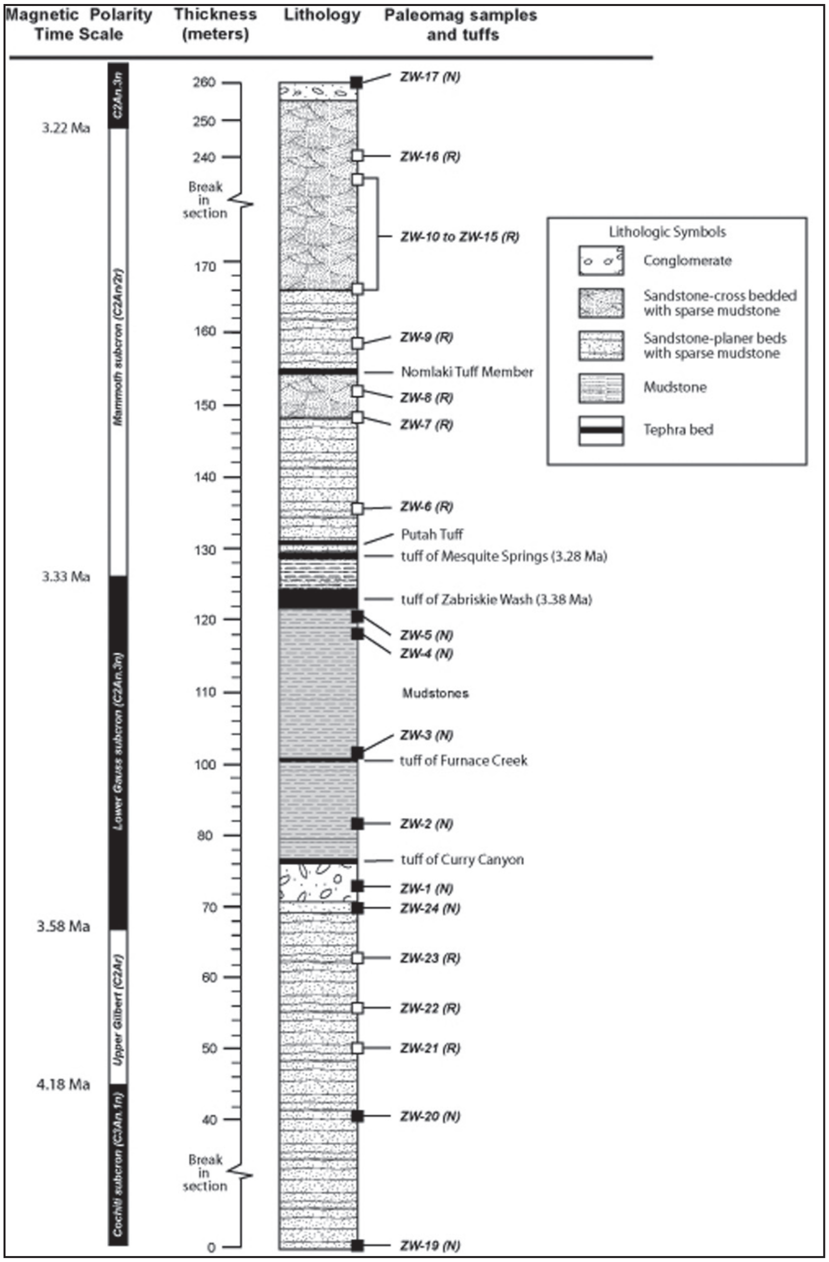


Figure 2. Stratigraphic section correlated to the magnetic polarity time scale. Subchron boundary ages are from Berggren et al. (1995). Section thickness determined from mapping by McAllister (1970). Subchron boundaries are estimated in most cases. Shading indicates fine-grained, laminated to finely bedded mudstones with occasional sandstones interpreted as perennial water conditions.

north side of the wash. Original mapping of the upper Furnace Creek Formation (McAllister, 1970, 1973) assigned an age of middle Pliocene based on diatom and plant fossils.

The lower part of the section consists of interbedded mudstone, sandstone and conglomerate. This part of the section shows reverse polarity, and is within the Conchiti subchron, older than 4.18 Ma. About one-half mile from Highway 190 is a transition from sandstone and conglomerate to fine-grained mudstones (Figure 2). Above the tuff of Curry Canyon, the sediments are fine-grained, well-bedded, and interpreted as lake deposits. The tuff of Zabriskie Wash and the tuff of Mesquite Springs ("Double Ashes," Machette, 2001b) are within these lake deposits. These white, weathering to tan tephra layers are several meters thick, and the tuff of Mesquite Springs is distinctively pumaceous. Dating and paleomagnetic correlation indicate that the tuff of Zabriskie Wash is 3.35 Ma and the tuff of Mesquite Spring is 3.29 Ma. The Mesquite Spring tuff shows reverse polarity while the Zabriskie Wash tuff has normal polarity, indicating that the top of the section is <3.22 Ma.. The tuff of Furnace Creek is correlated with an ash found near Barstow (Cox report). This paleomagnetic transition corresponds with the 3.335 Ma Mammoth–Lower Gauss subchron boundary.

Above the Mesquite Springs tuff is the Putah Tuff that erupted from the Sonoma volcanic field north of San Francisco. The overlying 3.28 Ma Nomlaki Tuff Member of the Tuscan and Tehama Formations erupted from the southern Cascade Range and is found as far east as New Mexico. The section becomes sandier, indicating a drying of the lake (Knott et al., 2008). Return to vehicles. RETRACE to Highway 190.

105.8 (0.1) TURN LEFT (northwest) and continue on Highway 190 toward Furnace Creek.

108.4 (2.7) **Travertine Springs**. The canyon wall on the right is draped in carbonate (travertine) deposits from springs which serve as the water supply for the world-famous Furnace Creek Inn and restaurants, ahead.

109.2 (0.8) Junction with Badwater Road (left, south). Bear right, north, toward the Furnace Creek complex. This intersection also corresponds with sea level. We will be below sea level for the next 20 miles.

110.5 (1.3) The Death Valley Museum and Visitors Center is on the left (west).

This road parallels a strand of the northern extension of the Black Mountain fault zone. The normal-slip fault cuts off the ends of the small ridges and forms a narrow linear valley separating the ends of the ridges from the main ridge. The Black Mountain fault zone offsets late Pleistocene alluvial fan deposits to the north (Owen et al., 2010). Here, Klinger (2001) suggested that stone circles built by ancient Shoshone people are offset by late Holocene fault activity.

113.0 (2.5) **Mustard Canyon and Harmony Borax Works**. Entrance to the loop past Harmony Borax Works and through Mustard Canyon. The yellow-brown, poorly cemented mudstone of Mustard Canyon is thought to be Pliocene; but no direct dating is available. The working interpretation is that these deposits represent the deeper part of the playa lake whose near-shore deposits are found at Zabriskie Wash.

114.7 (1.7) Park Service maintenance facilities.

116.2 (1.5) **Three Bare Hills**. At 12 o'clock, the low, dark brown hill near the playa is the second of the Three Bare Hills, named for their lack of vegetation. Three Bare Hills were mapped as Miocene (?) (Hunt and Mabey, 1966), but they are most likely Pliocene deposits of the ancient Furnace Creek basin.

120.8 (4.6) Beatty Junction and highway to Nevada. The low hills on the right parallel to the road are the southern tip of the Kit Fox Hills. Based on lithology, the sedimentary rocks of the Kit Fox Hills are correlated with the Pliocene Furnace Creek Formation (Wright and Troxel, 1993). Continue northwest and past the right turn to Daylight Pass Cutoff—not to be confused with Daylight Pass Road, farther ahead.

121.7 (0.9) Cross the right-lateral Northern Death Valley fault zone. The fault zone is expressed as small hills (~5 m high) on the right. The Northern Death Valley fault zone is interpreted (Machette et al., 2001b) as a relatively recent (post Pliocene), cross valley fault. Initially, extension in this part the Death Valley was accommodated by the Furnace Creek fault zone; however, as the basin stretched, a new fault, the Northern Death Valley fault zone, was formed.

123.3 (1.5) Continue past a left turn to the Salt Creek picnic area. Between 9 and 12 o'clock are the Salt Creek Hills, assigned to the Furnace Creek Formation based on lithology (Hunt and Mabey, 1966; Wright and Troxel, 1993). Subsequently, the 3.35-3.28 Ma Putah Tuff was found confirming this correlation (Knott et al., 2008). Structurally, the Salt Creek Hills consist of multiple faulted folds. The actual cause of this compressive folding and faulting within a regime of extension is not quite clear.

Salt Creek itself is a short, shallow (~5 cm) stream that flows at the surface only through the Salt Creek Hills. Although short and shallow, the creek is the habitat for a subspecies of pupfish (Cyprinodon salinus) that endure salinity levels much greater than ocean water.

124.1 (0.8) Northward are several ridges in the Salt Creek Hills that are planed flat and capped by gravel deposits. These gravel deposits, in most cases, are shingled, oblate beach gravels from Pleistocene Lake Manly. The age of Lake Manly continues to be troublesome; however, based on cosmogenic radio nuclide and stratigraphic studies, the age of these and other deposits above sea level is 180–120 ka (Owen et al., 2010).

125.7 (1.6) **Lava Creek B Ash**. At 1 to 2 o'clock you will see a white bed cutting from right to left (left side lower) on the face of the hill. This is the 0.639 Ma Lava Creek B ash bed erupted from Yellowstone caldera (Klinger, 2001).

126.7 (1.0) Highway 190 bears left (west) toward Stovepipe Wells

127.1 (0.4) TURN RIGHT (north) toward Scotty's Castle, Ubehebe Crater, and Daylight Pass Road. After the turn, at 9 o'clock is a good view of the Mesquite Flat dune field. This star dune is formed by the varying wind directions found in this area of Death Valley.

127.7 (0.6) Proceed straight (north) past the junction with Daylight Pass Road and Scotty's Castle Road to Ubehebe Crater (Bonaccorsi, this volume). Rest facilities are ahead. Check your odometer—we will park on the right side of the road 1.4 miles ahead.

128.9 (1.2) Prepare to pull right.

129.1 (0.2) **Stop 2-3: Kit Fox Hills**. Park off the pavement on the right side of Scotty's Castle Road, 1.4 miles north of the previous junction. From here we will walk about one-half mile round trip to the light-colored outcrops at the foot of the Kit Fox Hills.

The Kit Fox Hills are found in the northern arm of Death Valley. The Kit Fox Hills north of Mud Canyon were assigned a Miocene age (Hunt and Mabey, 1966). Wright and Troxel (1993) mapped the Kit Fox Hills south of Mud Canyon and assigned the rocks to the Pliocene Furnace Creek Formation—the same as found

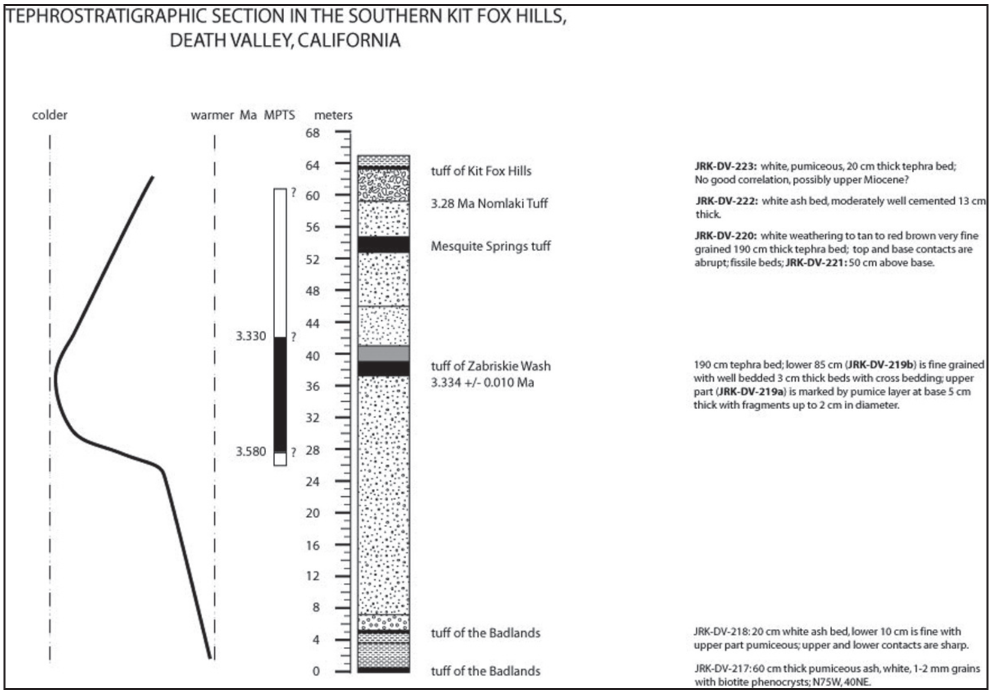


Figure 3. Tephrostratigraphic section in the southern Kit Fox Hills, Death Valley, California.

at Zabriskie Wash. Both age determinations are based solely on lithology.

North of Mud Canyon, a section exposes several tephra layers. The Nomlaki Tuff, Mesquite Springs tuff, and Zabriskie Wash tuffs are found here (Figure 3). Age control is based on a 40Ar/39Ar date of 3.334 ± 0.01 Ma on the tuff of Zabriskie Wash. The older tephra layers correlate by their glass shard composition to the tuffs of Fish Lake Valley. Similar to the Zabriskie Wash section, there is a previously unknown tephra layer at the top of the section that is informally named the tuff of Kit Fox Hills. This tuff is <3.28 Ma because it is stratigraphically above the 3.28 Ma Nomlaki Tuff.

Return to vehicles. From here, we will return to the Highway 190/Badwater Road intersection. Consider traffic and the firmness of the shoulder as you turn around—it may be easiest to go approximately 1 mile north to the road to the dunes and turn around there. Retrace to Furnace Creek.

131.1 (2.0) Stop at the junction with Highway 190. TURN LEFT and proceed south toward Furnace Creek.

137.4 (6.4) Continue past a left turn for the Daylight Pass Cutoff.

147.5 (10.1) Furnace Creek facilities. Proceed south on Highway 190 to the junction with Badwater Road.

149.0 (1.5) TURN RIGHT (south) at the junction with Badwater Road.

(149.5 (0.5) **Breakfast Canyon**. As you drive south, on the left are the deposits of the middle member of the Furnace Creek Formation (McAllister, 1970). These lacustrine mudstone-to-sandstone deposits are the western equivalent of the Zabriskie Wash deposits.

Note that some ridge tops are overlain in angular unconformity by alluvial-fan gravel deposits. These are the #2 gravel of Hunt and Mabey (1966). The #2 gravel is younger than the 180–120 ka Lake Manly deposits (Knott et al., 2002). From studies at multiple localities, the age of the #2 gravel is ~70 ka (Frankel et al., 2007; Machette et al., 2008; Owen et al., 2010).

150.2 (0.7) **Fault scarp**. Intermittently south along the mountain front are normal fault scarps along the Black Mountains fault zone (Brogan et al., 1991). Death Valley is anomalous in that the level of background seismicity is relatively low, yet scarps indicate Holocene earthquakes. Most of the scarps are found offsetting the #3 alluvial-fan gravel (Hunt and Mabey, 1966), dated in several locations by several methods at ~35–15 ka (Frankel et al., 2007; Owen et al., 2010; Sohn et al., 2007).

151.3 (1.1) **Village Fan**. The informal name for this location is derived from the numerous stone circles constructed on the #3 gravel here by ancient Shoshone. This may not seem like an ideal place to live, but in earlier times springs at the toe of the Furnace Creek fan watered mesquite groves that would have furnished food.

At many locations along the Black Mountains, the Shoshone constructed stone circles believed to support brush houses into the desert pavement developed on gravel #3 (Hunt and Mabey, 1966). Based on artifacts types, the estimated time that the Shoshone occupied these sites is ~2000 years ago. This indicates that the scarp formed over 2000 years ago.

153.4 (2.1) Watch for oncoming traffic. PULL LEFT (east) into Golden Canyon and park.

Stop 2-4. Golden Canyon. Here, the conglomerate in the lower Furnace Creek Fm is composed of Hunter Mountain batholith clasts from the Cottonwood Mountains to the northwest. It strongly contrasts with the Zabriskie section which contains Black Mountain and Funeral Mountain clasts and indicates that northwest–southeast-flowing system was cut off. In a rough interpretation, the Black Mountain debris started impinging on the ancient Furnace Creek basin 5–4 Ma.

The lower conglomerate unit of the Furnace Creek Formation is exposed at Golden Canyon (McAllister, 1970). This conglomerate is stratigraphically below the Zabriskie Wash section and, therefore, is >4.18 Ma. According to Wright et al (1999), the lower conglomerate is composed of 65% volcanic rock clasts with 35% Paleozoic carbonate and quartzite. In the underlying Miocene Artists Drive Formation, volcanic clasts represent only 12% and are associated with Mesozoic granitoid clasts from the Cottonwood Mountains on the northwestern side of Death Valley.

The interpretation of this change in clast composition is that:

1. During the Miocene, a northwest to southeast flowing river system occupied the Furnace Creek region.
2. In the early Pliocene, the Black Mountains, which contain abundant volcanic rocks, began uplift, and alluvial fans prograded westward into the ancient Furnace Creek basin. The source of the fans is unclear as to southeast or southwest; however they represent a major reorganization of the ancient Furnace Creek basin.

Return to vehicles, and drive west to Badwater Road.

153.6 (0.2) Stop at Badwater Road. From here, you may retrace the route north along the Badwater Road to Furnace Creek. Alternatively, Pliocene deposits containing the same tephra layers, but within the Funeral Formation, can be seen to the south at Artist's Drive, as described below.

TURN LEFT (south) and proceed toward Artist's Drive.

154.2 (0.6) The Gower Gulch fan is geomorphically different from other fans along the Black Mountains. The active channel is deeply incised into the fan and is very wide. This change in geomorphology is the result of the artificial (man-made) capture of the Furnace Creek Wash at Zabriskie Point in 1941 (Troxel, 1974). After passing Gower Gulch the road points directly at the Artists Drive structural block (Hunt and Mabey, 1966).

153.3 (1.5) **Desolation Canyon**. At 9 o'clock you can see an excellent example of a wine glass canyon. Wine glass canyons form in the following fashion:

1. Slow uplift of the mountain range causes a straight stream pattern.
2. The rate of uplift increases and exceeds the erosional rate of the stream, forcing the stream to erode laterally.

153.3 (0.1) Pass Mushroom Rock on the left. The narrow base is a product of intense weathering by salt at the shoreline of Holocene Lake Manly.

153.7 (0.4) Continue past the exit for Artist's Drive on the left. The small, boulder strewn hill on the right is informally named Mars Hill. This is the location where the Mars rovers were tested for mobility. Mars Hill itself is a terrace formed by Lake Manly. The boulders here and on higher terraces yielded cosmogenic radio nuclide ages of 465–109 ka (Owen et al., 2010).

154.8 (1.2) Continue past a right turn to West Side Road. To the west are two hills of Furnace Creek Formation conglomerate. Hunt and Mabey (1966) inferred that uplift along mid-basin faults formed these hills.

155.4 (0.6) **Stop 2.5: Hunt Canyon Hike**. From here, the Hunt Canyon outcrop is ~1 mile east in the foothills of the Artists Drive block. Exposed in Hunt Canyon are four tephra layers: oldest to youngest, tuff of Artists Drive (>3.58 Ma), tuff of Zabriskie Wash (3.35 Ma), Nomlaki Tuff Member of the Tuscan and Tehama Formations (3.28 Ma), and the tuff of Hunt Canyon (~3.1 Ma).

In contrast to facies containing similar age tephra layers at Zabriskie Wash, Salt Creek and Kit Fox Hills, tephra layers in Hunt Canyon are interbedded with upper Funeral Formation conglomerates interpreted as debris flow deposits of entirely volcanic clasts derived from the Black Mountains, showing deposition from east to west. The upper Funeral Formation was Pliocene until last year, and now is considered Quaternary. Proceed to Artist's Drive.

157.2 (1.8) Prepare for a left turn onto Artist's Drive for an optional side trip.

157.4 (0.2) Watch for oncoming traffic. TURN LEFT onto (one-way) Artist's Drive for an optional side trip. Artist's Drive is an interesting place to view Lake Manly deposits. Studies of the Manly terraces have recently produced data regarding paleowind velocity and paleocurrents (Knott and others, this vol.)

161.8 (4.4) PULL RIGHT into Artist's Palette turnout.

161.9 (0.1) TURN RIGHT (north) on to Artist's Drive.

166.3 (4.4) Stop at Badwater Road. TURN RIGHT (north) toward Furnace Creek.

169.0 (2.7) Continue past Golden Canyon.

171.0 (2.0) Stop, TURN RIGHT onto Highway 190 and proceed east toward Death Valley Junction.

174.4 (3.4) Continue past Zabriskie Point.

175.5 (1.1) Continue past 20 Mule Team Canyon.

181.8 (6.3) Continue past the road to Greenwater Valley and a park kiosk.

199.1 (9.3) Stop at Highway 127 and Death Valley Junction. TURN RIGHT and proceed south on Highway 127. Caution: slow through Death Valley Junction and sharp curves.

224.0 (24.9) Continue past a right turn for Highway 178 to Jubilee Pass. Enter Shoshone.

225.5 (1.5) **Stop 2-6. Lava Creek B ash quarry**. Park at the Shoshone Museum. Walk southwest to the uarry.

The Lava Creek B ash quarry south of Shoshone provides an excellent view of a volcanic ash that is the result of a super-eruption from the Yellowstone caldera, more than 1000 km northeast of the Tecopa basin. As seen in the west wall of the quarry, the 2-m-thick ash bed consists of silver gray glassy tuff with many laminar interbeds several centimeters thick. The tuff contains only minor amounts of locally derived detritus, although there is ample evidence that the upper part of the bed has been reworked by water currents. Well-preserved ripple laminations indicate a south-southwest current direction. The tuff is predominantly composed of platy glass shards with rhyolitic silica content (Sheppard and Gude, 1968). Chemistry of the fresh glass matches the elemental abundances found in the Lava Creek Tuff (Member B), which was dated as 0.639±0.002 million years near the Yellowstone source (Hillhouse, 1987; Lanphere et al., 2002). This quarry exposes ash that is unusually fresh; elsewhere in the Tecopa basin, the glass has been altered to zeolites, potassium feldspar, clay minerals, and opal (Sheppard and Gude, 1968). The pattern of alteration indicates that pore water within the Tecopa sediments was highly alkaline and saline in the center of the basin and was fresher near the margins.

Tracks of mid-Pleistocene Irvingtonian NALMA animals in mud-flow debris underlying the Lava Creek B ash (0.64 Ma) are very easy to date! Tracks remain from adult and juvenile mammoths or mastodons, large camels (Camelops sp.), and a herd of adult and juvenile horses (Equus sp. small). Tracks in a silty-sand matrix with large pebbles suggest a mudflow, and track impressions suggest variable moisture content. Tracks also indicate that these herbivores were stalked by wolves (Reynolds, 1999, 2001).

Return to vehicles and proceed south on Highway 127.

225.6 (0.1) Continue past a left turn to Highway 178E (to Pahrump).

230.6 (5.0) Continue past the road to southern Greenwater Valley. Prepare for a left turn.

230.7 (0.1) TURN LEFT on Furnace Creek Road toward Tecopa Hot Springs.

232.2 (1.5) Grimshaw Lake Wetlands are on the right (south). Watch for oncoming traffic and prepare to turn left.

232.6 (0.4) TURN LEFT on Furnace Creek Road before you enter Tecopa Hot Springs.

233.0 (0.4) **STOP 2-7. Lake Tecopa History**. "Pliocene" Lake Tecopa contains a great record of fine-grained sediment, interpreted originally as lacustrine, and fossil faunas in a framework of dated ashes. Although it was proposed that first lake filling was the result of compression forming the Tecopa Hump of the Sperry Hills (McMackin, 1997a; Menges, 2008), it is now clear from study of the sediment and microfossils, particularly ostracodes, that most, and maybe all, of the sediment formed in springs and marshes, much like the environment you see in lowlands in this area today. Incision of the Amargosa River through the Sperry Hills (Reynolds and others, 2000; Menges, 2008) was driven by a combination of overtopping of a lake(?) and spring sapping on the downstream side.

Tecopa Basin Overview. Well-exposed sedimentary beds in the Tecopa basin reveal a 2-million-year record of climate change, spring activity, and landscape evolution in the southwestern Great Basin. The chronostratigraphy of the lower Tecopa beds is well-known from the following timelines: Huckleberry Ridge ash (2.1 Ma), Glass Mountain ashes (0.8–1.2 Ma), Matuyama-Brunhes polarity transition (0.78 Ma), Bishop ash (0.76 Ma), and Lava Creek B ash (0.64 Ma). Enormous volcanic eruptions from the Yellowstone caldera are the sources of the Huckleberry Ridge and Lava Creek ashes. The Long Valley caldera of eastern California is the source of the Glass Mountain and Bishop ashes. Known with less certainty are paleomagnetic polarity timelines correlated to the Olduvai (1.77–1.95 Ma) and Jaramillo (0.99–1.05) polarity subchrons (Hillhouse, 1987). Except near the basin margins, the older Tecopa beds are dominantly fine-grained (Sheppard and Gude, 1968; Larson, 2000).

Above the level of the Lava Creek B ash, the beds give way to coarser alluvial deposits, occasional mudstones, and carbonate deposits related to spring activity. The youngest volcanic ash known in the Tecopa area has an approximate age of 200,000 years, as inferred from volcanic-ash stratigraphy, chemical correlations, and isotopic dating at Summer Lake and Pringle Falls, Oregon. Morrison (1999), who first reported the uppermost ash in the Tecopa beds, interpreted the associated sediments as evidence for the last high-stand (543 m elevation) of a large lake in the basin.

In recent times, the Amargosa River intermittently flows across the dissected lake basin and exits through a deep gorge below Tecopa. Several warm springs form perennial pools near Tecopa and Shoshone.

Tecopa Biostratigraphy. Fortunately, the fossil faunas of "Lake" Tecopa are constrained by the dated ashes and paleomagnetic sequences (Hillhouse, 1987). Late Blancan NALMA (formerly late Pliocene) faunas from the sediments include rabbits, kangaroo-rats, deer mice, wood rats and cotton rats (James, 1985; Woodburne and Whistler, 1991). Camels became stuck in Tecopa clays while searching for water. Their legs are preserved in a vertical position in the clay, but remains of their bodies have been removed by carnivores. Fossil camels include a llama, and another with the adaptive morphology of a goat! Unlike most late Tertiary camels, the goat-camel retained upper incisors and short, unfused metapodials. Presumably, this goat-like camel (Whistler and Webb, 2000) came down from surrounding mountains in search of water and got mired in clay.

The last fossils to be interred in Tecopa clays did so when sediments were dry. Late Pleistocene Rancholabrean (> 250,000 years) mammals, including mammoth, camel, horse, rabbit, and deer mouse are found in desiccation or tectonic fractures in the lake bed (McMackin, 1997b; Reynolds, 1991). The herbivores fell into and small mammals took shelter in fractures that developed after the surface of "Lake" Tecopa became solid, around 200,000 years ago (Morrison, 1991, 1999; Anderson and others, 1994). Proceed southeast.

233.6 (0.6) Furnace Creek Road turns right (south) at Hepatitis.

235.4 (1.8) Stop, TURN LEFT onto Old Spanish Trail.

235.6 (0.2) TURN RIGHT on Furnace Creek Road at the yellow China Ranch sign.

237.4 (1.8) Continue past a right turn to China Ranch.

239.8 (2.4) TURN RIGHT on pole line road.

240.1 (0.3) **Stop 2-8. Overview of Willow Wash Canyon**. We are standing at the edge of Willow Wash Canyon which drains as a tributary to the Amargosa River where it cuts through these hills. We are on the surface of a late Tertiary to Quaternary fan complex shed from the Alexander Hills, which lie to the southeast, and this same surface continues south across Willow Wash. This fan contains unique clasts that can only be derived from the Alexander Hills on the other side of the Willow Wash canyon, so the age of the fan places an upper constraint on the initiation of canyon cutting on this major tributary of Amargosa River in the Amargosa Canyon area. The surface characteristics of the fan suggest that it is mid-Pleistocene, Qia3, and from this point, looking west, you can see a similar fan extending eastward from the Sperry Hills. These fans merged in the low divide to our west during Qia3 time. The gradient appears to have been relatively low. You can see where these fans meet, but note that the canyon of the Amargosa River is entrenched across the toe of the Sperry Hills fan. By all appearances, that was the drainage divide between the Alexander and Sperry Hills until the formation of the Amargosa River canyon.

The oldest common terrace deposits inset within the incised canyons are Qia2 (about 90 to 30 ka), although scraps of Qia3 strath terraces indicate that the progressive incision of the Amargosa River began roughly at the end of Qia3 time (poorly constrained, but likely ~200 ka). Numerous springs emerge in the valley below and it is likely that incision was initiated by sapping and driven in part by spring-fed streams (modified from Miller and others, 2007).

This vantage point illustrates that a canyon connects two formerly isolated basins: the modern Amargosa drainage forms the major surface drainage to southern Death Valley. This canyon represents just one of several deeply incised interconnecting reaches on the Amargosa River (Menges, 2008). The integration of the river took place through a series of breaches of paleo-divides between late Miocene and late Quaternary time.

Return to vehicles, retrace to Furnace Creek Road.

240.4 (0.3) Stop, TURN LEFT (west) on Furnace Creek Road.

242.8 (2.4) Continue past a left turn to China Ranch (the best date-nut bread on the Amargosa).

244.5 (1.7) Stop at Old Spanish Trail; TURN LEFT (west) and proceed to Tecopa.

246.0 (1.5) Stop at Tecopa Triangle. A picturesque and educational walk is along the Tonopah & Tidewater railroad grade (Myrick, 1991; Mulqueen, 2001) south into Amargosa Canyon to see perched aquifers that feed hanging gardens of native plants (Lum and others, 2001). Proceed on Old Spanish Trail toward Highway 127.

249.8 (3.8) Stop, TURN LEFT (south) on Highway 127 toward Baker.

268.3 (18.5) Continue past Salt Springs.

269.3 (1.0) View north of "Lake Dumont," once proposed to be the most northerly basin in the Mojave River system to be filled with water (Anderson and Wells, 1997). Subsequent work has shown the sediments to be wetland deposits and the waters to be of chemistry that is inappropriate for Mojave River water (Miller and others, 2007; Bright and others, 2007). Fossils of the western pond turtle (Actinemys marmorata) were recorded as closely associated skeletal elements unassociated with cultural remains in what are probably Pleistocene sediments (Salt Springs, Jefferson 1990a, 1991; Ford, 2010, p. c. to Reynolds). Pond turtles feed on aquatic invertebrates, fishes, amphibians, algae, lilies, roots of aquatic plants, and carrion in a lacustrine environment. They can easily cross dry land to deposit clutches of eggs. This would apparently be the northernmost occurrence of the pond turtle along the Mojave River drainage into the Amargosa drainage, and supports the concept of a drainage system with ponds and wetlands extending from the San Bernardino Mountains. Actinemys (senior designation for Clemmys) is known from other Pleistocene sediments along the Mojave River, including Lake Manix, and populations survive in Afton Canyon (Lovich and Meyer, 2002). Was the western pond turtle present in the Mojave Desert drainage systems prior to the ~3 Ma uplift of the Transverse Ranges? Find out on Day 3.

296.4 (27.1) Stop at Main Street, Baker. TURN RIGHT (west) and enter I-15 westbound.

Fill your gas tank in Baker for tomorrow's 350 mile route. Proceed back to Desert Studies Center.

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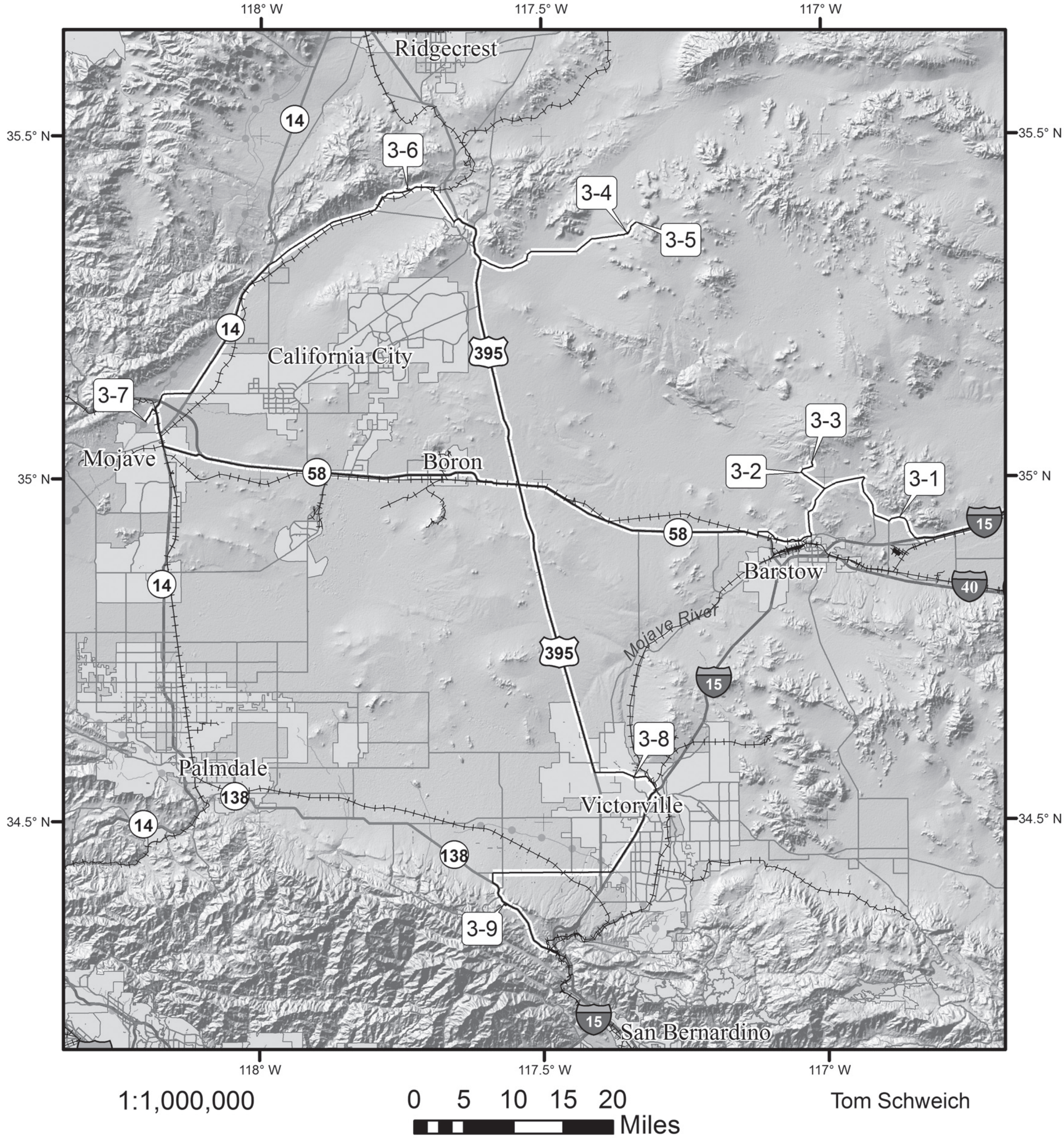
Day 3 Overview



The incredible shrinking Pliocene: Field trip guide, Day 3

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Recently, recognition that glacial cycles occupied the last ~1 Ma of the Pliocene has led to a redefinition of the beginning of the Pleistocene Epoch from 1.8 Ma to 2.6 Ma. Even shortened, the Pliocene was eventful. Global climatic events, such as gradual cooling and drying and the start of polar ice caps, and altered ocean currents from the closing of the Isthmus of Panama, are overprinted by regional events, such as the rise of the Transverse Ranges and the resulting rain shadow that created the Mojave Desert climate. Across the Mojave Desert many coarse gravel deposits have been assigned to the Pliocene. Today we will visit sediments that herald and record Pliocene tectonism and pluvial events.

A long period of time—at least nine million years—is represented by the unconformity between Miocene sediments and overlying Plio-Pleistocene sediments in the Calico Mountains and Mud Hills. We will compare the ages and sedimentary facies in the Calico Mountains area with similar facies at Owl Canyon in the Mud Hills.

How can we recognize the Pliocene in the Mojave Desert? There are sedimentary and volcanic rocks that fill the 5.3–2.6 Ma Pliocene period. The margins of the western Mojave Desert contain fault-bounded basins that record Pliocene uplift and denudation of tectonic highlands. We will visit volcanic rocks that help date faults and structural changes that cut those dated rocks and took place along major faults at the north (Blackwater Well), west (Mojave) and south (Mountain Top Junction) boundaries of the Mojave Desert geologic province. Do these sedimentary deposits signal climatic change or floral shifts? What animals and plants populated the Pliocene Mojave Desert province and what do they tell of changes in climate?

Convene at the CSUF Desert Studies Center; proceed north toward I-15. Be certain that your gas tank has been filled in Baker.

Enter I-15 westbound. Pass Afton Road and Harvard Road; pass under Minneola Road and through the California Agricultural Inspection Station. Pass te East Yermo Exit. EXIT I-15 at Calico Road.

0.0) Stop at Calico Road and reset your odometer. TURN RIGHT (north) on Calico Road.

0.8 (0.8) Continue past Camp Rock Road on the right. We are driving parallel to the southwestern margin of the Calico Mountains, which are underlain by sediments that contain fossils and trace fossils of Miocene animals, from proboscideans to flamingos to spiders (Jenkins, 1986; Park and Downing, 2001; Reynolds, 1998, 1999; Reynolds, and Woodburne, 2001, 2002). The Barstow Formation and Pickhandle Formation are cut by the northern strand of the Calico Fault. Tarman and McBean (1989) and Singleton and Gans (2005, 2008) suggest that this fault is responsible for spectacular tight chevron folding of Miocene sediments at the ghost town, adjacent to the fault. The Barstow Formation is ~13 Ma at its eroded top in the nearby Mud Hills. To the east, in the Yermo and Toomey hills, the Barstow beds are overlain unconformably by sand and gravel of the Yermo gravel, which is considered to be Pliocene to early Pleistocene in age (Miller and others, this volume).

2.7 (1.9) **Stop 3-1: Calico**. Park just west of the entrance to Calico Ghost Town (Weber, 1966, 1967). Inset Pleistocene sediments that run north under the town and school house underlie a surface that dips shallowly to the south. The sediments lie unconformably on folded Barstow Formation, and are truncated by a branch of the Calico Fault. Fossil woodrat, horse, and bird have been recovered from these sediments. The woodrat *Neotoma* (*Teanopus*) cf. *N.* (*T*) *albigula* dates between 0.9–1 .9 Ma (Lander and Reynolds, 1985), and is therefore from the Irvingtonian North American Land Mammal Age (NALMA) of the middle to early Pleistocene.

3.8 (1.1) TURN RIGHT on the Yermo Cutoff.

5.4 (1.6) Stop, TURN RIGHT (north) on Fort Irwin Road.

9.0 (3.6) Cross the northwest-trending trace of the

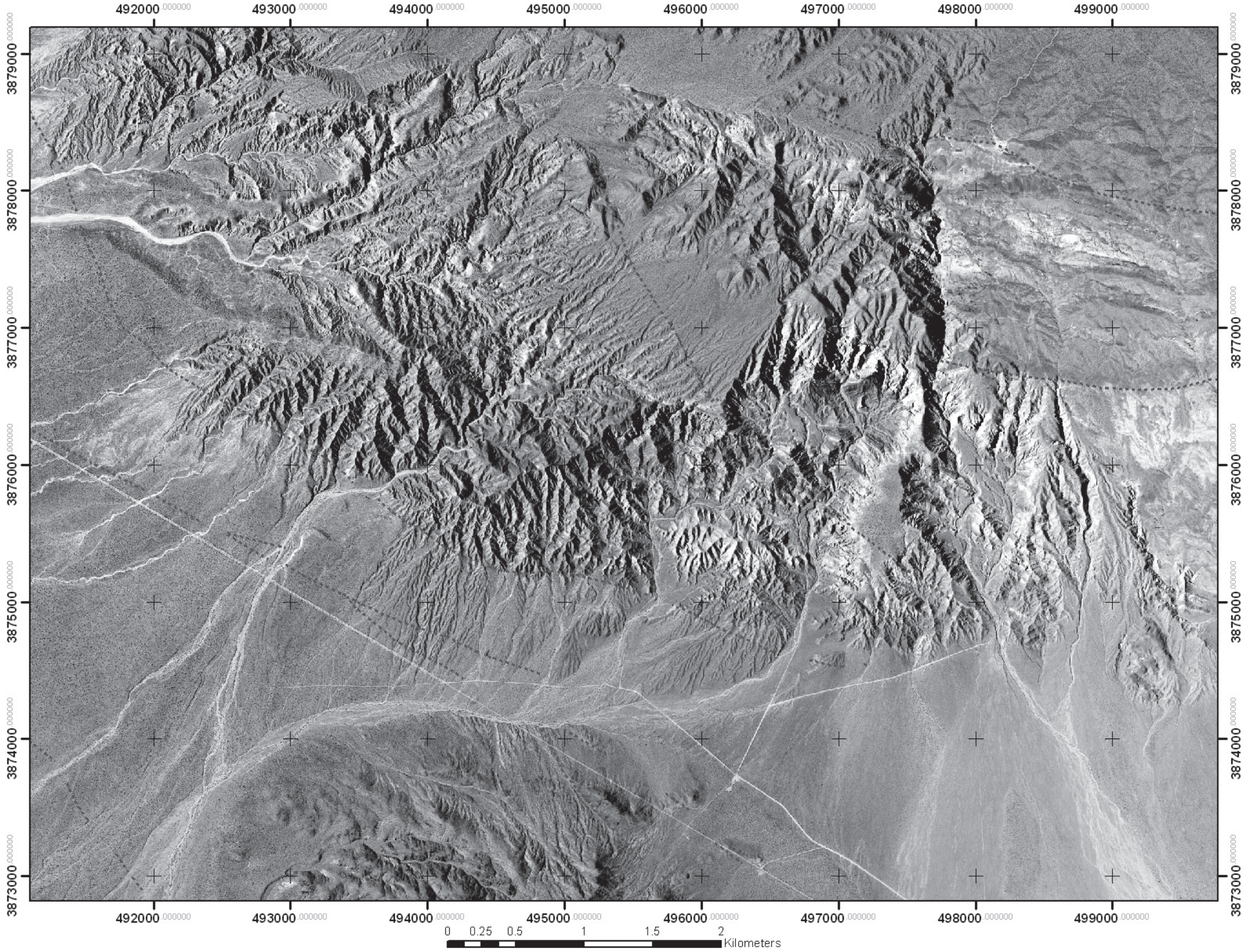

Figure 3-2.Oblique aerial view north of the Mud Hills showing “flat” areas of Pleistocene alluvium cut by northwest-trending faults.

Calico Fault (Bortugno and Spittler, 1986). In this area, the fault is not expressed in Quaternary sediment but probably is represented by alignments of Miocene outcrops.

9.4 (0.4) TURN LEFT (west) on Old Fort Irwin Road. Careful—high speed traffic!

12.7 (3.3) Continue past Copper City Road (Vredenburgh, this vol.).

13.6 (0.9) TURN RIGHT on Fossil Bed Road. We are paralleling the suspected trace of the Miocene Fossil Bed Road Fault (Dokka, 1986).

16.5 (2.9) **Stop 3-2: Mud Hills**. Entrance to Rainbow Basin loop road. View north to Pleistocene arkosic sands that unconformably overlie deformed Miocene sediments. These sediments are uplifted on the trace of the Coon Canyon Fault (Dibblee, 1968), and bear soils and surface attributes that are similar to the Qia3 family of alluvial fan surfaces elsewhere in the Mojave Desert (Amoroso and Miller, 2006). The fan sediments lie angularly across folded Miocene sediment of the Barstow Formation and are faulted in at least one place. The Mud Hills apparently have been domed up as well as faulted, since the Pleistocene deposit lies on such a high stranded surface, well above modern drainages.

PROCEED NORTH on Rainbow Basin Loop Road and TURN RIGHT to the Owl Canyon Camp ground (facilities available) to look at the unconformity. We are crossing the trace of the Coon Canyon Fault. Fossils in the Coon Canyon Fault Crevice (Reynolds and Fay, 1989: Bell and Reynolds, 1991) are from a xeric habitat, suggesting that some of the activity on the northwest-trending Coon Canyon Fault happened during the warm Holocene Period. This fault demonstrably cuts intermediate-age alluvial fans west of here (Amoroso and Miller, 2006).

16.7 (0.2) TURN RIGHT on Owl Canyon Road and enter the campground. Park near space #6 (facilities available).

18.2 (1.5) **Stop 3-3: Owl Canyon Campground Angular Unconformity**. Miocene sediments of the Barstow Formation are folded and faulted by the Calico and Coon Canyon faults and are capped by relatively flat-lying middle Pleistocene arkosic sands. This relationship suggests that the folding took place during the Pliocene; followed by erosion and deposition of arkosic sands. RETRACE to Fossil Bed Road.

19.9 (1.7) Stop at Fossil Bed Road, TURN LEFT and proceed east to Old Irwin Road.

22.8 (2.9) Stop at Old Irwin Road, TURN RIGHT (south).

24.4 (1.6) Pass a right (west) turn to the microwave station and Waterman detachment fault (Glazner, 1989) on Microwave Hill. Proceed south through the Waterman Hills.

25.7 (1.3) Leave the Waterman Hills and cross the northwest-striking Harper Lake Fault, which acts as the northeast margin of Harper Lake and the southwest margin of the Barstow Formation in the Gravel Hills (where it is known as the Gravel Hills Fault). This fault system displays scarps cutting Holocene fan sediments in several places, and evidently represents more youthful faulting than does the northern Calico Fault (Amoroso and Miller, 2006; Miller and others, 2007).

28.1 (2.4) Stop at Old Highway 58. Proceed to the next stop sign.

28.2 (0.1) Stop, TURN RIGHT on Old Highway 58.

31.7 (3.5) Pass Community Boulevard. As Old Highway 58 bends northwest, we drive parallel to the northwest-striking Mt. General Fault. This fault cuts early Holocene deposits (Miller and others, 2007).

34.1 (2.4) TURN LEFT (south) on Lenwood Road.

34.4 (0.3) Stop at signal. TURN RIGHT (west) onto Highway 58 toward Kramer Junction.

42.2 (7.8) Pass Hinkley Road and cross the trace of the northwest-striking Lenwood–Lockhart Fault that passes from here to the southwestern margin of Harper Lake. Look north toward Black Mountain where Pliocene basalts (3.77 Ma; Oskin and Iriondo, 2004) cover deformed sediments of the Barstow Formation. These basalts are highly deformed by both the Blackwater and the Gravel Hills faults.

45.9 (3.7) Enter the 4-lane section of Highway 58, crossing ancestral Mojave River deposits.

50.0 (4.1) Continue past the turnoff to Harper Lake Watchable Wildlife Area at the intersection of Harper Lake Road (north) and Helendale Road (south).

55.1 (5.1) Slow as Highway 58 reduces to two lanes. This arch of sediment the tip of the Helendale Fault is probably compressive feature as surface strain dies out on the fault. The sediments in the fold are probably Pliocene in age but have not been studied beyond knowing that they underlie middle Pleistocene alluvial deposits. Farther south the Helendale Fault deforms Qia3 deposits dated ~190 ka (K. Maher, unpubl. U-series age) suggesting recent activity.

62.8 (7.7) Stop at Kramer Junction, where services are available. TURN RIGHT (north) on Highway 395, cross the railroad tracks, and park on the right. We will consolidate passengers into large-capacity, high-clearance vehicles at this stop, and return to vehicles left at this point in the afternoon. Proceed (north) on Highway 395 toward Johannesburg and Red Mountain.

64.2 (1.4) The entrance to the solar power-production site is on the left. This facility uses parabolic mirrors to focus solar energy on oil flowing in a pipe down the center of the mirrors, and then uses the heated oil to produce steam and drive turbines. Excavation for facility development produced mid-Pleistocene mammalian fossils (Reynolds, 1989, 1991b).

68.6 (4.4) Continue past a left turn into the federal prison.

69.5 (0.9) Continue past a right turn to the Buttes, Black Mountain, and Harper Lake. Cross the trace of the northwest-striking Lockhart Fault.

81.1 (11.6) Continue past 20 Mule Team Parkway, the approximate route of borax wagons that ran northeast from Mojave across Cuddeback Lake to Blackwater Well, Granite Well at Pilot Knob, through Panamint Valley, and down Wingate Wash to the Furnace Creek borate deposits and Harmony Borax Works in Death Valley (Faye, 1999; Kaldenberg, this vol.).

83.5 (2.4) Enter the Atolia Mining District. Scheelite (calcium tungstate, $CaWO_4$) caused trouble for dry-placer gold miners since it was heavy (SpG 6.0) and concentrated with the gold. It was recognized as a commercial ore for tungsten in 1903. The best scheelite production from Atolia was from 1916 to 1918, with a payroll of over $60,000 per month and total production of nearly $10 million (Clark, 1997). The district was referred to as the "spud patch" because of the round, light brown tungsten nuggets.

84.9 (1.4) Enter Atolia.

85.4 (0.5) The highway bends to the left. Prepare to exit right.

85.7 (0.3) EXIT RIGHT on the road heading southeast around Red Mountain. We cross a projected fault trace on the southwest side of Red Mountain that might be a northern continuation of the Gravel Hills Fault. However, recent mapping by Amoroso and Miller (2006) found no evidence for that fault extending north beyond Cuddeback Lake (Willard Lake, Mendenhall, 1909). Alternatively, a Miocene fault related to detachment tectonics may be responsible for this linear mountain boundary.

90.4 (4.7) Continue straight at a road junction with a well.

90.6 (0.2) Bear north at the pole line road junction.

91.2 (0.6) Y-turn; take the right fork at the ranch site. Almond Mountain is visible ahead.

91.6 (0.4) TURN RIGHT at road fork.

92.4 (0.8) Watch for a dip in the road. Signal Butte is at 11:00.

93.2 (0.8) Pass through the crossroads.

95.0 (1.8) Continue past another section line crossroad.

96.0 (1.0) Continue past a junction with a corral at a section corner.

96.1 (0.1) Drive straight (east) at Y junction.

96.8 (0.7) Bear left (northeast) at reverse Y intersection.

Figure 3-4. Blackwater Well in January 2011.

97.6 (0.8) Take the right fork.

97.7 (0.1) Proceed through intersection.

98.8 (1.1) Bear right at the crossroads.

102.0 (3.2) Pass through a fenced crossroads.

102.3 (0.3) TURN LEFT to a corral and Blackwater Well.

102.4 (0.1) **Stop 3-4: Blackwater Well**. This was the home of "Cowboy" Frank Curtis (Kaldenberg, this vol), one of the last ranch hands to live on public lands in the western Mojave Desert. It was the first water stop for mule teams hauling borax wagons from Mojave to Death Valley between 1883 and 1888, although the water source had been known at least as early as 1870 (Kaldenberg, 2010; this vol.). "The well was dug by government troops ...when freshly cleaned is sweet... When not used, the water becomes dark...ill smelling and foul from the bodies of desert rats..." (Mendenhall, 1909). The well is one of the few in the northwestern Mojave dug into granite (Thompson, 1926). Historic freight routes that lead northeasterly from Blackwater Well reach Granite Spring at the base of Pilot Knob (Thompson, 1926). The route east reaches Copper City (Vredenburgh, this vol.). Proceed northeast through the Blackwater Well complex; take the left (northeast) fork at the Y junction ahead.

103.2 (0.8) Stay right at the junction.

103.7 (0.5) A trench on the north side of the road explores fault gouge parallel to the NW strike of the Blackwater Fault. The heavily prospected hill to the north is made up of light-colored Tertiary volcanics sitting on bleached quartz monzonite (Jennings and others, 1962).

103.9 (0.2) **Stop 3-5: Blackwater Fault.** Park on the fault trace and explore for fractured outcrops. The fault strikes southeast and cuts a 7.2 Ma dacite lava flow in the Black Hills about 1 mile distant (Oskin and Iriondo, 2004), which earlier was referred to as early Pleistocene basalt (Jennings and others, 1962) The dacite lies on granitic rocks, and shows evidence for offset between 0.3 and 1.8 km. Sediment ponded on the southwest side of the dacite is cut by scarps that apparently are Holocene in age (Oskin and Iriondo, 2004). To the northwest, the fault cuts Almond Mountain Volcanics of early Pliocene age (5–4 Ma), which overlie the late Miocene Bedrock Springs Formation that contain fossil faunas of middle to late Hemphillian NALMA (7–6 Ma, Tedford and others, 2004). Farther southeast and out of view, the Blackwater Fault cuts the 3.8 Ma basalts of Black Mountain (north of Harper Lake), where1.8 km of right-lateral offset can be demonstrated. In most places, the fault cuts Pleistocene deposits. Retrace.

104.6 (0.7) Bear left at fork.

105.5 (0.9) Blackwater Well. We will retrace to Highway 395.

105.8 (0.3) Proceed west on the southwest fork at the fence line intersection.

109.0 (3.2) Bear left at the fork.

109.2 (0.2) Bear left at the fork.

110.0 (0.8) Bear left at the fork.

110.1 (0.1) Proceed straight through the crossroads.

111.0 (0.9) Bear right at the junction.

111.8 (0.8) Pass through the corral.

112.5 (0.7) Proceed straight through intersection.

113.7 (1.2) Proceed straight at crossroads.

115.4 (1.7) Bear left at the junction.

115.8 (0.4) Pass the site of an old house.

115.9 (0.1) Bear right at the junction.

116.3 (0.4) Cross a pole line road. The road bears right after the junction.

116.6 (0.3) Pass through the junction at a tank.

116.9 (0.3) The red paleosol visible in the road supports a thick cover of Erigonum inflatum, unlike the surrounding sandy Holocene soils.

121.3 (4.4) View left (southeast) to Cuddeback Lake. A projection of the Gravel Hills Fault would line up with the southern margin of the lake.

125.7 (4.4) Stop, TURN RIGHT (north) onto Highway 395.

127.5 (1.8) Continue past a left turn to Randsburg. View northwest of the 1990 Yellow Aster Mine dumps.

127.9 (0.4) Sign: "Entering Red Mountain." The Kelly silver mine lies to the west, its head frame has been dismantled. It became California's largest silver deposit with over 20 million ounces produced between 1919 and 1942. The ore occurs in quartz–carbonate–chalcedony veins. Silver mineralization consists mainly of Ag–Cu–Sb sulfosalts (miargyrite and pyrargyrite) and Ag chlorides with minor native silver. Arsenopyrite is the chief gangue mineral.

128.1 (0.2) Continue past Osdick Road.

128.3 (0.2) View west of the remaining Kelly Mine control building.

129.3 (1.0) Continue past Trona Road (right) to Searles Lake (see Reynolds, 2002). Steam Wells Valley is to the north. Some of the pumps on the wells that provided Johannesburg and Randsburg with water were operated by steam, an early use of geothermal power (Mendenhall, 1909; Reynolds, et al,1998).

131.0 (1.7) Enter Johannesburg and Kern County. Randsburg and Johannesburg were the twin metropolises of the Rand Mining District. Randsburg was the company town, while Johannesburg was a planned community for miners with families (Clark, 1997). They functioned as major trans-shipping points for rail and stage lines. Ore from the district was initially shipped south to Barstow for milling, but with the construction of a 100-stamp mill in 1901 the district began to thrive. Large-scale gold mining continued until 1918. Gold production from the district was substantial into the 1930s and early 1940s, and there has been intermittent mining since, most recently from 1989 to 1995 at the Yellow Aster. Total estimated production from Randsburg mines up to 1940 is estimated at $40 million. The Yellow Aster was shut down in 2004 and the dumps and heap leach piles have been "reclaimed."

132.0 (1.0) Prepare for a left turn across oncoming traffic.

132.2 (0.2) TURN LEFT (west) to Randsburg via the Redrock–Randsburg Road. Randsburg has a museum and a recently active single stamp mill.

132.7 (0.5) At the Disposal Site signs, TURN RIGHT (north) on Goler Road and proceed north 4.2 miles to Garlock Road. View right (northeast) of Summit Diggings district. Placer gold deposits to the northeast are called Hard Cash Gulch and Summit Diggings (Reynolds, et al, 1998). Auriferous gravels of Summit Diggings may have been derived from Goler Gulch, three miles to the west. Restoration of movement on the left lateral Garlock Fault would place auriferous gravels at the mouth of Goler Gulch. Farther east, the trace of the Garlock Fault on the south shore of Searles Lake at the

2,250 foot shorelines is marked with tufa dated at 50 ka. Since the dated shoreline deposits are not cut by the Garlock Fault, that date constrains the latest movement on that portion of the fault to greater than 50,000 yr (Smith, 1962, 1964). Of course, most segments of the Garlock Fault show evidence for much younger activity, including several ruptures during the Holocene (Dawson and others, 2003, Clark and Lajoie, 1974). We are entering Fremont Valley, an active graben bounded on the north by the Garlock Fault and on the south by the Cantil Valley Fault.

134.1 (1.4) Pass gravel dumps from hydraulic mining operations.

135.7 (1.6) Pass through low hills of Pleistocene alluvium elevated above the axial drainage of Fremont Valley by the south-side-up Cantil Valley Fault.

136.2 (0.5) Cross Fremont Wash and the Cantil Valley Fault.

136.6 (0.4) Railroad crossing, watch for trains. Prepare to turn left (west).

136.9 (0.3) STOP at Garlock Road. Look for oncoming traffic. TURN LEFT (west) onto Garlock Road. The trace of the Garlock Fault is to our right. The first mining for lode gold, silver, and copper ore in the El Paso Mountains was in 1863 on Laurel Mountain, east of the El Paso Peaks.

John Goller, survivor of the 1849 Death Valley party, found gold nuggets on his trek across the desert. Although he regularly searched for his lost "mine," placer gold was not rediscovered here until 1893. Miners named one of the prospects Goler Gulch, after Goller. By 1896, a half-million dollars of gold had been recovered (Vredenburgh, 2009; Vredenburgh and others, 1981).

138.1 (1.2) Continue past Goler Road on the left. The Goler Formation to the north (not visible) consists of a two mile (3 km) thick section of fluvial sediments capped by fossiliferous marine sediments (Lofgren and McKenna, 2002; Cox and Edwards, 1984; Cox and Diggles, 1986; McDougall, 1987). Intense prospecting for fossils by the "Goler Club" has resulted in a suite of small mammals that represent four NALM ages that span the Paleocene (Lofgren, et al., 2009). This is the best section west of Wyoming and Colorado for studying Paleocene faunas (~60 Ma). No fossils have been recovered from the lower members (1 & 2) of the Goler Formation, but if rates of deposition can be considered constant, lower strata project as Cretaceous in age (Cox, 1998). Clasts in the Goler Formation tell us that the Mojave Block on the south side of the Garlock Fault was elevated in the early Tertiary (Cox, 1998).

140.7 (2.6) TURN RIGHT (north) on Charley Road, which leads north to the Garlock Fault scarp

140.9 (0.2) **Stop 3-6: Garlock Fault Scarp**. The southern flank of the El Paso Mountains is north of this escarpment. The rocks making up this portion of the El Paso Mountains are generally Paleozoic metamorphic rocks and Mesozoic granitoids (Dibblee, 1952; Jennings and others, 1962). The east–west-striking El Paso Fault (south side down) lies at the base of the slope and a playa has formed between it and the Garlock Fault. Look southeast across Cantil Valley to old alluvial ridges that mark the trace of the Cantil Valley Fault that parallels the Garlock Fault on the south side of Koehn Lake.

The 160 mile long Garlock fault zone marks the geologic province boundary between the Mojave Desert to the south and the Sierra Nevada and Basin and Range to the north. Movement along the Garlock Fault is thought to have begun at about 10 Ma (Burbank and Whistler, 1987, 1992). While no surface rupture has occurred on the Garlock Fault in historic times, there have been a few sizable quakes. The most recent was a magnitude 5.7 near the town of Mojave on July 11, 1992 (SCEC earthquake database). It is thought to have been triggered by the Landers earthquake, two weeks earlier (Jones, Mori and Hauksson, 1995). Trenching suggests other ruptures occurred in 1050 A.D. near Tehachapi and 1500 A.D. near our present location. At least one section of the fault has shown movement by creep in recent years. Numerous studies have been published citing slip rates along the fault (LaViolette, et. al., 1980; Clark and Lajoie, 1974; Carter, 1980, 1982, 1987; Smith, 1962, 1975; McGill and Sieh, 1993; Petersen and Wesnousky, 1994; Dawson and others, 2003; McGill and others, 2009). Reported rates of sinistral slip vary from 2 to 11 mm/yr. The western portion of the fault, near its junction with the San Andreas Fault, appears to be the most active with slip rates exceeding 7 mm/yr. In contrast, the eastern terminus of the fault, south of Death Valley, has been characterized by little or no Holocene slip (Smith, 1998).

Return to Garlock Road.

141.1 (0.2) Stop at Garlock Road pavement, watch for cross-traffic, and TURN RIGHT. As we proceed west, note the depression on the north side of the road:

a left-laterally offset portion of Goler Gulch, the next drainage west (Reynolds and others, 1998). The cement foundation of an ore mill remains on the north scarp of the depression. One-half mile west, tamarisk trees mark the site of Cow Wells, where Garlock found water at 30 feet, and where the Yellow Aster mill was built in 1898. The view west shows the El Paso Fault on the right, Garlock Fault on the left, and a terrace between.

144.0 (2.9) The town of Garlock was a water source for cattlemen and traders seeking to avoid a trek through the El Paso Mountains. Gold was discovered in 1887 and caused a gold rush. By 1898 the population of Garlock reached over 200. By 1904, Garlock was abandoned.

145.1 (1.1) The Red Rock–Randsburg Road joins from the left. Continue west toward State Route 14. Scarps of the Garlock Fault are on the right. Green vegetation marks springs along the fault, especially along a high scarp that separates uplifted Irvingtonian sediment (Dibblee, 1952) from the alluvial fans of the valley floor.

151.0 (5.9) Continue past a left (south) turnoff to Saltdale (el: 2000 ft). The Consolidated Salt Company constructed plants and laid a narrow gauge railroad track onto the playa of Koehn Lake in 1914 (Hensher, Vredenburgh and Wilkerson, 1998). The plant produced around 20,000 tons of salt annually. The company pumped well water onto the lake floor where it was allowed to partially evaporate. The resulting brine was drained into ponds where a 6-inch layer of salt would form. The salt was cut into cakes that were cleaned, ground, sized, sacked, and shipped to Los Angeles. In 1972 the BLM found the claims to be invalid.

151.4 (0.4) Continue past the right (north) turnoff to Last Chance Canyon. Once the main access into the El Paso Mountains, this road now requires 4WD since flash floods have severely modified it.

153.8 (2.4) The site of Gypsite (south) in the Koehn Lake playa deposits produced gypsite (mixture of gypsum and clay) used for plaster and agricultural soil amendments (Hensher, 1998).

155.2 (1.4) Cross the channel of Red Rock Canyon Wash, a site of severe flooding in historic time.

155.7 (0.5) View south of Honda test facility.

156.0 (0.3) Continue past Cantil Road to the left.

156.8 (0.8) Cross a drainage.

159.1 (2.3) Neuralia Road is on the left just before we turn on CA 14. Stop at the intersection with CA 14. Watch for traffic and TURN LEFT (south) toward Mojave.

We cross the Garlock Fault shortly after the turn onto CA 14.

163.5 (4.4) Pass the site of Cinco.

168.3 (4.8) Continue past Phillips Road.

171.9 (3.6) Continue past Maury Lane.

174.0 (2.1) EXIT to the right on Randsburg Cutoff/California City Boulevard.

174.4 (0.4) Stop at Randsburg Cutoff Road. TURN RIGHT (west). The cutoff eventually bears south.

177.7 (3.3) Cross over Highway 58.

178.6 (0.9) Randsburg Cutoff joins Mojave/Barstow Highway. Merge to the right lane and prepare for a right turn.

178.9 (0.3) TURN RIGHT at the railroad crossing. Stop at the tracks and watch for oncoming trains. Cross the tracks cautiously. The road forks—take the right fork.

179.2 (0.3) Cross the lower LADWP aqueduct.

179.3 (0.1) TURN LEFT at the upper LADWP aqueduct and proceed southwest along the aqueduct.

179.8 (1.5) Park at the major wash. **Stop 3-7: Horned Toad Formation**. The Horned Toad Formation of early Pliocene age can be seen to the northwest. The formation records early Pliocene deposition in a basin along the Garlock Fault (May, 1981). Members of the Horned Toad Formation include (from the base):

> Member 1: moderately indurated, arkosic and conglomeratic sandstone. The color ranges from gray to tan with upward increasing amounts of red caused by paleosols (buried soil horizons).
>
> Member 2: resistant white, calcareous, thin layered silty sandstone.
>
> Member 3: dark olive green lacustrine mudstone.
>
> Member 4: brick-red, calcareous paleosols.
>
> Member 5: brick-red silty paleosols between tan lenses of arkosic sandstone.

Figure 3-7. Horned Toad Formation, showing (from left and oldest) Member 1, Member 2, and Member 3.

Sediments of the Horned Toad Formation contain fossil mammals from the late Hemphillian NALMA. It also contains the Lawlor Tuff (4.83 Ma; May, 1981) within Member 2 in the south and within Member 3 in the north (May, 1981). The Lawlor Tuff heralds the end of the Hemphillian NALMA.

Remains of pond turtle (generic name Actinemys is preferred over Emys or Clemmys; Ernst and Lovich, 2009) have been recovered from lacustrine Member 3 of the Horned Toad Formation. North, along Highway 395 through Red Rock Canyon, Actinemys has been recovered throughout the Miocene Dove Spring Formation, with the earliest occurrence at about 12 Ma (Whistler and others, 2009; Whistler p. c. to Reynolds, 2011). This suggests that Actinemys was present in Mojave Block wetlands and drainages prior to the uplift of the Sierra Nevada Range about 8 Ma. (Frankel et al. 2008) and the ~ 3 Ma uplift of the Transverse Ranges (Meisling and Weldon, 1989). The fossil record shows that Actinemys was widely distributed in the Pliocene. When the climate became dryer about 10,000 ybp, their range contracted and shifted toward the Pacific coast (Brattstrom and Sturn, 1959). The late Pleistocene history of the western pond turtle in the Mojave River drainage is a lesson in survival (Lovich and Meyer, 2002).

Retrace north along the aqueduct to Mojave/Barstow Highway.

180.3 (1.5) TURN RIGHT toward Mojave / Barstow Highway.

180.4 (0.4) Stop at Mojave / Barstow Highway (Highway 58). TURN RIGHT (south) and proceed into the town of Mojave (services).

182.7 (2.3) Stop at the junction with Highway 14.

184.0 (1 .3) Stop at the junction with Highway 58 to Barstow. TURN LEFT (east).

187.8 (3.8) Enter Highway 58 eastbound for Barstow. Mojave sits on a huge alluvial fan emanating from Cache Creek Canyon that Highway 58 takes into the Tehachapi Mountains. Streams traversing this fan pass either northeast to Koehn Lake, as they do now, or southeast through the Bissell Hills to Rogers dry lake, a part of Pleistocene Lake Thompson (Dibblee, 1967). Pleistocene faunas are found along the shoreline of Lake Thompson (Reynolds and Reynolds, 1991; Wilkerson and others, this volume).

198.7 (10.9) Continue past California City Blvd.

200.7 (2.0) Continue past Rosamond Blvd.

203.0 (2.3) Continue past Clay Mine Road.

207.3 (4.3) Continue past Twenty Mule Team Road. The early Miocene Arikareean NALMA Boron Local fauna (approx. 19 Ma; Woodburne and Reynolds, 2010) was recovered from the upper Tropico Group exposed in the Boron open pit mine (Whistler, 1984).

208.7 (1.4) Continue past Gephart Road.

210.7 (2.0) Continue past Borax Road.

213.7 (3.0) Continue past Boron Avenue.

216.3 (2.6) Lanes are reduced on Highway 58. Use caution while merging.

217.7 (1.2) Caution: cross the railroad tracks.

220.4 (2.7) Stop at Highway 395 in Kramer Junction and retrieve carpool vehicles. TURN RIGHT (South) on Highway 395.

221.8 (1.4) Continue south on Highway 395 to Air Expressway in Adelanto.

231.5 (9.7) Pass through the Miocene conglomerate of the Kramer Hills.

234.2 (2.7) Pass the early Miocene Tropico Group lacustrine limestone of the Kramer Hills.

244.8 (10.6) Continue past the junction of Silver Lake/ Shadow Mountain Road. At this point we are starting to drive across an elevated surface formed on lake and distal fan deposits of early Pleistocene age, the George surface (Cox and others, 2003). On the right are the Shadow Mountains, which consist of metamorphosed Paleozoic strata and Mesozoic granitoids.

254.9 (10.1) Enter Adelanto at the traffic signal at Chamberlaine Way. Continue south.

255.5 (0.6) Traffic signal at Bartlett Avenue. Continue south on Highway 395.

256.0 (0.5) TURN LEFT (east) at the traffic signal at Air Expressway.

256.5 (0.5) Continue past the traffic signal at Adelanto Road.

256.7 (0.2) Continue past the traffic signal at Gateway Road.

257.8 (1.1) Continue past the traffic signal at Phantom West.

258.5 (0.7) Continue past the traffic signal at Nevada.

258.8 (0.3) Continue past the traffic signal at George Road.

259.5 (0.7) Continue past the traffic signal at Phantom East. Prepare to turn right.

260.0 (0.5) TURN RIGHT onto Village Drive.

260.1 (0.1) Pull right and park in the turnout.

Stop 3-8: Victorville Stratigraphy at Village Drive. View northwest toward Southern California International Airport (George Air Force Base). Subsurface and outcrop stratigraphy here consists of three sedimentary units: lower, middle and upper (Reynolds and Cox, 1999; Cox and Tinsley, 1999; Sibbett, 1999; Cox and others, 1998, 2003).

The lower unit is an arkosic sand deposited by a southward-flowing axial stream system. Clasts of Jurassic and early Miocene volcanic rocks are from the Mojave Desert, not from the Transverse Ranges, and include lithologies from the Kramer Hills and outcrops near Barstow. Borehole magnetostratigraphy suggests that the top of the lower unit is about 2.5 Ma (Cox and others, 1999). This would be within the 4.1 to 1.5 Ma range of the Phelan Peak Formation on the north slope of the San Gabriel Mountains west of Cajon Pass. The Phelan Peak Formation records a reversal in its drainage direction from southward to northward in its depositional history (Meisling and Weldon, 1989), corresponding approximately to the age of the upper limits of the lower unit in Victorville.

The middle unit of lacustrine silt is seen in outcrop over a wide area. Magnetostratigraphic data indicate that the lacustrine middle unit is early Pleistocene (formerly late Pliocene), ranging from 2.5 to ~2 Ma (Cox and others, 1999; 2003). Ostracodes reinforce a Pleistocene age for the middle unit.

The upper unit overlies the lacustrine middle unit, and is an upward coarsening fluvial sequence of silt, sand, and gravel. Clast lithologies indicate a source for these ancestral Mojave River gravels from the northwestern San Bernardino Mountains. A suggested depositional history is that stream flow from the southeast deposited the lacustrine middle unit in the Victorville basin north of the San Bernardino Mountains. As the ancestral Mojave became a cohesive drainage, and as the mountains continued to rise, sediments overwhelmed the basin, and the river then flowed northward toward Harper Lake and then eastward to terminate in Lake Manix at about 500 ka (Reynolds and Cox, 1999). Retrace to Village Drive and TURN LEFT (north).

260.2 (0.1) TURN RIGHT (east) on Air Expressway.

260.4 (0.2) TURN RIGHT on National Trails Highway.

262.2 (1.8) TURN RIGHT to enter I-15 southbound.

268.0 (5.8) Continue past the Bear Valley Road exit.

270.7 (2.7) Prepare to exit at Main Street, Hesperia.

271.5 (0.8) EXIT at Main Street, Hesperia.

271.8 (0.3) Stop, TURN RIGHT on Main Street and continue west.

272.9 (1.1) Continue past the traffic signal at Highway 395.

275.9 (2.9) Continue past the traffic signal at Baldy Mesa Road.

279.9 (4.0) Continue past the traffic signal at Wilson Ranch Road.

281.9 (2.0) Continue past the traffic signal at Johnson Road.

283.0 (1.1) Continue on Phelan Road, passing the intersection of Sheep Creek Road.

284.0 (1.0) TURN LEFT (south) on Beekley Road. Continue south.

285.1 (1.1) TURN LEFT onto Highway 138.

287.0 (1.9) Mountain Top Junction. Continue past the right turn on Highway 2 leading to Wrightwood.

287.3 (0.3) Prepare to turn right on Oil Well Road.

288.0 (0.7) Slow at turnout.

288.1 (0.1) TURN RIGHT on Oil Well Road.

288.3 (0.2) TURN Right (northwest) on dirt road. Do not drop into ruts.

288.5 (0.2). Park in the loop and look northwest toward the Phelan Peak section.

Stop 3-9: The Phelan Peak Formation to the northwest, from lowest, starts as tan arkosic sandstone, grades upward into chocolate (playa?) and greenish-gray lacustrine silts, then upwards into tan arkosic sandstone. The lowest arkose contains clast lithologies from the Mojave Desert to the northeast, while the upper arkose contains clasts from the San Gabriel Mountains. This sedimentary section records the uplift of the eastern portion of the San Gabriel Mountains in the Transverse Range Province, and the reversal of drainages that formerly ran southwest and now run northeast into the Mojave Desert.

This reversal occurred within the 4.1 to 1.5 Ma deposition range of the Phelan Peak Formation (Meisling and Weldon, 1989) and corresponds approximately to the age of the upper limits of the south-flowing lower unit in Victorville (Stop 3-7).

Look eastward through west Cajon Valley. The Phelan Peak Formation covers an erosional surface on the Cajon Valley Beds (18–14 Ma; Woodburne and Golz, 1972; Reynolds, 1991a) and the Crowder Formation (18 Ma–younger than 6 Ma; Reynolds and others, 2008). This suggests that a major erosional event creating the unconformity occurred between 6–4 Ma. A question remains as to what forces would cause extensive erosion, and at the same time preserve the record of deposition in the Phelan Peak Formation.

Overlying the Phelan Peak Formation (>1.5 Ma), in stratigraphic order, are the Shoemaker Gravels and the even coarser Old Alluvium, all containing clasts from the San Gabriel Mountains. Locally, the Brunhes/Matuyama magnetic reversal, at ~758 ka, is in the upper Shoemaker Gravels, just below the unconformity that separates them from the overlying Old Alluvium. Since the Old Alluvium is the coarsest unit, it suggests that the San Gabriel Mountains did not reach their full height (11,000 feet) until half a million years ago (Weldon, 1985).

The right-lateral San Andreas fault zone is to our south, and the sediments underneath us are being translated to the northwest. Debris cones from the easily-weathered Pelona Schist are older toward Littlerock than those being deposited today along Sheep Creek (Weldon, 1985). The coarsening-upward sequence to our north—Phelan Peak, Shoemaker Gravels, Old Alluvium—may be a result of both lateral translation and uplift of the San Gabriel block

What have we seen?

On previous Desert Symposium trips, we have explored the development of large Miocene basins developed by extensional tectonics. With the 2010 reduction of the Pliocene Epoch to 5.3–2.6 Ma (Finney, this vol.), we have spent this symposium searching temporal gaps for elusive signs of deposition during the revised Pliocene Epoch.

Day 1 explorations found late Pliocene gravels unconformably overlying many eroded Miocene basin-filling deposits, probably heralding strike-slip faulting. Apparent lack of unconformities in the gravel sequence south of Alvord Mountain (Stops 1-6 to 1-9) suggest that further research there could fill important time gaps.

Exploration on Day 2 in the active half-graben of Death Valley (in the Basin and Range province) looked at dated late Pliocene sediments deposited on the east-side of the graben along fault scarps. In contrast, deposition along the Amargosa River drainage system left Plio-Pleistocene mid-valley fine-grained sediments and large fan deposits from lateral drainage systems active in the Pleistocene.

On Day 3 we noted long temporal unconformities between deformed Miocene basin-filling sediments and early to mid-Pleistocene sediments. The development of northwest-striking faults in the (new) Pleistocene cut latest Miocene sediments and late Pliocene basalt flows. Pliocene sediments apparently were best retained in basins developed along the major left-lateral strike-slip Garlock Fault or the right-lateral San Andreas Fault. Other Pliocene basins in the Mojave province, such as the Manix basin and Bristol basin, developed in the

Pliocene to early Pleistocene ,apparently as a result of interactions between strike-slip faults.

Return to vehicles, retrace to Highway 138.

288.9 (0.6) Stop at Highway 138 and watch for traffic. TURN RIGHT (east) toward I-15.

295.2 (6.2) Continue past the right turn to Lone Pine Canyon.

296.3 (1.0) Junction of Highway 138 and I-15. End of trip.

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Following the tracks of the Fresno: a chronological marker for the historic period

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Introduction

Gravel scrapings, divided by gravel windrows, are often seen in the desert west, mostly in proximity to highways (Figure 1) and railroads (Figure 2). Some, such as the Topock Maze, have been interpreted as prehistoric figures (Haenszel 1978). Recent research in conjunction with the Imperial Valley Solar Project (El Centro BLM), the Calico Solar Project (Barstow BLM), and the Inland Film Commission Project (Barstow BLM) has brought the interrelationships between the gravel features, railroads, and highways into sharper focus. It is suggested that the Fresno scraper, or a very similar contemporary implement, was the principal tool in manufacturing these patterns.

Figure 1. Gravel scrape along the Old National Trail Road, Barstow area.

Figure 2. Gravel scrape along the Union Pacific Railroad, Afton Canyon.

The interactive methodology of ethnohistoric research in archaeology

Had the relationship between windrow scrapes and Fresno scrapers ever been recorded as such in the DPR forms of California archaeology? And how many archaeologists would be capable of recognizing either the tool (scraper) or its track (the scrape and windrow pattern) if they came across one in the midst of a survey? For much of my professional career I have made the case, in projects as far apart as Wisconsin (Lange 1969) Barbados (Lange 1972, 1974, 1976; Handler and Lange 1978, 1979; Handler, Orser, and Lange 1979; Corrucini, Handler, Mutaw, and Lange 1982; Lange and Handler 1980a, 1980b, 1985; Lange and Carlson 1985), Nicaragua (Lange 2006) and now California (Lange 2006) for the value of the ethnohistorical approach to archaeological research.

The step-by-step articulation of historical and archaeological data regarding surface scrapes and the first generation of mechanical scrapers as contained in this article, was based on the "mining" of the historical data for details that were not initially being sought, and likewise a more careful perusal of the same historical data that suggested different approaches to the archaeological data. Furthermore, this articulation of history and archaeology produced interpretations that would have been difficult or impossible on the basis of historical data alone and probably impossible if only archaeological data had been available.

The Fresno scraper

James Porteous, a Scotsman, immigrated to Fresno, California in the latter quarter of the 19th century, where he started a wagon shop and patented the Fresno scraper. The Fresno scraper evolved from his patents and those he acquired from W. Deidrick, F. Dusy, and A. McCall. Porteous founded the Fresno Agricultural

Figure 3. Gravel scrape and windrow detail, Afton Canyon.

Works, which is still in operation today. The blade portion of the Fresno scraper accounts for the flat (Figure 3), cleared area while the parallel windrows were produced by gravel sliding off the end of the blade.

The Fresno scraper established the basis for modern-earth-moving and the influence of the "C"-shaped scoop on the Fresno scraper is still reflected in the shape of the loader on the front of the front end loader (Figure 4a and b). The scraping and spreading function of the Fresno is perpetuated by the so-called "belly scraper" (Figure 4a and c).

The Fresno scraper terminated the era of back-breaking hand labor for land leveling, ditch digging, road and railroad bed building, and the building of dams and canals (Figure 5). Between 1884 and the advent of tractor-drawn scrapers in the 1910s, thousands of "Fresnos" were used in agricultural for canals, ditches, and land leveling; in road and railroad grading; and in general construction not only in California, but throughout the U.S. and in many foreign regions including Australia, South America, India, the Orient, South Africa, and Europe, and played a vital role in the construction of the Panama Canal. Closer to home, Fresno scrapers were also used to remove the drifting sand from the wooden planks of the first plank road across the Imperial Sand Dunes.

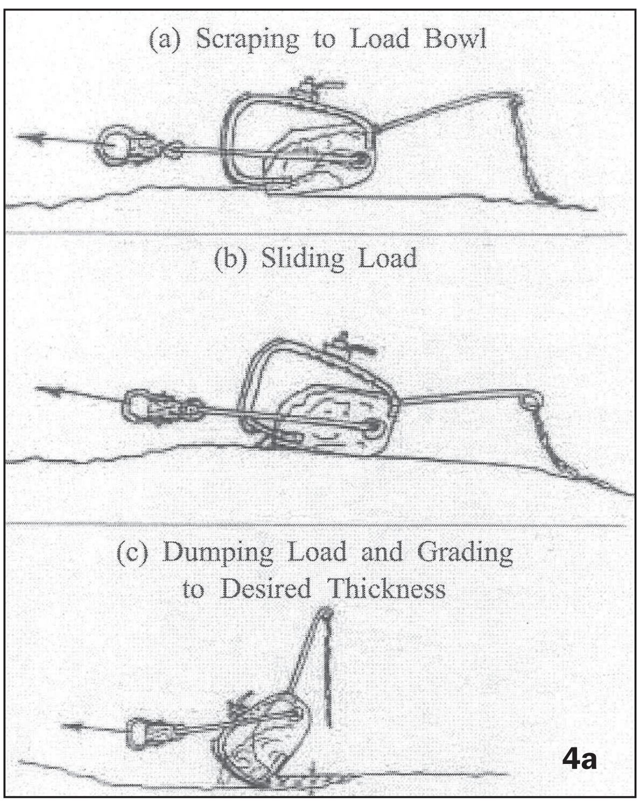


Figure 4. (a), above: Fresno scraper; (b), above right, front-end loader "C"-shaped scoop comparison; and (c), below right, belly scraper scrape and spread comparison.

Figure 5. Historic photograph of Fresno scraper use.

As the National Historic Mechanical Engineering Landmark designation states:

> The design of the Fresno Scraper forms the basis of most modern earthmoving scrapers, having the ability to not only scrape and move a quantity of soil, but also to discharge it at a controlled depth, thus quadrupling the volume which could be handled manually.

The blade scooped up the soil, instead of merely pushing it along, and ran along a C-shaped bowl which could be adjusted in order to alter the angle of the bucket to the ground, so that the dirt could be deposited in low spots.

Dating the scrapes

The 1884 to 1910 date range provides what historical archaeologists called a *terminus ante quem* (the date before which something was not produced) and *terrminus post quem* (the date after which something was not produced). These production markers permit the archaeologist to date the gravel furrows within a range of dates and, in the case of highway and railroad bed construction, to estimate when the work was done. Many archaeologists and geologists have calculated the difference between windrows, and from that measurement, extrapolated

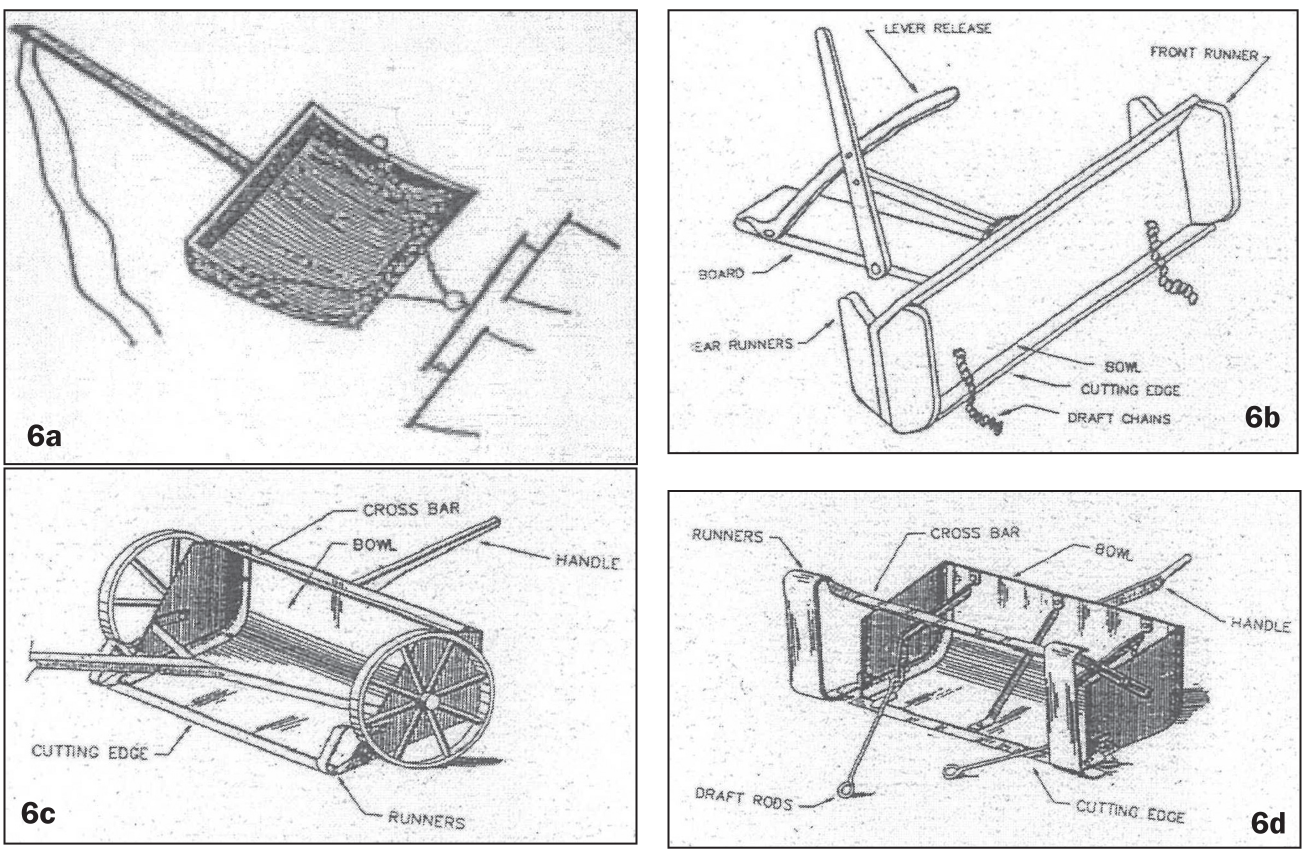
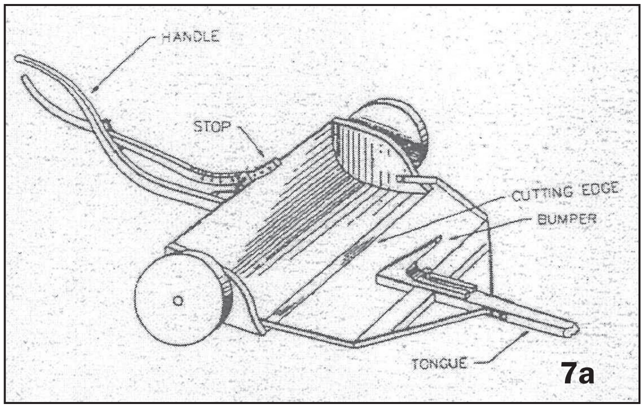
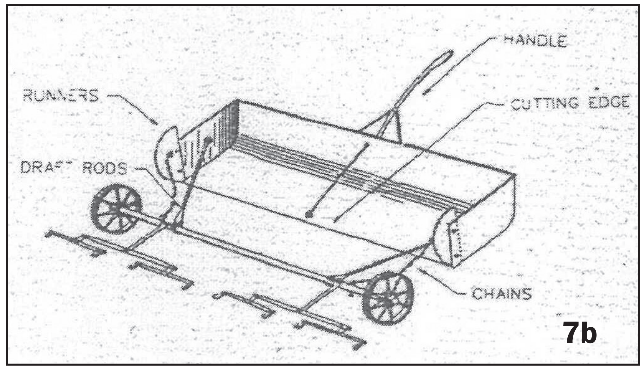


Figure 6. Fresno scraper and other patents: (a) slip/scoop; (b) buck scraper, Porteous' first patent; (c) dirt scraper, Porteous' second patent; and (d) dirt scraper, Deidrick patent.





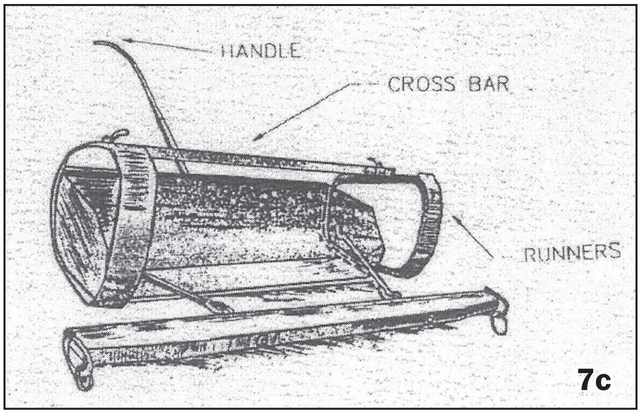


Figure 7. Fresno scraper and other patents: (a) dirt scraper, Porteous' third patent; (b) dirt scraper, Dusy and McCall patent; and (c) Fresno scraper manufactured by Fresno Agricultural Works.

the width or "fit" of the blade of the scraper.

Related to the "fit" of the width of the scrape with the width of the cutting edge, this paper highlights two other archaeological examples of artifact fit (with the certainty that there are many more). The first was the fit between loaf-shaped manos/handstones and trough widths in communal grinding bins at Sand Canyon Pueblo near Cortez, Colorado where specific households could be related to particular grinding areas by matching the width of the manos found in the houses with the width of the troughs in the communal grinding area.

The second example was an extraordinary demonstration of research on lithic reduction technology by Clay Singer (1984), who managed to rejoin two fragments of lithic debitage found 63-km apart in the Chuckwalla Valley. Since its invention in 1882, various Fresno scraper sizes have emerged, with the most common width having been 8 feet.

While the 25-year time period described above is definitely better than most archaeological chronological sequences, it may be possible to do even better by studying the various patent documents in more detail. Porteus and others filed seven successive patents and refinements with the U.S. Patent Office (Figure 6, a, b, c, and) and Figure 7 a, b, and c) and although not completely clear from cursory examination of the illustrations that have been published, it appears that the width of the Fresno scrapers definitely changed with time. These changes in cutting width would definitely

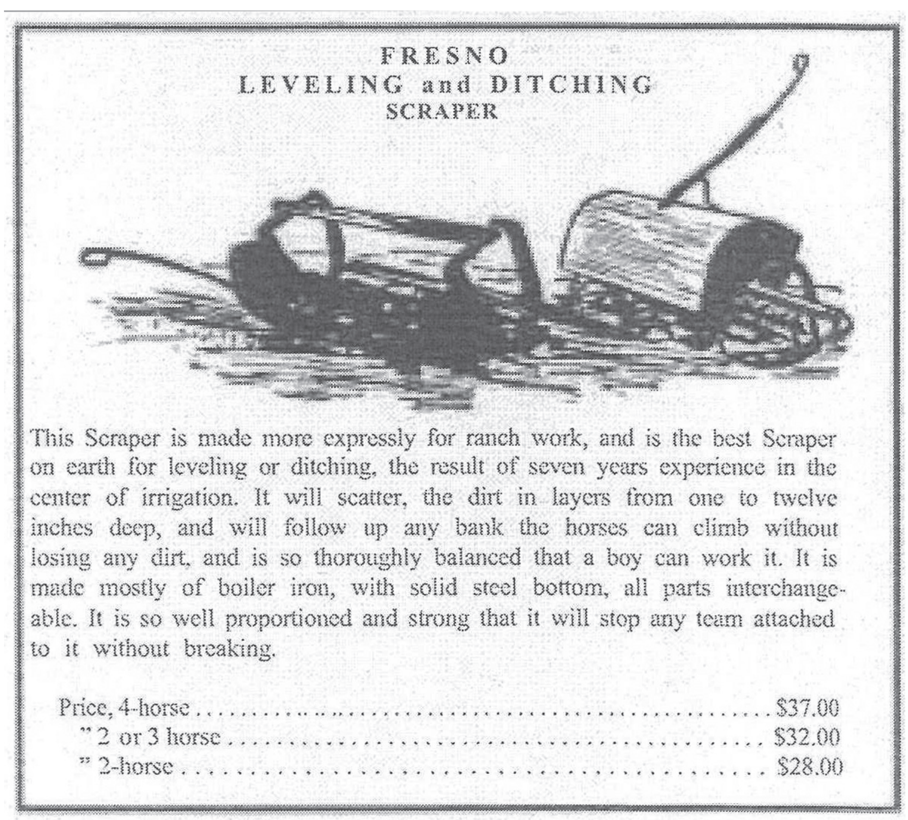


Figure 8. Fresno scraper advertisements.

be observable from the cuts made by particular models when they are observed in the field.

George Young (1907:315) has provided additional details regarding the varying uses of different kinds of scrapers that may also help us to pick out Fresno scrapings from a myriad of other patterns. Young stated that drag scrapers covered comparatively short areas of 200 feet or less; Fresnos were used to cover transects of 200–500 feet; and wheeled scrapers were used for distances beyond 500 ft.

If we integrate our width and distance measurements, we might come up with a context that was 350 feet long and 8 feet wide that we could, with some confidence, relate to a Fresno scraper (Figure 8). Compared with the confidence level in many prehistoric dating devices (Clovis points, Folsom points, Colorado Red-on-Buff ceramics, the Millingstone Period, etc.) our 25-year Fresno range seems almost impossibly precise.

Summary

In the present study, the historical evidence has alerted us to the potential of identifying the sites of a specialized construction activity, occurring primarily within a quarter-century between the end of an arduous human and animal work-force (ca. 1880), and the beginning of the era of mechanized excavation (ca. 1910). The historical documentation and archaeological features described in this article may help some of us to redirect our field recording and to be sensitive to the possibility of Fresno scraping "tracks" in a wide variety of contexts.

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Alvord Mine, San Bernardino County, California

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The Alvord Mine, located in the Alvord Mountains, was wishfully named after the lost Alvord lode. In 1860 Charles Alvord, while with a group searching for the Lost Gunsight silver lode, stumbled onto manganese ore infused with wire gold. After repeated attempts, he was never able to relocate his find.

Rich coarse gold was discovered in Alvord Mine on the southwest side of Alvord Mountain sometime before 1881. Some reports indicate an arrastre was used to mill the ore early during the mine's life. In February of 1881, the Alvord Consolidated Quartz Mining Company issued 75,000 shares of stock to raise money to develop their newly found mine, located about 20 miles east of Calico.

On June 25, 1883, H. S. Loveland leased the mine for a period of two years, agreeing to construct a Huntington mill to work the ore. A month later, it was reported that the mill had been "bought and active operations are beginning on this rich mine."

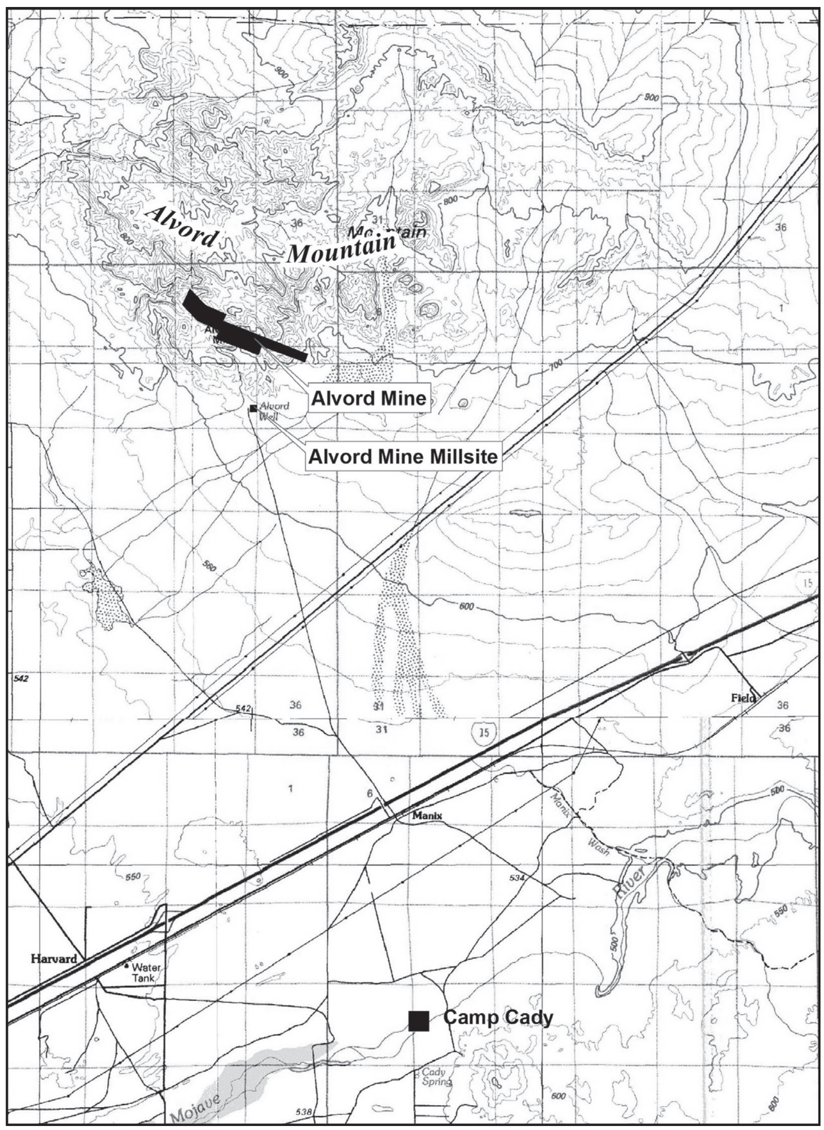
From 1884 until 1887 the mine was worked by J. B Osborn of Daggett. In May 1885 ore was daily hauled to Camp Cady, on the Mojave River, where a 5-stamp mill had been erected to help the existing Huntington centrifugal mill process ore. During this time $36,973 was recovered.

During the late 1880s ore was reduced at Hawley mill, in addition to Camp Cady.

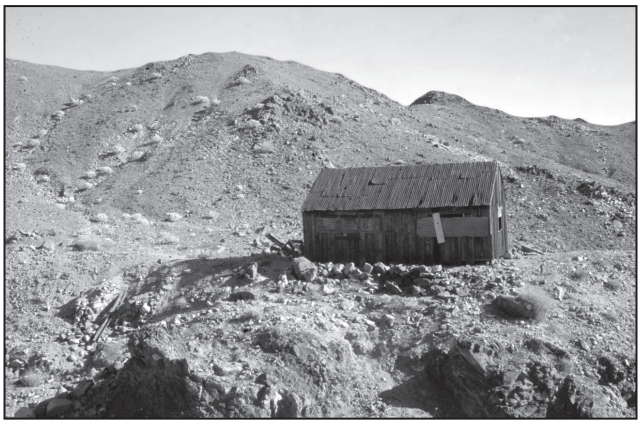
In the early 1890s, a mill was built, probably at Alvord Well, at the mouth of the canyon below the mine, which ran until it burned in September, 1891. During the last 10 days before the mill burned, $1,430 in bullion was produced from ore that assayed between $6 and $18 a ton. Total production of gold from the Alvord Mine up to that time was placed at $50,000.

In 1895, considerable prospecting was done on the property and in order to test the ore, the Alvord Mining Company of Pasadena erected a five-stamp mill 2 miles from the mine, probably at the site of the burned mill.

From 1906 to 1910, the Alvord Mining Company of San Diego operated the mine and installed a six-stamp Nisson mill near the mine. Perhaps this was C. L. Roseberry's operation. He was reported to have shipped 4 railroad cars of ore to the Selby smelter



Location map, Alvord Mine and millsite.



Buildings at the Alvord mine, 1970. Photos by the author.

(located across the bay from San Francisco). In November 1910 he sold the claims to A. C. Stanley who had planned to erect a 10-stamp mill. Two years later the Barstow Printer reported that Roseberry and Frank Ryerse were to build a 10-stamp mill at the mine. A brief note in June 1913 reported the mine and mill were active.

Six months later it was reported that the mine was running steadily, a half dozen miners working the mine tailings.

The Tintic Bonanza Mining Company of Salt Lake City operated the mine from 1916 to 1920. Charles McCormick, a resident of Yermo, was the owner in 1923. He reopened the mine and in 1924 two men were working the mine. In 1925, the Dell'Osso Gold Mining Company acquired the property and in 1931 patented 6 claims. The property was active for several months during 1932 and 1933. From December 1950 to January 1952 the mine was under lease to Roy Waughtel of Manix. The mine has been idle since 1952. The mill built in 1906 was used to treat ore intermittently until 1952. The mill was still on the property in 1955. The mill has been removed and one of the wooden buildings and a small bridge were burned in the early 1970s. Two stone buildings remained in the early 1970s.

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Magnetostratigraphy and tectonic rotation of the Miocene Spanish Canyon Formation at Alvord Mountain, California

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Initial results from a paleomagnetic study of Miocene sedimentary and volcanic rocks provide an opportunity to correlate magnetozones of the Spanish Canyon Formation of Byers (1960) at Alvord Mountain with the "astronomically tuned" Geomagnetic Polarity Time Scale (GPTS) of Ogg and Smith (2004) and to investigate possible vertical-axis rotation of the Alvord Mountain structural block. The Spanish Canyon Formation consists of a tuffaceous lower part overlain by two olivine basalt flows, as originally defined by Byers (1960). In his redefinition of the Spanish Canyon Formation, Fillmore (1993) excluded the tuffaceous section, calling it the "two tuffs," and proposed that the upper volcanic ash is a distal part of the Peach Spring Tuff, a widespread marker bed in the Mojave Desert (Young and Brennan, 1974; Glazner et al., 1986; Wells and Hillhouse, 1989; Nielson et al., 1990). Recently reported Ar40/Ar39 dating and correlation with the GPTS indicates a model age of 18.8 ± 0.1 (1 sd) Ma for the Peach Spring Tuff (Hillhouse et al., 2010). Herein, we follow Byer's (1960) definition that includes the tuffaceous sediments within the Spanish Canyon Formation.

Structure of the Miocene rocks east of Alvord Peak is dominated by a northward plunging (17°) anticline in which beds on the western flank dip 20° to 30° northwest; dips are somewhat steeper on the eastern flank, up to 45° northeast (Byers, 1960). Numerous normal faults cut northeastward across the anticline, dropping blocks generally down to the south. We collected paleomagnetic samples from two sites spanning the "two tuffs" and the olivine basalts, and studied the stratigraphy and petrology of the volcanic rocks. Site A spans two fault blocks on the northwest side of Spanish Canyon and is the location of a measured stratigraphic section presented by Byers (1960); site B is from the eastern limb of the anticline (Fig. 1). Hillhouse et al. (2010) reported paleomagnetic results from an incipiently welded ash flow located near Clews Ridge (site C; 0J001); the mineralogy and paleomagnetic inclination

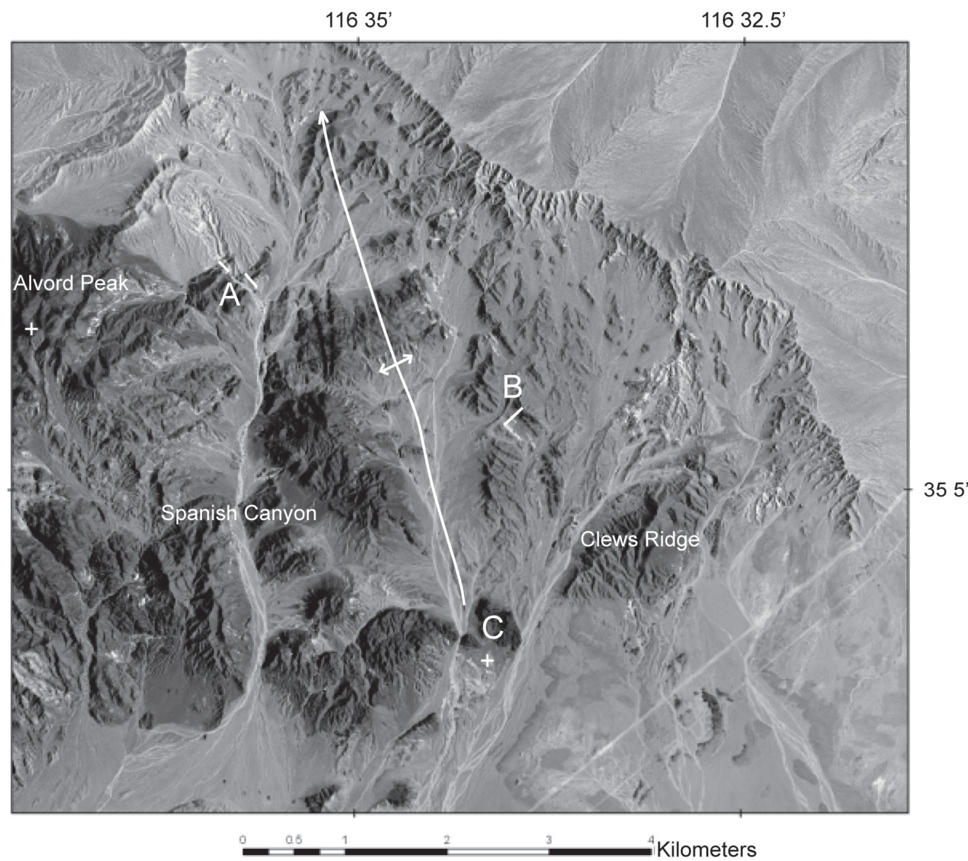


Fig. 1. Locations of paleomagnetic sampling sites in the Alvord Mountains. Site A, near Spanish Canyon (Figure 2); site B, eastern limb of anticline (Figure 3); site C, Peach Spring Tuff. Fold axis of anticline shown by long white line.

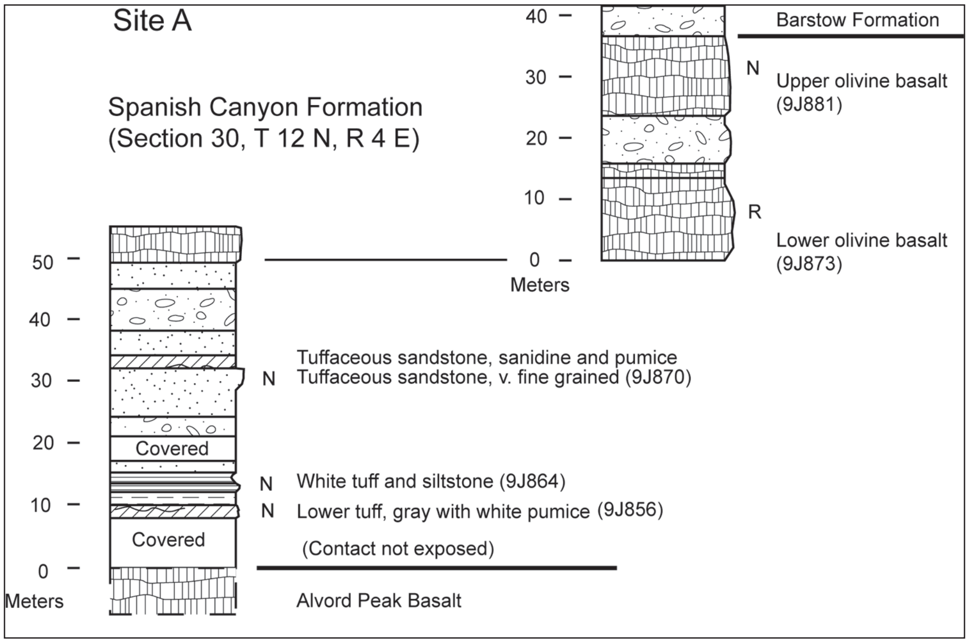
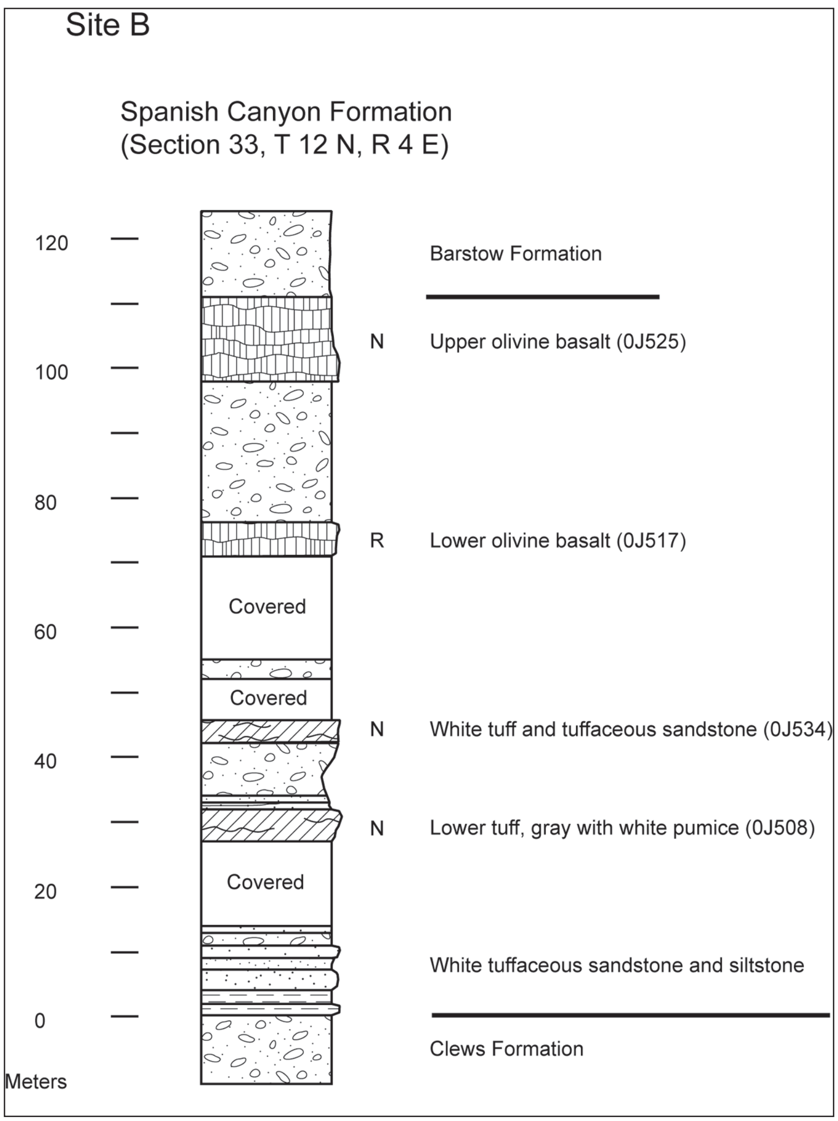


Fig. 2. Measured stratigraphic section in the Spanish Canyon Formation (site A), showing magnetic polarity of beds sampled for paleomagnetism.



of this flow support correlation with the Peach Spring Tuff. However, we remain uncertain about the stratigraphic position of site C in the context of our new sites due to poor exposure of the contacts between the ash flow and the nearby tuffaceous sediments of the Spanish Canyon Formation.

At sites A and B, the lowest paleomagnetic samples were taken in a gray vitreous ash-flow tuff, which contains compacted white pumice fragments (<2 cm). This gray tuff is overlain by several well-bedded units composed of very fine-grained white tuff and tuffaceous sandstone (Figs. 2 and 3). The upper tuffs appear to be reworked, waterlain sediments. After alternating field treatment to remove secondary magnetizations, sites A and B revealed consistent magnetostratigraphy with normal polarity in the gray tuff and white tuffaceous units, reversed polarity in the lower olivine basalt, and normal polarity in the upper olivine basalt. If Fillmore's (1993) correlation of the Peach Spring Tuff within the "two tuffs" is correct, the best fit of the Spanish Canyon magnetozones to the GPTS is to chrons C5E and C6n, or within the interval of approximately 18.0 to 19.7 Ma. The lower olivine basalt is within C5Er (18.52-18.75 Ma) and the transition from C5Er to C5En (18.52 Ma) occurs between the two olivine basalts (Fig. 4). From the vicinity of site A, WoldeGabriel et al.

Fig. 3. (left). Measured stratigraphic section in the Spanish Canyon Formation, east limb of anticline (site B), showing magnetic polarity of beds sampled for paleomagnetism.

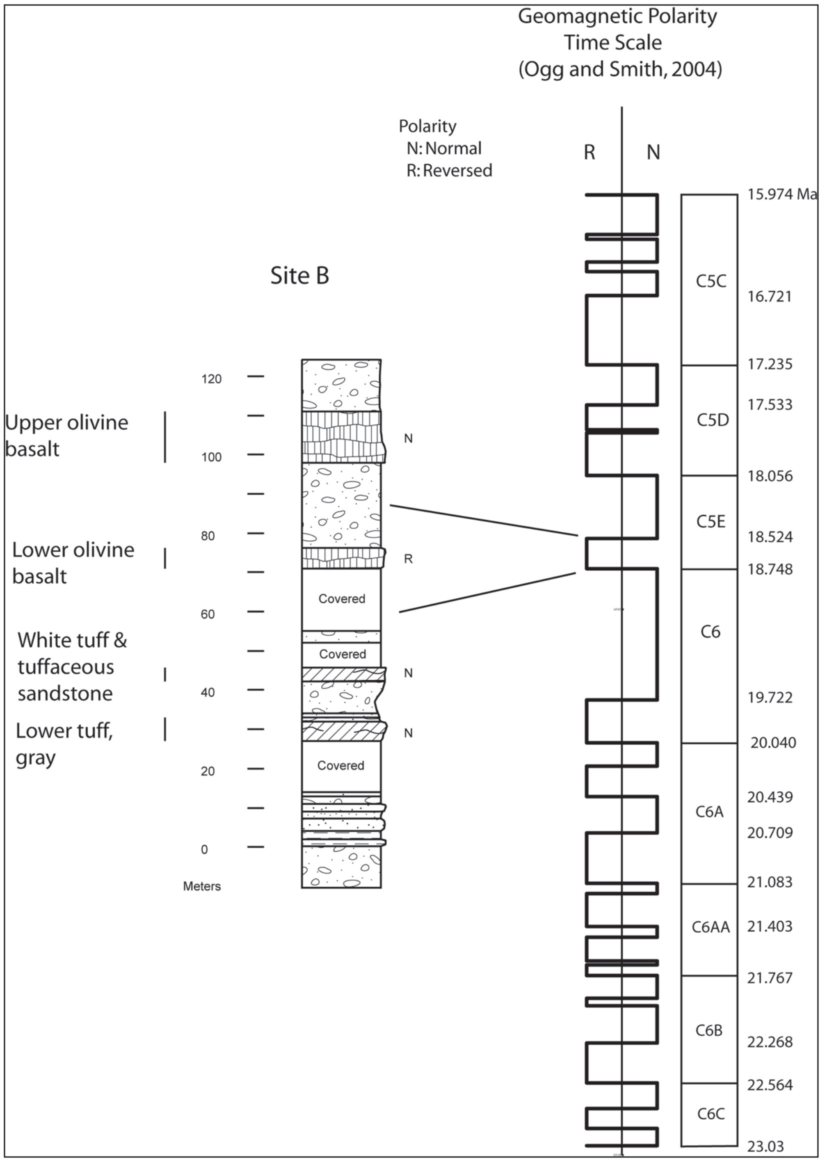


Fig. 4. Proposed correlation of site B magnetozones with Geomagnetic Polarity Time Scale.

(1996) reported single-crystal Ar40/Ar39 ages from an olive-green ash-flow tuff that is probably correlative with the lower gray tuff reported herein. The mean age from five crystals of plagioclase is 18.9 ± 0.8 (1 sd) Ma (isochron age of 19.40 ± 0.07 Ma) and is consistent with our magnetostratigraphic correlation. We note, however, that the study of WoldeGabriel et al. (1996) focused on the dating of authigenic minerals in altered ash-flow tuffs, and the alteration may account for considerable scatter in the resultant emplacement ages.

The magnetozones from Spanish Canyon bear similarity to the pattern of paleomagnetic results obtained by MacFadden et al. (1990) in the Hector Formation of the northern Cady Mountains. In the upper 150 m of the Hector Formation, the Peach Spring Tuff occurs in a normal-polarity zone that is overlain by a thin reversed-polarity zone, consistent with the Spanish Canyon magnetozones and the proposed correlation of the Peach Spring Tuff within the "two tuffs" at Alvord Mountain. Our preferred age model for the Hector Formation places the Peach Spring Tuff just beneath the C6-C5E boundary to account for revisions in the dating of the tuff and recalibration of the GPTS (Hillhouse et al., 2010). In contrast, the original interpretation of the Hector Formation magnetostratigraphy placed the Peach Spring Tuff in the upper part of C5E (MacFadden et al., 1990; Woodburne, 1998).

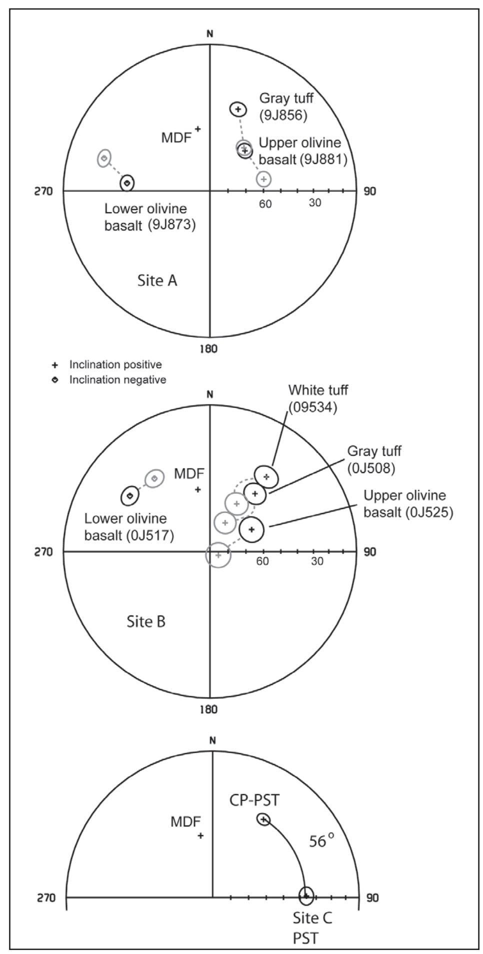


Fig. 5 (right). Directions of remanent magnetization with 95% confidence limits from paleomagnetism sites at Alvord Mountain (gray shading, without tilt correction for bedding; black, after tilt correction). Sample numbers in parentheses refer to samples shown in figures 2 and 3. MDF, Miocene dipole field (Besse and Courtillot, 2002; 20 Ma); CP-PST, Peach Spring Tuff reference direction from Colorado Plateau (Wells and Hillhouse, 1989). Equal area stereographic projection.

Previous paleomagnetic studies near Alvord Mountain suggested that the Miocene volcanic rocks of the area have rotated approximately 55° clockwise (Ross et al., 1989; Hillhouse et al., 2010). In particular, magnetic declination of the Peach Spring Tuff (site C; 0J001) indicates a clockwise, vertical-axis rotation of 56.1° ± 5.6°, at 95% confidence. Our new sampling of sites A and B, however, has not yielded directions of remanent magnetization that we can confidently link to the Peach Spring Tuff (Fig. 5). The white tuffaceous parts of the Spanish Canyon Formation that we have examined so far are largely reworked and do not exhibit the primary ash-flow characteristics of site C. Paleodeclinations from sites A and B are well east of the expected magnetic field direction for the Miocene and are consistent with large-scale clockwise rotation inferred from earlier results. In addition, results from the lower gray tuff and the olivine basalts indicate that the eastern limb of the Spanish Canyon anticline is rotated clockwise ~25° relative to the western limb.

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Pliocene and early Pleistocene paleogeography of the Coyote Lake and Alvord Mountain area, Mojave Desert, California

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Abstract

Coarse-grained gravel and sand deposits underlie low-relief hills scattered across much of the area around Coyote (dry) Lake and Alvord Mountain, including hills whose deposits are exposed in several cuts along Interstate 15. The gravels previously have been mapped as Quaternary and Tertiary in age but few firm age assignments existed before regional mapping by USGS and subsequent detailed studies that verified that most gravel deposits are early Pleistocene and Pliocene. Relatively rare beds of tephra, some newly discovered, are early Quaternary to Pliocene in age, and improve the age constraints for these deposits.

The gravel deposits contain distinctive suites of clasts that mark source areas, including the Goldstone area of southwestern Fort Irwin for a broad sweep of gravels that lies north of Alvord Mountain, the Calico Mountains area for a wide swath of gravels that extends from the Yermo Hills to east of Manix Wash, the Alvord Mountain area for gravels that lie south of that mountain, and the Cady Mountains area for a swath of gravels that lies along the Mojave River and includes Buwalda Ridge. The gravels south of Alvord Mountain are interlayered with gravels sourced in the Calico Mountains and Goldstone, and evidently represents a long-term sink. These relations suggest that four source areas have been persistently high topographic regions for at least 4 M.y., but that other areas have changed greatly in relative topographic position. The most remarkable changes are associated with the fluvial gravels that were shed south and east from Goldstone to east of Alvord Mountain, for those deposits have been warped down into the Coyote Lake basin and warped up over Alvord Mountain. In addition, smaller pop-ups along strike-slip faults represent changes in paleogeography since the Pliocene and some pop-ups deform middle Pleistocene strata. In contrast, the area along the modern Mojave River course from Manix Wash to Afton Canyon has been a persistent topographic low. The section south of Alvord Mountain and north of Buwalda Ridge extends from underlying middle Miocene deposits of the Barstow Formation upward to active alluvial fans, in an apparently unbroken stratigraphic sequence that records shifting topographic position and changing source areas.

Introduction

The area of Coyote (dry) Lake and Alvord Mountain (Figure 1), herein called the Coyote-Alvord area, is underlain by widespread alluvial fan and fluvial plain deposits of Quaternary age (Meek, 1989, 1994; Jefferson, 2003; Dudash, 2006; Reheis and others, 2007) above which small hills and mountains project. The hills and mountains are underlain by Miocene and older materials, in many places sedimentary and volcanic rocks, and in a few places Mesozoic granitoids and Paleozoic strata that are variably metamorphosed (Miller and others, 1995; Miller and Walker, 2002). These old materials are overlain by gravel deposits assigned Pliocene and Pleistocene ages in many cases; these latter deposits are the subject of this paper. The geologic maps of this area laid out this basic framework over 50 years ago (Byers, 1960; McCulloh, 1960; McCulloh, 1965; Dibblee and Bassett, 1966), and studies focused on Miocene and

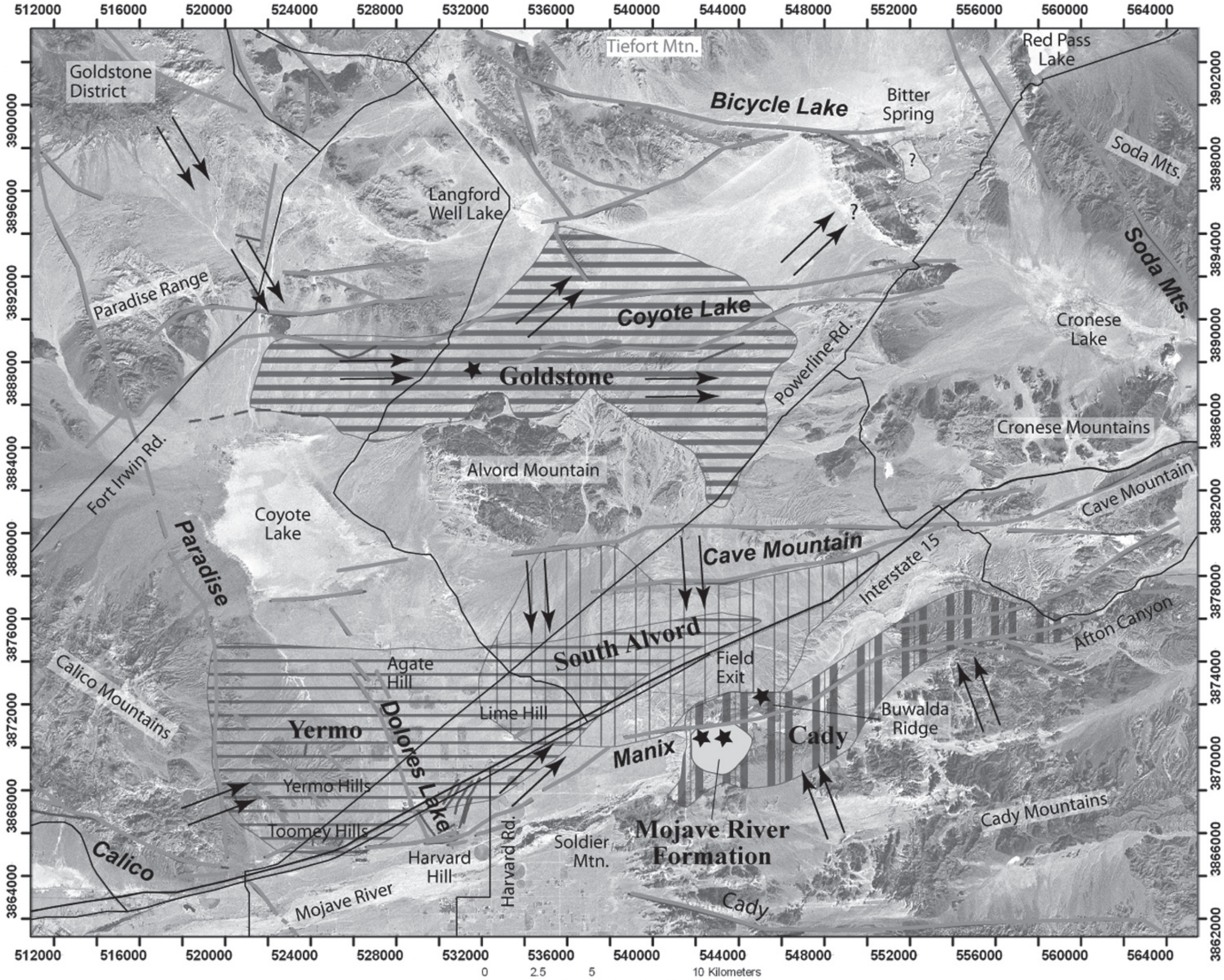

Figure 1. Location map of the Coyote Lake and Alvord Mountain area. Faults (gray lines) are from Miller and others (2007) and unpublished mapping by D.M. Miller. Lined areas with bold labels are four gravel packages described in the text. Arrows show general direction of sediment transport; stars show locations of ash beds. Faults are labeled in bold italic font.

Mesozoic tectonics and sedimentation have added considerably to the understanding of the area (Walker and others, 1990; Fillmore, 1993; Yount and others, 1994; Miller and others, 1995; Miller and Walker, 2002; Miller and Yount, 2002).

As studies have improved knowledge of the age, provenance, and tectonic setting of the deposits of the Coyote-Alvord area, one set of deposits mapped by the early workers remained virtually unstudied: coarse gravels that overlie the Miocene strata and underlie Quaternary deposits. These strata were assigned Pliocene and Pleistocene ages by the various mappers, but no chronological data were recovered during field work. One important study that bears on the coarse gravels is that of Nagy and Murray (1991) who studied fine-grained deposits near the intersection of Manix Wash and the Mojave River that grade laterally to coarser Quaternary alluvial fan gravels. They recovered tephra in the fine-grained deposits, which they assigned to a basin-axis playa depositional setting. The tephra layers correlated chemically with eruptive products known to be late Pliocene and early Pleistocene in age. Their original assignments of age are adjusted now by the redefinition of the Quaternary as extending from about 2.6 Ma to present (Gibbard and others, 2009); thus, the entire playa unit (the informally named Mojave River formation of (Figure 1) Nagy and Murray, 1996) is now considered to be Quaternary in age, ranging from ~2.4 to ~1.0 Ma on the basis of tephra and magnetostratigraphy (Pluhar and others, 1991). This paper will henceforth use the new age assignments for the Quaternary. The work of Nagy and Murray thus demonstrated that part of the adjacent gravel deposits was early Quaternary in age.

Another important study of the post-Miocene gravel deposits was that of Miller and Yount (2002), who showed that a distinctive light-colored gravel deposit that crops out along the southern edge of Fort Irwin, north of Coyote Lake and Alvord Mountain, contains a ~3.4-Ma tephra. This study examined provenance of the gravels and established that the source terrane was in the vicinity of the Goldstone District (Figure 1) based on a distinctive clast population of metamorphic rocks, garnet-muscovite granite, and lesser proportions of other rocks typical of the Goldstone area.

We have investigated the post-Miocene gravel deposits from the Yermo Hills to Alvord Mountain, and south to the Mojave River. In this paper we describe the deposits, tephra layers that have been recovered from them, and their relations with underlying and overlying deposits. We use this new information, along with data from previous studies, to describe changing paleogeography during the time the gravels were deposited. Although tectonic and climatic controls on the gravels were important, we don't address those aspects in this paper. This study contributes to the study of similar deposits across much of the Mojave Desert, in a nascent effort to unravel the Pliocene and early Pleistocene period of sedimentation and tectonism.

General description of the gravel deposits

Coarse gravel deposits and interbedded sand are common through the Coyote-Alvord area (Figure 1) and can be broken into several types by clast populations. To the north lies the Goldstone gravel distinguished by Miller and Yount (2002), a light-colored gravel bearing noticeable nearly white garnet-muscovite granite clasts. In the southwest, in several hills known as the Yermo Hills, Toomey Hills, and Agate Hill (Figure 1) is the Yermo gravel of McCulloh (1965). This gravel bears a distinctive assemblage of clasts derived from a source similar to the modern Calico Mountains: light-colored silicified limestone, dacite, and lesser proportion of a variety of volcanic rocks, granite, and metavolcanic rock. Hills south of Alvord Mountain contain gravel with clasts sourced from a terrane similar to the modern Alvord Mountain area: metamorphic rocks including sparse marble, granitoids rich in intermediate-composition rock and also including diorite or gabbro, leucocratic granite, and a wide variety of volcanic rocks. Farther south of Alvord Mountain the south Alvord gravel interfingers with gravel derived from the Cady Mountains: clasts of andesite and metavolcanic rocks progressively overwhelm the gravel near Buwalda Ridge, north of the Mojave River. The Cady source contributes to gravels that extend from the Buwalda area east to Afton and probably beyond.

The coarse gravel and sand deposits are deformed in many exposures. Deformation is commonly expressed in homoclinal tilt of the deposits, but the Goldstone and Alvord gravels are folded and faulted (Byers, 1960) and the Yermo gravel also is (McCulloh, 1965). Buwalda Ridge has been uplifted and moved laterally along the Manix Fault. In addition, several Quaternary faults cut the gravels across the Coyote-Alvord area (Miller and others, 2007).

Age of the gravel deposits—general relations

General relations of the gravel deposits with underlying and overlying deposits provide chronologic constraints. Underlying units in many places are Miocene: the Barstow Formation (~19-~13 Ma; Woodburne and Reynolds, 2010, and references therein) in the strict sense and also the Barstow Formation as used by Byers (1960) in the Alvord Mountain area, which is comparable in age to the type section of the Barstow Formation. In some places, such as north of Coyote Lake, the gravels lie on Mesozoic granitoids. Overlying the gravels in many places is a suite of Quaternary alluvial fan deposits that are fairly well dated locally and regionally. Using the terminology of Miller and others (2009), intermediate-age fan deposits are widespread on the coarse gravels. Two widespread intermediate fan deposits are dated as ~80 and ~180 ka in the Calico Mountains (D.M. Miller and K. Maher, 2006, unpublished U-series ages on soil silica). Since these fan deposits are derived from deeply eroded hills composed of the coarse gravels, the underlying gravels must be significantly older than ~180 ka. In the northern Yermo Hills, one, and locally two, thick calcic horizons formed on the eroded coarse gravels. Each calcic horizon consists of as much as 2 m thickness of stage III carbonate, capped by 5 to 15 cm of laminar stage IV carbonate. This degree of calcic horizon development is typical of deposits 500 to 1000 ka in age (Machette, 1985; Miller and others, 2009). In the eastern Mojave Desert, deposits with this degree of carbonate development contain the Bishop Ash or a similar ash of similar age (760 to 1200 ka) (McDonald and others, 1995; D.M. Miller and P.A. Stone, 2009, unpublished mapping). These relations in the Yermo Hills establish the coarse gravels in the Yermo Hills as younger than ~13 Ma and older than ~1 Ma.

Tephra layers recovered by Miller and Yount (2002) in the Goldstone gravel in southern Fort Irwin and in the present study near Buwalda Ridge (described later in this paper) provide all the direct chronology for these

Figure 2. Photograph of the Goldstone gravel on Miocene strata (Barstow and Spanish Canyon Formations) at Alvord Mountain. Dashed line highlights the unconformity

gravels at this time, as no definitive paleontology or isotopically dated material is currently available. The Goldstone gravel contains an ash bed that is about 3.4 Ma (Miller and Yount, 2002), indicating that some of the gravel deposits are Pliocene in age.

The south Alvord gravel near Buwalda Ridge interfingers with the middle and upper Mojave River formation, forming the alluvial facies of that unit (Nagy and Murray, 1991, 1996). This formation contains several tephra layers correlated with the tuffs of Blind Spring Valley (2.2-2.1 Ma), Huckleberry Ridge Tuff (2.1 Ma), and older tuffs of Glass Mountain and Emigrant Pass (2.1-1.9 Ma; Nagy and Murray, 1991; Sarna-Wojcicki and others, 1991, 2005). Based on these tephra layers and paleomagnetic measurements (Pluhar and others, 1991) in the Mojave River formation, the south Alvord gravel in that area ranges from 2.1 to about 1.0 Ma. It may be older, but existing exposures of the lower fine-grained facies of the Mojave River formation do not contain gravel. Arkosic gravel that may represent the uppermost part of the south Alvord gravel also interfingers with lacustrine deposits of the younger (~500-25 ka; Jefferson, 2003) Manix Formation (unpublished mapping of M.C. Reheis and D.M. Miller, 2009).

The Goldstone gravel

The Goldstone gravel (new informal name) was described by Miller and Yount (2002) as a light-colored, granite-dominated gravel and sand that lies along the south margin of Fort Irwin. They described the distinctive garnet-muscovite granite dike rock in the gravel and red-and-green striped metamorphic rocks as being uniquely derived from the Goldstone Mining District area (Figure 1). Byers (1960) also noted that clasts in the gravel indicate derivation from the west. Rhyolite lava and tuff clasts are minor, but widespread, and apparently derive from rhyolite flows and tuffs that lie on the muscovite granite pluton (Yount and others, 1994). Much of the section is gravelly coarse- to medium-grained sand, and sparse cross beds indicate generally easterly flowing currents. North of Coyote Lake and farther east, angular boulders of local origin suggest side-canyon or canyon-wall debris was introduced into a trunk stream system. In a few places these local clasts lie in debris-flow beds, which are otherwise absent in the fluvial-dominated sediment of the Goldstone gravel. North of Alvord Mountain the lower part of the section is interbedded with gravel sourced by Alvord Mountain rocks: dark-colored monzodiorite, biotite schist, and rare marble. East of Langford Well Lake, the gravel contains well-rounded basalt boulders that apparently were derived from the north, from the Bicycle Lake basalt of about 5.5 ± 0.2 Ma (Schermer and others, 1996).

The Goldstone gravel lies on Mesozoic rock in most places but in the Alvord Mountain area it lies on the Barstow Formation, and therefore is younger than ~13 Ma (Byers, 1960). Along much of the exposure where the Goldstone lies on Barstow, the units appear to be gradational (Figure 2), but there are local angular unconformities (Byers, 1960; Wyatt, 2005). In most places, a massive pebbly tuffaceous sand lies at the base of the Goldstone, above which lie bedded gravel and sand that contain the distinctive clasts of muscovite granite. As noted by Byers (1960), bedding in the gravel generally dips less steeply than does bedding in the underlying Barstow Formation. The tuffaceous sand may represent local deposition form proximal Barstow source materials. Upward, much of the lower section contains well-rounded pebbles of the Goldstone source clasts and more angular cobbles to boulders of dark-colored granodiorite, diorite, and basaltic andesite that are similar to rocks at Alvord Mountain. Black quartzite, white quartzite, and coarse-grained marble clasts in these beds may represent sources from either Goldstone or Alvord Mountain. Some parts of the section have continuous sand, pebble, and boulder beds that extend for hundreds of meters; the lateral continuity of these beds suggest an environment of deposition similar to modern broad washes. The section north of Alvord Mountain is about 1200 m thick.

We have not been able to trace the Goldstone gravel more than a few km east of Alvord Mountain. Gravels exposed farther east, extending nearly to Bitter Spring (Figure 1), are mixed source and require further study. However, fine- and medium-grained arkosic sand at Bitter Spring contains muscovite, a relatively rare mineral in the region, and might possibly be a distal facies of the Goldstone gravel depositional system. That sand appears to underlie the Bicycle Lake basalt, although outcrops do not show conclusive evidence of the contact.

Another location of Goldstone-type gravel lies south of Alvord Mountain, where the unit is sandwiched between other gravels. This package is described in the section on the south Alvord gravel.

Northwest of Alvord Mountain, and apparently fairly high in the stratigraphic section, the Goldstone gravel contains a lens of ash that was correlated with a similar, dated ash (3.4 ± 0.2 Ma) near Fort Irwin (Miller and Yount, 2002). The ash chemically correlates with the Tuff of Mesquite Spring, which is dated in Death Valley at 3.28 ± 0.07 (Knott and others, 2008). The Goldstone gravel therefore is Pliocene. However, if the muscovite-bearing arkosic sand at Bitter Spring is distal Goldstone gravel, it is older than the 5.5 Ma Bicycle Lake basalt (Schermer and others, 1996) and implies that the lower Goldstone gravel is late Miocene in age.

In most exposures of the Goldstone gravel, the deposit is folded and faulted (Byers, 1960; Yount and others, 1994). North of Alvord Mountain, beds in the unit dip generally 25 to 30 degrees northward, and dips on some fold limbs are as great as 60 degrees. The

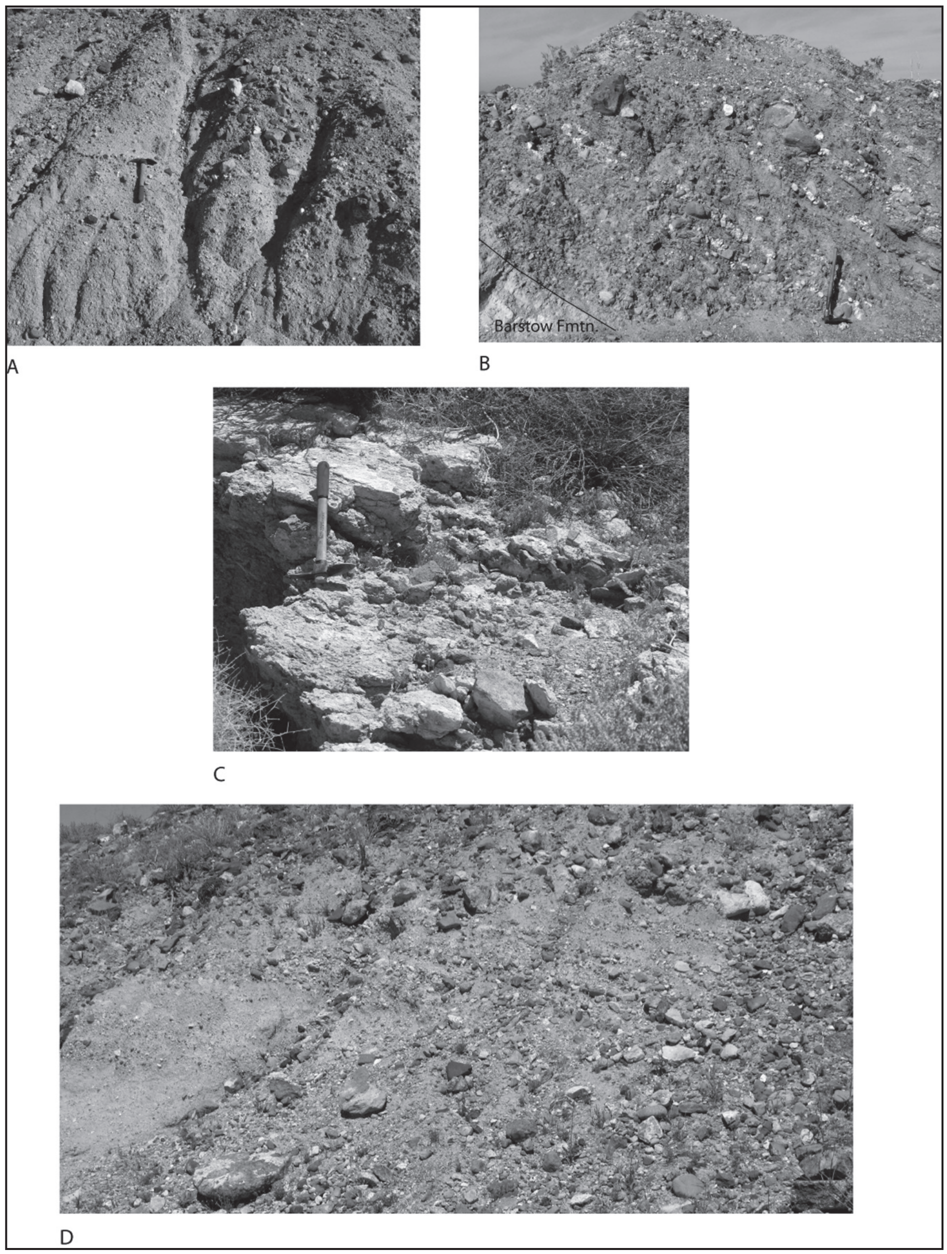

Figure 3. Photographs of the Yermo gravel, Yermo Hills and Toomey Hills. A, typical gravelly sand (fine facies) of the unit; B, Boulder-cobble gravel facies, at the base of the unit in Toomey Hills; Barstow Formation under the gravel at lower left; C, Thick calcic soil mantling the top of the unit, northern Yermo Hills; D, Pebble gravel overlying fine facies.

gravel unit wraps around northern and eastern Alvord Mountain in a huge arc that is nearly 20 km across. In contrast, north of Coyote Lake many beds dip southward toward the dry lake.

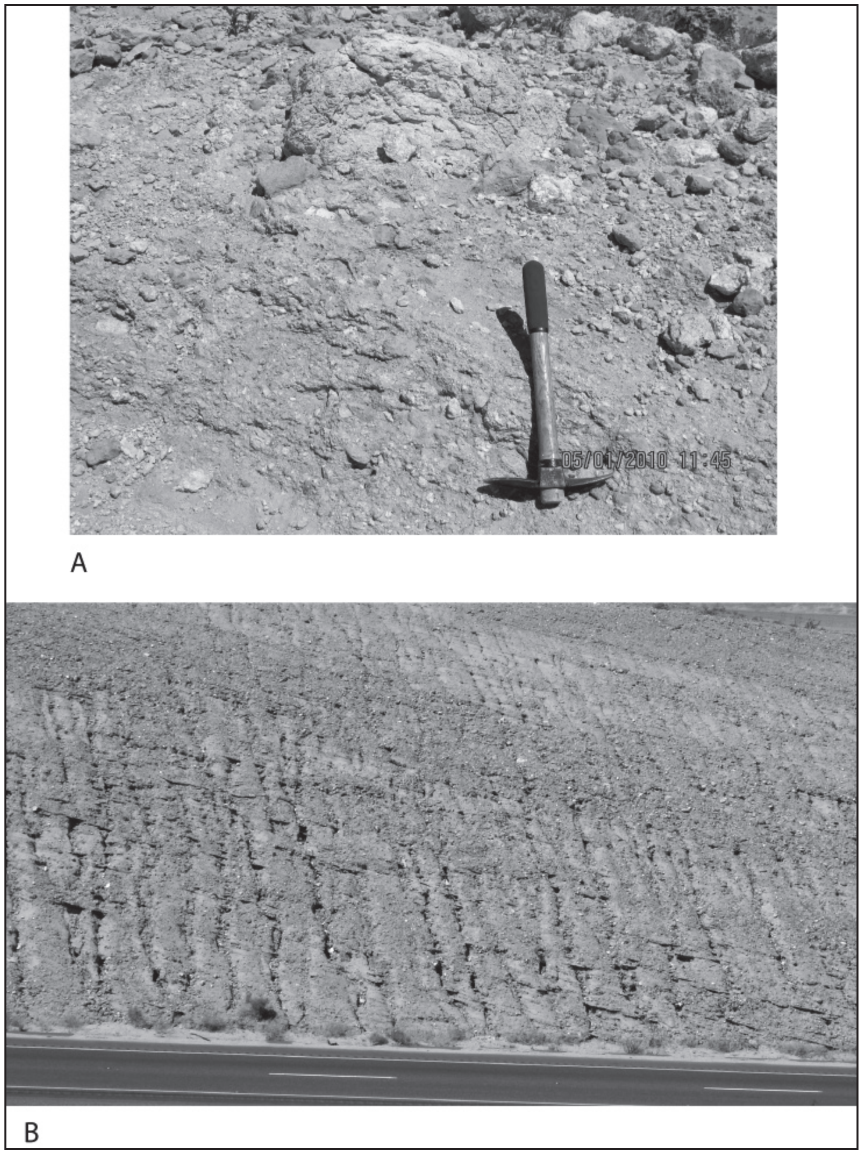

Figure 4. Photographs of the Yermo(?) gravel at Lime Hill (Fig. 1). A, Basal unconformity, with greenish beds of the Barstow Formation below the sedimentary breccia of the gravel unit; B, upper gravels of mixed Alvord and western sources in freeway road cut.

The Yermo gravel

McCulloh (1965) mapped the Yermo gravel as a Pleistocene and Pliocene complex south and east of the Calico Mountains. It is best exposed in the Yermo and Toomey Hills (Figure 1), where it lies unconformably (angularly) on the Miocene Barstow Formation. In some places a massive calcareous soil and groundwater-discharge deposit lies at the base of the Yermo but in many sections soils lie within the Yermo and not at the base. In these hills, faults sliver the exposure into a complex pattern, and as a result it is difficult to construct a consistent stratigraphic section of the generally poorly exposed Yermo gravel. We divided outcrops into four facies, from finer to coarser: fine gravelly sand facies, well-sorted sand facies, pebble gravel facies, and boulder-cobble gravel facies. We described these facies as well as rare debris-flow beds at 400 sites.

The fine gravelly sand facies (Figure 3a) is by far the most common, constituting 60% of the exposures. It ranges from clayey, sometimes tuffaceous, fine sand to coarse sand, generally with floating pebbles. Bedding is poorly developed to absent. Pebbles commonly are angular. The sand matrix ranges from reddish to gray to buff in color. The rare (3%) well-sorted sand facies displays crossbeds that indicate generally easterly flow of streams; it is commonly calcite-cemented. The pebble gravel facies (Figure 3d) is represented by 13% of the exposures, and is typified by moderately-sorted, well-bedded pebble gravel. Clasts are subrounded to subangular. The coarse boulder-cobble gravel facies (Figure 3b) is represented by 22% of the exposures. It consists of clast-supported boulder to cobble gravel, generally very poorly sorted with a sand matrix. In general, beds are medium to thick, locally with cross-beds. Matrix is commonly angular, and boulders are subangular to subrounded. In places, this facies fills channels, and it also represents the youngest unit along the south side of the Yermo Hills, where it commonly forms south-sloping mesas. Boulder gravel is locally present at the base of the unit, on the Barstow Formation (Figure 3b). A north-dipping mesa-forming unit along much of the northern extent of the Yermo Hills consists of interbedded fine, pebble, and boulder-cobble gravel facies, and is topped by one or two calcic soils (Figure 3c) as described in the section on general age relations. In this location the section is about 150 m thick. Debris flows are cobble and boulder gravel supported by a fine matrix, generally sand, and occur as discrete beds in otherwise fluvial-dominated sections.

Debris-flow beds are most prevalent in the westernmost 1 km of the Yermo Hills, and boulder gravel facies is somewhat more common in the west as well.

Most bedding in the Yermo gravel is lenticular and sediment is poorly sorted, suggesting alluvial fan deposition. The dominant clast types derive from a source similar to the modern Calico Mountains: dacitic volcanic rocks of several types and silicified limestone. In the northern Yermo Hills granite is a notable constituent, and in the Toomey Hills, Sidewinder-type metavolcanic rocks are a constituent (R. Lallatin, written commun. 2007) as well as common granitic rocks and less common basalt and limestone. The distribution of these rocks generally matches the distribution in the Calico Mountains, where Sidewinder Volcanics rocks are present in the south and granitic rocks are present in the north (McCulloh, 1965). Although boulders are as large as 3 m in diameter, in general boulders are less than 40 cm and the boulder-cobble facies is well-bedded, indicating fluvial conditions for deposition. The least stratified facies is the fine facies, which apparently represents proximal reworking of fine materials from underlying tuffaceous lacustrine rocks of the Barstow Formation. The simplest interpretation of the observations is that the Yermo gravel represents a broad alluvial fan shed from a source similar to the Calico Mountains, and in a position similar to the Calico Mountains.

At Agate Hill (Figure 1), the Yermo gravel overlies the Barstow Formation and is made up of similar clast types as in the Yermo Hills but with some notable differences. In addition to the silicified limestone and dacite that indicates derivation from the Calico Mountains, andesite, rhyolite lava and tuff, and granitic dike rock are common at Agate Hill. Sparse boulders of red conglomerate or sedimentary breccia, itself composed of well-rounded volcanic clasts, are notable. The matrix for cobbles and boulders is generally arkosic sand, suggesting input from a granite-dominated source. Mafic granodiorite is present in a few beds. A conspicuous lack of clasts typical of the Goldstone area suggests that the Yermo gravel at Agate Hill was derived from the northern Calico Mountains area, and possibly north to the Paradise Range, but not farther north.

At Lime Hill, gravels differ from those described above, so we designate it the Yermo(?) gravel. The lower part lies angularly across the underlying Barstow beds (Figure 4A). The lower part is pale in color and is composed chiefly of white limestone and silicified limestone, as well as green tuff and tuffaceous sandstone. Similar limestone, tuff, and sandstone are present in the underlying Barstow beds and in the Barstow exposed in the central and eastern Yermo Hills, but rocks types are dissimilar to Barstow beds in Harvard Hill, Agate Hill, and the Calico Mountains. Distinctive silicification that occurs as lacey webs of silica in the white limestone are characteristic. Also present are sparse well-rounded boulders of andesite, diorite, and phyllite, all of which are consistent with a source in Alvord Mountain. Overall, this lower part is extremely coarse grained with little matrix; it probably originated as a sedimentary breccia. The pale-colored sedimentary breccia is about 140 m thick. Upward in the section at Lime Hill, the gravel changes color to dark, and it is thick- to very-thick-bedded. The stratigraphically highest beds of dark gravel appear paler in color owing to calcic soil development; elsewhere in the section soils are absent. This dark gravel is well exposed in quarries near Yermo Road, where cross-beds and imbrication indicate stream flow to the east and northeast (Figure 4B). Common clasts include a wide range of volcanic rocks, leucocratic granite, and quartzite, all moderately- to well-rounded. Dacite similar to that derived from the Calico Hills is very common. Less common are mafic granodiorite, orthogneiss, black quartzite, and mylonitic rocks. Rare cobbles of brown platy limestone (derived from the Barstow Formation) and red silicified sedimentary breccia occur. In some beds, common fine-gravel-sized chips of white siliceous material may indicate a continuing source from silicified limestone of the Barstow. Laterally continuous beds are visible on aerial photographs. This evidence, coupled with the well bedded and moderately size-sorted deposits, suggests valley-axis stream systems, not alluvial fans, are represented by this part of the Yermo(?) gravel. Disparate clast types, possibly sourced from the Newberry and Calico Mountains areas and Alvord Mountain, reinforce this interpretation. The upper section is about 170 m thick.

No definitive dated material is available for the Yermo gravel. It overlies Barstow Formation that is considered to be as young as ~13 Ma, and underlies ~1 Ma soil horizons (Fig. 3c) along the north side of the Yermo Hills. Owen and others (2011) examined the minimum constraining age for Yermo gravel near the Calico Early Man Site, by studying the gravels using cosmogenic methods. They concluded that the gravels are older than ~200 ka. A tuff we collected in Barstow beds at Lime Hill is correlated to 12 to 10 Ma tuffs in the region (sample M10NS-452), suggesting that the Barstow may be a bit younger in that location, and the Yermo therefore must be younger than about 10 M.y. The geomorphology of the Yermo gravel deposits reflects arching and faulting, and the fan of which the deposits were part is now separated from its source area. These criteria--lack of attachment to a source area and completely modified geomorphology--have been used successfully to class deposits as early Pleistocene to Pliocene during regional surficial mapping (e.g., Bedford and others, 2010). This relative age assignment remains the best until firmer criteria are discovered.

The South Alvord gravel

South and southeast of Alvord Mountain, Byers (1960) considered gravel exposed in low, rounded hills to be Quaternary and Tertiary in age. He divided the gravel into a lower granitic unit (QTcg) and an upper volcanic unit (QTg) based on clast composition. The gravel lies on, or is faulted against, Miocene strata of the Barstow Formation and the Spanish Canyon Formation. The south Alvord gravel exposed in small hills near the mouth of Spanish Canyon contains clasts (in order of abundance) of granitic (monzodiorite and granodiorite), metamorphic (schist and marble), and volcanic (primarily andesite) rocks. It is thin- to medium-bedded, poorly sorted, and probably represents alluvial fan deposits. A few debris-flow beds lie in an otherwise fluvial section. All clasts are similar to rocks exposed in Alvord Mountain. One cobble of muscovite granite may represent a dike rock from the Alvord Mountain area or a reworked clast from the Goldstone gravel.

Farther south, gravels underlie pediment exposures and a broad hill that stretches from the powerline road to Field exit of Interstate Highway 15 and beyond to Buwalda Ridge (Figure 1). Here, four distinctive units are present in stratigraphic order: lower granitic conglomerate (QTcg of Byers, 1960), a volcanic-limestone gravel (QTg of Byers, 1960), another granite-rich gravel containing muscovite granite (not distinguished by Byers, 1960), and an upper heterolithic gravel.

The lowest unit is sandstone and conglomerate with mainly granitic source. It lies on a poorly exposed contact with Barstow Formation; the contact may be a fault. Leucocratic biotite granite is the main granitic rock, but dark-colored monzodiorite and granodiorite, diorite or gabbro, mylonite, quartzite, schist, and calcsilicate rock also are present. These rock types generally match those described by Miller and Walker (2002) for Alvord Mountain rocks, but the common clasts of leucocratic biotite granite are represented only by sparse outcrop in Alvord Mountain. In addition, the mylonite has stronger affinities with that in the Cronese Hills to the northeast. These rock types may be derived in part from recycled clasts originally deposited in the lower Miocene Clews Formation (Fillmore, 1993). The lower unit is well-bedded and sparse crossbeds indicate easterly (northeast, east, and southeast) flow, but a few crossbeds indicate west and southwest flow. Beds generally dip greater than 20 degrees south near the top. The lower unit is notable in that it is cemented by calcite and highly folded. It is roughly 635 m thick.

The second unit is dark-colored and not cemented, but is interbedded with the lower unit over an interval about 15 m thick. Its basal part contains clasts similar to those in northern exposures of the south Alvord gravel, and closely matching the Alvord Mountain bedrock types, Upward it rapidly transitions to a gravel that has few clasts that match the Alvord Mountain source area, instead being more similar to the upper Yermo(?) gravel at Lime Hill: dacite, silicified limestone, andesite, basalt, red conglomerate, and silicified tuffaceous sandstone. Some limestone clasts consist of stromatolites. The gravel in this area is medium bedded and the matrix is arkosic sand. In many exposures bedding is uniform and sorting is medium to poor. These combined characteristics are consistent with a valley-axis stream system. The unit thins from west to east: 310 m to 155 m. Dips in the second unit are generally less than in underlying conglomerate and sandstone.

Overlying the dacite-limestone gravel is a very pale-colored sand and gravel unit that is very similar to the Goldstone gravel. Coarse beds consist of moderately sorted pebbles and cobbles. Clasts are mostly muscovite granite, along with red-and-green calcsilicate rock, mafic granodiorite, mylonite, diorite, basalt, and dacite. Most clasts are well rounded and form beds that are thin to medium in thickness and exhibit moderate sorting. Thin-bedded to very-thin-bedded pebbly sand is the most common facies. The clast composition clearly denotes a Goldstone source, possibly with admixtures from the Alvord Mountain area, although the admixture clast types are not diagnostic. The simplest interpretation is that of distal broad wash deposit. The unit is about 310 m thick.

The fourth and highest unit in the sequence is a heterolithic alluvial fan gravel that interfingers with playa deposits of the Mojave River formation and thus its southern distal margin is constrained at the base to no younger than 2.1 Ma and at the top to ~1.0 Ma (Nagy and Murray, 1991; Pluhar and others, 1991). This gently southeast-tilted unit contains lenticular, poorly sorted beds of pebbly sand and gravel, generally with a maximum clast size of small boulders. Arkosic pebbly sand is the most common lithology. Clasts range widely in composition, including all of the typical clasts of the underlying three units and of bedrock types in Alvord Mountain. The unit contains numerous weak to moderate paleosols, consisting of minor carbonate accumulations and Bw horizons, giving it a distinctive pink-and-white striping viewed from a distance. It is approximately 850 m thick.

The upper part of the south Alvord gravel sequence is difficult to separate from younger alluvial fans. Our observations show that lithologically similar gravel interfingers with lacustrine deposits of Lake Manix (<500 ka), but this may represent a younger fan sequence. On the south side of Buwalda Ridge, arkosic pebbly sand similar to the south Alvord gravel is faulted against volcaniclastic gravel. In one locality on the south side of the Mojave River south of Buwalda Ridge (site M10-90, UTM 11S, 544673E, 387144N), fine-grained playa and alluvial deposits of the Mojave River formation grade up into arkosic sand and gravel interpreted as equivalent to the upper unit of the south Alvord gravel. Within 10 m above the base of this arkosic gravel, it contains increasing amounts of volcaniclastic rocks derived from the Cady Mountains; farther west, this volcanic-rich gravel (the Cady gravel) interfingers with basal Lake Manix deposits. Recent studies of the Manix Formation, including paleomagnetic analysis and re-dating of the source rhyolite for the Manix tephra, indicate a range of ~500-25 ka (Reheis and others, 2009). Around the northeastern margin of Buwalda Ridge, relations at a few outcrops suggest that arkosic gravel interfingers with reddish, matrix-rich volcaniclastic gravel with paleosols. These relations suggest that the base of the south Alvord gravel in this area may overlap in age with the older part of the Cady gravel (described below).

The Cady gravel

The Cady gravel (new informal name) is a dark-colored, largely mafic volcaniclastic gravel lying north of the Cady Mountains, extending from near Afton Canyon on the east to Soldier Mountain on the west, and largely south of the Mojave River (Figure 1). We include the partly lithologically similar gravel that underlies Buwalda Ridge in this unit, which extends its age range considerably. The Cady gravel includes clasts of a variety of volcanic rocks, mainly basalt, andesite, andesite breccia, and minor rhyolite. In the Manix Wash area, it contains dark metavolcanic clasts that are probably sourced from Sidewinder Volcanics exposed in the northwestern Cady Mountains. In the Afton area, the Cady gravel conformably overlies a boulder fanglomerate shed from Cave Mountain, and underlies late Pleistocene deposits of Lake Manix (Figure 5). This Cady gravel was previously termed the "gray conglomerate" by Ellsworth (1932) and Meek (1989). Near and southwest of Buwalda Ridge, the gravel conformably overlies the Mojave River formation and locally interfingers with lacustrine units (Nagy and Murray, 1991; Jefferson, 2003). In both these areas, the beds are mostly 0.5-2 m thick with sand to cobbles and locally, boulders, in a grayish brown matrix. The unit has weak to moderately developed paleosols throughout, consisting of minor carbonate accumulations and B horizons.

There are two other outcrop areas of mafic volcaniclastic gravel that are stratigraphically older, and sedimentologically and lithologically somewhat different than, the Cady gravel as previously recognized. The ≥120-m thick mass of gravel and sand that underlies Buwalda Ridge mainly consists of alluvial-fan deposits similar to the younger part of the Cady gravel (but apparently contains no metavolcanic clasts). However, the basal part, as much as 35 m thick, is a sedimentary breccia composed of matrix-supported, angular to subangular to well-rounded, cobbles to large boulders that lack visible bedding. The angular to subangular clasts are mainly composed of andesite and lesser basalt. In sharp contrast, the rounded clasts—as much as 25% of the total—are mainly composed of granitoids, including meta-diorite, granite, and epidotized siliceous dike(?) rocks. This breccia may have deposited as a landslide originating in older alluvial deposits. Upward in section and westward along Buwalda Ridge, the proportion of these granitic clasts decreases to a few percent. Along the northeastern margin of Buwalda

Figure 5. Photograph of the Cady gravel south of Afton.

Ridge, the unit locally contains finer-grained fan deposits that are intercalated with red, matrix-rich, carbonate-bearing paleosols, and that appear to grade up into, or interfinger with, arkosic south Alvord gravel. In one area on the eastern edge of Buwalda Ridge, the unit grades up into mafic distal-fan and playa deposits. Along the south side near the Manix Fault, the gravel is sheared and locally rotated to vertical dips.

The other outcrop area lies south of the Mojave River east of Buwalda Ridge. Here, cemented, largely andesitic gravel and sand that is generally finer grained and more evenly bedded than the Cady Gravel elsewhere underlies younger, weakly indurated gravel containing roughly equal proportions of mafic volcanic and granitic clasts, as well as lenses of reworked aeolian sand, along an angular unconformity. Near the base of the exposed section of the older gravel is a package of coarser cobble-boulder gravel that contains well rounded granitoids and siliceous rocks similar to those in the sedimentary breccia of Buwalda Ridge, as well as quartzite. It is tilted and faulted, with dips up to 45° locally, and contains angular unconformities.

The age of the Cady gravel ranges from at least middle Pliocene to middle Pleistocene. Near the top of Buwalda Ridge, the gravel contains two closely spaced lenses of tephra, which have been identified as the Tuff of Mesquite Spring, dated in Death Valley at 3.28 ± 0.07 (Knott and others, 2008). Thus, this local gravel package is equivalent in age to the Goldstone gravel to the north. However, the age of the basal sedimentary breccia is unconstrained and could be as old as late Miocene. No age control currently exists for the cemented gravel and sand to the southeast of Buwalda Ridge. In the Afton area, the Cady gravel overlies fanglomerate derived from Cave Mountain. This fanglomerate contains a tephra whose chemical composition matches a range of late Pliocene and Quaternary samples from diverse study areas, but may be most closely matched with the 2.4-Ma Ishi Tuff. Near Manix Wash, the Cady gravel interfingers with the basal Manix Formation, and is as young as ~400 ka from correlation with lake sediment in the Manix core (Reheis and others, 2009). In the Afton area, the Cady gravel is unconformably overlain by deposits of Lake Manix, the oldest of which just north of the river contain the ~184-ka Manix tephra.

Tectonic framework

During the Pliocene and early Pleistocene, the Coyote-Alvord area lay within a domain of sinistral shear associated with faulting that bled off of the San Andreas fault system, in a zone called the Eastern California Shear Zone (ECSZ) by Dokka and Travis (1990a). Faults in the sinistral domain strike approximately east, exhibit long-term sinistral offset, and are associated with clockwise vertical-axis rotation (e.g., Ron and others, 1984; Dokka and Travis, 1990b; Luyendyk, 1991; Schermer and others, 1996, Miller and Yount, 2002; Hillhouse and others, 2010). The western boundary of the sinistral domain interacted in a complex fashion with dextral faults farther west (Schermer and others, 1996; Miller and Yount, 2002) and this boundary may have changed position with time (Miller and others, 2010). Using the young faults mapped by previous workers, the Quaternary faults described by Miller and others (2007), and our unpublished mapping of Quaternary faults (shown on Figure 1), it is possible to relate the gravel deposits and the inferred paleotopography they represent to fault blocks, fault domain boundaries, and faults themselves. That work will be the subject of a future publication but the framework is important for understanding the subject of this paper, paleogeography.

The paleogeographic maps show a few generalized fault locations. We used the following assumptions to arrive at these generalizations, principally by extrapolating faults across covered areas:

1. Most mapped faults represent segments of long fault systems that are approximately linear. The identified segments tend to have a component of shortening across the fault, resulting in uplift and exposure of pre-Quaternary deposits. Other parts of the fault system are assumed to be in conservative strike-slip mode or have a component of extension across the fault. This provides a basis for "connecting the dots" between mapped fault segments.
2. All Quaternary faults have been active since early Pliocene time and probably earlier. We have no firm basis for this simplifying assumption.

In addition to the principal strike-slip faults shown in Figure 1 (Coyote Lake, Cave Mountain, Manix, Calico, and Paradise faults), several smaller intra-block faults have been mapped. The Dolores Lake fault (Meek, 1994; Dudash, 2006; Leslie and others, 2010) and several faults within the Yermo Hills (D.M. Miller unpublished mapping, 2010) are dextral transpressive faults that lie within the block bounded by the Manix-Cave Mountain fault pair. Sets of graben (Leslie and others, 2010) and other minor faults and folds strongly suggest that more faults lie within this block. The emerging picture is one of complex internal deformation of the block.

Nagy and Murray (1996) and Meek and Battles (1991) argued that the appearance of Cady Mountains volcanic rocks in alluvial fan deposits near Afton marks the time of onset of a compressional tectonic regime that caused uplift of the Cady Mountains. Based on magnetostratigraphy within the Cady subbasin, this change occurred ~1.1 to 0.78 Ma (Nagy and Murray, 1996). However, we have identified much older volcanic gravel with Cady Mountains composition. At Buwalda Ridge, the Cady gravel is Pliocene in age and possibly older. The basal sedimentary breccia, containing a mix of mafic volcanic and granitic rocks, suggests derivation from a nearby steep range front. Southeast of Buwalda Ridge, faulted and tilted volcanic-rich gravel unconformably underlies relatively untilted Cady gravel. These relations suggest that uplift of the Cady Mountains began no later than Pliocene time. At present, the Cady gravel at Buwalda Ridge is surrounded on the west, north, and east by arkosic deposits of the south Alvord gravel (themselves arched and tilted), and is faulted on the south against the fine-grained, arkosic Mojave River formation. Buwalda Ridge may have been translocated along the Manix Fault from a source adjacent to the Cady Mountains about 6-8 km to the east of its present location. If this is correct, the age near the top of this gravel unit implies a maximum left-slip rate of ~1.8-2.4 mm/yr on the Manix fault.

Another example of left separation along a fault is indicated by our study. The south branch of the Cave Mountain fault separates the south Alvord gravel from a tall hill composed of Mesozoic granitoids, gneisses, and metamorphic rocks in the southwest Cronese Hills (Walker and others, 1990). The south Alvord gravel at this location contains no clasts similar to the adjacent hill, indicating tectonic juxtaposition by a minimum of several kilometers of left slip on the Cave Mountain fault.

Paleogeographic interpretation

To interpret paleogeography from gravel deposits, knowledge of the source for clasts is needed as well as an interpretation of the mode of deposition and direction of sediment transport. We have described source areas for clast assemblages and transport directions in the preceding. We make the following assumptions for interpreting the depositional mode of the sediments.

1. Valley-axis drainage deposits are indicated by laterally persistent bedding, moderately- to well-sorted sediment, and mixed sources for clasts. Examples are the Goldstone gravel and the upper Yermo(?) gravel at Lime Hill (Figure 4b).
2. Proximal alluvial fan deposits are indicated by boulder gravel, poorly sorted deposits, debris-flow deposits, and generally angular clasts. Examples are Buwalda Ridge (Cady gravel), the western Yermo Hills (Yermo gravel), and northern exposures of the south Alvord gravel.
3. Medial and distal alluvial fan deposits are indicated by cobble and pebble gravel that are well bedded as lenticular bedforms, and by generally more rounded clasts than for proximal fan deposits. Examples are the eastern Yermo Hills (Yermo gravel; Figure 3) and much of the Cady gravel (Figure 5) and south Alvord gravel.
4. Deposits adjacent to fault scarps and cliffs are indicated by sedimentary breccia and rock avalanche deposits with extremely poor sorting and highly angular fragments. Examples are basal Buwalda Ridge deposits and the base of the Yermo(?) gravel section at Lime Hill.

Age information for the gravels is imprecise in most locations. We make the following assumptions for the paleogeographic maps:

1. Goldstone gravel. This unit is firmly dated northwest of Alvord Mountain in its upper part as 3.3 Ma. Its lower part may be older than 5.5 Ma, so we assume that it ranges from late Miocene(?) to Pliocene.
2. Yermo and south Alvord gravels. Each of these units is assumed to range from Pliocene to early Pleistocene. The Yermo gravel in the northern Yermo Hills can be no younger than early Pleistocene. The south Alvord gravel is in part early Pleistocene and may locally be as young as middle Pleistocene.
3. Cady gravel. This unit is early Pleistocene in age in nearly all exposures south of the Manix fault, but the part that lies north of the fault, at Buwalda Ridge, is Pliocene and possibly older.

The inferences for depositional environments and ages of gravel units as described above are used to make maps of Pliocene and early Quaternary sediment sources, transport, and deposition (Figure 6).

Pliocene paleogeography

Sources for gravels shed in the Pliocene were in the Goldstone area, the Calico Mountains, and Cady Mountains. In addition, Alvord Mountain rocks were shed into nearby gravels, although for reasons described below the current Alvord Mountain configuration was probably not the source. Additional sources for Pliocene gravel in a valley-axis depositional setting at Lime Hill and south of Alvord Mountain apparently lay to

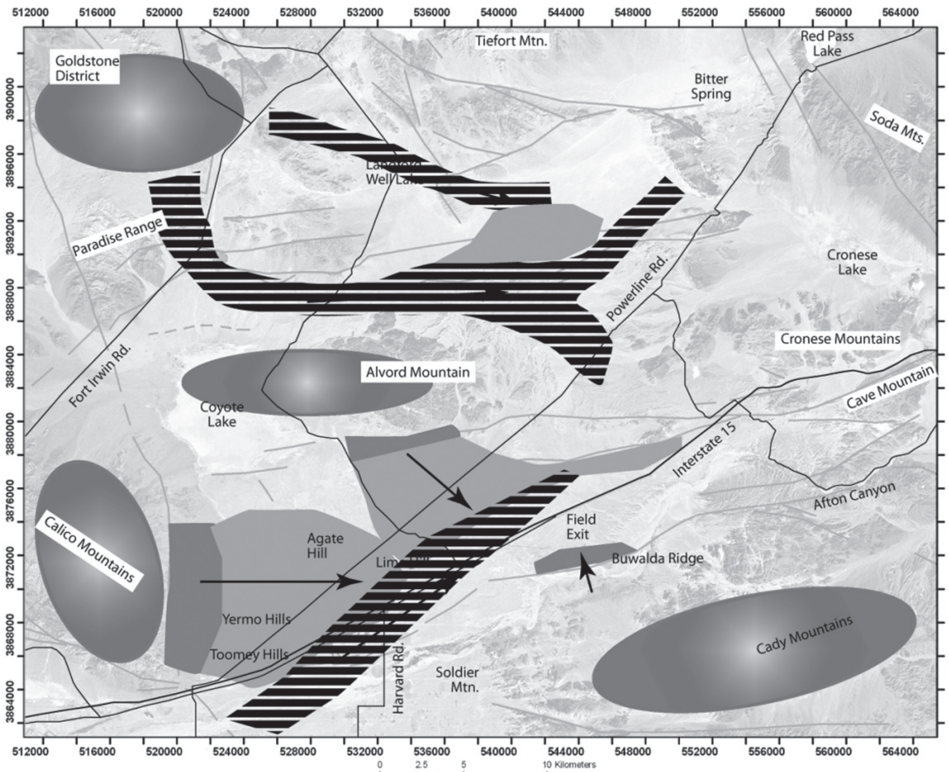

Figure 6. Paleogeography in A. Pliocene time, B. early Pleistocene time. Quaternary faults are not restored, but are shown for clarity. See text for descriptions of depositional environments. Dark gray ovals are high areas shedding gravel; light gray outlined by black line are playas. Dark gray are proximal fan deposits; lighter gray are distal fan deposits. Black striped zones represent valley-axis sedimentation. Arrows indicate sediment transport direction.

the southwest, perhaps in the Newberry Mountains area. Thus, many of the modern broad high mountains were sources for gravels in the Pliocene.

Depocenters for Pliocene sediment were two east-oriented long troughs, one approximately coincident with the Coyote Lake fault and one approximately coincident with the Manix fault. In both cases, the troughs held streams that flowed eastward but also received sediment from mountains to the north and south. Modern topography in northern Fort Irwin (north of Figure 1) offers an analog for this paleogeography. Because overall topography slopes southward, streams currently flow from Nelson Lake basin southeast to a broad east-sloping valley north of Tiefort Mountain, ending in a playa. Down-to-the-north scarps on the major east-striking faults limit the south transport of detritus, serving as barriers that funnel streams eastward (Miller and Yount, 2002). From the transport of Goldstone gravel eastward past the future site of Coyote Lake we can infer that the Coyote Lake low did not exist, but rather a north-facing scarp lay in the area north of Coyote Lake or the entire Coyote basin was a topographic high.

The Goldstone gravel deposits indicate a major east-directed stream system north of Alvord Mountain but similar deposits also lie north to Langford Well Lake. Rhyolite clasts are more common in the north, and since they are derived from outcrops on the north side of the muscovite granite body that contributes the most distinctive clasts, they may indicate a northern source and perhaps a separate route across what is now a high pediment dome, named "Noble's Dome" by Byers (1960). On this basis it is possible that doming took place between the Goldstone area and Langford Well Lake during or after the Pliocene.

Pliocene alluvial fans were shed east from the Calico Mountains in the modern Yermo Hills area, and as a valley-axis deposit reached as far east as the Buwalda Ridge area. These gravels intermixed with other sources from the Lime Hill area and eastward.

The Alvord Mountain source contributed sediment to alluvial fans south of the mountain as well as farther west, at Lime Hill. However, leucocratic biotite granite is a common constituent for the lowest gravel unit south of Alvord Mountain, but is a minor modern bedrock element in Alvord Mountain; as a result, the source for south Alvord gravel may have been a predecessor mountain that had a different proportion of bedrock.

The Cady Mountains were a source area for Pliocene gravel exposed at Buwalda Ridge. Sedimentary breccia apparently was shed from fault faces along Manix fault. Sedimentary breccia also occurs in the lower Yermo(?) gravel at Lime Hill, suggesting fault-scarp derivation nearby.

If the Goldstone gravel unit south of Alvord Mountain is Pliocene, like the unit north of Alvord Mountain, it constrains the underlying mixed-source valley axis gravel with a Calico Mountain source to be Pliocene as well. This would imply that the similar valley-axis gravel deposit at Lime Hill also is Pliocene in age. However, the Goldstone gravel unit south of Alvord Mountain is not connected with the Pliocene arc of Goldstone gravel farther north, and permissibly may represent a different stream system, probably younger in age and possibly making use of a route through the current down-sagged Coyote Basin. If this scenario is correct, the southern Goldstone gravel unit only is constrained to be older than 2.1 Ma, because the overlying south Alvord gravel must be older than 2.1 Ma at its base. It would therefore be earliest Pleistocene or late Pliocene in age.

Early Pleistocene paleogeography

Topographically high source areas during the early Pleistocene were very similar to the modern topography, with alluvial fans shed north from the Cady Mountains, east from the Calico Mountains, and south from Alvord Mountain. The Goldstone source area was probably shedding directly into the Coyote basin, as it does now, although a short-lived stream system may have fed to south of Alvord Mountain as the Coyote basin started to sag, as described above. Alvord Mountain tilted northward and rose, deforming the Pliocene Goldstone gravel into an arc around the uplift. As it rose, more of the Miocene strata may have been exposed, leading to a shift to a volcanic-rich upper part of the south Alvord gravel.

Low areas during the early Pleistocene, as during the Pliocene, were similar to modern topography. The development of a broad sag to form Coyote Lake basin was the biggest change from Pliocene paleogeography. The enigmatic north Coyote escarpment (Meek, 1994; Albert, 1998) may owe to the down-dropping of the basin, and could represent a normal fault, a thrust fault, or south-tilted stratigraphic units of the Goldstone gravel. The relief along the southeast front of the Paradise Range probably formed at this time. The Mojave River formation south of Buwalda Ridge formed in an internally drained low as a playa with alluvial fans feeding it from the north and south (south Alvord and Cady gravels, respectively) and poorly defined, probably valley-axis, systems on the east and west. Farther east, two unlike facies of gravel met near the modern basin axis occupied by the Mojave River, indicating that the valley was elongate east-west. Little information is available for this time period along the Mojave River course to the west, but an internally drained valley probably lay southwest of Lime Hill because future Lake Manix occupied a large basin in that area (see below).

Changes since the early Pleistocene

The best Pleistocene timeline available in the Coyote-Alvord area is the introduction of the Mojave River and the deposition of Lake Manix beds beginning about 500 ka (Jefferson, 2003; Reheis and others, 2007). These beds are uplifted and deformed at Harvard Hill and the Toomey Hills (Reheis and others, 2007; Leslie and others, 2010) but are only slightly warped at Buwalda Ridge and apparently are undeformed at Lime Hill. Evidently, the latter two pop-ups rose in early to middle Pleistocene time, but uplift waned in the late Pleistocene. In addition, Agate Hill is bounded on the south by uplifted and deformed Mojave River gravels that indicate late Pleistocene deformation. As a result, it appears that the several hills that seem to be pop-ups along Quaternary faults have slightly different histories and these areas provide potential local sources for recycling of older materials.

Broad areas domed up after the early Pleistocene. Early Pleistocene and older gravel deposits such as those exposed in the Yermo Hills and south of Alvord Mountain were uplifted and incised by streams during the late Pleistocene, in an ongoing process.

Conclusions

Two Pliocene east-trending topographic troughs lay astride the Coyote Lake and Manix faults, each funneling sediment along stream courses from topographic highs that lay to the west. Tributary channels from bordering highlands north and south of each trough contributed to the sediment, but the bulk was derived from two persistent highs in the Calico Mountains and the Goldstone Mining District area. Early Quaternary paleogeography was similar in the southern trough, but the northern trough was disrupted by a prominent sag at Coyote Lake as Alvord Mountain was warped up and tilted to the north, each of these features deforming the Pliocene gravels of the former northern trough. During early and middle Quaternary time, several pop-ups along the Manix fault rose to expose Pliocene gravels. Some of the pop-ups deform middle Pleistocene Lake Manix beds, and may be continuing to rise. South of Alvord Mountain a sequence of gravels may record continuous deposition from the middle Miocene Barstow Formation to late Quaternary alluvial fans, all exposed in a domed and tilted sequence.

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The Ubehebe Volcanic Field (Death Valley, CA): a high-fidelity analog site supporting MSL11 integrated science mission goals

Clay cycle and habitability potential under arid hydroclimatic conditions

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Introduction

The Mars Science Laboratory (MSL) mission will primarily search for potentially habitable, ancient geological environments, as a preliminary step to future life detection e.g., the ESA/US 2018 Pasteur ExoMars, and sample return missions. All MSL site candidates include hydrated clay minerals, or phyllosilicates, and have been evaluated by context, diversity, habitability, and preservation potential of organics. Phyllosilicates are unambiguous indicators of past aqueous activity on Mars, and of particular interest due to their high preservation potential.

MSL science goals will require a highly-integrated science approach simultaneously involving: a) the understanding of role of (liquid) water/climate, and time scales involved in weathering processes and conducive to life (as we know it); and b) the identification of geological targets enabling concentration as well as preservation of biological and nonbiological organics.

In the above context, we have identified high-fidelity analog sites at the Ubehebe Volcanic Field (UVF) (Death Valley National Park, California, USA), Figure 1. Overall, the UVF combines multiple analogies (geological, geomorphologic, mineralogical, and hydro-climatic) of setting and processes argued for MSL sites and other Martian sites.

The UVF comprises three main subsystems, or areas of prime science interest, each one with a specific, and/or general feature relevant to MSL sites (underlined).

1. The Ubehebe Crater (UC), the largest in the area, is ~0.8 km wide, 150 to 237 m deep, and ~2 to 4–7 thousand years old. The exposed wall lithology consists of a hundreds meters-thick heterogeneous fluvial deposit (e.g., reddish mudstone), and a rhyolitic tuff outcrop uniquely localized. They are overlain by thinly bedded/laminated pyroclastic deposits (pumice and basaltic ash) of Recent age. Wall deposits supply

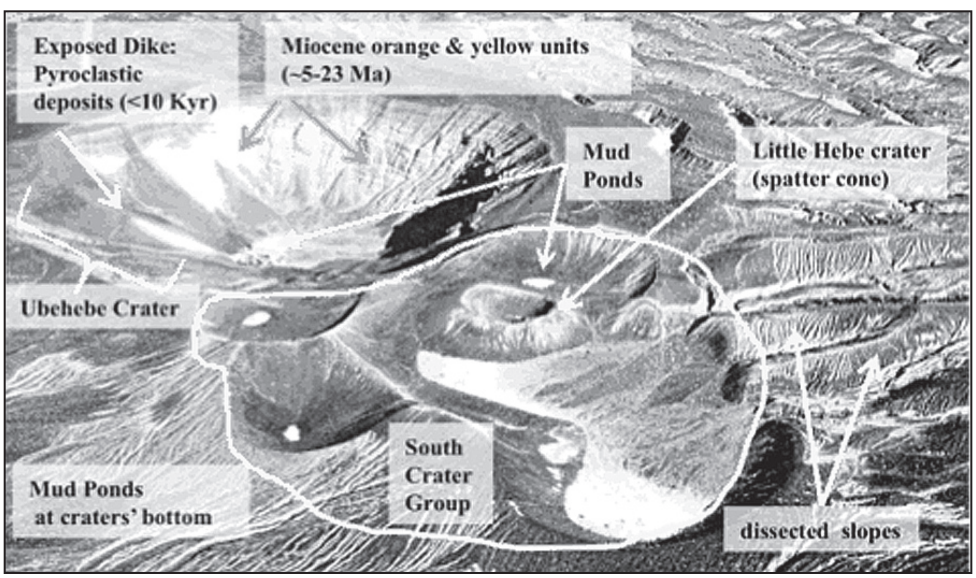

Figure 1. Aerial view (~2 km by ~2 km) out of 25 km^2 including target features of the UVF at a spatial scale (few hundreds of meters to 4-5 km traverse) reachable by a rover. The Ubehebe Crater is centered at 37°0'35"N, 117°27'01"W at an elevation of ~655-meters. Road access is on the left-upper corner

weatherable material to intra-crater fill deposits rich in Al-smectites (Mawrth/ Eberswalde) and of unknown thickness.

2) The Southern Craters Group (SCG) has a shallow drainage and more extended alluvial features (Holden_ Crater) with respect to the other sites; and 3) the Little Hebe (LH) is a small spatter cone, whose rim consisted of molten scoriaceous lava. This lava contains partially oxidized hematite, layered sulfates unique at this site, and clays (mineralogical variability/Gale Crater).

A comprehensive set of integrated investigations can be conducted at each location to address general and specific mission goals and to test science-driven hypotheses (multiple Science Merit Related to Mission Objective).

- The UVF is a cratered terrain (caldera) formed by subsequent phreatomagmatic eruptions 2–7 thousand years ago and presents a distinct drainage system. This enables direct measurement and quantification of sedimentary processes, moisture conditions, and clay formation from a unique source, or a few identifiable ones.
- The UVF geology is relatively young—oldest formations are of Miocene age—with respect to that argued for the MSL sites (e.g., Noachian–Hesperian). As such, the analogy refers to a past wetter/warmer Mars rather than to the present dry and cold Mars.
- UVF developed under desert conditions and timescale (~10^3 to 10^4 years to present), which are analogs of hydro-climatic conditions and timescale inferred by some for the Noachian–Hesperian transition, i.e., characterized by episodic (maybe seasonal) long-term arid–semi-arid rainfall (~10^4 years)[1]. Mission Elements: Understanding time scales of sediment weathering in the function of liquid water exposure and subsequent formation of clays from geologically different parent materials. Hypotheses: Are Al-smectites produced in situ, or are they (wash-out) from elsewhere?
- UVF includes a diversified set of sedimentary analog environments (fluvial, alluvial, lacustrine, and pyroclastic) at landing sites. Mission Element: Identification of the best target for concentration/preservation of organics. Main question: How will different depositional settings influence habitability and preservation potential?
- UVF subsystems account for a high mineralogical variability: within 1 km^2 different types of phyllosilicates (Marwth) and/or more mineral types (clays, Fe-oxides, detrital silicates, sulfates, and carbonates). Mission Element: Prioritizing the search for organics/habitable environments by the CheMin-SAM suite based on non-contact, remote information from ChemCam. Hypotheses: Evaluation of habitability and preservation potential in clay-rich vs. nonclay background materials (follow the minerals and the water!).

Current Investigations

To address prime science questions we have been focusing on the Ubehebe Crater fill deposit (mud pond). Here we can test hypotheses centered on recycling vs. neo-formation of clay minerals as analog processes of forming smectites on Mars. Preliminary Q&A, based on a still limited set of observations, follow below.

1. Are currently arid hydro-climatic conditions sufficient to form smectites from recycled sedimentary components?

   Yes: up to hundreds meters of fine-grained sediment can rapidly accumulate and weather to Al-phyllosilicates under arid conditions (118 ± 42 mm/y rainfall over year

Table 1: Scientific merit of the analogue site to MSL/ExoMars missions

Site Name	Ubehebe Crater and Ubehebe Volcanic Field
Prime Science Questions 1	See main text above
Distance of Science Targets from nearest road or airstrip	Ubehebe Crater Bottom—10-15 min walk 0.3 km to park lot Little Hebe – 20 min-walk 1.5 km to park lot Southern Crater Group—2 km to park lot
Environmental features	Max temp: Air 52°C, Min temp: -10°C Precipitation: see main text. Vegetation coverage: 0 to 20-50% bush, depending on season and location.
Previous studies at analogue site	[8-10]
Primary Landing Site Target	MSL: e.g., Mawrth, Eberswalde. Any smectite-rich area of Mars.

2004 to date) similar to those argued for the Noachian–Hesperian transition[1].

The bulk mineralogical composition (XRD data) of red mudstones (N=6) from wall materials (fluvial) is typically detrital (major amounts of quartz, carbonates, plagioclase, k-feldspar), and minor inherited clays (chlorite, muscovite/illite, and possible smectites). In contrast, the intra-crater fill (mud ~99wt.% avg., N=5) contains higher amounts of primary products from weathering of glass and feldspars to Ca-montmorillonite (Al-smectite). Al-smectite-bearing horizons at Mawrth Vallis[2-4] may represent a late sedimentary, or altered pyroclastic deposit[5] draping the topography[6-7], which appears to be the case for the Ubehebe Crater.

In Water Year (WY) 2010 two extreme rainfall events delivered 75 mm rain in about 7 days (January and February 2010). We assume that from the two events combined, the crater bottom received up to 3–5 mm average (N=7) silty clay from direct erosion of the rhyolitic tuff outcrop (surface area of 4,263 m^2). A major contribution ~11.6 ± 1.7 mm (N=38) was from the wall (surface ~55,062 m^2). By assuming a constant average sediment rate of ~1 cm/y since the crater formed (2–10 thousand years) we can estimate a present-day thickness of about 33 to 167 m-depth.

2. How long does water have to be in contact with surface minerals in these sediments to form smectites?

   In WY 2010 the two rainfall events formed a 20 cm-deep pond (volume 286 m^3), conditions not reproduced in WY 2011, yet. Pond moisture varies from 2–3 wt.% water content in summer/dry conditions to ~50-55 wt.% (saturated conditions).

Other Investigations

We have been focusing[8-10] on distinguishing preservation from habitability potential. Particularly in testing (microbial) hypotheses in clay-rich vs. nonclay (background) materials: 1) clays are environments relatively low in living microbial content; 2) clays can preserve organic remains of microbes. Detailed explanation is beyond the scope of this abstract and will be provided as the opportunity arises.

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The sounds of silence in the west Mojave: a summary of historic Blackwater Well and Steam Well and the folks who lived there

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For much of the last 10,000 years the western Mojave was filled with life. Beginning over 160 years ago, the sounds of teamsters with their draft animals and the creaking of their wagons loaded with minerals on their way to market and with supplies from the small towns and railheads headed back to camp filled the air. Cattle and sheep grazed on the forage and used the water at places such as Blackwater, which was on the route between southern California destinations and Death Valley and mining camps in the east. Today the sounds of silence are deafening. Even the noisy windmill which once provided a constant source of water at Blackwater Well is gone. The public lands are used for weekend recreation; desert characters that once lived here are gone from the landscape. This paper recounts and summarizes what we know about Blackwater Well and discusses a bit about Steam Well in the Lava Mountains.

Introduction

Long before the Manly party lost their way trying to leave Death Valley in 1849, Indians used the water and resources at Blackwater Well and Steam Well. Petroglyphs at Steam Well left a permanent record of their use of that place, which was special to them. Today Steam Well is in a designated wilderness area and is naturally silent except for the din of vehicles in the distance or overflights entering and leaving the Naval Air Weapons Center at China Lake (NAWS China Lake). Only yesterday, as time goes, Virgil "the Steam Man" Ramey lived there and regaled the public with tall tales of the desert. Blackwater Well shows the evidence of Indian use by the rich dark midden soil and rock artifacts scattered about the seep. The sounds of the last cowboy, "Cowboy" Frank Curtis, no longer hang in the desert air. His home and appurtenances remain only in the files of local history or in our fading memories (Figure 1).

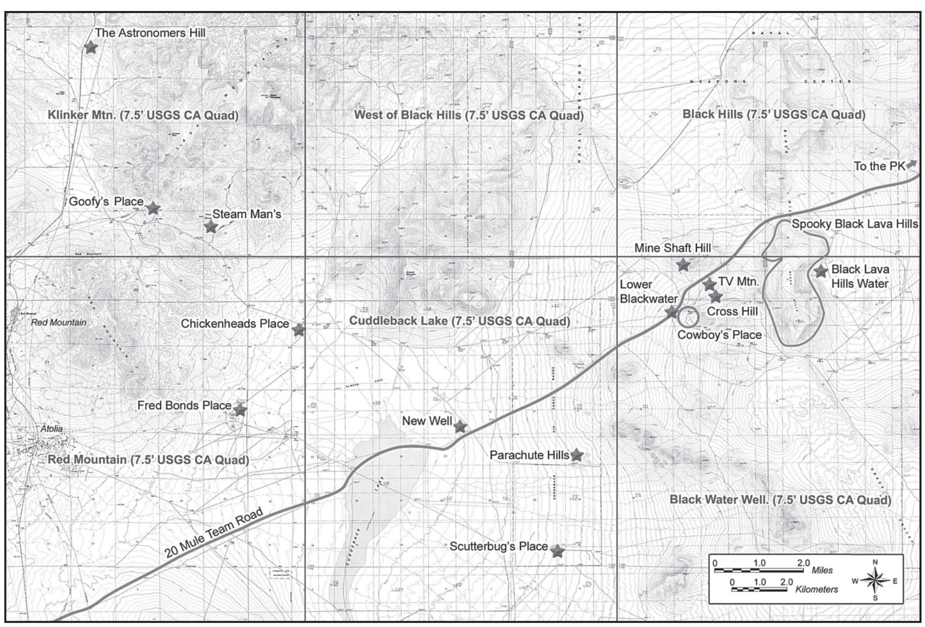
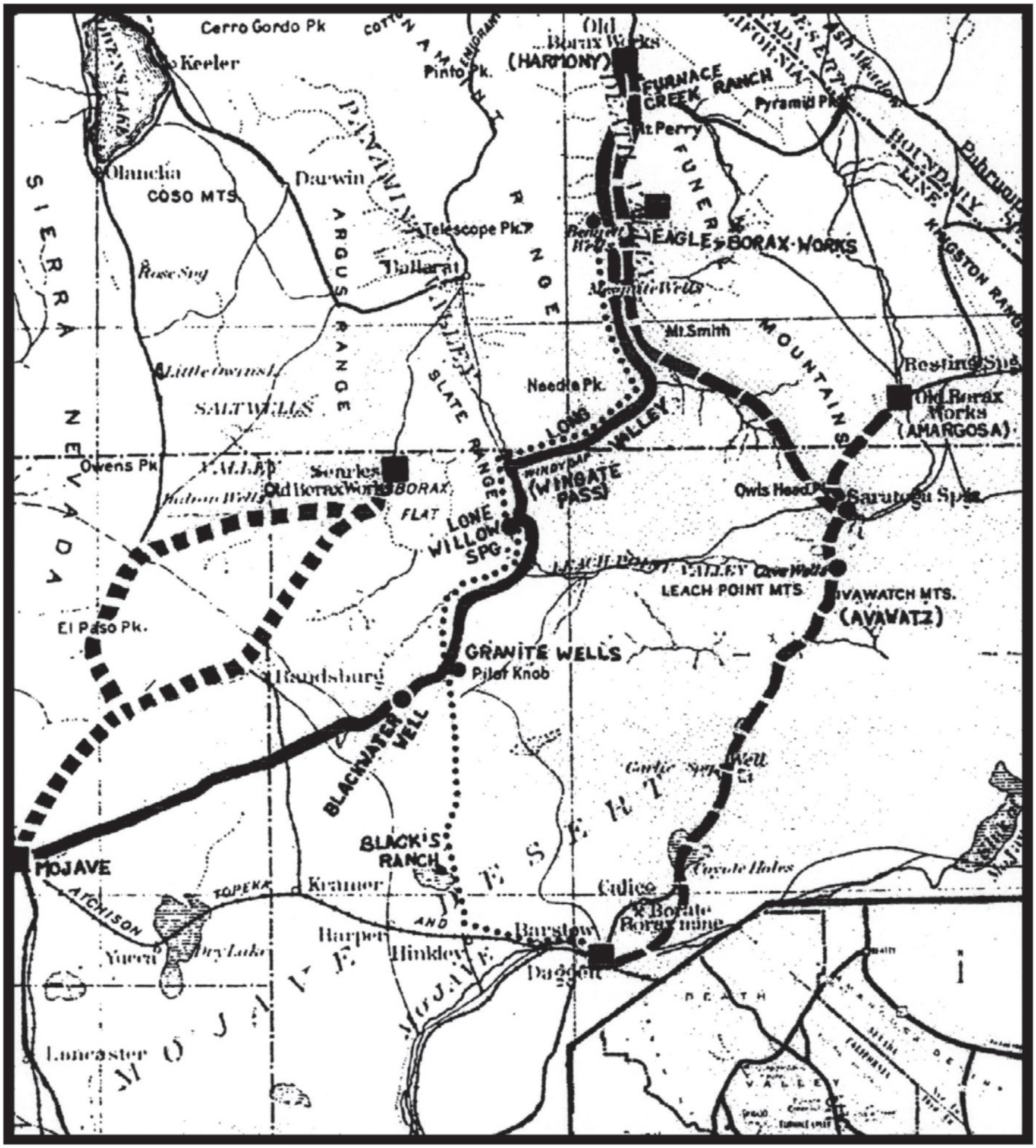


Figure 1. Map of Blackwater Well vicinity indicating local names of geographic places (Kaldenberg 2010:37).

In the middle of nowhere

The history of the land lying at the confluence of Kern, San Bernardino, and Inyo counties has yet to be adequately written. More histories focus on Death Valley than its surrounding geography. Part of the reason is that access has been restricted to the military lands in the Echo Range of the NAWS China Lake since the middle 1940s. Other issues involve the difficulty of access to the history of mining in the region and to the remoteness of the area.

Blackwater Well is located in northwestern San Bernardino County south of the China Lake Naval Air Weapons Station (Figure 2), north of Cuddeback Dry Lake, east of Red Mountain, and south of the China Lake Naval Air Weapon Station's Mojave B or Echo Range. It is about 20 miles east of the small towns of Atolia, Johannesburg, Randsburg, and Red Mountain.



Dotted Line: Ed Stiles' route hauling first borax from Eagle Works to Daggett.
Long Dashes: Route old-timers say was used from Harmony and Amargosa before opening of Mojave Road.
Solid Line: Famed 1883–1888 Death Valley-Mojave route of the 20-mule teams.
Short Dashes: Routes followed from middle 70s from Searles borax works.
Base Map: Reconnaissance of Borax Deposits of Death Valley and Mohave Desert, (USGS 1902), based upon map of U.S. Dept. of Agriculture 1891 Death Valley Expedition.

Figure 2. Various wagon routes of the western Mojave Desert indicating the location of Blackwater Well (Courtesy of Zee Malas).

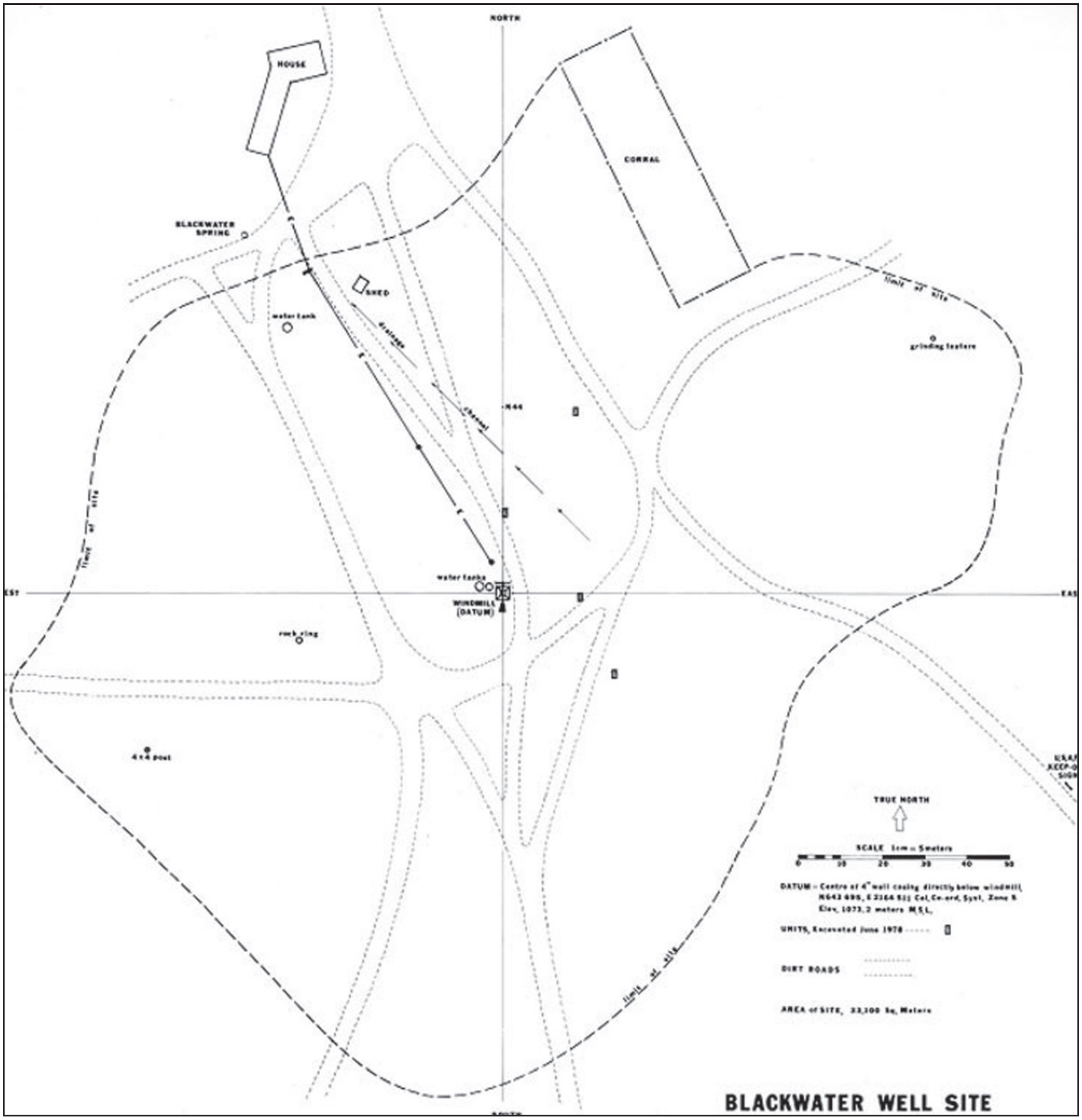


Figure 3. Blackwater Well, San Bernardino County, California

The prominent features in this portion of the Mojave Desert are the volcanic mountains dominated by the Lava Mountains to the west, Pilot Knob to the north, and the Black Mountains to the east. To the south lies the creosote-dominated landscape of the windswept Mojave Desert as it transitions into aeolian deposits around the numerous dry lakes, low hills near Kramer Junction, and the flat landscape of Edwards Air Force Base, before the elevation rapidly ascends to the steep terrain of the San Gabriel and San Bernardino ranges. The area has extensive deposits of sheet wash, Tertiary volcanics, and alluvial washes. The Parachute Hills, as they have been called by locals for a long time, just south of Blackwater Well are an isolated series of solitary hills which rise to an elevation of 200–400 feet above the general trend of the terrain. The Black Hills, which bound Blackwater Well to the northeast, are dark-patinated volcanics speckled with naturally formed rock shelters and large volcanic boulders on jumbled talus slopes. The terrain ranges in elevation from 3200 to 4500 feet above mean sea level.

Franklin Curtis lived there during the late 1960s–mid-1980s caretaking the grazing allotment for the Mendiboro Cattle and Sheep Company. Frank is one

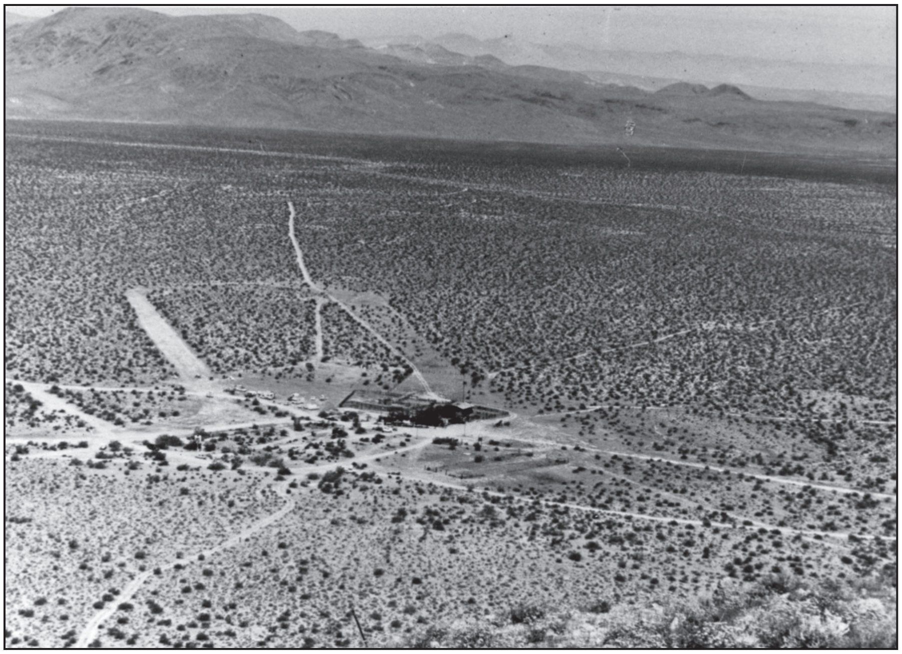


Figure 4. Blackwater Well, San Bernardino County, California

that source; the source discusses a fictional General Wingate (Hufford 1902:11) or Mendenhall's account which stated that "government troops dug the well" (Mendenhall 1909:92) which may also have come from Swamper Ike's stories.

Prehistoric land use

Early archaeological work on the desert focused on attempting to locate the oldest sites (Pourade 1966), Campbell et al. (1937), Rogers (1939), Simpson (1958), perhaps in order to indicate that Native Americans came after an earlier migration of "European" immigrants.

While Davis (1978) Simpson (1980) and Budinger (1981) have proposed occupation of the western Mojave Desert many millennia before conventional evidence indicates North America was populated, most scientists are convinced that sites containing chopper/chopping tools are components of the processing activities associated with food exploitation and not evidence of pre-Clovis migration and use of the desert (Basgall 2003, 2007a, 2007b). Pre-Clovis use of the Mojave Desert is not ruled out, but most scientists believe that the best current model is the conservative one which follows prehistoric migration either along the California Coast or the Ice-free Alaskan/Yukon corridor, following game animals, and eventually ending up at the tip of South America.

Late Pleistocene Period—Paleoindian—Lake Mojave/Silver Lake

Perhaps dating to around 13,000 years before present (YBP), towards the end of the Pleistocene, the Mojave Desert made a transition from a cooler and wetter period with steppe-like conditions towards the hotter and drier modern environment (Davis 1978). This period of human prehistory is affected by a melting of the glacial snowcaps on the high mountain ranges and the filling of the lake beds (Davis 1978; Madsen 1999). During the earliest portion of this time period the peoples who foraged along the lake margins were Clovis or Folsomoid folks with much the same tool kit as their relatives in northeast Asia. Davis' work at Lake China (1978) and Basgall's (2003, 2007a, 2007b) recent work have expounded upon their presence in the western

of a lost group of characters who once spread across the Mojave Desert, occupying mining claims, tending cattle and sheep, living in line shacks, and eking out a living from the public lands. While characters like Frank were here before the BLM began managing the public lands from field offices, they did not last too long after the BLM began enforcing residency rules associated with the use of these lands. Their mere presence helped protect resources and added quaintness to the landscape of the Mojave Desert (Figure 3). Their disappearance has removed a lively part of the past from of our history. Few of these characters have written their own history; it is up to others to do so. Dennis Casebier (2010) has an active program to record the oral history of the East Mojave. To date, little if anything has been done in the western Mojave to record the history of those who made it come alive during the 20th century.

For a review of the prehistory and early history of Blackwater Well the reader is directed to Kaldenberg, Leonard, and Reed (2009:159–208).

A recent publication (Schoffstall 2010:29) indicates that the U.S. Army dug the well at Blackwater Well. Based upon my 40 years of research this is as unlikely as the stories about a place on NAWS China Lake being called Fort Coso (Kaldenberg 2008) and being associated with the army. There are no army records indicating that Blackwater Well was a well dug by the army or that the army was ever there or ever even visited the site, let alone excavated a well there. Schoffstall may have read Swamper Ike's tale of his adventures on the Mojave Desert and derived the information from

Mojave Desert. Their tool kits included an assortment of fluted spear points and darts, crescentics, chopping tools, scrapers and other tools associated with processing large game. They ranged through the west but were probably a very small group of immigrants.

Based upon archaeological evidence it is very difficult to separate Late Pleistocene time period sites from Early Holocene sites. The time marker which separates the sites are the flutes on the blades which appear to be Clovis or Folsom-like while Lake Mojave (Great Basin Stemmed Blades including Borax Lake, Lake Mojave, Silver Lake, and San Dieguito), time period blades are characterized by stemmed-lanceolate styles with an elongated and slender design (Justice 2002:85-124). On the coastal early sites, they are referred to as the San Dieguito complex (Warren 1966; Kaldenberg 1976). The Lake Mojave sites studied by Warren and DeCosta (1964) are representative of this era of human occupation in the Mojave Desert.

Research at Searles Lake and Panamint Lake proposed by a number of scientists may shed light on the relationship between these early hunters and big game which were found along the lake shorelines. Davis was noted for referring to the lake margins as a "paleogrocery store," reinforcing her belief that the lake margins attracted hunters and foragers because they contained lush vegetation and foraging animals. (See also Sutton 1996 for a generalized discussion of work conducted in the western Mojave Desert.) Dillon (2002) questions early human occupation of the western Mojave because no Clovis or Folsom-like style points have been in an archaeological context. All of the reports and collections he studied appear to have been found on the surface or came from collections made by looters. Wells and Backes (2007:21) indicate a fluted point was found on the surface of CA-SBr-47, northwest of Blackwater Well.

Cuddeback Lake would have held water at the end of the Pleistocene and appears to have been connected to Searles Lake through Pilot Knob Valley, and perhaps to Rogers Dry Lake near Palmdale. During wet periods, such as occurred on the Mojave Desert during 1976-1979, Cuddeback Lake held water for several months. This attracted wildlife, both terrestrial and avian. Recent research by Ramirez de Bryson (2005) suggests that Teague Wash and portions of Searles Lake were infilled by local water sources and contained water sporadically until the recent era.

The western Mojave Desert as a whole experienced a hyper-arid and hot period, called the Altithermal in paleo-climatic reconstructions, between about 8000 and 4000 YBP. This Middle Holocene Period is referred to as the Pinto period in much of the Mojave Desert, but others (Bettinger and Taylor 1974) use the term "Little Lake" after the excavations at the Stahl Site (Harrington 1957). This time period is marked by a warmer, drier climate with a general rise in summer temperatures and a shift in precipitation to the summer, which may be responsible for the introduction of the pinyon pine and juniper into the environment some 6,600 years ago.

Seminal work by Schroth (1994) and studies by Basgall and Hall (1993) in the north central portion of the Mojave Desert, Harrington (1957) at the Stahl Sit, Rogers (1939), Bettinger and Taylor (1974), and Warren (1980) have all looked closely at the Pinto period, particularly as they are represented by point typologies, which were dominated by leaf-shaped blades probably for use as fixed points on atlatls for game hunting. Warren's work in the Joshua Tree National Park (1986) has provided significant contributions to the understanding of the Pinto period. During this time period it appears that populations moved away from lakeshores and focused on flowing water and spring sites. Grinding stones make a pronounced appearance as settlement appears to be focused at sites with regular water and plants for some sedentary food processing. (See Moratto 1984; Grayson 1993; Warren 1986; Schroth 1994; and Sutton 1996 for additional detailed discussions of this time period.)

The Gypsum or Newberry Periods (ca. 4,000-1,500 YBP)

General environmental conditions improved dramatically around 3,500 YBP, a point marked by the establishment of basic site settlement patterns in the region that seems to have continued into historical times (Whitley et al. 1988). The period around 3,500 YBP has been cited as experiencing a desert wide expansion in human population with intensive human use in a variety of ecological zones (Whitley 1994, 2000, 2005).

The climate during the early part of the late Holocene marked a general pattern of cooling with an increase in precipitation. Adaption of pinyon pines to the Great Basin seemed to be enhanced. Pinyon pine produced a good seasonal crop of nuts which could be stored for winter use (Moratto 1984; Sutton 1996). There is also a significant increase in the number of archaeological sites, and in diversity of habitats in which these sites are found (Grayson 1993). Caves, such as Newberry Cave (Davis and Smith 1981) were the focus of archaeological inquiry and have provided for the preservation of important data about this time period. Bettinger (1977), Thomas (1970) and Thomas and Bierwirth (1983) provide much information about the increase in human use of the arid west during this time period. Time markers included the following styles of points, all of which were hafted as spears: Gypsum, Elko series and the Humboldt Concave Base series (Moratto 1984) which replaced the Pinto style points of the previous period (Hester and Heizer 1973:5-13; Justice 2002:85-124). It appears that during this time period the gathering and processing of plants with millingstones resulted in stabilized settlements around water and food resources (Moratto 1984:420; Warren and Crabtree 1986).

Environmental conditions during the period of prehistoric occupation in the area of Blackwater Well are thought to be somewhat wetter and contained a greater variety of vegetation than today (see Elston 1982).

Rose Spring or Haiwee Period (ca. 1,500-600 YBP)

During the Rose Spring or Haiwee period, the climate of the Mojave Desert appears to have become markedly warmer and drier, peoples seemed to have been scattered throughout the Mojave Desert, and the influence of Southwestern contact increased as evidenced by intrusions of southwestern ceramics and exploitation of turquoise at Halloran Springs in the eastern Mojave Desert (Rogers 1929; Leonard and Drover 1980; Moratto 1984). Points which seem to be time markers during this era of human use of the area are the bow and arrow points referred to as the Rose Springs and Eastgate points and Elko (Moratto 1984). Significant harvesting of seeds took place with grinding implements being significant parts of the prehistoric tool kits (Wells and Backes 2007:22). This pattern of use of the Rose Springs, Eastgate and Elko points dominates the sites in the Great Basin and Mojave Desert (Yohe 1998). Deep, rich middens indicate the stable use of the same locations for village sites on a seasonal basis. Sites which appear to date from this time period dominate all of the east trending canyons of the southern Sierra Nevada Mountains, the El Paso Mountains, San Bernardino Mountains and the Coso Mountain Range (Bevill and Nilsson 2004).

Late Prehistoric/Marana Period (ca. 1,000-100 YBP)

Between about 1,000-800 years ago, when western North America experienced a severe and prolonged drought, a number of village sites in the western Mojave desert appear to have been abandoned (see Whitley et al. 1988; Whitley 1994, 2000). Much research in this time period focuses on the Numic spread or the Shoshonean entry into the Mojave Desert (Bettinger 1977). The diagnostic points used as time markers during this time period are a smaller type of projectile point called the Desert Side-notched and Cottonwood Triangular projectile points which are scattered throughout southern California as well as the Great Basin (Moratto 1984; Sutton 1996). Various pottery types, but primarily brown wares, are found at archaeological sites and were in use at the time of European contact. Baskets were used as utilitarian ware. Many of them bore elaborate and colorful designs. This pattern of continues until contact with Europeans. A cold period, known as the Little Ice Age, dominated much of the last three hundred years and may be responsible for the clustering of sites away from the cold interior of the western Mojave Desert towards the coast and interior valleys (Whitley et al. 2007).

Historic Era (AD 1776-present)

The western Mojave Desert was first visited by Spanish explorers in 1776 when Father Garces passed through the Mojave Desert on his way to the missions of coastal southern California. He was probably followed by any number of unknown Spanish and Mexican explorers looking for gold and silver. American explorers, including Jeddiah Smith (Lavender 1972:84-90; Weber 1990:18-19, 40), Joseph Reddeford Walker (Bailey 1959:81; Lavender 1972:114-115), and Edward M. Kern (Lavender 1972:128, 133), and John Fremont (Lavender 1972:122-3,128-30), passed through the area (Boyd 1972:12). Some of them may have stopped at Blackwater Well, but there is no extant information to indicate they did. By 1849 migration to California was in full force when the plight of Death Valley 49ers brought attention to the Mojave Desert (Latta 1979). For the next fifty years the western Mojave Desert was full of gold and silver seekers, borax industrialists, and the railroad which brought sidings and towns to the Mojave Desert. Water was precious; spring sites were occupied and developed for the mining and grazing industry.

Native Americans were displaced and became labor for ranches and mines. Blackwater Well was no exception. The borax industry used it for a water station (Weight 1955) and the cattle and sheep industry grazed the plants and occupied the water source. The Bureau of Land Management (BLM) began administering the public lands after being created by the consolidation of the General Land Office and the Grazing Service in 1946. The active presence of BLM in that portion of the Mojave Desert began about 1968.

Warren (1986) provides a useful model for the general pattern of prehistory in the western Mojave Desert which contrasts with Bettinger and Taylor (1974).

Native American presence in the vicinity

Ethnographically the area is debated as being the territory of the Kawaiisu or the Vanyume/Serrano (Kroeber 1925). Zigmond (1981,1986), Earle (2003) and Underwood (2007) place Blackwater Well in Kawaiisu territory while Kroeber places the area within Vanyume/Serrano territory (Kroeber 1925). Both are Shoshonean or Numic groups and it is possible that both groups used the area over the past millennium. Wells and Backes (2007:18-20) do an outstanding job of synthesizing the ethnographic data on the area which would include Blackwater Well. Monastero (2007) includes a discussion of Coso/Timbisha ethnohistory which he describes as potentially overlapping with Serrano and Kawaiisu in the southern portion of the Panamint and Pilot Knob Valleys. This would probably include the area of Blackwater Well. Ethnicity is rarely determined by archaeological evidence. In the case of work at Blackwater Well, there is nothing preserved that can contribute to the understanding of which group may have used Blackwater Well. A basketry materials collected at Blackwater Well Cave by Eton, however, is briefly discussed later in this paper.

Recent studies in the vicinity by Allen (2004, 2005), Becker (2007), Clewlow et al. (2007), Giambastiani (2007), Hildebrandt and Darcangelo (2006), Kaldenberg (2005), Monastero (2007), Walsh and Backes 2005a, 2005b), Wells and Backes (2007), Walsh and Clewlow (2003a, 2003b), and Yohe (1992), are assisting to provide much needed detailed information concerning the archaeology of the area.

Archaeological investigations at and around Blackwater Well

In 1929 Malcolm Rogers, archaeologist from the San Diego Museum of Man (SDMM), visited the site and recorded it as M-129, an Amargosa 1 and Shoshonean site. He noted that relic hunters had dug into the site, disturbing it. As is described by Allen (2004 and 2005), Rogers excavated portions of two sites nearby, at Indian Springs. There is no indication that he did anything but collect samples at Blackwater Well to build a collection for the SDMM. Rogers indicated that he began conducting archaeological surveys in San Bernardino County in 1925 (Rogers 1930:1), but work was suspended until the fall of 1930 when he received a grant from the Smithsonian Institute to conduct seven weeks of reconnaissance. His fieldwork was in association with the Eastern California Museum and focused on the archaeology of the western region of the "Mohave Desert between October 24 and December 6, 1930" (Rogers 1930:1-2). He used the "U.S.G.S. Water Supply maps for locating and recording sites" (Rogers 1930:2).

Rogers' hand written notes state that "Blackwater Well located (sic) at the base of a fan. Recent wells have to be dug to a depth of 15 feet to obtain water. The occupation here is of a mixed nature and all of a surface nature and on the same type of terrain. Past collecting has distorted the picture. Playa planes present one Pinto Type II point found but the bulk seems to be Shoshonean work. Metates and manos present" (Rogers 1929). Rogers' typed notes (Rogers ndb) indicate that "relic hunters have looted the intensively occupied area around the wells so that NY-1 is merely suspect and the final Shoshonean occupation which composes the bulk of the debris has been so thoroughly picked over that even an intact arrowpoint was not found." Rogers also noted that about two miles north of Blackwater Well, in walled-off "Panamint Caves" the flaking was all of "Coso Obsidian" (Rogers ndb).

In 1958, Gerald R. Smith, with the San Bernardino County Museum (SBCM) developed a one page site report for the archaeological site and collected artifacts for the San Bernardino County Museum which are curated at the SBCM. Smith apparently visited the site several times over the next two decades as was recounted by Frank Curtis, caretaker of the Mendiboro Cattle and Sheep Company which had the grazing permit for the Pilot Knob (PK) Allotment and improvements at the site and throughout this part of the Mojave Desert.

During the 1950s, Baron Otto Rudolph Dijon Martin von Monteton (known as O.R. Mont Eton, Sr.), collected extensively from a rock shelter near Blackwater Well. He died in 1962 (Searles Review 1962). The material he collected and loaned to William Wallace included a large fragment of a stone hand tool, two blades, 75 sherds, four assembled sections of brown ware pots, one mano, 10 late period points and fragments, an antler knapping tool with notches, two thin leather/chamois fragments, seven wood tool/arrow shaft fragments, two pieces of twisted cordage, the start of a basket using willow and devil's claw (Figure 6); one small stick, and two pieces of braided cordage. The notation also states Mont Eton may have a mining claim in the area (Davenport 2006). The braided cordage, which may be the beginning of a basket, should be examined by a basket specialist who may be able to identify which Shoshonean group used the site. The excellent preservation of the vegetal fibers might provide important radiocarbon data if a small fragment were dated chronometrically.

The University of Redlands and the Archaeological Survey Association of Southern California (ASA) made several trips to the site from the 1968-1974 and collected many "pounds" of artifacts which they provenienced with labels that often identified the item collected by the name of the volunteer (University of Redlands Fieldnotes 1968-1974) . As many as 104 participants at one time, under the direction of Gil Becker and Don Hardy, collected artifacts and, in at least one instance, excavated at the site (University of Redlands Field Notes 1970:2-3). Their area of interest was "close to the house and in the main well area." Their notes state that "permission to make survey and take artifacts from caretaker." Items collected included an incredible amount of temporally diagnostic artifacts. Their notes state the following were collected: slate pendants; Olivella shell beads; drilled Chione beads; a bone bead; projectile points including willow-leaf shaped, Pinto, Elko Corner-notched, Elko Eared, Rose Spring, Cottonwood, and Desert Side-notched points; black and white southwestern pottery sherds; Brown Ware sherds; a ceramic pipe fragment; inscribed bone; a basalt stone bowl; an awl; manos and mano fragments; a pestle; keeled scrapers; flakes measured by "pounds;" quartz crystals; scrapers; cores; and worked bottle glass (University of Redlands Fieldnotes 1970:118). Their notes indicate that "artifacts were found by all members." Scanned photographs of projectile points (1970:125, 127, 179) reveal the incredible number as well as time depth of the materials collected. It is difficult to decipher where the artifacts wound up, but notes indicate that some were placed in a drawer while others were "glued to 3X5" index cards. In 1978, Dr. Roger Baty and Gil Becker provided Kaldenberg with what they could locate. There was nothing in the collection such as was discussed in the field notes. Kaldenberg queried some of the members of the crews and they indicated that many of the "interesting artifacts" were loaned to family and friends. The portion of the collection which was retrieved is now curated at SBCM. It primarily contains broken artifacts and debitage.

Looters collected from the site from the time of Malcolm Rogers' notations in 1929 until recently. Large collections by a local group from the Boron area were shown to Kaldenberg and Leonard in 1977. Many of these items were time-diagnostic bifacally flaked artifacts. A few were photographed such as a Gypsum point which was in the collection of George Kostoposelos of Boron, but none were ever transferred to the appropriate repositories. Perhaps some of the important temporally diagnostic artifacts can be located again and transferred to the BLM for curation at the SBCM.

During June of 1978 an approximately fifty-person strong volunteer archaeological project took place at Blackwater Well, supported by Paul H. Ezell, with the San Bernardino County Museum Association (SBCMA), ASA, the Society for California Archaeology (SCA), the San Diego County Archaeological Society (SDCAS) , Pacific Coast Archaeological Society (PCAS), Mojave River Valley Museum Association (MRVMA), the Maturango Museum and BLM as primary participants). The work included an intensive pedestrian survey of 2400 acres, intuitive inventory of specific areas surrounding the site, and a test excavation of four 1x2-meter units within the black midden at the Blackwater seep. The excavation indicated that the site had a depth of 120 centimeters in some areas. The area of interest focused on the lands near the Mendiboro grazing headquarters and the home occupied by "Cowboy" Frank Curtis. A windmill at the well was the source of water for the grazing operation and domestic water for the residence. Mendiboro Cattle and Sheep Company provided water and other support. Besides being of prehistoric import, the site was also important historically since it served as the first water stop for the Twenty Mule Team Borax wagons.

Research questions focused on site and use, and collection of faunal remains, charcoal, prehistoric artifacts, and any historic items. One of the postulations was that with the proximity of the site to Cuddeback Dry Lake (known in the ninetieth century as Willard Dry Lake) the prehistoric record might reveal avian fauna that would indicate that the lake was exploited for avian species. The other research question focused on faunal species which would be found in the midden, as the seep, either dug by prehistoric peoples or an active naturally occurring seep, would attract mammals which would be hunted by the site's occupants (Kaldenberg 1978, 2006).

Additional goals of the project were to determine the extent of the site, extent of site damage, complexity of the site, and whether it met the criteria for eligibility for listing in the National Register of Historic Places pursuant to 36 CFR 60.4.

Our historic knowledge

The earliest known mention of Blackwater Well is from the 1870 diary of a John App who, with his son John Quincy App, traveled from Jamestown, California to the Ivanpah Mines in eastern San Bernardino County. His diary states that on Monday, April 4, 1870 they "left El Paso [eastern Kern County, California] and traveled 22 miles to Black Water Holes. Missed the Panamint Holes. Black Water Holes on the left side near the road. On Monday April 4 we left Black Water at 7 o'clock and reached Surveyors Wells at 11 am" (App 1870:17). App returned to Black Water Holes at 2 p.m. on May 8th (1870:36).

Spears (1892:86-87) discusses the Pacific Coast Borax Company's "Twenty Mule Team Borax" treks between 1883–1888 from Mojave to the first water stop on the return to Death Valley as being "… just 50 ½ miles across this desert—a desert where the sand-laden wind forever blows and the sun purrs down with intolerable fierceness in summer—to the first spring, which was called Black Water (See Figure 4). Beyond Black Water, 6 ½ miles away was Granite Spring….".

Figure 5. 1952 View of windmill and Automobile Club of Southern California 1906-era sign. Lucile Weight photograph courtesy of Dennis Casebier (Kaldenberg 2010:19).

"Swamper Ike," a borax team swamper, said that "our first stop after leaving 'Joburg' was at Blackwater Well, dug nearly a century ago by General Wingate, on his trip to that region. The water here is jet black and was used for horses or cooking" (Hufford 1902:11). Evidentially, "Swamper Ike" visited the site between the times when the well was cleaned out. No records exist of any general in the United States Army by the name of Wingate (Casebier 2010). Wingate Pass, about 30 miles north of Blackwater Well, was supposedly named after this non-existent general (Casebier 2010) but the name may simply be a derivative of Windy Pass, its original name (Palmer 1980:80).

The California State Department of Highways placed guide posts on the California deserts for "… the guidance of mining prospectors and others" during 1906 (San San Francisco Call 1906). One of the guide-posts was erected at Blackwater (Figure 5).

When Mendenhall (1909:52) stopped at Blackwater Well in 1909, he found black, ill-smelling water filled with dead rats.

> **Blackwater Well, San Bernardino County (#94)**—This well is one of the important camping and watering places on the main road from Johannesburg to Death Valley and Resting Springs. It is on a divide about 18 miles east of Johannesburg. The road eastward from the town runs past the railroad roundhouse toward the City Wells, which can be seen toward the northeast. About 2 miles from Johannesburg it forks; the left branch, bearing to the north, goes to Ballarat via Searles Lake; the right-hand branch runs directly toward the City Wells, and when nearly south of them turns down the canyon to the southeast. At the foot of the hill this road runs eastward to the base of Lava Mountain and north of Willard Dry Lake. In the distance a low ridge is seen, lying at right angles to the road-that is, in a north-south direction. Blackwater Well is nearly at the crest of this ridge. The main road crosses several of the old Death Valley borax-works roads, which come in from the south in the direction of the dry lake, and these roads must be avoided, as there is no water on them for 25 miles in either direction. When the summit is reached the well can be located by the bare ground in its neighborhood, from which campers have stripped all vegetation. The well, which was dug years ago by government troops, is about 15 feet deep and is in the form of a shaft, 5 by 7 feet. The water in it is usually from 2 to 3 feet deep. When the well

> has not been used for a long time the water becomes dark colored and ill smelling and is often foul from the bodies of desert rats and rabbits, but when freshly cleaned it is sweet and wholesome and free from alkali. It is probable that if the well were deepened a much more abundant supply would be procured. Water was at one time piped down the slope for a distance of one-half mile to the old Death Valley borax-works road. The remnants of the trenches and pipes aid in locating the well. A road that turns off at the wells crosses the divide to the east and extends to Copper City, a small mining camp. The road to Death Valley starts northward from the well, reaching the summit in about one-half mile, and the north end of a black lava ridge in about 3 miles. There it turns east directly toward Pilot Peak. From the foot of the lava point it is a heavy climb for 6 miles up the mountain to the base of Pilot Peak, where Granite Wells are located (Mendenhall 1909:52).

In 1917 Thompson (1929:ix)) visited Blackwater Well "…as one of the duties of the United States Geological Survey (USGS) are those of determining the water supply of the United States, the investigation of underground currents and artesian wells, and the preparation of reports upon the best methods of utilizing the water resources." He describes the well as:

> apparently dug in granite. Rock hills stand near by, and if the well does not reach rock it can not be far below the surface. The well is dug and is about 5 by 7 feet in diameter. On October 5, 1917, it was 32.6 feet deep, and the depth to water was 31.6 feet. On January 24, 1920, the depth to water was only 21 feet-that is, 10 feet higher than in 1917. In 1917 the well was equipped with a small gasoline engine and pump, but in 1920 there was no pump in the well. An iron tank in a corral on lower ground about 500 feet north of the well had water in it. A ditch led from this tank toward the well, and although no pipe was visible the tank is doubtlessly fed from the well, the supply being regulated by a float valve. There was no other means of obtaining water unless one had a rope and bucket. The well is used for watering cattle for domestic use. The name Blackwater is said to have come from the fact that the water becomes dark after standing, but this feature was not observed in a sample collected by the writer (Thompson 1929:231).

Weight (1955) provides a discussion of the Twenty Mule Team Route from Mojave to Harmony Borax Works, probably taken from Spears (1892), and provides a photograph of Blackwater Well as it appeared in 1952 (1955:9) complete with an Automobile Club of Southern California diamond-shaped sign which states "Blackwater Well Obtain Water at Trough" (Figure 5).

From the middle 1950s through the 1980s the water well at the site and others throughout the area were managed as the Pilot Knob Grazing Allotment by the Mendiboro Cattle and Sheep Company. BLM established a "designated roads and trails" management area for the public lands around Blackwater Well (USDI 1979). Today, Blackwater Well abuts the Grass Valley Wilderness to the east.

The allotment was transferred to the Desert Tortoise Preserve during the 1990s. Nothing remains to remind the visitor of Franklin. Even the windmill, dating back as far as anyone remembers, is gone, removed in an effort to save tortoises. Today, history at Blackwater Well is invisible.

Cowboy Frank Curtis was described by many visitors to Blackwater Well as an electronic genius (Figure 6). His line shack had more means of electronic communication and entertainment than had many folks who lived in areas connected to the power grid. The place he lived started out life as a surplus railroad refrigerator car, which he significantly altered over the years (Figure 7). The wind was often so constant—and during the winter, cold—that he added a room to the east side of the refrigerator car, then built a walled and roofed porch onto the side of the room, forming a maze of entrances to break the wind. When the roof leaked, he added another roof several feet above the original one, creating a tunnel for the wind to blow through to keep the house cooler during the summer (Atkins 1978). Other associated buildings included a barn, corrals, a windmill, and water tanks, as well as appurtenances such as television and radio antennas, water pipe, and fences (see Figure 3).

The proximity of the line shack to a major archaeological site gave the site and associated historic buildings protection from vandals. When you entered the gate to his "stockade," about 200 yards from the house, a battleship siren (also described as a firehouse siren) was triggered. The loud noise woke up everything for miles around. Next, a casual visitor was greeted by

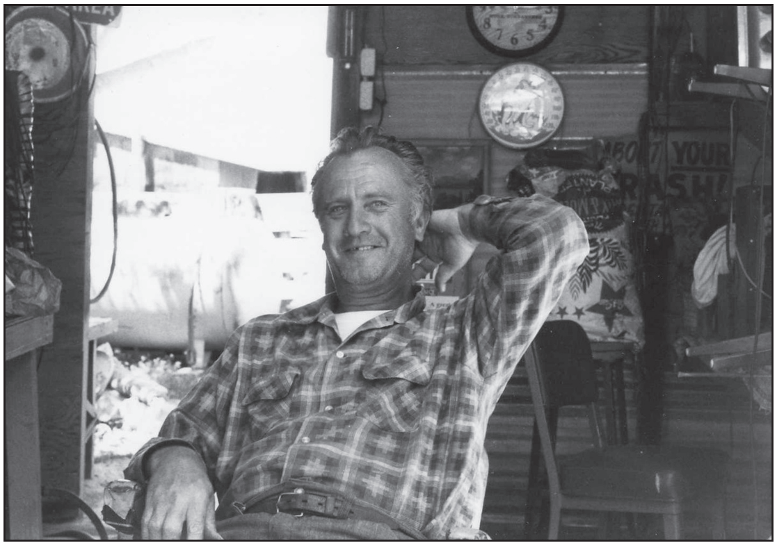


Figure 6. Franklin "Cowboy" Frank Curtis inside his home at Blackwater Well, 1978 (Kaldenberg 2010:12).

Cowboy's mongrel dog he called Beep.

The ranch lessee brought in cattle and sometimes sheep to graze each year for about 90 days. One year Cowboy said that 3,500 head of cattle were trucked in. It takes about 6 inches of rain to get good grass in this part of the desert. There was not nearly enough water in Blackwater Well for the cattle. A thousand head drink 4,000 gallons in one night. The water they need is brought to the site in tanker trucks.

When the season was over Cowboy maintained the windmills, tanks, corrals and fences. He also had more time for his electronic devices, including a CB and FM radio, color TV set, a juke box, and a microwave oven. He had a propane hot water heater and he cooked on a 1902 vintage wood stove in the kitchen. High fidelity speakers were inside and outside his home so he could listen to news or music while he tended to his work.

His basic power source was a 12 volt system powered by a wind charger with a 10 foot blade. A side room was filled with storage batteries. Wind is plentiful during most of the year. When the wind diminished during the summer months, gas-powered generators provided power.

He spent time searching for various forms of entertainment (Kaldenberg 2010:21). In 1968 he installed a sophisticated motorized TV antenna on a hill (elevation 4200' amsl) about one-half mile from his house. By operating a telephone dial from inside the house, he could bring in seven TV channels from Los Angeles. He could also select a variety of radio frequencies, from FM stations to aircraft, police calls and could call telephone operators and chat with them.

He grew tomatoes, lettuce, and beets and planted poplar trees to help break the wind around his house. He was a prolific reader, always asking folks to leave books for his entertainment. His nearest neighbors were 11 miles west at Steam Well, Blackhawk Mill, and the old Bowen Ranch.

During one of my visits his neighbor, the Steam Man stopped by to see the Cowboy. Both Frank Curtis and Virgil Ramey saw themselves as desert characters and sometimes embellished their roles. Neither had any money except for what they received from disability checks and, in the case of Cowboy, from his work for Mendiboro Cattle and Sheep Company. They were always living on the edge and depended upon visitors to help them with food and drink. They truly enjoyed having visitors and spinning stories. I was lucky to be able to call them friends from the late 1970s through the mid-1980s. I brought them food and mailed them treats regularly. They were appreciative.

The language used by Frank and others during the interview was collected to the best of my ability. Vernacular was used by Frank and others, some for what seemed to be silliness, other words was just how they folks spoke. As an example, Frank never used the word confused, he would always say "cornfused." He frequently said "ya better believe it," "would I lie to you?" and "that's another story."

I conducted several interviews with Cowboy Frank. These interviews were recently published by the San Bernardino County Museum (Kaldenberg 2010:12-51). A short article in the Bureau of Land Management's publication, Newsbeat, was written by Tom Evans and published in 1978.

The essence of Cowboy's stewardship at Blackwater Well

Frank's presence at Blackwater Well kept the ranch buildings, windmill, house, and archaeological site from being disturbed by vandals (Figure 7). A loud siren from a battleship was tripped by the weight of automobiles driving in from the southwest and alerted Frank that visitors were present. It provided a desert character a place to use as his base for storytelling, and served as a place for others to congregate and share desert information. Many were tall tales, but others were important stories about the history of the western Mojave Desert and of the Death Valley region.

Frank explored the area on horseback and by pickup truck and via a souped-up dune buggy. He visited places on the Navy's Echo Range before all of the fences

Figure 7. Frank Curtis' home at Blackwater Well.

called the flatlanders who visited the Red Mountain area and the Steam Well petroglyphs. He was full of fun stories that he shared with his guests. His presence at Steam Well probably helped protect the petroglyphs from vandalism.

Steam Well was not as impressive as Blackwater Well. It contained a shack where Virgil lived and collected junk. His junk was always valuable and he did not want to get rid of it. Sometime in the 1960s vandals had spray painted the petroglyphs. Virgil's presence prevented it from happening again. BLM cleaned the paint off the petroglyphs during 1977.

He was a great story teller, he was closer to Highway 395 than was Frank so he received more urban visitor's than Frank received at Blackwater Well. He frequently attempted to sell partial interests in his mining claims as he felt that he was always a few days away from a gold or silver strike. Virgil, sitting in his wheel chair,

were erected and travelled all of the way to Death Valley. He claimed that he had saw an antelope and a wolf. He claimed that he saw deer and bighorn sheep and he also claimed that he was visited by the Charles Manson gang in their trucks and dune buggies (Kaldenberg 2010:45-47). He relied on the goodness of visitors to keep him in some food and drink. When his time was over at Blackwater Well as the BLM did not want the public living on public land as it was illegal, he moved to Red Mountain and opened Frank's TV repair shop, which he operated until his death. He wanted to stay and provide protection for the resources. It just did not work out for him. As he is gone, so are the historic features which he protected and cared for. The archaeological sites and their components remain as a tribute to Frank. They are listed in the National Register of Historic Places.

Virgil "the Steam Man" Ramey and his legacy

Steam Well was occupied and protected by "the Steam Man" for a decade as a mining claimant. He came from the Los Angeles Basin after he had enough of the traffic, smog, and having his small shop robbed several times (Figure 8). "The Steam Man" served as a tour guide for what he

Figure 8. Virgil "the Steam Man" Ramey with friends at his abode at Steam Well (Kaldenberg 2010:23).

was often found picking at a side of a hill and smiling at the results of his bucket of soil which he always thought was his "Eureka." It, of course never happened for Virgil. He eventually just could not longer live out in the middle of the western Mojave Desert without adequate medical care. He moved to Red Mountain and lived out his life there in a casual clapboard home. To give the readers a flavor of Virgil's personality I have include a small part of his conversation from Kaldenberg (2010:43-45):

Virgil interrupting says "Hey, I want to talk a little, why give that rascal Cowboy all of the privilege? Will someone help me to the outhouse? My buggy (wheelchair) don't do so well in the sand. [Virgil's Dodge Dart he called "White Spot" had just died, pooped out, and he was looking or another vehicle priced at about $350; so he went all the way to Lancaster to do so.

Virgil had been staying with a friend, Homer Richards, in Red Mountain. He lived on Yumpah Street on the north end of Yumpah.]

Talking to the author, who Steam Man called "Ranger Russ" "Ranger, you know my spring, I call it Steam Man Spring. Last time you were out it was running about a gallon of water a minute. Pretty good stream of water. Hey, Cowboy says I have a lot of guests, yeah I do, but I discourage people from making themselves at home and make them think that I am around and would be right back. This I do with my CB radio. I have a base radio station and I call myself from White Spot and talk to myself and people think I am around when I am not. White Spot is the second car I have gone through. My first one was Wrinkles, which is in a pile behind my house. It was an old green 1968 Plymouth Valiant. It is called Wrinkles because of all of the dents in it. White Spot is named that because it sometimes has one clean white spot on it. (Virgil roars with laughter while Cowboy smirks; there seemed to be a bit of jealousy at the transfer of attention from Cowboy to Steam Man.)"

The end of the story

Frank Curtis lived at Blackwater Well until the middle 1980s. During the early 1980s he was robbed and tied up and left abandoned for several days before anyone found him. His prized Wurlitzer juke box was stolen, his guns, and the little money he had. He was severely beaten. He told me it was one of the Manson gang that did it. He said that he recognized their faces but not their names. He thought they might have come in from Trona but he never found out who did this and stole his pride and feeling of security. Frank got into a scrape with the law when he was drinking too many Cowboy Franks and driving. He eventually lived out his life in Red Mountain, on the west side of Highway 395, visiting frequently with Virgil, the Steam Man, and probably occasionally seeing the others who had made his life less lonesome at Blackwater Well.

Everything is gone from there now—all of the evidences of Frank's existence have been removed. Even the sound of the windmill's blades lazily turning at the chance of a gentle breeze is gone. That part of our history is gone forever. The Desert Tortoise Preserve manages the place for tortoises and not for history. The Cowboy Franks and the Steam Man Rameys of the western Mojave Desert are all memories now; their lives are partially preserved in the memories of their visitors and the occasional documentation in newspapers, court records, BLM files, and the like. Our history is richer due to their existence; it is poorer due to the disappearance of all of the historic buildings that surrounded them. While none of their buildings likely met county building codes, they certainly provided for picturesque photos of the desert and as a setting for the telling of interesting stories and tall tales regarding desert history.

For those wanting to know more about Frank Curtis and Virgil Ramey I direct them to a recent publication by the San Bernardino County Museum Association titled *You Don't Know What Lonesome Is* (Kaldenberg 2010).

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Copper mining in the vicinity of Copper City and Pilot Knob, San Bernardino County, during the late 1890s and early 1900s

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Thirty-seven year old Newton Morrow was hired by Governor Waterman in 1885 to run the Waterman mill, located just west of present day Barstow. After the mill shut down in 1887 Newton and his sons discovered copper ore (or turquoise as his son "Penny" described it) some 35 miles north of Waterman and began small-scale mining. Eventually the Morrow Mining District was established.

The Morrow's dubbed their mine camp Copper City. The camp was located about 4 miles southeast of Pilot Knob.

Little is known about mining here until the late 1890s. In December 1898 mining periodicals reported that the United Copper Company, "a New York syndicate," had a large force of men employed at Copper City Camp.

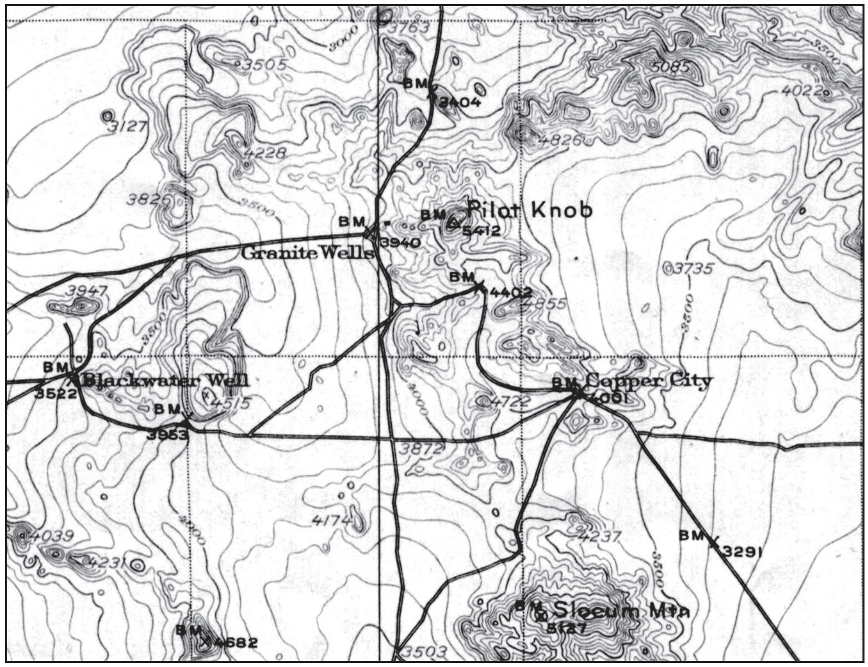
In 1897 claims known as the Juanita Mines numbers one through ten were located by Thomas J. Baldwin, George L Branch and J. I Crowell. By 1899 the Juanita Mines were owned by the Feejic Mining Company organized under the laws of the State of Maine. In 1900 it was reported that the Juanita mine, owned by the Union Development Company of Boston, was developing the Juanita Group of claims. The Union Development Company had reportedly purchased 38 claims from the United Yucca and Feejic mining companies for $5 million. In 1898 the main shaft had been sunk to 90 feet and by 1900 it had been deepened to 212 feet.

In an 1902 article about San Bernardino County's "booming" mining progress, Copper City is listed as one of "a large number of copper claims being developed.."

In 1903 a promotional pamphlet which extolled the Sta Bueno (or Santa Buena) Mining, Milling and Development Company, of Riverside County, mentions that its mines are "10 miles south of Pilot Knob near the foot of which Senator W. A. Clark, of Montana,

Figure 1. The Morrow family working their Ramon Mine, Copper City. Taken by J. Irving Cronwell, Jim Morrow in center with arms crossed. Mittie on the far right was born in 1877.

Figure 2 (right).
1915 Topo Map showing the location of Pilot Knob and Copper City.



owner of the famous United Verde copper mines of Arizona, has some fine copper claims. In this same vicinity also is the famous Copper City with its rich copper and gold mines which are so rich that they are being fought over in court." The Los Angeles Mining Review reported that, "the company is capitalized for $1,000,000, in shares of $1 each, of which 500,000 shares are in the treasury. A considerable quantity of ore has been taken from the claims, mostly copper ore, some of which aretaken from a 12-inch vein 44 feet from the surface assayed 29.88 per cent copper. Some ore from the bottom of an 80-foot shaft showed a higher percentage in copper. There are eight claims in the group."

By 1907 the Juanita had been idle for a number of years.

Pilot Knob/Granite Wells

Granite Wells, was sometimes facetiously referred to at Granite City, so named because of the ruins of two stone cabins that stood at the site (Redlands Citrograph 14 July 1894).

In December 1898 it was reported that "Toppy" Johnson sold a three-quarter interest in his copper mine at Pilot Knob and was in Kansas City closing the deal. Only a few months later, in March 1899 the Los Angeles Mining Review reported Johnson, owner of the Tiptop group of copper claims near Granite Wells, had sold half interest to C. A. Burcham of the Yellow Aster Mining Company. In 1907, the Granite Wells Mining Company of Los Angeles held a number of claims here, and claimed to have extracted 200 tons of rich copper ore that was waiting to be shipped. The

Figure 3 (right).
Outline of the Morrow Mining District, from A. Russell Crowell's, 1903 Miners Map

Toppy Johnson mine, by 1912 renamed the Homestake Copper, was owned by E. E. Teagle. He had extracted 15 tons of ore from the 140-foot level of the 240-foot deep shaft. This ore which was said to assay $136 per ton was to be shipped to the Needles smelter in a few days.

In 1910 miner Joseph Foisee was mining a promising copper property south of Pilot Knob, and had made arrangements to haul twenty-five tons of ore for processing.

A footnote to keep in mind; this Copper City, should not be confused with the settlement with name the same located south of Cave Springs, now within Fort Irwin. This later Copper City was primarily active during 1907 to 1908.

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Lake Thompson Pleistocene mammalian fossil assemblage, Rosamond

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A significant mammalian fossil assemblage containing *Mammuthus columbi, Paramylodon, Equus, Bison antiquus (?),* and a large camel has been discovered within the City of Rosamond, Kern County, California. The presence of *Bison* indicates that the deposit is of late Pleistocene Rancholabrean North American Land mammal Age (NALMA) (Woodburn, 1987) ranging from approximately 250,000 to 10,000 years (Woodburn and Swisher, 1995). Rancholabrean age *Paramylodon, Equus, Bison*, and camel are previously known from the Mojave Desert and surrounding portions of Inyo, Kern, Madera, Los Angeles and San Bernardino Counties, California. Relatively complete mammoth skeletons are rare from California; the Rosamond mammoth specimens we observed or excavated include portions of skull, tusk, shoulder, teeth, rib and limbs. *Bison* material from Rosamond includes portions of pelvis, cervical, thorasic and lumbar vertebrate and humerus. The *Paramylodon* is represented by dermal ossicles, seven articulated thorasic and lumbar vertebrate, and portions of skull and jaw. Horse and camel remains include fragments of teeth, ribs, leg bones and scapula.

The discovery came to our attention on May 5, 2006 when several anonymous phone calls to the Buena Vista Museum of Natural History (BVMNH) reported that mammoth bones had been found near Rosamond.

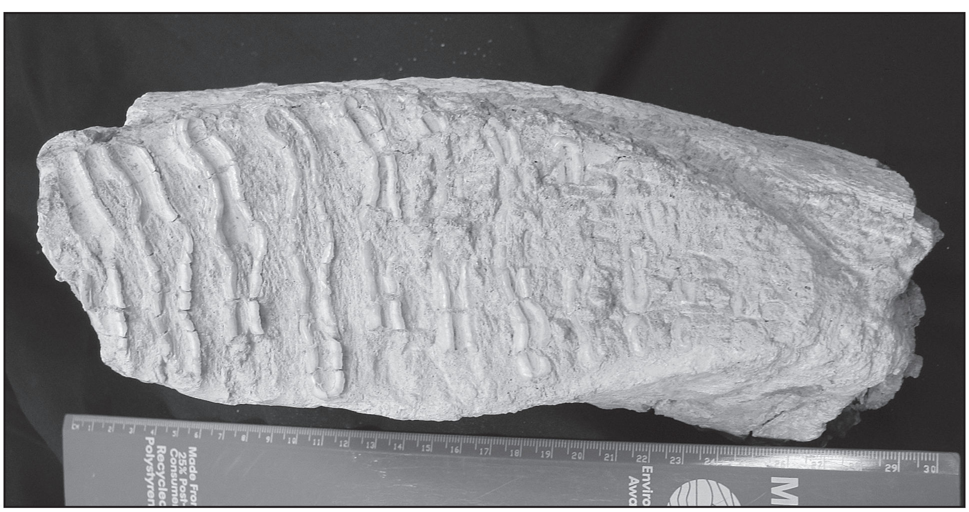

Figure 1. *Mammuthus meridionalis* molar, Rosamond site

Museum staff was told that sometime between April 10 and May 5, 2006 mammoth specimens were uncovered by construction workers preparing home lots for a housing development. This development is 5/8 of a mile (1 km) south of the Highway 14-Rosamond Boulevard interchange. The Kern County Conditions of Approval required no paleontological monitoring and Kern County officials assured the developer that no fossils would be found at the Rosamond site. Fortunately, the developer had some experience and training in paleontological resource management. Upon learning of the presence of fossils, the developer immediately diverted work away from the area where the fossils were discovered, and called the paleontologist who trained him and BVMNH was called in to conduct a salvage excavation. Unfortunately, before this happened, several construction-workers who had collected fossils from the spoil piles reported that they were told to stop collecting and to destroy or bury the ones remaining. According to workers, four mammoth specimens were destroyed by scrapers, churned up, and the soil and bones dumped on a spoils pile. Some of the workers retrieved a section of mammoth tusk from the spoils pile along with other large bone fragments. The spoils piles were then re-transported and compacted on construction pads. Also, several hundred specimen fragments collected from the spoil piles were taken to homes. Some of the workers gave some of the fossils to their neighbors. These activities permanently removed most of the fossil discoveries from science. One of these neighbors called BVMNH, and related what had happened. The neighbor also gave the name and phone numbers of the workers who had given her some of the fossils. Both the neighbor and some workers were contacted. Some workers agreed to show BVMNH volunteers

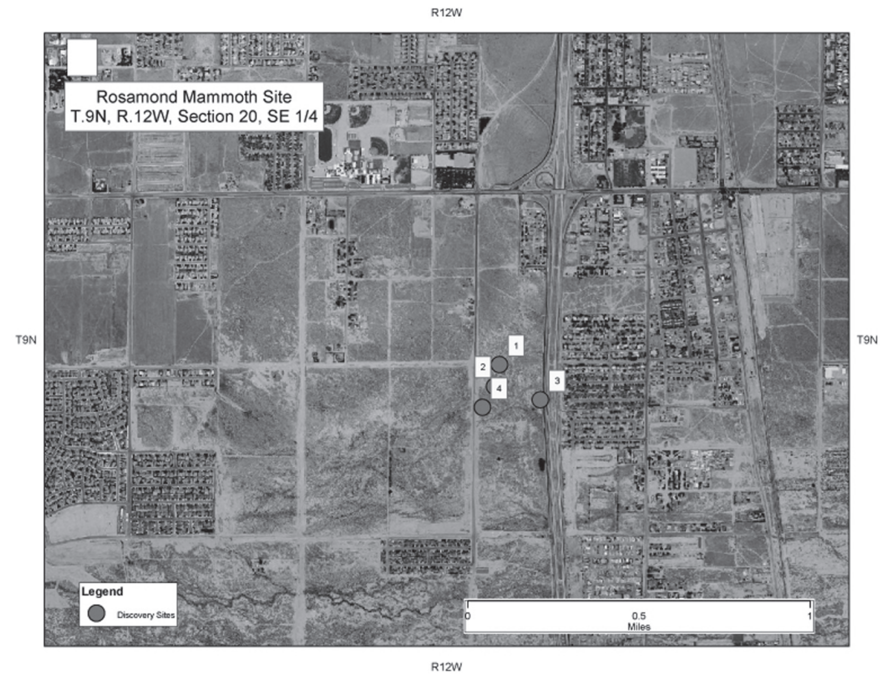

Figure 2. Aerial photograph of discovery sites

the sites where discoveries had been made and to show them the fossils. The specimens collected by the workers, which BVMNH inspected, included many bones and bone fragments. Included in these were parts of skulls, a mammoth tusk fragment, teeth (Fig. 1), shoulder bones, rib bones, leg bones and foot bones. *Paramylodon* (Harlan's ground sloth) dermal ossicles were collected, as well as camel or horse bones. GPS locations were made of the sites where construction workers reported collecting fossils, and of salvage excavations made by BVMNH volunteers authorized by the developer. These sites are shown in Figure 2. BVMNH on-site coordinators for this salvage effort were Gregg Wilkerson, Mark Hodson and Dennis Clayton. The fossils, which were the property of the developer, were donated to BVMNH.

The fossil assemblage was discovered at T.9N, R.12W, Section 20, NW1/4SE1/4, San Bernardino B&M. The discovery site is bounded by State Highway 14 and Laurel St. to the east, Poplar Drive to the north, 25th St West to the west, and Alpaca Avenue to the South.

The surface geology at the site is mapped as Pleistocene lacustrine clays (Dibblee, 1967, 2008). One mile to the north are the Rosamond hills that are composed of Mesozoic granite and rhyolitic Miocene volcanics. Lake Thompson (Orme, 2004, 2008; Yuretich, 2009, Fig. 3 this paper) was a pluvial glacial lake in which depocenters are influenced by graben tectonics, which raised the Rosamond hills to the north while lowering the area of the pluvial lake to the south. Rosamond Dry Lake is a recent relic of a portion of Lake Thompson now 3 miles east of the site.

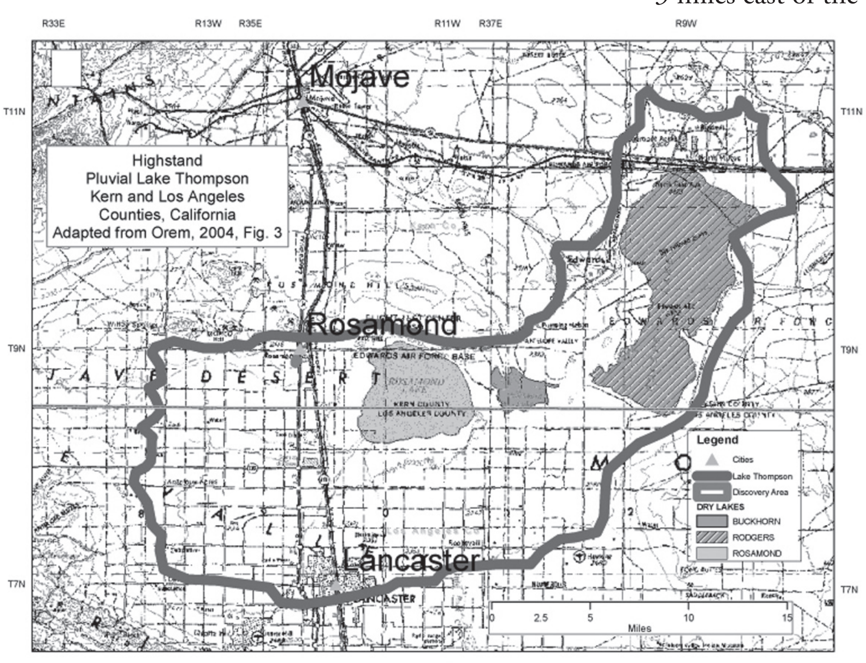

Figure 3. Map of Lake Thompson, from Orem, 2004, Fig. 1, p. 3

The fossils were found mostly in well-sorted medium, well rounded sand lenses within and sitting upon dark gray clay with abundant brown organic plant material. Many of the specimens had matrix of sand on them. The bison (excavated by Dennis Clayton) and some other specimens were extracted from hard grey clay. The uniformity of the grain size and textures of the sands suggest that they are beach deposits, reworked by wave action on the shores of ancestral Lake Rosamond. Our preferred model for the death assemblage is that unstable strata at the lakeshore trapped the animals when they came down to feed on vegetation surrounding the lake.

The discovery of mammoth and other vertebrate remains at Rosamond could have provided important geologic and paleontologic information to the scientific community. The vertebrate specimens were likely articulated prior to being excavated, churned up by scrapers, and later reburied by the earthmoving contractor. Most of the easily obtained large bones of the discovery spoil piles are likely still in the possession of the workers who took them from the site. We estimate that BVMNH salvaged 10% of the materials that could have been recovered, had scientific techniques been applied to this site immediately after discovery. We hope that future housing and commercial developments in the Rosamond area will include systematic paleontological surveys prior to earthmoving activity. A lesson to learn from the Rosamond case is that lead agencies should require paleontologists on site when construction projects are going on in areas formerly occupied by pluvial Lake Thompson.

The remnant fossils from the BVMNH salvage operation are open to inspection and study by any qualified party at the museum's facility in Bakersfield, California.

Acknowledgements

We are grateful for the assistance of Shelley Cox, Page Museum for assistance in identifying bison, mammoth and sloth fossils.

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Recently exposed fumarole fields near the Salton Sea

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New field observations are reported of three formerly submerged fumarole complexes that have recently been exposed as the Salton Sea level dropped. The main NE striking field is irregular in outline and is roughly 400 meters long and 120 meters wide. It consists of approximately one hundred warm to boiling hot mud volcanoes (gryphons), several hundred mud pots, and countless CO2 gas vents. Unusual shaped mud volcanoes in the form of vertical tubes with central vents were observed many in many places. Mud and water compositions were analyzed. With other geothermal features, the fumaroles define a well-defined line marking the trace of a probable fault.

1. Introduction

In the deepest part of the Salton Trough lays the Salton Sea (Figure 1), a below-sea-level saline endorheic lake created by an irrigation canal accident[1] in Mexico near Yuma, AZ in 1905. Near its southeastern shore lies the Brawley Seismic Zone (BSZ), a region of enhanced seismicity that contains the northernmost spreading center of the East Pacific Rise. Here the plate boundary[2] makes a right hand step along an active spreading center from the San Andreas Fault to the Imperial Fault. In some parts of the BSZ, the geothermal gradient exceeds 4.3 degrees C/m, enough to support a number of geothermal electricity generating plants.

Geothermal features are common in the Salton Trough, the most accessible being the mud pots and mud volcanoes[3-6] on the NE corner of Davis and Schrimpf Rds (DS, ~1.2 hectares). Until about 1939, a larger fumarole field near Mullet Island was a popular tourist attraction[7]. Since being submerged and until recently, the only evidence of the field was a steam cloud rising from the Salton Sea southeast of Mullet Island.

As the water level in the Salton Sea dropped[8], previously submerged land areas were exposed. In 2005 the

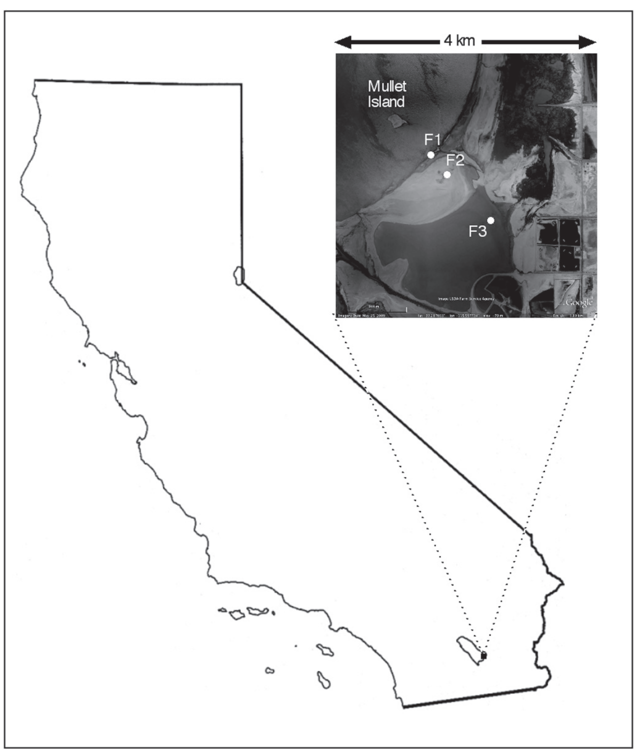

Figure 1. Index map of the region of study.

Figure 2. Photo of the main vent in F2 taken in 2005 when the field was covered by a few cm of water.

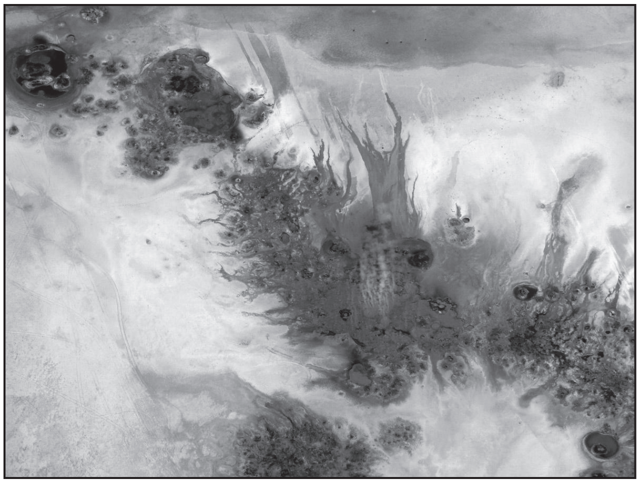
Figure 3. Aerial photo of the central part of F2 taken April 6, 2010. Image is approximately 250 m wide. (Courtesy Dr. David Tratt)


Figure 4. Low altitude aerial photo of F2 taken 13 August 2010 looking SW. The long (~vertical) axis of the fumarole field is about 400 m long. (USGS photograph by Dr. Kenneth Hudnut)


Figure 5. View though F2 taken January 18, 2011 looking SW. Foreground volcano is about 1.5 m high.


Figure 6. Large mud pot. Virtually all of the active mud is dark gray.

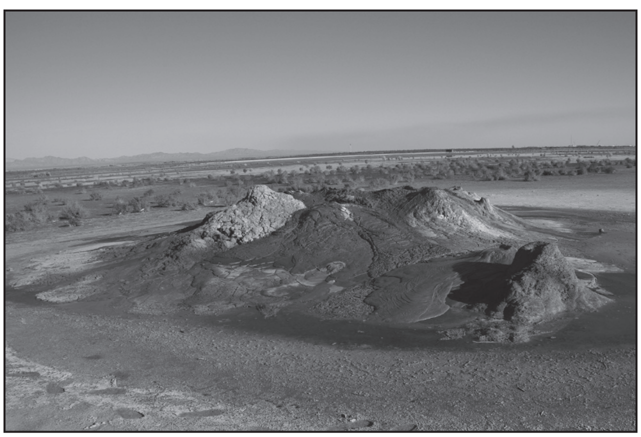
Figure 7. Approximately eight mud volcanoes merged into a single complex. Note the depressed, water-filled encircling moat.


Figure 8. Another volcano complex showing a ring scarp on the periphery of the moat.

author visited the area in the US Fish and Wildlife Service airboat (Figure 2) and found the main vent near Mullet Island (M4, M5 & M6 in Lynch and Hudnut)[4] was violently ejecting hot water, dark gray mud and steam clouds. Beginning in about 2008 the fumarole field surfaced episodically with seasonal lake level changes. By 2009 it was permanently above lake level, though only by a few cm.

In this paper we present recent observations of the newly exposed fumarole fields (here called F1, F2 and F3) and describe some of their main characteristics.

Figure 9. Volcano complex with active mud/gas venting at its summit, and Pahoehoetextured surface mud on its flank

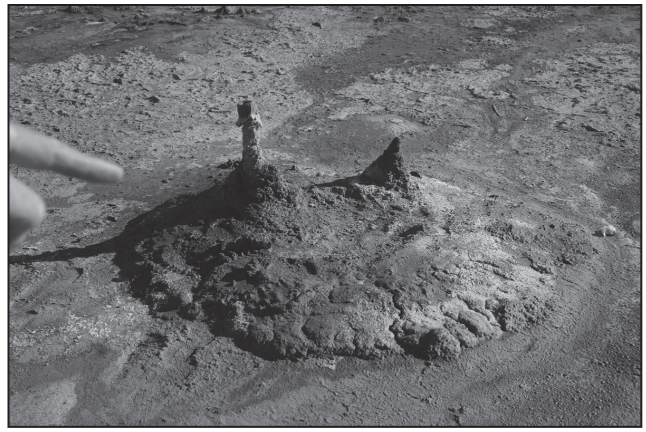

Figure 10. Mud tower with active central vent approximately 0.6 m high on a circular base about 1.3 m wide.

2. Field observations

The first detailed photographs[9] of F2 (N33.2184 W115.6011, -70 m MSL) were taken April 6, 2010 (Figure 3) followed by very low elevation imagery on Aug 13, 2010 (Figure 4). Between Aug 2010 and Jan 2011 the lake level had dropped enough to expose F1. On 18 January 2011, the author visited the site, taking photographs, movies and soil measurements to document the early formation stages of the geothermal structures (Figure 5).

F2 is about 1 km SE of Mullet Island. It is roughly 400 m by 120 m (~5 hectares) and strikes generally NE. F2 consists of approximately one hundred mud volcanoes and many more mud pots (Figure 6) and other irregular low lying bubbling springs. All the volcanoes were active, hot and emitting copious steam clouds. Soft mud—in many places too hot to comfortably touch —and abundant standing water permitted only limited foot access to the features.

Volcanoes ranged in height from a few cm to 1.5 meters. Volcano flank slopes seldom exceeded 45 degrees and were usually much less. Many had merged to form complex irregular cones with several spitting vents (Figure 7). These large complexes showed the characteristic moats and ring scarps (Figure 8) noted by many[6]. Mud flowing down the flanks often formed into ropey, pahoehoe-like surfaces (Figure 9). Emission from the vents included water, mud, CO2 and in a few places H2S and NH3, as judged by smell. The field was noisy, hissing and making "bloop-bloop" sounds as rising gas bubbles burst through the viscous mud.

About a dozen curiously shaped mud volcanoes were observed in the form of slender, vertical tubes (Figure 10), some actively spitting mud, others quiescent. Their heights ranged from 0.1 – 0.4 meters and often sat atop more conventionally shaped conical volcanoes. Although their formation process would seem similar to other gryphons, to our knowledge their tubular morphology is unique to this fumarole field.

F1 (N33.2210 W115.6036) is about 650 m SE of Mullet Island and 350 m NW of F2. It is about 25 m by 50 m (~0.1 hectares) and had very few elevated structures (Figure 11).

There were many active bubblers and they were generally much closer together than at F2.

Soil in F1 and F2 consists of fine-grained Colorado river sediments, much of it infused with evaporates (primarily NaCl) and products of hydrothermal alteration entrained in the rising CO2 and mud. Ground surfaces contained brown and dark gray mud, and white and

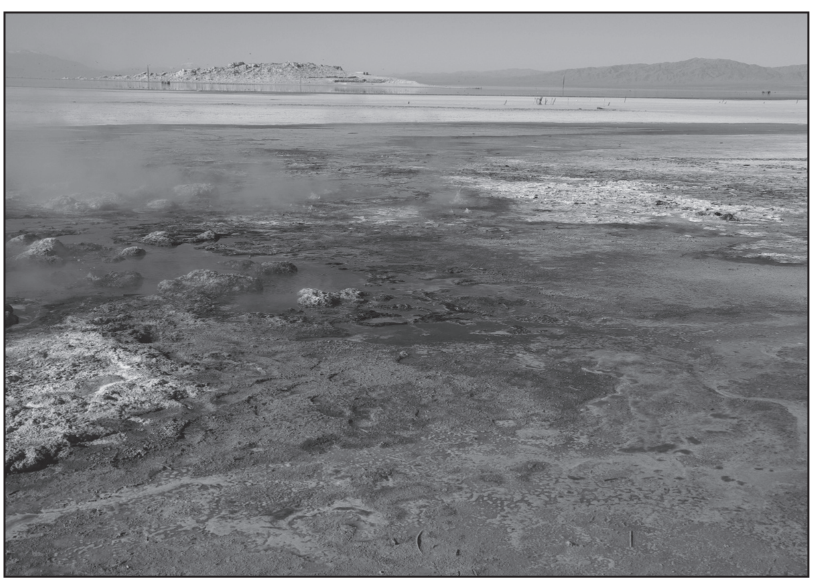

Figure 11. F1 field looking NW. Mullet Island in the background at upper left.

Figure 12. Google Earth image (2009) showing the locations of Mullet Island, F1, F2, F3 and the Davis-Schrimpf field. They fall along a straight line indicative of a fault, probably the Calipatria fault.

yellow granular crystals of salt and other evaporates. Volcanoes were almost uniformly composed of dark gray mud as were most of the mud pots. Algae were common in the runoff, but flowering plants were rare. None were higher than about 0.5 m, not surprising in view of the short amount of time they had to sprout and grow since the land was uncovered.

Both F1 and F2 show features that change rapidly with time. A visit to them on Jan 26, 2011 (8 days after the initial survey) revealed changed mud tower morphology, algae and amount of standing water.

Being in an enclosed bayou, F3 was inaccessible. Based on six-point triangulation, F3 is located near 33.212, -115.594. When the locations of DS, F1, F2, F3 and Mullet Island are plotted, they fall along a nearly straight line (Figure 12), an almost certain indication of a fault. This is probably the Calipatria fault, a feature that has been previously postulated[4].

3. Summary and conclusions

Three newly-exposed fields of hot springs, mud volcanoes and mud pots have been preliminarily surveyed. A third inaccessible field was discovered but not visited. The new fields are hotter, wetter and more active than the DS fields, though the morphologies of the new geothermal structures are similar. Soil compositions in F1, F2 and DS appear to be identical. The fumarole fields define the trace of a heretofore only suspected fault.

4. Acknowledgments

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The coming land bridge to Mullet Island

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As the Salton Sea level drops, a land bridge will form connecting Mullet Island to nearby land. This will allow raccoons, coyotes and other land predators to reach the island's cormorant nesting sites. On Jan 25, 2011, water depth measurements indicated that the coming land bridge is 12 inches below the current Salton Sea level (~ -231 ft MSL). The level is expected to reach land bridge stage of -232.4 inches MSL some time in 2012. Owing to local, state and federal regulations, the formation of this land bridge is inevitable. All parties involved are aware of it and its probable consequences to the bird populations in the area. Our goal here is to highlight the opportunity to study the "before-and-after" ecological studies that can and almost certainly will be done.

1. Introduction

Land bridge formation usually results in a sudden change in ecological conditions. Many occur on geological times scales (Panama Isthmus, Bering Strait, Sinai Peninsula), others more rapidly as with the 1979 appearance of a land bridge to Negit Island in Mono Lake, CA[1]. The development of a land bridge may result in habitat fragmentation, though it may not occur immediately after the land bridge is in place. In the case of Negit Island, canid invasion did not happen for about a year[1]. As lake/sea levels rise and fall, land bridges come and go. It seems inevitable that a new land bridge will soon form in the Salton Sea between Mullet Island and the mainland.

The modern day Salton Sea was formed in 1905–1907 by an irrigation accident in Mexico near Yuma[2]. Previously the ephemeral fresh-water Lake Cahuilla had occupied the Salton Trough, reaching a high stand of +13 m (39 ft) during Holocene times[3]. Heavy rains and occasional channel shifts by the Colorado River have produced fresh water lakes in historic times[4]. By area, the Salton Sea is the largest lake in California.

Mullet Island (Figure 1) is one of five volcanic necks[5] near the Salton Sea, rising about 40 ft (-191 ft MSL) above the surrounding sea (-231 ft MSL). The rocky rhyolitic knoll became known as Mullet Island in 1905 when the nascent Salton Sea rose and surrounded it. Marcia Rittenhouse Winn, writing for Westways in February 1975, tells of going to live on Mullet Island in the mid-1920s. "It wasn't really an island then but was connected to the mainland by a rough dirt road."[6]. This land bridge endured until 1948 when the rising lake reached an elevation of 240–235 ft below MSL and again isolated the island.

Figure 1. Mullet Island seen from the end of a recently-surfaced spit extending southward from the island. (25 Jan 2011)

Over 450 bird species and subspecies have been documented at the Salton Sea[7]. The lake supports 30% of the remaining population of the American white pelican, and is also a major resting stop on the Pacific Flyway. The island is currently covered with bird guano, the result (in part) of massive double-crested cormorant (Phalacrocorax auritus) nesting that began in the 1990s[8]. With its white coating, the island stands out sharply against the dark encircling water.

In this note we draw attention to the virtually certain formation of a

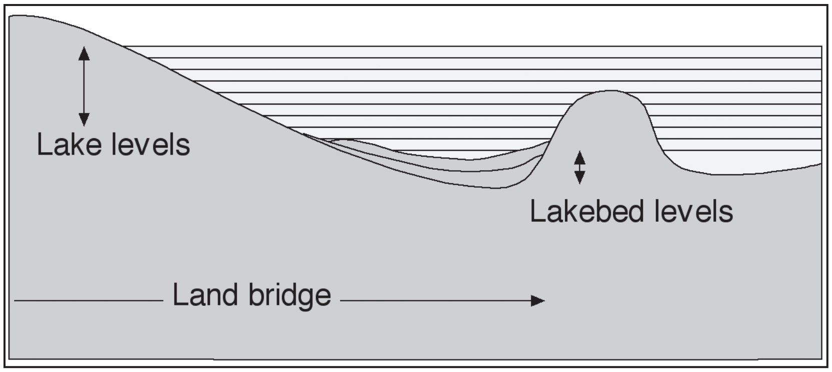

Figure 2. Cartoon showing how both lake level elevation and lakebed elevation determine the occurrence of a land bridge.

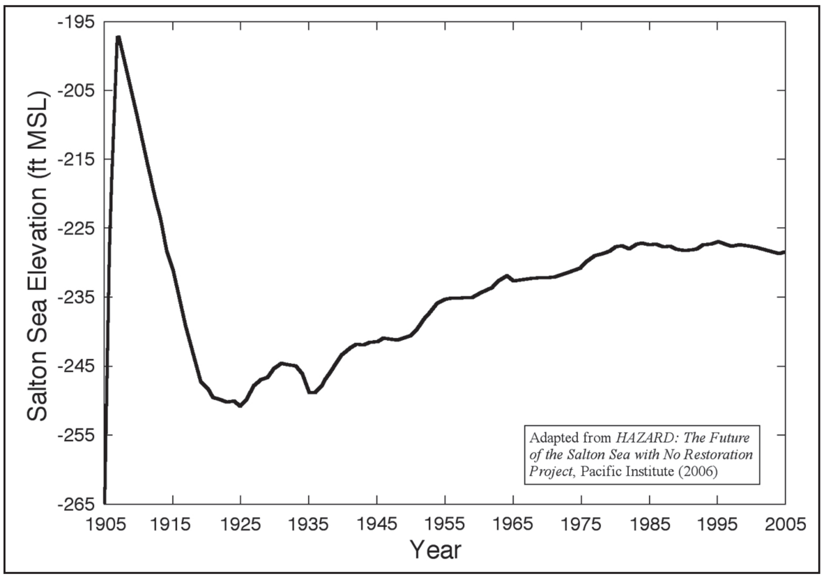

Figure 3. Historic water levels of the Salton Sea since 1905 (adapted from Cohen and Hyun 2006)[9].

land bridge to Mullet Island, perhaps as early as 2012. Our goal is to highlight an ideal ecological experiment in which the effects brought about by the land bridge can be studied before, during and after the event.

2. Land bridge

The current lake level (25 Jan 2011) is at -231.4 ft MSL9. It appears that a Mullet Island land bridge may form when the lake level drops to around -232.4 ft MSL. This is based on a quick-look bathymetric survey carried out on 25 Jan 2011. Previously, Krantz10 estimated that the land bridge would appear when the level was about -234 ft MSL. Cohen and Hyun11 argue that when the level reaches -235 MSL in 2018-2019, Mullet Island will no longer be an island. In view of the somewhat unpredictable level of the lake, Mullet Island will probably sprout a land bridge – perhaps transient for some period of time – between 2011 and 2018. From the most recent measurements reported here, it appears that the land bridge will form earlier than previously anticipated.

The emergence of the land bridge depends on two things, the Salton Sea level and the elevation of the submerged lake bottom (Figure 2). Both can change with time.

Water levels are monitored by the United States Geological Survey (USGS) and Imperial Irrigation District (IID)9. Figures 3, 4 & 5 show historic and recent water levels. Annual fluctuations are on the order of one foot. The largest source of water is agricultural runoff that originates in the Colorado River, IID's regulation of Colorado River water, and rain (directly and via the Alamo, New and Whitewater rivers). Evaporation is the only natural sink.

The most recent bathymetry of the sea in 1997 showed the deepest water east and south of Mullet Island at about -240 MSL12 (Figure 6), but this may not have detected the old narrow road. There are many unknowns and gaps in the history of lake

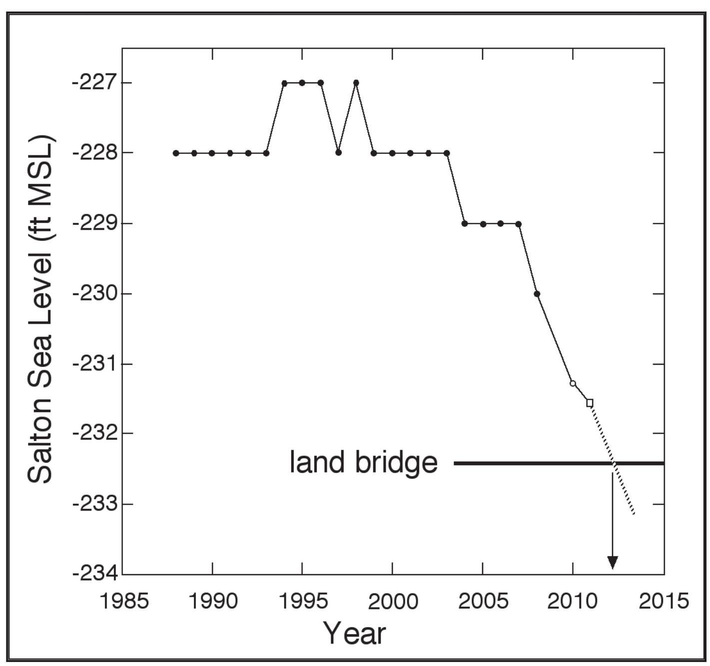

Figure 4. Recent water levels of the Salton Sea from the Westmoreland Gauge7. Solid circles are the annual means, the open circle is the 2010 annual mean estimated from daily water levels, and the open square is the water level on 25 Jan 2011. The dashed line is a crude estimate of the future water level.

Figure 5. Daily water level for 2010 and early 2011[7]. Note the annual cycle.

bottom, but -240 ft is about eight ft lower than the expected elevation of the imminent land bridge (~-232 ft MSL). One way to reconcile the difference is to suppose that the lakebed elevation has changed over time. Currents could deposit or remove sediments from the lake floor. Sediments carried into the lake could also influence bed level.

The present day terminus of the Alamo River is about 1.8 km SSE of Mullet Island, and meets the lake in an ever-growing delta (Figure 6). A slightly elevated ridge extends below lake level in a NW direction from Mullet Island and could represent the Alamo River delta. The predominant current in the southern lobe of the Salton Sea is counter-clockwise13. Flowing north from the mouth of the Alamo River, such a current could displace Alamo river sediments northward to Mullet Island and accumulate to form the observed underwater delta. To account for a 6 ft rise in 63 years (1948 – 2011), the sedimentation rate would have to have been prodigious, ~28 mm/yr. Were this the case, it is possible that a sudden event—like a flood—could produce 9 ft of sediment in a short time.

3. Visit to Mullet Island

On 25 January 2011, personnel from the US Fish and Wildlife Service (Sonny Bono Salton Sea National Wildlife Refuge) took me to the island on their airboat. Extreme care was taken not to disturb the birds or nests. I walked around the island for about two hours, searching the shore for evidence of the old road and any other location where a land bridge might form.

Most of the cormorant nests are on flat or gently sloping open ground near the summit, and are packed closely together. Any ground predator would have easy access to the nests. I looked specifically for evidence of rodents, dogs, or raccoons, e.g. tracks, droppings, and disturbed nests, but none were found. A number of canid tracks were seen on nearby land and sand bars, but whether these were from coyotes or peoples' pets is unknown.

After several trips around the island by boat, we returned to the south and eastern waters between the island and shore. Here we made water depth measurements, guided primarily by wading birds

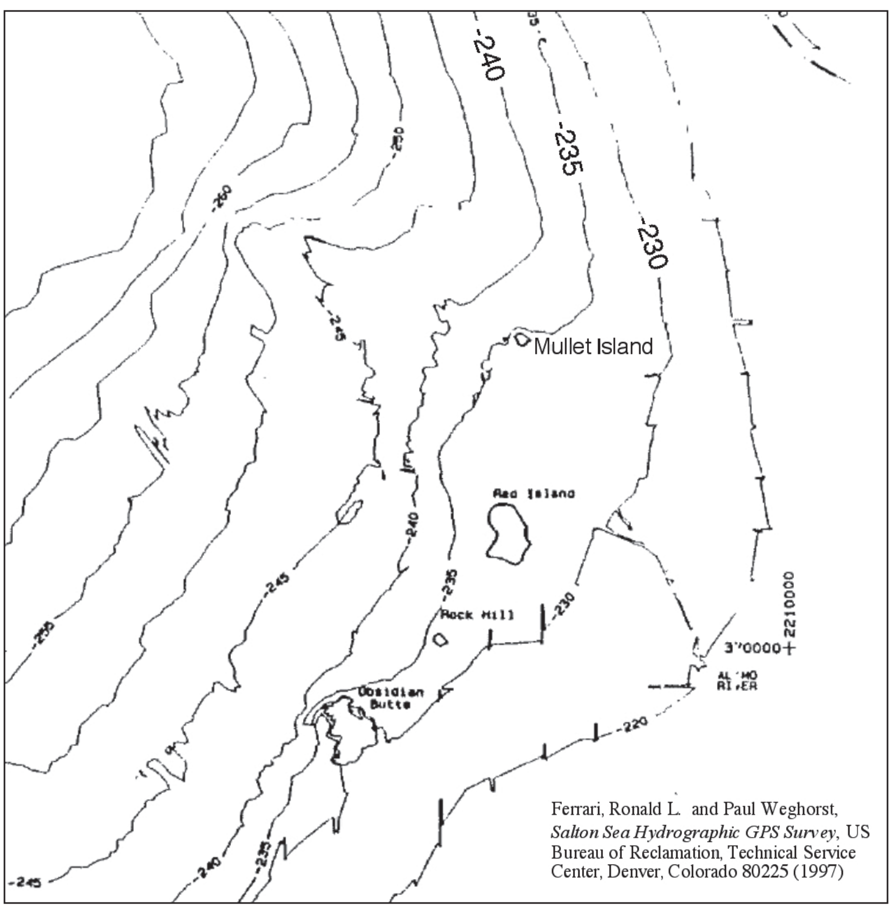

Figure 6. Bathymetry near Mullet Island in 1997[10].

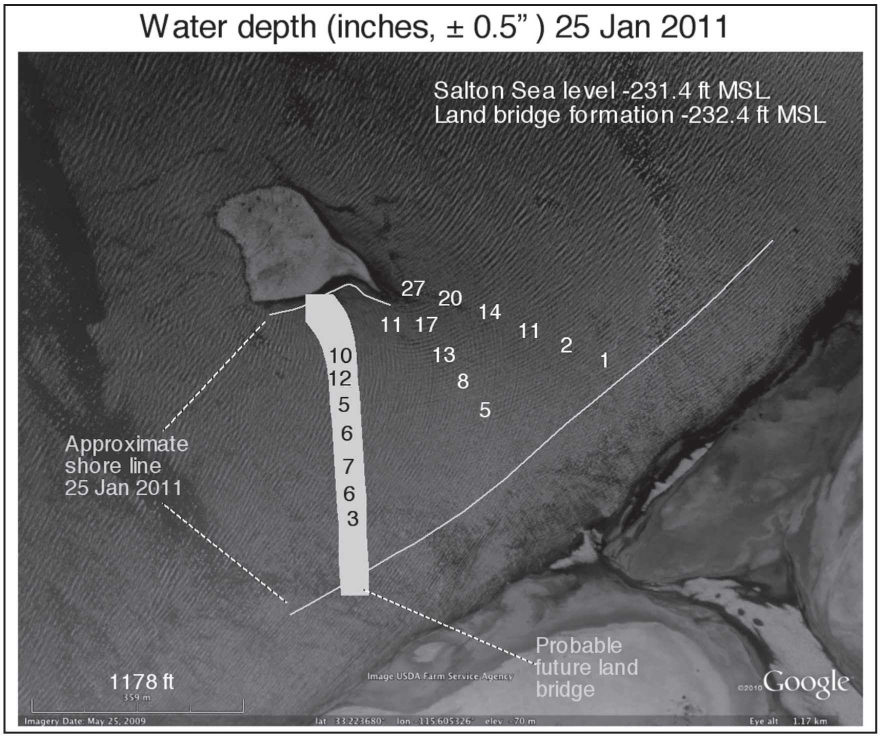

Figure 7. Water levels measured by the author on 25 Jan 2010. The ~vertical white bar shows the mostly likely location of the emergence of the first land bridge.

that stood in the shallowest waters. Depth was determined by placing an ordinary carpenter’s metal tape measure into the water and reading off the depth. The lakebed was firm and without soft mud, so the depth measurements were robust. While not a complete bathymetric survey, the shallowest water was readily apparent south and east of the island. Three short tracks were recorded (Figure 7). Based on these measurements, it appears that the land bridge will form south of the island along an old pole line road (Figure 8).

Regardless of the time when the land bridge will be permanently above water (now estimated to be mid 2012), the water will be shallow enough for larger land predators (e.g. coyotes) to easily wade across and reach the island before the land bridge surfaces. Indeed, the current maximum depth across the anticipated land bridge is only twelve inches, so in principle coyotes could reach the island today.

4. Discussion

Mullet Island provides one form of habitat. But it is the function of Mullet Island that matters, not its form. Many other forms can provide the same function, i.e., a safe, enduring place for the birds to live. While some may regret the imminent loss of habitat, long-term survival of the birds must take precedence over their short-term protection14. Such issues must be balanced against the shrinking wetlands of California and the key role the Salton Trough plays as part of the Pacific Flyway.

The 2003 Quantification Settlement Agreement15 governs water distribution to the Salton Sea. Signatories include San Diego County Water Authority (SDCWA), Coachella Valley Water District (CVWD), Imperial Irrigation District (IID), Metropolitan Water District of Southern California (MWD), State of California and the U.S. Department of the Interior. The Salton Sea Ecosystem Restoration Program16 describes California’s plan to manage the Salton Sea. It is an ongoing and evolving effort.

Figure 8. The expected land bridge will probably form along the old pole line extending south from the island. This line probably defines the location of the old road used to access the island. View is looking south from Mullet Island.

5. Summary and conclusions

Based on recent Salton Sea levels and a January 2011 survey of Mullet Island and the surrounding waters, it appears almost certain that a land bridge will surface and connect Mullet Island to the mainland sometime in the next couple of years (~2012). Such an event will expose bird nesting sites to land predators.

6. Acknowledgments

We appreciate information provided by Randy Von-Nordheim of the California Dept of Fish and Game, and assistance visiting Mullet Island from Christian Schoneman, Danny Gomez, Aaron Eaton, and Juan Guzman of the US Fish and Wildlife Service. H. Lee Case and Douglas A. Barnum (USGS) provided helpful guidance while writing this paper. Kathy Molina contributed useful information about birds in the area.

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Drought and naturally occuring surface water in Mojave National Preserve

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Springs and seeps are an essential resource for wildlife populations and form a key ecosystem component in desert environments. The mandate of the National Park Service to perpetuate in a natural state the desert ecosystem of Mojave National Preserve is inextricably linked to the spatial and temporal distribution of surface water. From 2002 through 2010 park staff and volunteers have developed a database of 262 locations in the Preserve where water exists near surface and is available permanently or seasonally, often through developments consisting of small tunnels. Topography in the Preserve ranges from 274 to 2,438 m elevation but all the springs, with one important exception (MC Spring), occur between 860 and 1827 m elevation. These springs typically are found near the foothills and in the canyons of the prominent mountain ranges (Figure 1). Higher elevations receive more precipitation, which is collected and focused by topography towards canyon drainages and stored in small, perched aquifer systems in shallow sediments. Springs and seeps emerge at geologic structures and bedrock outcrops. Two important exceptions to this pattern are MC Spring on the western edge of Soda Dry Lake and Piute Spring in Piute Gorge on the eastern edge of Lanfair Valley. MC Spring is a small, limnocrene spring at a low elevation near the edge of the Mojave River terminal basin while

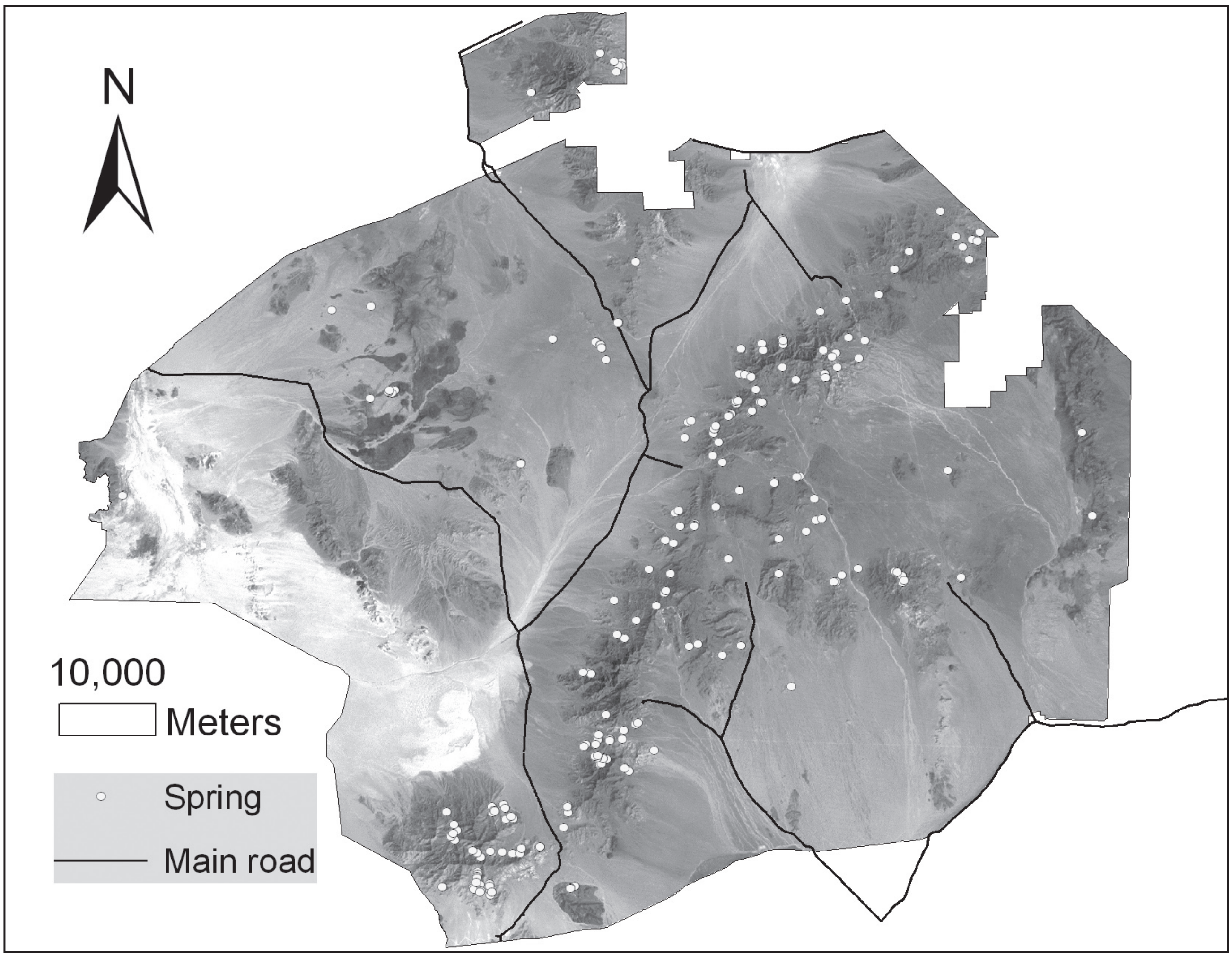

Figure 1. Map of Mojave National Preserve, San Bernardino County, California showing the locations of potential seeps and springs primarily associated with the prominent mountain ranges.

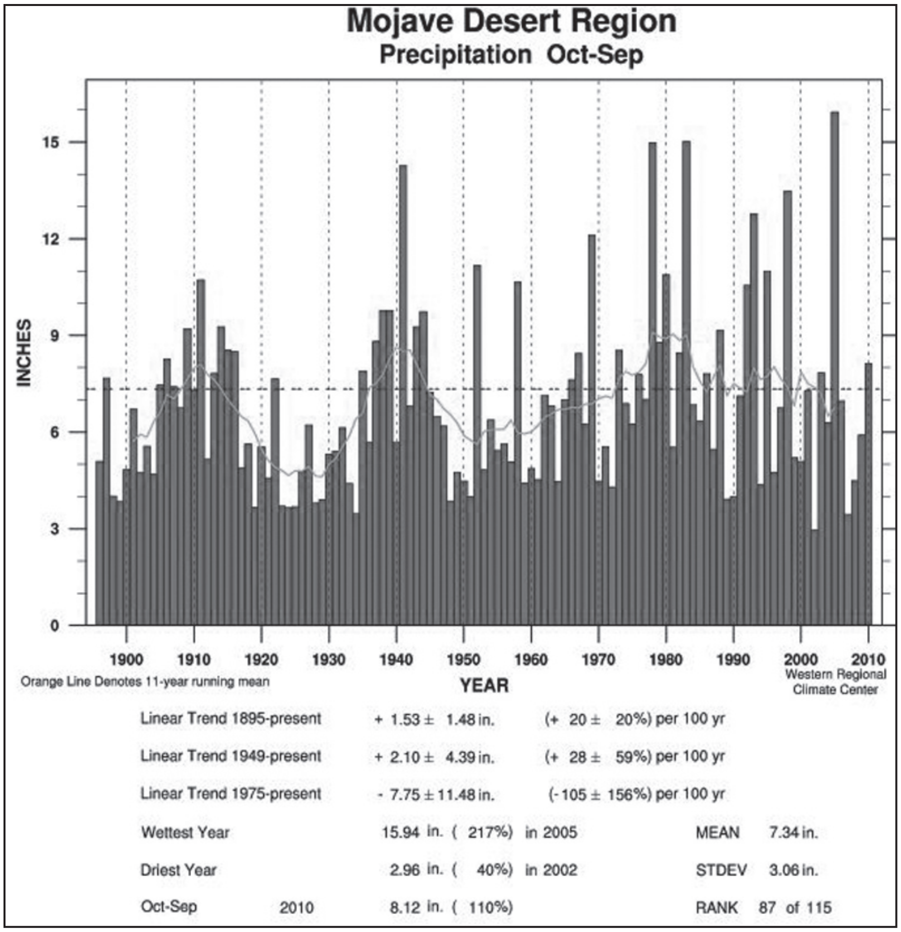

Figure 2. Precipitation data from the California Climate Tracker (Abatzoglou et al. 2009) for the Mohave Region, available through the Western Regional Climate Center, for the water year from October through September show multi-year droughts in the mid-20th century and increasing variability in the 21st century. The two driest years in this record (2002 and 2007) and the wettest year (2005) all occurred during the first decade of the 21st century.

Piute Spring is a rheocrene spring fed by the alluvial aquifer in Lanfair Valley. Both of these are connected to aquifers of a larger extent than the majority of mountain-front, perched aquifer-fed springs.

Precipitation data for the Mohave Region of the California Climate Tracker (Abatzoglou et al. 2009) show multi-year droughts in the decades of the 1920s through mid-1930s and from the late 1940s to early 1960s (Figure 2). More severe droughts in the western US are evident in tree rings during the periods 1118-1179 AD and 1276–1299 AD (e.g. Meko et al. 2007, Douglass 1929). Recent model predictions indicate a transition to a more arid climate in the southwest with increasing variability in precipitation from year to year (Diffenbaugh et al. 2008). A return to more arid conditions beginning around 1999 (Cook et al. 2009), along with precipitation data spanning 115 years, that show the wettest year occurring in the Mojave Desert in 2005 and the two driest years occurring 2002 and 2007 appear to align with these model predictions. Both models and data indicate that park planning should prepare for the consequences of multi-year periods with low precipitation.

Spring discharge will decrease during periods of low precipitation as an approximately exponential function of time (Chow et al. 1988) with an exponential constant characterized by the hydrologic properties of the aquifer. For simplified aquifer geometry it can be shown (Gelhar and Wilson 1974) that this constant has the form (SA)/(3Kb) where, for a water table aquifer, S is approximately effective porosity, A is aquifer area , K is hydraulic conductivity, and b is saturated thickness. Although hydraulic conductivity can vary by orders of magnitude at small scales, this heterogeneity tends to diminish when averaged over large volumes, while aquifer porosity is typically fairly uniform (Bear and Verruijt 1987). Thus, as a first order approximation, the response time of spring discharge to drought should scale proportionally with aquifer area. A cursory examination of maximum possible aquifer area for springs in the Preserve using digital elevation models and satellite imagery suggests that most will respond to dry conditions on a time scale of a few years to at most a few decades. Piute Spring, which is associated with a larger alluvial aquifer, could have a response time on the order of hundreds of years.

Starting in 2004 and continuing through 2009 the Preserve organized an annual volunteer spring survey to assess the proportion of potential spring sites where surface water was available in the fall of each year. These data, although limited, indicate a rapid response to rainfall with surface water available at 84% of the potential spring locations during a wet year but declining to 58% following two sequential dry years (Figure 3). Repeat photography and soil moisture probes located at two seasonally ephemeral springs suggest that the transition from wet to dry can occur rapidly, within a few days or weeks.

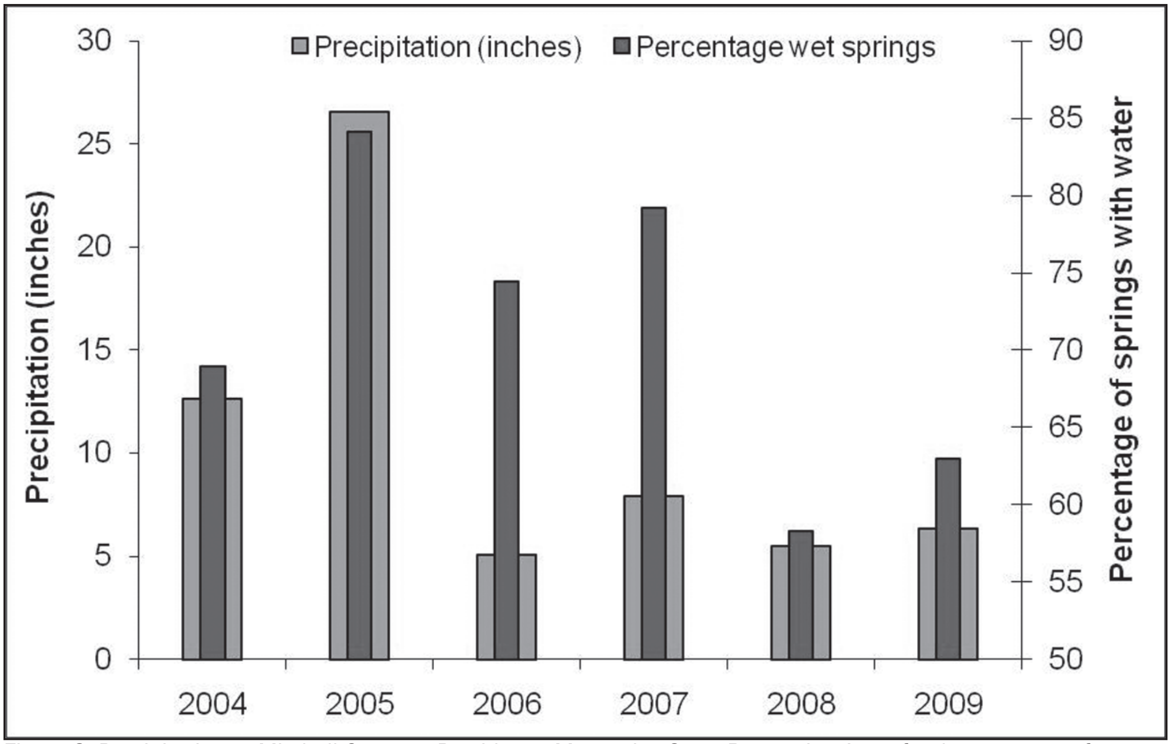

Figure 3. Precipitation at Mitchell Caverns, Providence Mountains State Recreation Area, for the water year from October through September (wide bars) compared with the percentage of springs with available surface water (narrow bars) indicates springs respond rapidly to precipitation and 25% disappear after two dry years.

Historical precipitation records show that severe decadal droughts are likely on a century time-scale and that multi-decadal mega-droughts are likely on a millennial time-scale. Global climate models indicate a general drying trend in the southwest into the 21st century with increasing variability in precipitation from year to year, suggesting that the likelihood of multi-year droughts may be increasing (Cook et al. 2009). Annual observations indicate that surface water disappears at 25% of the springs in the Preserve after two years of low precipitation while a simple model suggests that nearly all would be threatened by drought lasting more than a decade. Mojave National Preserve is beginning a three year process to develop a comprehensive water management plan. In the face of global change it may not be possible to maintain park resources both unimpaired and in a natural state, if natural is taken to mean no intervention. Resource managers should consider all possible techniques and approaches, including active manipulation methods, to maintain ecosystem components in a functioning condition.

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The ant fauna of the Mojave National Preserve

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Abstract

Between 2000 and 2008 we intensively surveyed the ant fauna of the Mojave National Preserve employing a variety of sampling methods. We detected 74 native ant species including one previously unknown species. No non-native species were detected. The collection includes a number of range extensions and new state records. Most of the fauna is generally typical of the Mojave Desert and is composed of species that thrive under warm, arid conditions and relatively mild winters. Our prediction that the higher elevations in the Preserve would support cold adapted species typical of the Juniper-steppe climate of the Great Basin was not borne out. An annotated checklist summarizes these collection records and the natural history of these species

Introduction

The biota of the Mojave National Preserve in southeastern California, hereafter referred to as "the Preserve", is rich owing to its climatic and elevational range and to its complex biogeographic history. It contains floristic elements from the Great Basin and Sierran influences as well as Hot Desert elements which approach from the south along the Colorado River valley and from the west along the Mojave River drainage.

The presence of White Fir (*Abies concolor*) on north-facing exposures of both New York Peak and Clark Peak (Thorne et al, 1981) is indicative of a much more extensive Pleistocene distribution of the northern and montane floras at elevations as much as 1,200 m lower than they extend today (Van Devender et al, 1987; Koehler et al, 2005; Smith et al, 2000; Wells, 1983). Studies reviewed by Cronquist et al. (1972) suggest an "almost continuous Wisconsin-age woodland corridor between the Spring Mountains of southern Nevada and the San Bernardino Mountains of southern California".

Studies of plant remains in the ancient middens of packrats (*Neotoma* spp), (King, 1976; Thompson, 1990) come to the same general conclusions. Koehler et al. (2005) describe a Pleistocene flora including Juniper steppe woodlands in the valleys north of about 36° N latitude and a warmer mild-mesic woodland to the south of that latitude. Woodrat midden data from across the region indicate a drying, warming trend with *Larrea divaricata* (Creosote Bush) reaching the Marble Mountains from the southeast by about 7900 years BP with a concurrent retreat by *Pinus monophylla* (Single-leaf Pinyon) southward and westward. These conclusions are reinforced by a study of relict modern populations of *Neotoma fuscipes* in the region (Smith et al, 2000). These authors (their figure 5, p 491) illustrate probable historical habitat corridors along which species could have gained access to the mountains of the Preserve. Johnson (1995) analyzed the spring bird fauna of Clark Mountain in an effort to identify the geographical origin of the fauna. The birds of the New York and the Kingston ranges show comparable patterns, (Cardiff and Remsen, 1981). The mountains of the Great Basin, Sierras, Rockies and southern Arizona provide the source populations. Together, these affinities suggest that similar patterns might exist in the ant fauna.

The ants of the Preserve have not been carefully surveyed. Considering the historical and biotic complexity of the region it is reasonable to expect an ant fauna richness corresponding to the richness of the rest of the biota in the Preserve. Wheeler and Wheeler (1986) carefully described the ants of Nevada, and Snelling and George (1979) studied the ants of the Mojave Desert but they indicate (p. 4) that they emphasized the Hot Desert (Creosote Bush Scrub), considering the Cool Desert (Great Basin Sagebrush Desert) to be marginal, and they generally excluded the Pinyon-Juniper Woodlands as being an element of the Cool Desert. Sanders et al. (2003) surveyed the ant fauna along an altitudinal gradient in the nearby Spring Mountains, Nevada. They discovered that ant species diversity increases with elevation above about 1,100 m and is correlated with increasing precipitation and lower temperatures. The lower edge of the Joshua Tree Woodlands and Joshua/

Juniper woodlands at an elevation of around 1,100 m appears to demarcate the Hot Desert influence from the Cool Desert influence. The Preserve straddles the perimeters of the only two careful taxonomic studies of ants available. The higher elevations within the Preserve can be thought of as sky islands and might constitute a refugium for montane and northern ant taxa but these areas have not been surveyed.

Ward (2004) observed a total of 37 species at five locations in the Preserve. All of those records appear in our annotated list. Nash et al. (2004) have done the only other ant study we are aware of within the boundaries of the Preserve. All three of their study sites in the Preserve were in the Creosote Scrub community. Eight species in their list of 32 species did not appear in our survey. Seven of those are evidently undescribed species and the eighth, *Pheidole sitarches*, would be a new state record. The voucher specimens for their study are deposited at the USDA-ARS Jornada Experimental Range, New Mexico. We were unable to see these interesting specimens as the authors failed to reply to our inquiries about them. We, therefore, did not include them in our annotated list. Given this preliminary state of understanding it was our intent to sample the ants across this biotic range.

The region

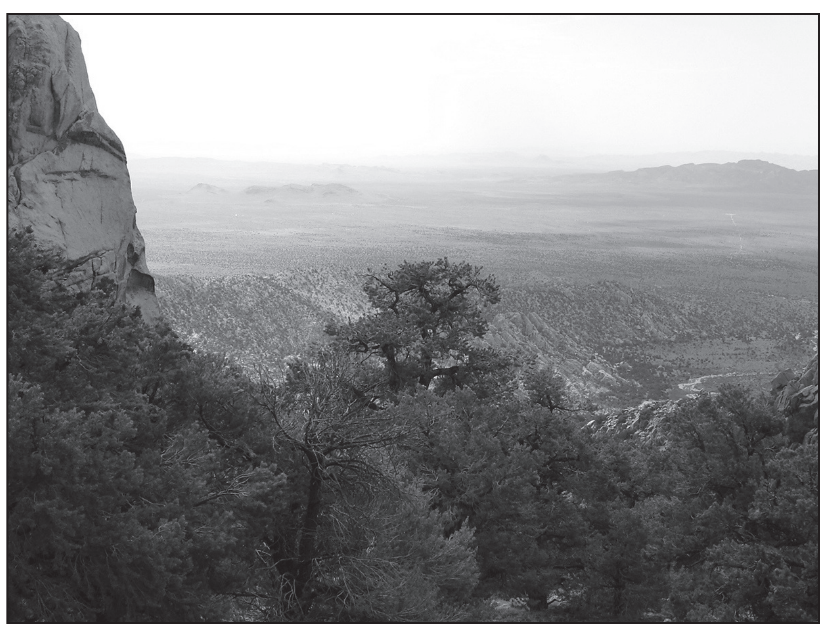
The Mojave Nature Preserve covers about 607,000 ha in the Mojave Desert and lies between N34.580°–34.717° and W114.950°–116.183°. The elevation ranges from about 285 m at Soda Lake to about 2410 m at Clark Peak. The rainfall varies within the preserve from about 86 mm at Soda Lake near Baker to around 229 mm in the mountains to the east. Approximately 25% of the precipitation comes as summer monsoon rain. Two research stations reside within its boundaries, the Sweeny Granite Mountains Desert Research Center of the University of California and the Desert Studies Center of the California State Universities.

A careful description of the climate of the region can be found in Thorne et al. (1981). These authors recognize 15 plant communities. However, the region is dominated by only a few of those communities—Pinyon/Juniper/Oak Woodlands, Juniper/Sagebrush Scrub, Mixed Desert Scrub, Blackbush Scrub, Joshua Tree Woodland, Creosote Bush Scrub, Desert Psammophytic Scrub and Desert Wash Scrub. The boundaries of these communities regularly interdigitate or intergrade along elevational or soil type gradients. The result is an exceedingly complex mosaic of habitats embedded within the Creosote Scrub community that typifies the Mojave Desert (Hickman, 1993). This region is also described from the point of view of ant ecologists (Snelling and George, 2003). André (2006) has inventoried the plants of the Preserve.

For most of the last century the region was subject to seasonal cattle grazing. The impact of the grazing was most severe around water sources, both artificial and natural. The cattle were removed from most of the areas we sampled in the year 2001. Since then, the forb ground cover has increased dramatically in some areas and the populations of quail, doves, and lagomorphs have shown corresponding increases (pers. obs.). However, Veblen (2010) has preliminary results showing little native vegetation recovery since 2001 with some increase in invasive species density near water sources.

Materials and methods

Under authority of the appropriate research permits and access agreements in the Mojave National Preserve, San Bernardino Co., CA, ants were systematically collected throughout the year during the period 2000–Jan 2008. A total of 33 sampling sites were established, largely along road transects scattered in the Clark, Granite, Providence, and New York Mountains and the north end of Midhills along Cedar Canyon Road. Another transect ran along Kelbaker Road between Granite Pass and Baker, then along Cima/Kelso Road



Caruthers Canyon viewed from the New York Mountains.

Table 1. Ant diversity within plant communities

Plant Community	% of Preserve Area	% Trapping Effort	# Ant Species
Creosote Bush Scr.	41.2	15.6	44
Joshua Tree Woodl.	22.6	16.1	47
Mojave Yucca Scrub	15.9	13.2	25
P/J Woodland	5.9	13.3	48
Dune Scrub	3.1	6.7	15
Desert Wash	3	16	30
Blackbrush Scrub	1.7	19.1	39
Nonnative or other	6.6	0	

Percentage of the sampled habitat types and the sampling effort in each of the habitat types. The number of species collected in each habitat type is shown in the third column. Total Preserve area=607,000 ha. Total sampling effort=62,797 trap nights.

between Kelso and Interstate Hwy 15. The perimeters of the Granite and Clark Mountains were also surveyed. Likely collecting sites and records of occurrence were also gleaned from Snelling and George (1979) and the website AntWeb.org. The most intense collecting effort was made in Caruthers Canyon between the canyon mouth and New York Peak. An informal effort was made to sample the range of plant communities described above.

Ants were collected by hand, pitfall traps, and various bait traps on the ground and hanging in vegetation. Hand collecting including opportunistic wandering and surface scanning; turning stones, fallen logs, and litter; breaking twigs; chopping in standing and fallen dead wood; lifting dead bark; digging into active nests; and sieving litter.

Table 2. Ant species diversity of the most common genera

Ant Genus	Functional Group	# of species	# of Species records	% of Species Records
Pheidole	GM	13	346	21.3
Myrmecocystus	HCS	13	163	10.1
Crematogaster	GM	3	141	8.7
Camponotus	SC	7	139	8.6
Solenopsis	HCS/CS	4	127	7.8
Pogonomyrmex	HCS	5	117	7.2
Total		45	1033	63.7

Functional Groups	# of species
CS = Cryptic Species	1
GM = Generalist Myrmicine	16
HCS = Hot Climate Specialist	21
SC = Subordinate Camponotine	7

The six most common genera ranked by the number of species records they contributed to the collection. The large majority of species in these common genera are members of only two functional groups.

The majority of the collection was gathered by using pitfall traps. At each sampling site an array of four plastic beverage cups (9.2 cm diameter) were placed under the north-side dripline of four haphazardly chosen shrubs, trees or overhanging boulders. Borgelt and New (2005) discuss the advantage of using traps as large as these. Each trap was covered by a 15 cm x 15 cm plastic roof that was anchored above the ground by long nails in each corner of the cover. A gap between the soil surface and the roof of a few cm was maintained to allow the free movement of ants and yet shelter the traps from falling debris and precipitation. This protocol underestimates the diversity and numbers of both arboreal and subterranean species because, to be sampled by the pitfall traps, an individual must be moving on or very near the soil surface. The traps were filled about half full with ethylene glycol as a killing agent. This preservative was used instead of propylene glycol because it doesn't evaporate in the summer heat. These traps were left in place for approximately one year and were refreshed four or five times to allow sampling across seasons. Each time the traps were refreshed the contents of the traps were poured through a 2 mm mesh sieve and the collected contents of the site were stored for later analysis.

Ants were identified by reference to Wheeler and Wheeler (1986), Snelling (1976, 1982), Snelling and George (1979, 2003) and AntWeb.org (2008). Identifications of species were checked by Andrew Suarez (then at UC, Berkeley) and Philip Ward (UC, Davis). Voucher specimens are deposited in the Bohart Museum at the University of California, Davis in accordance with the permitting requirements of the Mojave National Preserve.

The areas of plant communities within the Preserve were extracted from mojavedata.gov/datasets by John Donoghue in Sept 2006.

Results and discussion

Our survey involving 62,797 trap nights produced 74 native species represented by 1621 species records and 23,966 individual specimens. The collection includes five

Table 3. The Most Common Ant Species

Ant Species	# of Species Records	% of Species Records
Pheidole desertorum	134	8.3
Solenopsis xyloni	101	6.2
Crematogaster depilis	84	5.2
Monomorium ergatogyna	57	3.5
Pheidole cerebrosior	51	3.2
Temnothorax neomexicanus	51	3.2
Total	478	29.6

The six most common ant species in the sample. Six species out of 74 make up nearly 30% of the records.

subfamilies; Ecitoninae (4 spp.), Ponerinae (1 sp.), Dolichoderinae (6 spp.), Myrmicinae (38 spp. including one newly discovered species), and Formicinae (25 spp). There were no non-native ant species detected.

Table 1 illustrates the ant species composition of the various plant communities. Our trapping effort was not representative of the relative areas of the plant communities in the Preserve. Both Creosote Bush Scrub and Joshua Tree Woodland were undersampled. As a result we cannot make any quantitative analysis of the habitat-specific distribution of ant species. However, the sheer size of the trapping effort gives us some confidence that we have a reasonable assessment of species diversity and relative abundance in both of these communities.

More than half of all species records are of members of six genera (Table 2). The genus *Pheidole* with its 13 species represents about 21% of all the records and is by far the most commonly encountered genus. Thirteen species of *Myrmecocystus* also appear in the collection so that together with *Pheidole* they represent about 35% of the ant fauna and about 32% of the species records. The Generalist Myrmicines and the Hot Climate Specialists (Andersen, 1997) dominate the ant fauna with 38 of the 45 species that occupy these two ecological roles.

The six commonest species are all in the subfamily Myrmicinae and make up nearly 30% of the species records (Table 3). The most common, *Pheidole desertorum*, is an aggressive predator/scavenger that was collected in all but the sandiest, lowest elevation sites. The Functional Groups (Andersen, 1997, Blondel, 2003) represented in the collection are those that might generally be expected in hot desert regions (Fig. 2). *Formica* (2 spp), *Temnothorax* (6 spp), *Lasius* (2 spp) and *Stenamma* (1 sp) are the only Cold Climate Specialists we encountered. In contrast Sanders et al (2003), using a short-term sampling method, found in the Spring Mountains of southern Nevada ten species of *Formica*, six species of *Temnothorax* and two species of *Lasius* over the same elevation range that we sampled. They encountered two species of *Myrmica* above 2000 m elevation and we found none. Much of the Spring Mountains diversity occurs in Ponderosa Pine forest which is restricted to elevations above about 2000 m. This is a plant community that is entirely absent in the Preserve and from the fossil packrat midden record in the region (Koehler, 2005). So, these easily detected Cold Climate Specialists occur within 80 km of Clark Mountain and 120 km of the New York Mountains but show much diminished diversity in the much smaller sky islands of the Preserve. Snelling and George (1979) excluded the Pinyon/Juniper Woodland from their survey judging that it represented a component of the Cool Desert association. Nevertheless, the higher elevation habitats in the Preserve don't support the number of Cold Climate Specialists that might be expected from their proximity in the nearby Spring Mountains to the north and from the presence of other relict populations in the Preserve (Smith et al, 2000). Thus our suggestion in the Introduction that we might find more representatives of the Cool Desert or Pleistocene expansions has not been borne out. Perhaps the Preserve's location in the mild, mesic woodland south of the Pleistocene limit of Juniper steppe woodland (Koehler et al, 2005) at about 36° N constituted a dispersal barrier to those ant species.

Annotated checklist

The annotated list of species that follows includes the Functional Group of the genus (Andersen, 1997), feeding notes, plant communities in which the species was collected, elevation ranges, months in which the species was collected, nesting notes, number of records, some representative collection sites. Additional notes about range records or vexing taxonomic problems also appear in some records. One previously unknown species, *Pyramica* ca01, was discovered and is thus far known only from a single, dealate queen collected 1 mi. west of Pichalka Spring.

The natural history notes, food, and nest records were gleaned from our own observations and from the sources cited above as well as Andersen (1997), Mackay and Mackay (2002), Snelling and George (2003), Ward (2005), Wheeler and Wheeler (1973) and Wilson (2003). The locations listed in each note are arranged more or less from south to north and most were selected with ease of access in mind and distances and elevations are expressed in miles and feet because those are the units used in the commonly available maps. Additional species records were gleaned from the literature, especially Snelling and George (2003).

Ecitoninae

Neivamyrmex leonardi (Wheeler, W. M., 1915) Cryptic Species. Predatory, subterranean raids Pheidole nests. Blackbrush Scrub, Pinyon/Juniper Woodland between 4900–5535 ft. May–Aug. Nests in soil. 9 records. Pichalka Spring, Curtis Canyon.

Neivamyrmex wilsoni (Snelling and Snelling, 2007). Cryptic Species. Predatory, subterranean. Probably raids on Pheidole nests. Pinyon/Oak/Juniper Woodland, Juniper Oak grassland at 5600–5700 ft. March. Nests in soil. 2 records by PH Ward. Caruthers Canyon.

Neivamyrmex nigrescens (Cresson, 1872) (shiny form). Tropical Climate Specialist. Predator on various ants, especially Pheidole, and other insects. Desert Wash, Joshua/Juniper Woodland, Blackbrush Scrub, Pinyon/Juniper Woodland between 3900–5500 ft. Jun–Oct. Bivouacs in soil, nests of other ant species and litter cavities. 22 records. Granite Pass, Dorner's Camp, Rock Spring, Cima, Pichalka Spring, Curtis Canyon. The distinction between this shiny form and the next mentioned typical form of *N. nigrescens* has been evaluated by Ward (1999).

Neivamyrmex nigrescens (Cresson, 1872). See preceding record. Desert Washes, Mojave Yucca and Blackbrush Scrub, Pinyon/Juniper woodland between 3900–5500 ft. May–Oct. 29 records. Granite Pass, Vulcan Mine Rd, Pichalka Spring.

Ponerinae

Hypoponera ca-01. Cryptic Species. Hypogaean predator probably on collembola and other soil arthropods. Blackbrush Scrub and Pinyon/Juniper Woodland between 4900–5700 ft. Mar–Aug. Nest in fine soil. Associated with rotten roots of dead shrubs. 6 records. Caruthers Canyon, Pichalka Spring, Curtis Canyon.

Dolichoderinae

Conomyrma. See *Dorymyrmex*

Dorymyrmex bicolor (Wheeler, W. M., 1906). Dominant Dolichoderinae. Hemipteran tending opportunist. All habitats between 2150–4900 ft. Apr–Oct. Nest on exposed soil. 37 records. Willow Spring Basin, length of Kelbaker Rd., Rock Spring, Pichalka Spring.

Dorymyrmex insanus (Buckley, 1866). Dominant Dolichoderinae. Hemipteran tending opportunist. All habitats between 1000–5700 ft. Every month. Nest on exposed soil. 48 records. Dorner's Camp, length of Kelbaker Rd., Rock Spring, Caruthers Canyon, Pichalka Spring, Keystone Canyon.

Forelius mccooki (McCook, 1879). (=*F. foetidus*). Dominant Dolichoderinae. Hemipteran tending scavenger. All habitats between 1000–7200 ft. May–Oct. Nest in soil or under stones. 47 records. Budweiser Spring, Kelso Dunes, Rock Spring, Caruthers Canyon, New York Peak. This and the next species are very close and might hybridize (PS Ward. pers. comm., 2010).

Forelius pruinosus (Roger, 1836). Dominant Dolichoderinae. Hemipteran tending scavenger. All habitats between 1000–7200 ft. Every month. Nest in soil or under stones. 45 records. Dorner's Camp, Kelso Dunes, Rock Spring, Caruthers Canyon, New York Peak.

Liometopum luctuosum (Wheeler, W. M., 1905). Dominant Dolichoderinae. Hemipteran tending opportunist. Pinyon/Oak/Juniper associated with oaks. Mar–Sept. 5400–6100 ft. Nest in oak cavities. 23 records. Caruthers Canyon, Keystone Canyon.

Tapinoma sessile (Say, 1836). Hemipteran tending opportunist. Creosote Scrub to Pinyon/Juniper Woodland between 1000–5700 ft. May–Jan. Nest in soil or any handy cavity. 10 records. Dorner's Camp, 1.5 mi e Baker, Caruthers Canyon, Pichalka Spring, Curtis Canyon.

Myrmicinae

Aphaenogaster boulderensis M.R. Smith, 1941. Opportunist. Blackbrush Scrub, Mojave Yucca Scrub, Desert Wash, Joshua Tree Woodland between 3200–4100 ft. Every month. Nest probably under stones. 9 records. Willow Spring Basin, Coyote Spring, Cedar Canyon Rd 1.6 mi e of Kelso Cima Rd.

Aphaenogaster cockerelli (E. Andre, 1893). Opportunist. Creosote/Joshua Tree/Blackbrush Scrub between 4200 ft. Every month. Nest in exposed compact soil or under stones. 16 records. Granite Pass, Vulcan Mine Rd., 7 mi nne Kelso, Piute Spring, Morningstar Mine.

Aphaenogaster megommata M.R. Smith, 1963. Opportunist. Creosote Scrub/Desert Wash/Blackbrush between 2700–3900 ft. Sept–Jan. Nest under stones or exposed. 7 records. Vulcan Mine Rd. Kelbaker Rd 9 and 18 mi n Kelso.

Crematogaster depilis Wheeler, W. M., 1919. Generalist Myrmicinae. Tends hemiptera. All habitats except dunes and sandy washes between 3000–5700 ft. Every month. Nest, soil in and among roots. 84 records. Willow Spring Basin, Granite Pass, Rock Spring, Caruthers Canyon, Cima Rd @ Teutonia Peak Trail, Keystone Canyon, Curtis Canyon, Piute Spring.

Crematogaster larreae Buren, 1968. Generalist Myrmicinae. Tends hemiptera. Wherever Creosote Bush is common between 2900–5500 ft. Oct–May. Nest in roots and stems of creosote bush. 7 records. Dorner's Camp, Kelbaker Rd. 9 mi n Kelso, Cedar Canyon Rd 3.8 mi e Kelso Cima Rd, Pichalka Spring. This species may be synonymous with dark forms of *C. depilis* (PS Ward, pers. comm. 2008).

Crematogaster mormonum Wheeler, W. M., 1919. Generalist Myrmicinae. Tends hemiptera. All habitats except blow sand between 3600–7200 ft. Every month. Nest, in wood or under stones. 50 records. Willow Spring Basin, Kelbaker Rd, 1.5 mi e Baker, Caruthers, Keystone and Curtis Canyons.

Ephebomyrmex. See *Pogonomyrmex*

Leptothorax. See *Temnothorax*

Messor pergandei (Mayr, 1886). Hot Climate Specialist. Seed harvester. All habitats below the Pinyon/Juniper Woodland between 1000–5500 ft. Every month. Nest in exposed soil. 34 records. Any place on the sandy shoulder of any road in the valleys, eg. around the Kelso Station.

Monomorium ergatogyna Wheeler, W. M., 1904. (=*M. minimum*?). Generalist Myrmicinae. Omnivore. All habitats except blow sand between 2700–7200 ft. Every month. Nest in soil or handy cavity. 57 records Granite Pass, Coyote Spring, Rock Spring, Caruthers Canyon, New York Peak, Pichalka Spring, Curtis Canyon.

Pheidole barbata Wheeler, W. M., 1908. Generalist Myrmicinae. Probably a seed harvester. Blow sand Creosote Scrub, Blackbrush Scrub between 2100–3900 ft. Mar–Sept. Nest in exposed, sandy soil. 8 records. Kelso Dunes, Vulcan Mine Rd.

Pheidole bicarinata Mayr, 1870. Generalist Myrmicinae. Seed harvester, omnivore. Creosote Scrub upward through P/J, Oak Woodland between 2700–5700 ft. Mar–Nov. Nest under stones or wood. 22 records. Kelso/Cima Rd., 7.6 mi ne Kelso, Rock Springs, Caruthers Canyon.

Pheidole cerebrosior Wheeler, W. M., 1915. Generalist Myrmicinae. Seed harvester, scavenger. All habitats except blow sand between 2700–5700 ft. Every month. Nest under stones. 51 records. Granite Pass, Rock Springs, Caruthers Canyon, Pichalka Spring, Curtis Canyon. We have collected this species alive in the tumulus piles of *Pogonomyrmex rugosus*.

Pheidole clydei Gregg, 1950. Generalist Myrmicinae. Insect scavenger. Joshua Tree and Pinyon/Juniper/Oak Woodland between 4600–7200 ft. May–Jul. Nests obscure, in boulder cracks or rubble. 4 records. Rock Spring, New York Peak.

Pheidole desertorum Wheeler, W. M., 1906. Generalist Myrmicinae. Aggressive predator and scavenger, rarely gather seeds. All habitats between 2200–7200 ft. Every month. Nest under stone or exposed soil. 134 records. Granite Pass, Budweiser Spring, Kelbaker Rd, 18 mi n Kelso, Rock Spring, Caruthers Canyon.

Pheidole gilvescens Creighton and Gregg, 1955. Generalist Myrmicinae. Seed harvester, scavenger. All habitats except blow sand between 2200–5500 ft. Mar–Nov. Nest in exposed sandy soil. 39 records. Coyote Spring, Granite Pass, Kelso Dunes, Rock Spring, Pichalka Spring, Keystone Canyon.

Pheidole hyatti Emery, 1895. Generalist Myrmicinae. Omnivore and seed harvester. All habitats except blow sand between 2700–7200 ft. Jan–Oct. Nest in soil under plants. 25 records. Kelbaker Rd, 9 mi n Kelso, Midhills Campground, Caruthers Canyon, Rock Spring, Curtis Canyon.

Pheidole pilifera (Roger, 1863). Generalist Myrmicinae. Seed harvester. Pinyon/Juniper/Oak Woodland between 5700–7200 ft. May. Nest under stones or exposed soil. 2 records. Caruthers Canyon, New York Peak.

Pheidole psammophila Creighton and Gregg, 1955. Generalist Myrmicinae. Seed harvester. Creosote Scrub between 2900–3800 ft. Jul–Sept. Nest in exposed, shifting sand. 3 records. Budweiser Spring, Kelbaker Rd at Hwy I 40, Kelso Cima Rd. 7.6 mi ne Kelso.

Pheidole rugulosa Gregg, 1959. Generalist Myrmicinae. Omnivore and seed harvester. Creosote Scrub between 3000–4100 ft. May–Oct. Nest in exposed soil or under stones. 7 records. Kelso/ Cima Rd., 7.6 mi ne Kelso, Cedar Canyon Rd., 1.6 mi e Kelso Cima Rd.

Pheidole sciophila Wheeler, W. M., 1908. Generalist Myrmicinae. Omnivore, seed harvester. Yucca and Blackbrush Scrub between 3800–5500 ft. Every month. Nest obscure, often close to stem of a shrub. 14 records. Budweiser Spring, Granite Pass, Coyote Spring, Vulcan Mine Rd, Pichalka Spring.

Pheidole vistana Forel, 1914 (=*P. gallipes*). Generalist Myrmicinae. Insectivore. One record from Ft. Piute by Snelling and George (1979), Creosote Scrub at 2800 ft. October. Nest in soil under shrub.

Pheidole xerophila Wheeler, W. M., 1908. Generalist Myrmicinae. Seed harvester and scavenger. All habitats except blow sand and Blackbrush Scrub between 2900–5700 ft. Jan–Sept. Nest in exposed, sandy soil. 36 records. Granite Pass, Coyote Spring, Caruthers Canyon, Curtis Canyon, Morningstar Mine.

Pogonomyrmex californicus (Buckley, 1867). Hot Climate Specialist. Food includes seeds, vegetation, dead insects. All habitats except Blackbrush Scrub between 1000–5700 ft. Every month. Nest in exposed sandy soil. 47 records. Budweiser Spring, Granite Pass, Kelbaker Rd, 1.5 mi e Baker, Kelso Dunes, Rock Spring.

Pogonomyrmex (=*Ephebomyrmex*) *imberbiculus* Wheeler, W. M., 1902. Hot Climate Specialist. Food includes dead insects and some seeds. All habitats except sandy places between 3600–4900 ft. Mar–Nov. Nest under stones. 15 records. Budweiser Spring, Granite Pass, Morningstar Mine Rd, Pichalka Spring.

Pogonomyrmex magnacanthus Cole, 1968. Hot Climate Specialist. Seed harvester. Blow sand, Creosote Scrub, Joshua Tree Woodland between 1000–4800 ft. Jan–Oct. Nest in exposed, sandy soil. 18 records. Kelbaker Rd, 1.5 mi e Baker, Kelso Dunes, Rock Spring.

Pogonomyrmex maricopa Wheeler, W. M., 1914. Hot Climate Specialist. Feeds on seeds, dead insects. Joshua Tree Woodland, Desert Washes between 4600–4800 ft. Jan–Oct. Nest in sandy soil. 5 records. Rock Spring. At this location the nests of *P. maricopa* are found in stable soil on the bench above the sandy wash while the nests of *P. californicus* are found in the sandy wash a few feet below.

Pogonomyrmex rugosus Emery, 1895. Hot Climate Specialist. Feeds on seeds, dead insects. All habitats except sandy places between 3600–5700 ft. Every month. Nest in exposed soil. 32 records. Budweiser Spring, Granite Pass, Caruthers Canyon, Keystone Canyon, Teutonia Peak near Cima Rd.

Pyramica ca-01. Cryptic Species. Hypogaean. Congeners feed on collembola. This previously unknown species is represented by a single dealate queen collected 1 mi w Pichalka Spring in Blackbrush Scrub at 4600 ft. Jan.

Solenopsis amblychila Wheeler, W. M. 1915. Hot Climate Specialist. Probably feeds on seeds, omnivore. Three records near Coyote Spring in the Granite Mtns. at 3290 ft in Blackbrush Scrub, Acacia Scrub. Apr–Jul. Minor workers of this and the next species can be distinguished by the lower density of standing pilosity on the anterior part of the pronotum of this species.

Solenopsis aurea? Wheeler, W. M., 1906. Hot Climate Specialist. Probably feeds on seeds, omnivore. Creosote Scrub, washes, Joshua Tree Woodland between 2700–4600 ft. Every month. Nests under objects on coarse soil. 10 records. Coyote Spring, Kelbaker Rd, 9 mi and 18 mi n Kelso, Cedar Canyon Rd, 3.8 mi e of Kelso Cima Rd. PS Ward (pers. comm. 2008) notes that some *S. xyloni* in the California desert become quite light and resemble *S. aurea*. He suspects that *S. aurea*, a desert grassland and woodland species, does not occur west of Arizona. Molecular studies will be required to resolve this uncertainty.

Solenopsis molesta (Say, 1836). Cryptic Species. Omnivorous. Blow sand, Creosote Scrub, Blackbrush Scrub between 1000–5700 ft. Mar–Oct. Nest under stones or in nests of larger ants. 13 records. Budweiser Spring, Kelso Dunes, Caruthers Canyon, Pichalka Spring, Curtis Canyon.

Solenopsis xyloni McCook, 1880 (=*S. maniosa*). Hot Climate Specialist feeds on seeds, omnivore, raids other ants. All habitats between 1000–5700 ft. All months. Nest under stones or litter, exposed soil. 101 records. Any location in the valleys, eg. Budweiser Spring, Granite Pass, Coyote Spring, Kelso Station, Pichalka Spring.

Stenamma californicum Snelling, 1973. Cold Climate Specialist. Preys on litter microarthropods. A single individual at Caruthers Cyn. in Pinyon/Oak Woodland at 5700 ft. May. Nest in litter. A surprising record for a species typically from much more mesic settings to the west.

Temnothorax andrei (Emery, 1895). Cold Climate Specialist. A generalist forager. Possibly an inquiline. P/J Woodland, Blackbrush between 3200–7200 ft. Mar–Aug. Nest under stone. 13 records. Coyote Spring, Caruthers Canyon, New York Peak, Curtis Canyon, 1 mi w Pichalka Spring.

Temnothorax neomexicanus (Wheeler, W. M., 1903). Cold Climate Specialist. A generalist forager. Creosote Scrub, Acacia washes, Joshua to P/J Woodlands between 1000–5700 ft. Jan–Oct. Nest in soil under stone. 51 records. Budweiser Spring, Granite Pass, Rock Spring, Coyote Spring, Caruthers Canyon, Teutonia Peak, Pichalka Spring, Curtis Canyon.

Temnothorax nevadensis (Wheeler, W. M., 1903). Cold Climate Specialist. A generalist scavenging forager. Creosote Scrub, Joshua Tree Woodland, Blackbrush Scrub, Pinyon/Juniper Woodland between 3700–5500 ft. Mar–Oct. Nest in soil under stone. 14 records. Budweiser Spring, Pichalka Spring, Curtis Canyon, Rd NN699 @ Perimeter Rd near Coliseum Mine.

Temnothorax nitens (Wheeler, W. M., 1903). Cold Climate Specialist. Scavenger, preys on soil microarthropods, tend aphids. Pinyon/Juniper Woodland. One March record from Curtis Canyon Rd, Clark Mtns. at 5435 ft.

Temnothorax obliquicanthus (Cole, 1953). Cold Climate Specialist. A generalist forager. Scavenging and prey on soil microarthropods. Joshua Tree and Pinyon/Juniper Woodland between 4400–5700 ft. Mar–Sept. Nest in exposed soil. 4 records. Caruthers Canyon, Teutonia Peak.

Temnothorax whitfordi (Mackay, 2000). Cold Climate Specialist. A generalist forager. feeding ecology not known. Pinyon/Juniper Woodland between 4900–5700 ft. Mar–Oct. One nest found 8 ft above ground in beetle galleries in Juniper. 3 records. Caruthers Canyon, near Mountain Pass.

Veromessor. See *Messor*.

Formicinae

Acanthomyops. See *Lasius*.

Brachymyrmex depilis Emery,1893. Cryptic Species. Tends hemipterans. A single queen record from an Ephedra/Acacia wash at 3770 ft at Willow Spring Basin. October. Nest subterranean, under stone.

Camponotus fragilis (Pergande, 1894). (= *festinatus* in part) Subordinate Camponotini. Observed carrying insect parts. Creosote, Mojave Yucca Scrub, Desert Washes, Pinyon/Juniper Woodland between 2700–5700 ft. Jan–Sept. Nest under objects. 21 records. Willow Spring Basin, Granite Pass, Vulcan Mine Rd, Kelbaker Rd, 18 mi nw Kelso.

Camponotus hyatti Emery, 1893. Subordinate Camponotini. Honeydew feeder. Creosote washes, Joshua Tree and Pinyon/Juniper Woodlands between 3700–7200 ft. Apr-Oct. Nest in dead wood galleries. 14 records. Willow Spring Basin, Caruthers Canyon, New York Peak, Curtis Canyon.

Camponotus ocreatus Emery, 1893. Subordinate Camponotini. Creosote, Joshua, Blackbrush Scrub; Pinyon/Juniper Woodland between 3000–5700 ft. Mar–Nov. Nest under stones, often on rocky slopes. 32 records. Budweiser Spring, Granite Pass, Rock Spring, Caruthers Canyon, Keystone Canyon, Pichalka Spring.

Camponotus sansabeanus (Buckley, 1866). Subordinate Camponotini. Omnivorous scavenger. Joshua Tree Woodland, Blackbrush Scrub, Pinyon/Juniper Woodland between 4800–5700 ft. Nest in soil, some under stones. 38 records. Caruthers Canyon, Keystone Canyon, Teutonia Peak, Curtis Canyon.

Camponotus sayi Emery, 1893. Subordinate Camponotini. Pinyon/Juniper Woodland at 5700 ft. Mar-Jul. Nest in tree cavities, often beetle galleries. 4 records. Caruthers Canyon.

Camponotus semitestaceus Snelling 1970. Subordinate Camponotini. Hemipteran tender. All habitats except blow sand and Yucca scrub between 4180–7200 ft. Mar–Nov. Nest under stones. 26 records. Rock Spring, Kelbaker Rd 18 mi nw Kelso, Teutonia Peak, Pichalka Spring, Curtis Canyon.

Camponotus yogi Wheeler, W. M., 1915. Subordinate Camponotini. Joshua Tree/Juniper Woodland at 4800 ft. Feb–Aug. Nest in dead wood galleries or under stones. 4 records. Rock Spring. These records represent a southward extension of the known range for the species (PS Ward, pers comm, 2010).

Formica gnava Buckley, 1866. Opportunist, tend hemiptera. Pinyon/Juniper Woodland between 5400–7200 ft. Every month. Nest in sandy soil, under stones and thatch. 42 records. Midhills, Kelso Cima Rd, 7.6 mi ne Kelso, Caruthers, Keystone and Curtis Canyons.

Formica xerophila M.R. Smith, 1939. Opportunist. Creosote Scrub, Joshua Tree Woodland, Blackbrush Scrub, Pinyon/Juniper Woodland between 2900–5700 ft. Every month. Nest in soil, exposed or under cover. 12 records. Granite Pass, Piute Spring, Caruthers Canyon, Kelbaker Rd, 9 mi n Kelso, Curtis Canyon.

Lasius (Acanthomyops) californicus Wheeler, W. M., 1917. Cryptic Species, hemipteran tender. A temporary social parasite on other Lasius. Pinyon/Juniper and Oak woodland between 5600–7200 ft. Nov–Aug. Nest in soil under rocks. 21 records. Caruthers Canyon, New York Peak.

Lasius (Lasius) crypticus Wilson, 1955. Cryptic Species, tends hemiptera on roots, scavenge insects. Pinyon/Juniper and Oak Woodland between 5600–7200 ft. Mar–Aug. Nest in soil under stone. 7 records. Caruthers Canyon, New York Peak.

Myrmecocystus christineae Snelling, 1982. Hot Climate Specialist. diet undescribed. Creosote/Acacia sandy scrub, Desert Washes, Joshua Tree Woodland between 3300–4200 ft. Apr–Oct. Nest a cone in exposed sandy wash (pers. obs). 12 records. Willow Spring Basin, Kelbaker Rd, 9 mi n Kelso, Morningstar Mine Rd, 9.5 mi nne Cima.

Myrmecocystus flaviceps Wheeler, W. M., 1912. Hot Climate Specialist. Scavenger–predator, honeydew gatherer. All habitats except blowsand and Yucca Scrub between 1000–5700 ft. Every month. Nest in exposed soil. 47 records. Budweiser Spring, Coyote Spring, Kelbaker Rd, 1.5 mi e Baker, Rock Spring, Midhills Campground, Rock Spring, Pichalka Spring.

Myrmecocystus kennedyi Snelling, 1969. Hot Climate Specialist. Nectar, honeydew gatherer, scavenger. Creosote Scrub, blowsand between 2100–3600 ft. Jan–Oct. Nest in exposed, coarse sandy places. 19 records. Budweiser Spring, Kelso Dunes, Kelbaker Rd, 18 mi nw Kelso.

Myrmecocystus lugubris Wheeler, W. M., 1909. Hot Climate Specialist. General forager. Creosote Scrub, blow sand at 2500 ft. April. Nests in fine, exposed sand. One California Dept. Agriculture record. Kelso Dunes. This is an old record gleaned from Snelling andGeorge (1979) and might be viewed with some skepticism.

Myrmecocystus mendax Wheeler, W. M., 1908. Hot Climate Specialist. Predator, scavenger, gathers honeydew, nectar. All habitats except fine sandy areas and Pinyon/Juniper Woodland between 1000–4900 ft. Mar–Oct. Nest in stony soils, obscure. 10 records. Granite Pass, Morningstar Mine Rd, 9.5 mi nne Cima, 1 mi w Pichalka Spring.

Myrmecocystus mexicanus Wesmael, 1838. Hot Climate Specialist. Honeydew, dead insects, vertebrate carrion. All habitats except sandy areas between 2700–4800 ft. Jan–Sept. Nest in coarse soil on high ground. 22 records. Budweiser Spring, Coyote Spring, Granite Pass, Lanfair Valley Rd, 12 mi s Ivanpah, Rock Spring.

Myrmecocystus navajo Wheeler, W. M., 1908. Hot Climate Specialist. Tends hemipterans, flower nectar, dead insects. Creosote Scrub, sandy washes between 1800–4600 ft. Mar–Jul. Nest obscure in sandy soil. 5 records. Budweiser Spring, Cedar Canyon Rd, 3.8 mi e Kelso Cima Rd, Kelbaker Rd, 9 mi n Kelso.

Myrmecocystus placodops Forel, 1908. Hot Climate Specialist. Predator, scavenge insects, flower nectar. CreosoteScrub, washes, Mojave Yucca Scrub, Blackbrush scrub between 1000–5500 ft. Jan–Oct. Nest in exposed, stony soil. 5 records. Dorner's Camp, Vulcan Mine Rd, 1 mi w Pichalka Spr.

Myrmecocystus romainei Hunt and Snelling, 1975. Hot Climate Specialist. Omnivore. Creosote/Joshua Tree ecotone, Pinyon/Juniper Woodland between 4200–5700 ft. Mar–Apr, through summer. Nest in exposed, deep sandy soil. 4 records. Caruthers Canyon, Teutonia Peak, Morningstar Mine Rd, 9.5 mi nne Cima.

Myrmecocystus tenuinodis Snelling, 1976. Hot Climate Specialist. Nectar feeder, scavenger. Blow sand, Creosote Scrub between 1000–3000 ft. Mar–May. Nests in exposed fine sand. 7 records. Kelso Dunes, Kelbaker Rd, 1.5 mi e Baker; Kelbaker Rd, 2.3 mi s Kelso.

Myrmecocystus testaceus Emery, 1893. Hot Climate Specialist. Feeds on honeydew, plant secretions, live and dead insects. Creosote Scrub, Joshua and Pinyon/Juniper Woodlands between 3700–5700 ft. Feb-Jul. Nest in exposed soil. 21 records. Budweiser Spring, Rock Spring, Caruthers Canyon, 0.6 km ne Teutonia Peak.

Myrmecocystus yuma Wheeler, W. M., 1912. Hot Climate Specialist. Feeds on live or dead insects, honeydew. Creosote Scrub, Joshua Tree Woodland between 2900–3600 ft. Jan–Mar. Nest in exposed sand. 5 records. Kelso Cima Rd, 7.6 mi ne Kelso, Morningstar Mine Rd 9.5 mi nne Cima.

Nylanderia (=*Paratrechina*) cf. *terricola* (Buckley, 1866). Opportunist. Omnivorous scavenger. Sandy washes, Creosote Scrub, Mojave Yucca Scrub, Blackbrush Scrub, Joshua Tree Woodland between 2700–5500 ft. Jan–Oct. Nest in soil under wood or stone. 16 records. Dorner's Camp, Kelbaker Rd 18 mi nw Kelso, Pichalka Spring, Curtis Canyon.

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A new Miocene flora from the Round Mountain Silt

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Abstract

The Eagle Crest Flora is the first described flora from the Round Mountain Silt contains 18 taxa including algae, grasses, shrubs and trees gathered by streams that flowed through a riparian/aquatic community to deposit waterlogged organic debris in a marine environment. A few taxa suggest a non-adjacent coniferous woodland. The Eagle Crest Flora and associated bone bed contain invertebrate and vertebrate fossils: marine mollusks, sharks, fish, mammals, and horse. The bone bed may be similar in age to, or older than the 15.5 Ma Sharks Tooth Hill Bone Bed. The flora is compared with other Miocene floras from southern California.

Background

Residential development in the greater Bakersfield area during 2006–2008 included construction excavation in the Rio Bravo area along the south side of the Kern River , central Kern County, California. Development north of the Kern River Highway (SR-178) required resource monitoring and salvage to protect significant, non-renewable paleontological resources—fossils.

Paleontological resources

The Eagle Crest bone bed in the Miocene marine Round Mountain Silt produced a minimum of 90 distinct taxa identified from more than 3,657 vertebrate and non-vertebrate fossil specimens. Invertebrate taxa include 16 species of pelecypods, 9 species of gastropods, a scaphopod, pencil urchins, and crustaceans. Marine vertebrates include seven taxa of fish, three genera of rays, 19 shark taxa, a skate, and a sea turtle. Mammals include Ten marine mammals and one land mammal have been identified. A unique collection of Miocene fossil plants with at least 18 species is associated with the marine mollusks and marine mammals.

Eagle Crest Flora

The plant specimens collected during the monitoring program at Eagle Crest are apparently the first fossil plants to be described from the Round Mountain Silt, and represent 18 new plant species. These plants were probably washed from inland river banks and forested hills by continental drainage systems that developed distal back bays and deltas along the coast line. Mats of leaves and small logs would drift to sea, become waterlogged, and sink to depths in quiet ocean water that contained seaweed and marine fossils. Some of the logs became silicified, perhaps saturated with silica from volcanic ash in marine silts. In most cases, leaves and fronds are represented by spaces highlighted by brown stains of pyrolusite. Miocene fossils recovered during this study were associated with rounded pebbles and cobbles that may help describe the rocks in the source highlands east of the shoreline.

The intermittent stream system transporting the flora had variable rates of flow, perhaps because of seasonal climate or storms. The variable energy and carrying capacity of the stream was sometimes great enough to support logs, yet gentle enough to move fragile charcoal and leaves at other times.

Table A: The Eagle Crest Flora

Family	Scientific name	Common name
Algae - Rhodophyta?	Masses of red algae	Seaweed
Poaceae	Emergent monocot	Grasses
Equistraceae	*Equisetum* sp.	Horsetail
Palmacea	*Sabalites* sp,	Palmetto
Rosacaea	*Amelanchier*? sp	Serviceberry
Rosaceae	*Cercocarpus* sp.	Mountain mahogany
Betulaceae	*Betula*? sp	Birch
Lauraceae	*Laurus? sp*	Laurel
Magnoliaceae	*Magnolia* sp	Magnolia
Platanaceae	*Platanus* sp.	Sycamore
Lauraceae	*Persea* sp.	Avocado
Lauraceae	*Umbellularia* sp.	Bay
Salicaceae	*Populus* sp.	Cottonwood
Ericaceae	*Rhododendron* sp.	Rose bay or azalea
Anacardiaceae	*Rhus* sp.	Sumac
Salicaceae	*Salix* sp.	Willow
Pinacea	*Cupressus* sp.	Cypress?
Pinacea	*Pinus sp.*	Pine

Table B. Taxonomic comparison of southern California Miocene floras. TE=Tehachapi; EC=Eagle Crest; MH=Mud Hills; MC=Mint Canyon; RI=Ricardo; AN=Anaverde

Marine							
Rhodophyta?	red algae		X				
Aquatic							
Emergent monocots	Emergent monocot		X				
Riparian							
Anacardiaceae	*Rhus sp.*	X	X	X	X		
Betulaceae	*Betula?*		X				
Lauraceae	*Umbellularia sp.*	X	X				
Lauraceae	*Laurus?*		X				
Lauraceae	*Persea sp.*	X	X		X		X
Magnoliaceae	*Magnolia sp*		X				
Arecaceae	*Sabalites sp,*	X	X	X		X	X
Arecaceae	*Washingtonia sp*			X			
Platanaceae	*Platanus sp.*	X	X		X		X
Rosacaea	*Amelanchier?*		X				
Salicaceae	*Populus sp.*	X	X		X		X
Salicaceae	*Salix sp.*	X	X		X		
Sapindaceae	*Sapindus*						X
Woodland							
Aquifiliaceae	*Ilex*				X		
Berberidaceae	*Mahonia*	X					
Cannabaceae	*Celtis*	X			X		
Cupressaceae	*Cupressus sp.*	X	X			X	
Ericaceae	*Arbutus*	X					
Ericaceae	*Rhododendron sp.*		X				
Fabaceae	*Leucaena*	X					
Fagaceae	*Quercus*	X		X	X	X	X
Juglandaceae	*Juglans*				X		
Myricaceae	*Myrica*	X					
Pinaceae	*Pinus*	X	X			X	X
Rosacaea	*Lyonothalmnus*	X			X		
Rosacaea	*Heteromeles*	X					
Rosacaea	*Prunus*	X					
Sapotaceae	*Sideroxylon*	X					
Vitaceae	*Vitis*				X		
Woodland shrub							
Cupressaceae	*Juniperus*			X			
Ericaceae	*Arctostaphylos*	X			X		
Fabaceae	*Amorpha*	X					
Fabaceae	*Robinia*	X			X	X	
Oleaceae	*Fraxinus*	X					
Rhamnaceae	*Ceanothus*	X		X	X		X
Rhamnaceae	*Colubrina*						X
Rhamnaceae	*Karwinskia*	X					
Rhamnaceae	*Rhamnus*	X			X		X
Rosaceae	*Cercocarpus*	X	X		X		
Rosaceae	*Chamaebataria*	X					
Rosaceae	*Holodiscus*				X		X
Rosaceae	*Laurocerasus*				X		
Sapindaceae	*Dodonea*	X					X
Sterculiaceae	*Fremontodendron*	X			X		
Thorn-scrub							
Anacardiaceae	*Pachycormus*				X		
Arecaceae	*Brahea*				X		
Burseraceae	*Bursera*	X			X		
Crossosomataceae	*Crossosoma*				X		
Ebenaceae	*Diospyros*				X		
Euphorpiaceae	*Acalypha*				X		
Euphorbiaceae	*Euphorbia*	X					
Fabaceae	*Acacia*				X		
Fabaceae	*Diphysa*	X					
Fabaceae	*Eysenhardtia*				X		X
Fabaceae	*Leucanea*	X					
Fabaceae	*Lysiloma*				X		
Fabaceae	*Pithecellobium*	X			X		
Fabaceae	*Prosopis*	X					
Fouquieriaceae	*Fouquieria*				X		
Moraceae	*Ficus*	X					
Rubiaceae	*Chiococca*				X		
Rhamnaceae	*Colubrina*	X			X		
Rhamneae	*Condalia*	X			X		
Sapindaceae	*Cardiospermum*				X		
Sapindaceae	*Dodoneae*	X			X		

*From Axelrod, 1976

The Tehachapi Flora (TE) is early Miocene, and associated with Hemingfordian NALMA taxa (Buwalda, 1916; Quinn, 1987; Axelrod, 1939, 1976) dated at 17 Ma (Evernden and others, 1964).

The Eagle Crest Flora (EC) is approximately 15.5 Ma (Prothero and others, 2008a, 2008b).

The Mud Hills Flora (MH) recovered from the Green Hills Member of the Barstow Formation (Alf, 1970) dates between 15.7–15.4 Ma (Woodburne, 1991).

The Mint Canyon Flora (MI) has been dated by its association with mammalian taxa (Jahns, 1940; Axelrod, 1940) as late Barstovian to Clarendonian NALMA (12 Ma, Evernden and others, 1964).

The Ricardo Flora (RI) is associated with Clarendonian NALMA mammalian taxa (Stock and Furlong, 1926; Webber, 1933; Axelrod, 1976) and dates at approximately 10 Ma (Evernden and others, 1964).

The Anaverde Flora (AN) near Palmdale corresponds to the early Hemphillian NALMA of the late Miocene (8 - 9 Ma; Axelrod, 1950, 1976)

The preservation of leaves from different floral habitats along with red algae (seaweed) and marine mollusks sows that the stream carried plant debris from a wide drainage area and deposited them in a quiet marine environment.

Age of the Round Mountain Silt

Fossil deposits along the Pacific coast that allow comparison of marine faunal events to continental fauna and flora are rare. This is significant because it helps compare the timing of marine and terrestrial events, including the flora that was adjacent on the continent. Magnetic stratigraphy and strontium-isotope dating places the time of deposition of the Sharks Tooth Hill bone bed at 15.5 Ma (Prothero and others, 2008a, 2008b). The Eagle Crest Bone Bed has more molluscan taxa in common with the older, underlying Olcese Sand than with the Lower or Upper Round Mountain Silt (Addicott, 1970), suggesting an earlier age. Alternatively, a gray, glassy ash directly below the Eagle Crest Bone Bed chemically resembles USGS sample buf94-617, dated at>15.2 Ma (Dave Miller p. c. to Reynolds, 2009).

The Sharks Tooth Hill bone bed produces middle Miocene land mammals representing the Barstovian NALMA (Tedford and others, 2004; Prothero and others, 2008a). Fossils salvaged program from Eagle Crest may be earlier. The scaphoid (wrist bone) of a small Miocene horse associated with marine mammals, mollusks, fish, and sharks compares favorably with that of the small Miocene three-toed horse Archaeohippus mourningi. The edges and margins of the proximal and distal surfaces of articulation are sharp and unworn, suggesting it was not reworked from older sediments into this deposit. Archaeohippus sp. is constrained to the late Hemingfordian and early Barstovian North American Land Mammal Age (NALMA), between 17 and 15 Ma. (Woodburne and Swisher, 1995; Tedford and others, 2004; Pagnac, and Reynolds, 2006; Reynolds and others, 2008). The precise age of the Eagle Crest Flora and bone bed remains undetermined.

Environment of deposition

The Eagle Crest locality contains Miocene fish, rays, skates, and sharks which represent mid-ocean, near-shore, surface, and bottom-dwelling species. The taxa lived in open water, kelp beds, the surf zone, and rocky habitats.

Like the fish, the Miocene marine mammals from the Eagle Crest locality come from a variety of mid-ocean and near-shore marine habitats:. open water, kelp beds, the surf zone, and rocky shores. Seals, sea lions, and walrus live and raise young on the shore but seals hunt in the ocean and walrus search for mollusks along rocky shores. The desmostylid probably had habits like a hippopotamus, living in salt, fresh, and estuarian water and feeding on aquatic vegetation.

Plant habitats

Several habitat zones are represented by the Eagle Crest plants. The red algae (seaweed) is restricted to a marine coastal shoreline. Grasses and horsetails grow along slow moving streams, ponds, and estuarian deltas. Willow, birch and cottonwood are members of the stream-side riparian community. Avocado and mountain mahogany might be found on coastal slopes; cypress and pine grow on higher hillsides. The presence of palmetto, avocado, and magnolia indicate a temperate climate. The plant association is similar to other assemblages found in near-shore Miocene marine deposits (Spicer, 1980; Tidwell, 1932; Reynolds, 1999; Kinoshita, 1997) in southern California.

The taxa of the Eagle Crest Flora are herein compared with other Miocene floras to the south and east in the Los Angeles Basin and Mojave Desert. The floras are arranged by age, the Tehachapi Flora being the oldest (Table B):

Geographic relationships of Miocene floras

The Eagle Crest Flora was deposited in a marine environment, as indicated by associated mollusks, fish and marine mammals, and is the only flora in Table B associated with marine seaweed (red algae). The Eagle Crest Flora may have been transported along streams through a back bay before reaching the ocean, and therefore includes two aquatic plant taxa, absent in the other Miocene floras (Table B). Transport along a stream system gathered eleven riparian taxa. Only four

Table C. Plant Taxa in common with Eagle Crest Flora by floral community. TE=Tehachapi; EC=Eagle Crest; MH=Mud Hills; MC=Mint Canyon; RI=Ricardo; AN=Anaverde

Community	TE	EC	MH	MC	RI	AN
Marine	0	1	0	0	0	0
Aquatic	0	2	0	0	0	0
Riparian	7	11	3	5	1	5
Woodland	12	3	2	6	3	2
Woodland shrub	11	1	2	8	1	5
Thorn-scrub	10	0	0	16	0	1

Table D. Plant Taxa in common with Eagle Crest Flora by age. TE=Tehachapi; EC=Eagle Crest; MH=Mud Hills; MC=Mint Canyon; RI=Ricardo; AN=Anaverde

TE 17 Ma	EC 15.5 Ma	MH 15 Ma	MC 12 Ma	RI 10 Ma	AN 9 Ma
10	18	2	6	3	5

plant taxa are present in the Eagle Crest Flora which indicate the distant presence of a coniferous woodland community containing rose, bay, or azalea, mountain mahogany, cypress, and pine.

The Mint Canyon Flora is south of the Eagle Crest Flora; the other floras in Table B are east. The Eagle Crest Flora has the greatest number of taxa in common with the Early Miocene Tehachapi Flora, and also bears taxonomic similarities to the later Miocene Mint Canyon and Anaverde floras. Although the Mud Hills Flora is of similar age, it has the least number of taxa in common, perhaps because it was 130 miles east of the mid-Miocene coast line in a post-extensional setting.

Floral communities are stable over long periods of time, and taxa differ geographically with amounts of seasonal moisture and seasonal temperature change, the latter being partly related to elevation. Plant communities may be susceptible to greater change through tectonic events that change through time. For instance, a rain shadow was not developed in eastern California until after the Sierra Nevada Mountains started rising about 8 Ma.

Summary

The Eagle Crest deposit produced a collection of plant taxa deposited by streams. The streams probably passed between lowland slopes into marine back bays. The flora, with 18 plant species, is the first described from the Round Mountain Silt. When compared to other Miocene floras in Kern, Los Angeles and San Bernardino Counties, it adds to the geographic picture of mid-Miocene floras. The specimens have been curated into the collections of the Buena Vista Museum of Natural history under numbers CHO 0701, P0001 - P0142.

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The Round Mountain Silt Bone Bed of Sharktooth Hill, Kern County, California: recent research yields new answers to old questions

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This short paper presents a summary of previous research and provides an update on status of the Sharktooth Hill Bone Bed. We present no original research. Instead, we offer questions that still exist regarding the origin and preservation of the Bone Bed.

Introduction

The Sharktooth Hill area near Bakersfield is one of the oldest and best known megafossil localities in California. It is perhaps the most significant Miocene marine vertebrate locality in the world (Dupras, 1985.) The abundance and diversity of flora and fauna make it a treasured locality for paleontologic research. Sharktooth Hill is best known for remains of sharks, turtles, sea lions, dolphins, and whales. Marine trace fossils are locally abundant. Remains of terrestrial animals such as horses, tapirs, deer, elephant-like animals (Gomphotheres), and camels have also been found. Plant fossils, which are rare, have also been found: these include nuts and seeds of gymnosperms and angiosperms.

Most Sharktooth Hill fossil specimens have been recovered from "The Bone Bed," a thin (six inch to one foot thick), silty sand within the upper part of the middle Miocene Round Mountain Silt (Fig. 1). The Bone Bed is a reworked fossil assemblage, and its fossils are rarely articulated. However, large, articulated specimens have come from siltstone layers two to twenty feet above the Bone Bed. These strata above the Bone Bed often contain fossil-bearing calcareous concretions. Large vertebrate remains such as vertebrae or skulls appear to have functioned as nucleation points for calcareous concretion formation very early in the fossils' diagenetic history (Fig. 2). The Bone Bed and nearby layers have yielded at least 144 species of vertebrate fossils (Stegall, pers. comm., 2011). These fossils represent diverse life forms that lived in a Pacific Ocean embayment occupying the southern San Joaquin Valley 15–16 million years ago (Bartow, 1987 and Fig. 3, this paper).

Setting

The Bone Bed is exposed in low, dissected hills northeast of Bakersfield, where middle Miocene sediments outcrop along the easternmost part Bakersfield Arch. The arch is a southwest-plunging breached

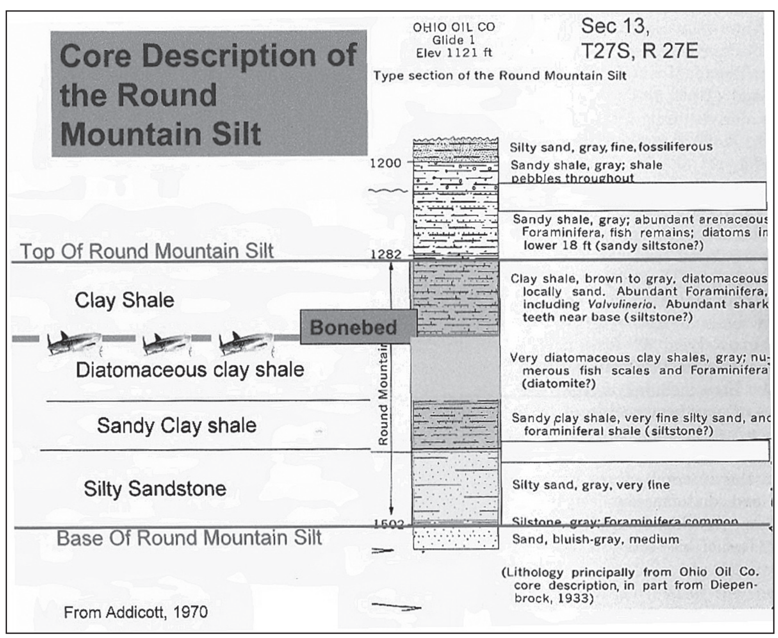

Figure 1. Lithologic descriptions of the Round Mountain Silt from oil well core. The location of the Bone Bed is denoted by green line. Though the well is several miles north of Sharktooth Hill, where the Round Mountain section is thinner, the descriptions are representative of Sharktooth Hill lithology. (After Addicott, 1970.)

Figure 2. A photo of a spectacular cross-section of a calcareous concretion which contains a whale vertebra. Variations in color around the white vertebra in the center are likely due to iron and manganese mineralization. Photo by Tim Elam.

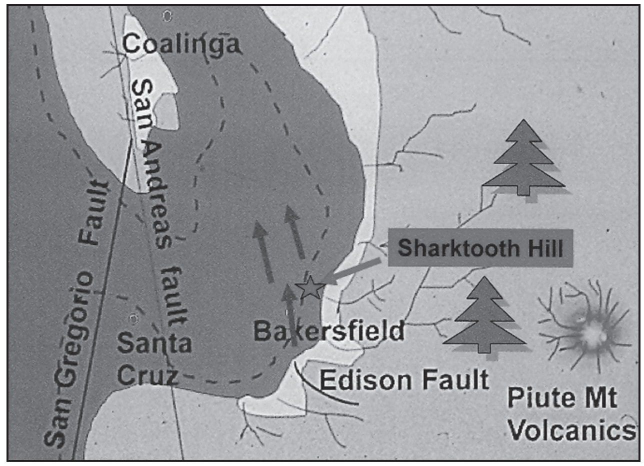

Figure 3. Map view of Middle Miocene paleogeography in the Bakersfield area. Blue arrows indicate generalized current directions. Image taken from Buena Vista Museum of Natural History display, after Bartow, 1987.

anticlinorium. Sharktooth Hill is a modest topographic feature of the area, rising to an elevation of 863 feet above sea level, in Section 25, T 28S, R 28E, Mount Diablo B & M. The apex of Sharktooth Hill is 380 feet above the nearby Kern River, which is one mile to the south (USGS, 1973). Bone Bed outcrops are rather predictable, since the stratigraphy is layer-cake and there is minimal (5–8^{0}SW) dip in the area (Fig 4.) A few faults, which have with offsets of up to 200 feet, affect the elevation and presence or absence of the Bone Bed. One of these faults is the east–west-trending Jewett Fault, which is also known as the Round Mountain Cross Fault (Bartow, 1984, and Fig. 5, this paper).

Visually, the Bone Bed is not easily distinguished from adjacent strata. It is dominated by fine to medium-grained sand, and thus is slightly coarser grained than beds above and below. But the presence of oxidized iron and perhaps relic organic carbon gives porous organic matter, such as bones, a distinctive orange-rust color that contrasts with tan-gray sediments (Fig. 6). Less porous fossils, such as teeth, often possess a more muted tan or gray color. Fossils often have small bulbous coatings of a black substance, which is generally thought to be a manganese oxide mineral such as pyrolusite. In some places the Bone Bed is underlain by dark gray clay shale, but in other places the layer below the Bed is tan-gray and silty, similar to the Bone Bed and layers above it. Pyenson et al. (2009) present a good discussion of Bone Bed lithology and stratigraphy.

Eroded to the east, the Bone Bed likely continues in the subsurface west of Sharktooth Hill. However, there is no surface evidence to document the Bone Bed's

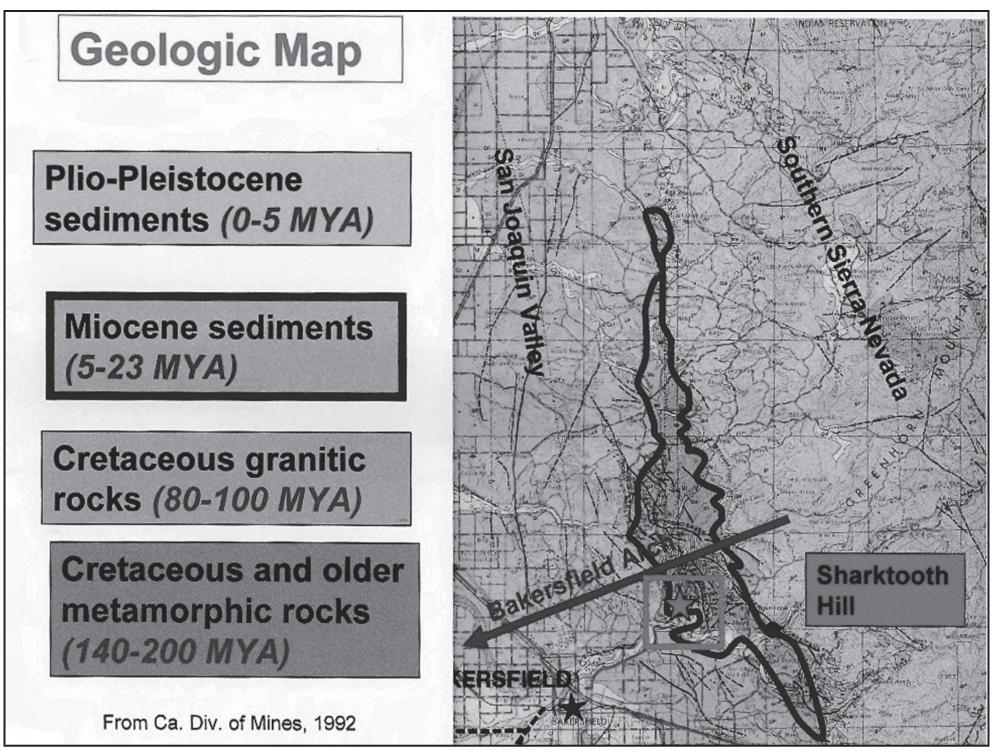

Figure 4. Geologic map of areas east of Bakersfield. Sharktooth Hill denoted by a red star within the Miocene outcrop exposed on the Bakersfield Arch. After California Division of Mines, 1992.

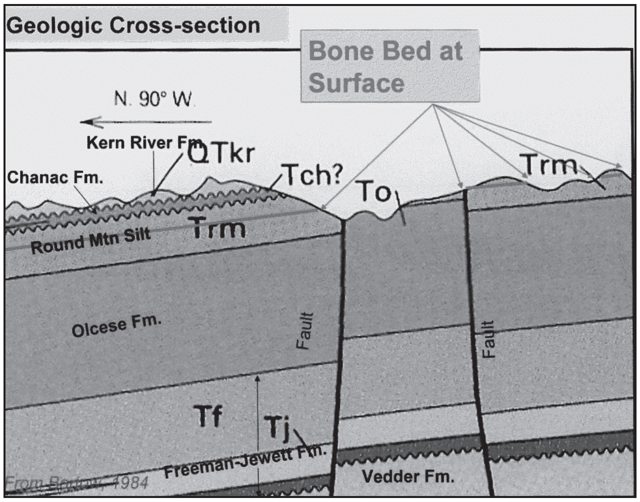

Figure 5. Portion of a geologic cross section from Bartow, 1984; section is annotated to show approximate position of the Bone Bed. Geologic dip, topography and faulting influence the somewhat erratic distribution of the Bone Bed. For scale, the Round Mountain Silt has a true stratigraphic thickness of 480' in the subsurface.

Figure 6. A concentration of rust-colored bone fragments highlights a fresh exposure of the Bone Bed at the Ernst West Quarry. At West Quarry, Round Mountain Silt lithologies above and below the Bone Bed are not distinctively different from the Bone Bed itself. Photo by Tim Elam.

westward termination. The Round Mountain Silt continues west at least 50 km (Pyenson, et al, 2009), and outcrops over a minimum area of 100 km^2 (Pyenson, et. al., 2007). The Bone Bed lies immediately above a minor unconformity within the Round Mountain Silt (Pyenson, et. al., 2009).

Fossils

Fossils at Sharktooth Hill were first documented in 1853 by William P. Blake. Blake made the discoveries while surveying rail routes throughout the western U.S. for the federal government (Mitchell, 1965). Blake's first fossil finds were passed to prominent scientists of the day for identification. One of these was naturalist Louis Agassiz. Agassiz was credited with identifying nine new animal species in 1856 (Mitchell, 1965.) The early taxonomic work by Agassiz and others made Sharktooth Hill the first studied and documented fossil location west of the Rocky Mountains. That distinction, plus the overall significance of the location, led Sharktooth Hill to be declared a National Natural Landmark (NNL) in 1976 (Butowsky, 1990). The NNL portion of Bone Bed outcrop, formerly property of Getty Oil Company, is a protected area now owned by Bakersfield College.

The Bone Bed outcrops as far north as the north side of Poso Creek, and as far south as bluffs on the south side of the Kern River. These bluffs, though privately

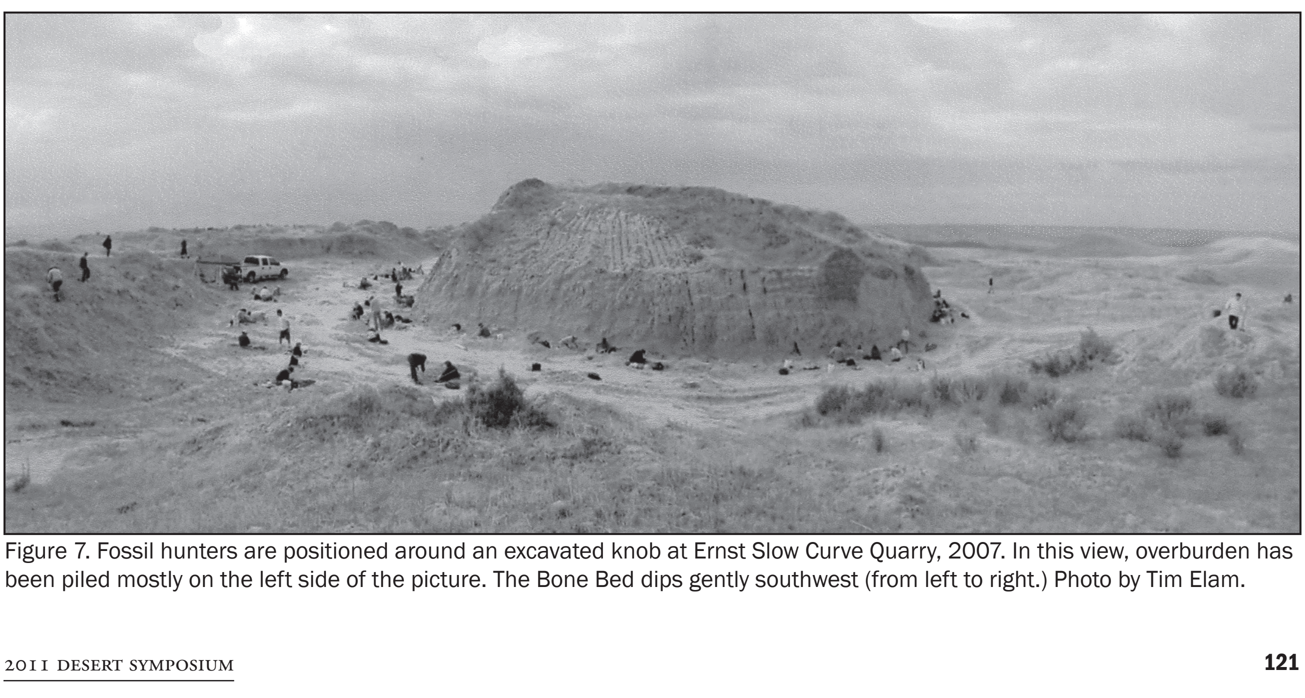

Figure 7. Fossil hunters are positioned around an excavated knob at Ernst Slow Curve Quarry, 2007. In this view, overburden has been piled mostly on the left side of the picture. The Bone Bed dips gently southwest (from left to right.) Photo by Tim Elam.

Figure 8. Cast of the sea lion *Allodesmus kernensis*, on display at Buena Vista Museum of Natural History in 2008. Photo by Tim Elam

owned, are where most fossil hunters have historically searched for fossils. Outside of the NNL, Bone Bed-bearing lands north of the Kern River are primarily used for grazing.

The Sharktooth Hill area has a long history of paleontologic research. Many fossils found in the 1800s in the Sharktooth Hill area and at nearby Barker Ranch were unfortunately destroyed in the 1906 San Francisco earthquake and fire (Mitchell, 1965). Those fossils were housed in the California Academy of Sciences. But significant, systematic studies in the 1920s by the California Academy of Sciences yielded many new species (Kellogg, 1931.) Renewed interest beginning in the 1960s was led by the Los Angeles County Museum of Natural History workers (Dupras, 1985).

In the last ten years, several significant new research efforts have been published, including:

- Turtles (Lynch and Parham, 2003)
- Land mammals (Prothero, et.al., 2008)
- Desmostylians (Clementz, et.al., 2003)
- Magnetic stratigraphy (Prothero, 2008)
- Bone Bed stratigraphy, origin, age, taphonomy (Pyenson, et.al., 2009)
- Cetaceans (Barnes, et.al., 2005)
- Birds (Stidham, 2004)

Many of the fossil finds of the past 35 years have been on exposures of the Bone Bed and adjacent strata owned by Bob Ernst. Ernst, a self-taught collector with an immense passion for these fossil lands, who began purchasing land parcels in the Sharktooth Hill area in the mid-1970s. He ultimately acquired 342 acres of land in the heart of the Bone Bed outcrop north of the Kern River. Ernst passed away in April, 2007. The Ernst family maintains ownership of most of the original 342 acres, although 85 acres of fossil-bearing land was sold in 2010.

Ernst opened several new quarries for excavation and extended exposed areas of existing quarries. These quarries have colorful, descriptive names such as "Slow

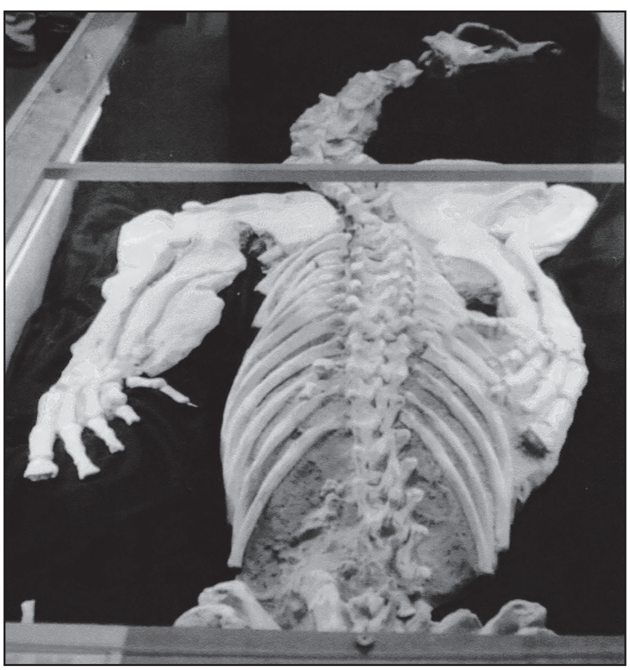

Figure 9. Fossil of the sea lion *Allodesmus kernensis* on display at Buena Vista Museum in 2009. This specimen was found fully articulated, a few feet above the Bone Bed, by Bob Ernst. Photo by Tim Elam.

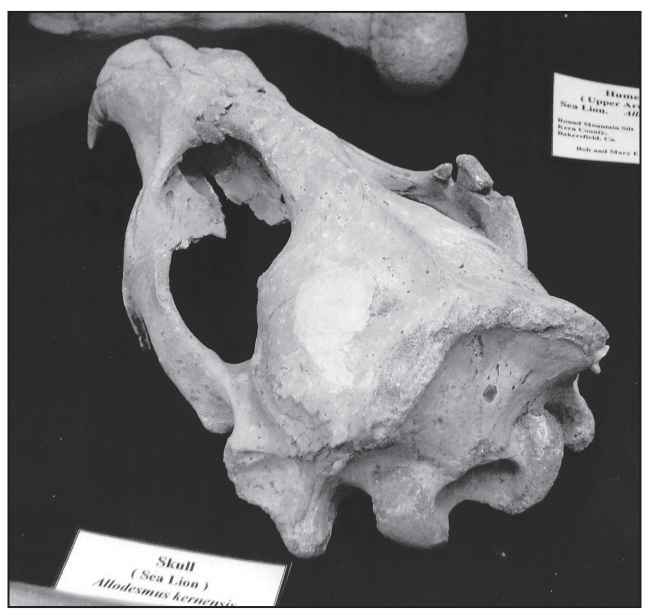

Figure 10. Skull fossil of sea lion *Allodesmus kernensis* on display at Buena Vista Museum in 2009. This skull is unique because it has an embedded shark tooth. The broken tooth is barely visible at the extreme left side of the picture, near where the skull connected to cervical vertebrae. Photo by Tim Elam.

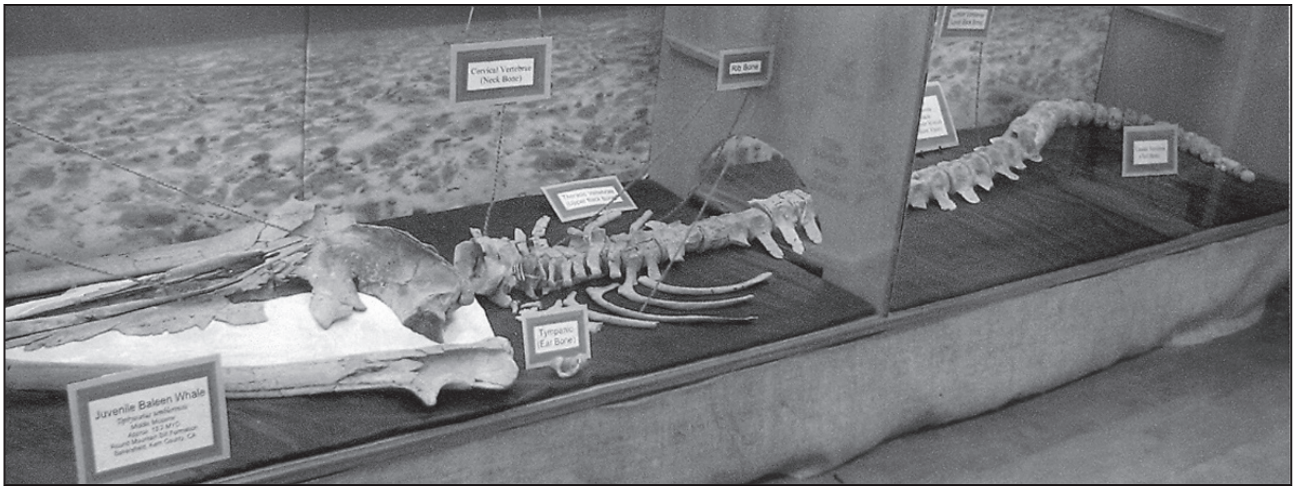

Figure 11. Fossil of juvenile baleen whale, *Tiphyocetus temblorensis,* on display at Buena Vista Museum, 2009. This composite specimen is 14 feet long, with bones of two different animals displayed. Photo by Tim Elam.

Curve," "Turtle Alley," "the Whale Quarry," "West Quarry," and "The Snake Pit" (Fig. 7). Though he was a dealer in fossil teeth, Ernst recognized the importance of involving paleontology experts in the recovery, study, restoration, and classification of fossils. Thus, personnel from the University of California Museum of Paleontology, San Diego Museum of Natural History, and Los Angeles County Museum of Natural History were frequent visitors and often communicated with Mr. Ernst. These institutions, along with the Buena Vista Museum of Natural History, excavated, restored, and recorded many fossils after their discovery by Mr. Ernst.

Perhaps the most famous of the large Ernst-collected fossils include:

1) two fully articulated sea lions, *Allodesmus kernensis,* (Fig. 8, Fig. 9, Fig. 10)
2) a juvenile baleen whale (*Tiphyocetus temblorensis)* (Fig. 11)
3) two sperm whale skulls

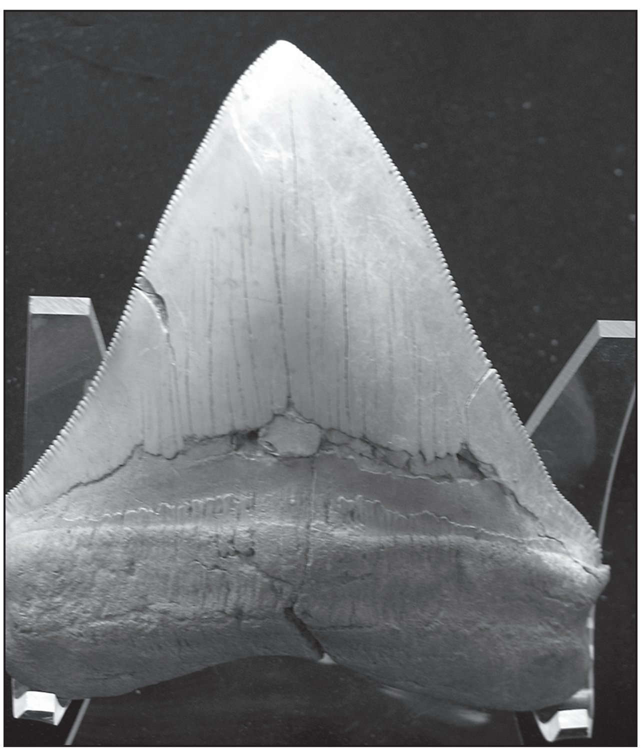

Figure 12. A six-inch fossil tooth of extinct giant shark *Charcarocles megalodon*. Note the sharp serrated edges of the tooth. Photo by Tim Elam.

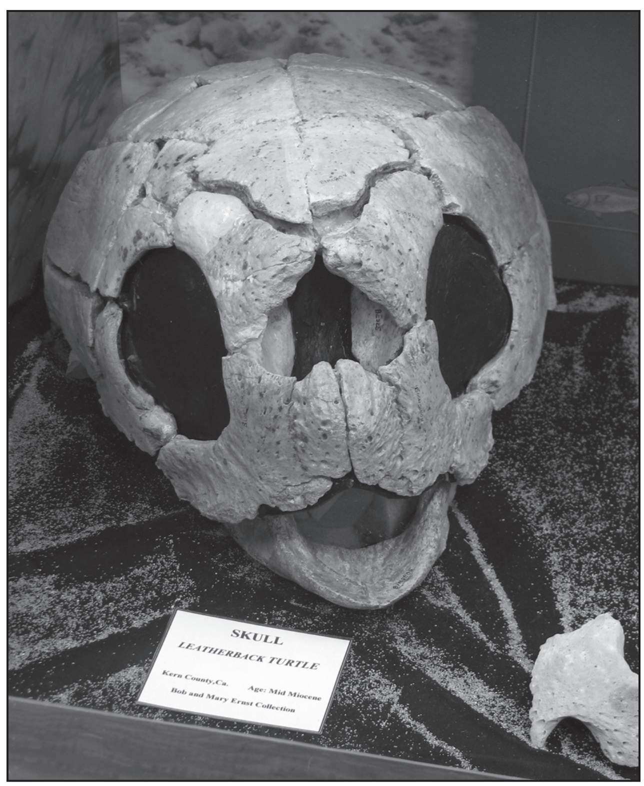

Figure 13. Front view of the fossil skull of a leatherback turtle housed at Buena Vista Museum, 2009. The skull is approximately one foot across. Photo by Tim Elam.

4) Hundreds of teeth up to six inches long from ancestral large sharks, *Charcarocles megalodon.* This shark, now extinct, grew to 60 feet in length (Fig. 12)
5) a leatherback turtle (Fig. 13)
6) a dugong (an extinct manatee-type creature)

A desire by Mr. Ernst to preserve and exhibit Sharktooth Hill fossils locally was the primary factor in the creation of Buena Vista Museum of Natural History in Bakersfield. The museum, which opened in 1995, continues to display a wide variety of Sharktooth Hill area fossils. The museum possesses a repository for fossils and a preparation/restoration lab staffed by trained volunteers. The museum has created an online database of vertebrate species found in the Round Mountain Silt (Stegall, per. comm., 2011).

Today, the museum partners with the landowners to hold "fee digs" for fossil collectors. Maintaining the integrity of scientific discovery is important to the landowners and the museum. Thus, all diggers sign an agreement to notify dig supervisors of any fossils that may be deemed scientifically significant. An example might be finding an articulated specimen or multiple vertebrae that warrants scientific reconnaissance. Dig supervisors review the discovery and make a decision whether to cease activity at the find. Fee digs resumed in 2010 after Mr. Ernst's death. This monitoring process has worked well at two fee digs held thus far, and more digs are planned for 2011.

Though the widespread Bone Bed has been the source of most study since its discovery 150 years ago, other Round Mountain Silt strata locally have prolific amounts of marine vertebrate fossils. In addition, older strata such as the Middle Miocene Olcese Sand and Early Miocene Freeman-Jewett Formation are well known for their fossil content (Addicott, 1970). These older units are primarily known for their abundant gastropod species (Addicott, 1970). But marine vertebrate fossils have been obtained from the Freeman-Jewett Formation. Shark tooth fossils from the Pyramid Hill Sand Member of the Freeman-Jewett are on display at Buena Vista Museum.

At least two other layers beneath the Bone Bed possess Bone Bed-type marine fossils. One is a layer on Ernst's land. A second layer, which has proved to be a very significant discovery, was documented by Reynolds (2009). This location is on the south side of the Kern River, several miles from the Ernst quarries. Previously unreported Pleistocene fossils were also documented at this location. Among the Round Mountain Silt flora and fauna documented in Reynolds report are:

- previously unrecorded flora (16 plant species)
- 15 new mollusk species

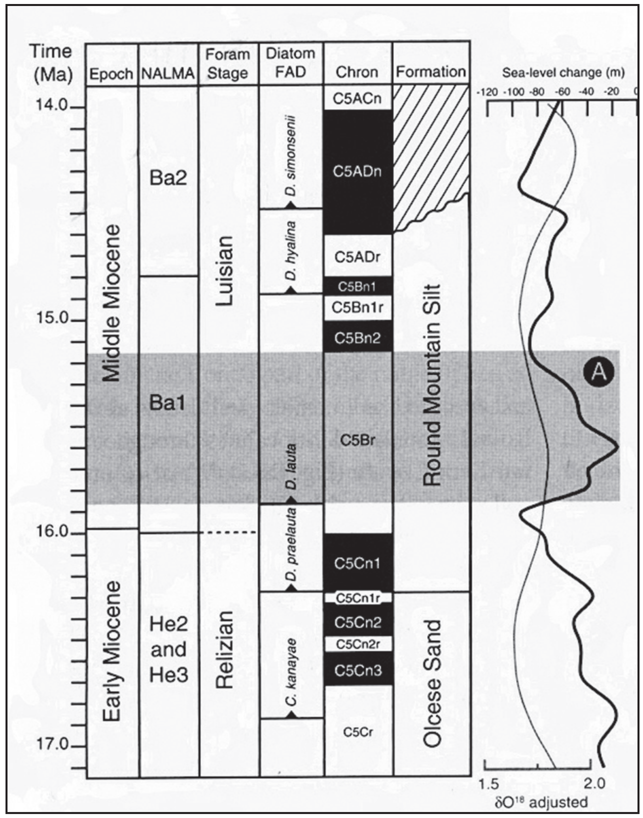

Figure 14. Chart displaying range of age dates of the Bone Bed. The shaded time, 15.9-15.2 mya represents the maximum and minimum ages of the Bone Bed. From Pyenson, et. al., 2009.

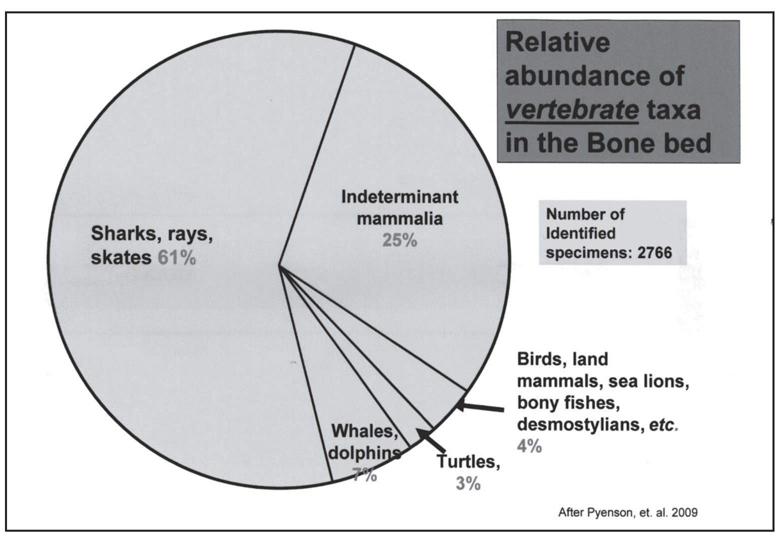

Figure 15. Pie chart showing relative abundance of vertebrate animals from Bone Bed collections studied by Pyenson et. al. 2009.

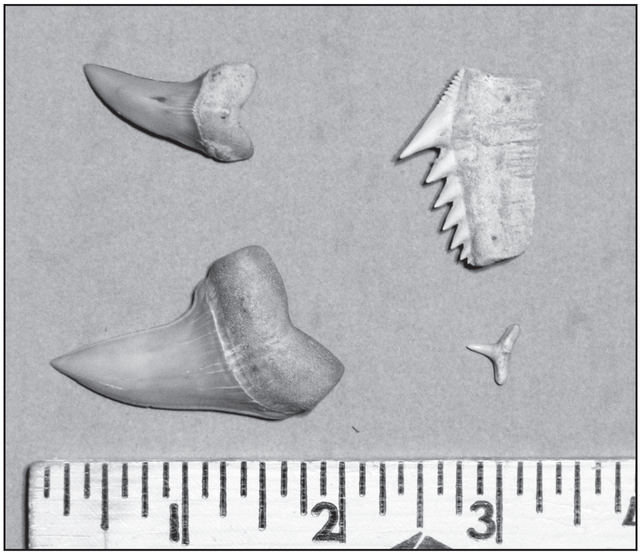

Figure 16. Clockwise from upper left, photo of cow shark, gray shark, and two mako shark teeth found at Ernst Slow Curve Quarry, 2007. Photo by Tim Elam.

- A complex suite of fish, shark, and sea turtle (29 species)
- Two new marine mammal species: a dolphin and a baleen whale
- A Miocene horse fossil

Buena Vista Museum's repository now houses these fossils documented by Reynolds (2009). Further study of these Miocene flora and fauna and comparison of them to Bone Bed species could be an interesting research project.

Research questions

Pyenson et. al. (2009) excellently summarized long-standing mysteries of the Bone Bed and offered answers to some of these mysteries.

1) The Bone Bed formed over a significant length of time in which there was little or no net sediment accumulation, coincident with the beginning of the middle Miocene Climatic Optimum.
2) It is unlikely Bone Bed formation was caused by red tide poisoning, a volcanic event, or any other catastrophic mass death event.
3) The Bone Bed age can be bracketed to between 15.9 and 15.2 million years old; age dating was done via land mammal, microfossil (diatom and foram), strontium isotope, and magneto-stratigraphic methods (Fig. 14).
4) The Bone Bed, on average has approximately 200 fossil specimens per cubic meter of rock.
5) Remains of sharks, skates, and rays make up 61% of the vertebrate organic remains (Fig. 15). The most abundant of the larger shark teeth found in the Bone Bed are mako shark teeth (Fig. 16).

Bone Bed questions and opportunities for research remain, such as:

- Even if winnowing and current-related phenomena concentrated only coarse-grained material in the Bone Bed, why does the Bone Bed have a dearth of invertebrate fossils? Invertebrate fossils, particularly gastropods, are common in other layers of the Round Mountain Silt.
- Is there a spatial variation to the concentration and diversity of fossils, including their preservation characteristics, diagenesis, etc. that might lead to a greater understanding of Bone Bed creation, local paleogeography, and taphonomy?
- What might a sedimentologic/mineralogic study of the Bone Bed tell us?

In summary, the Bone Bed has been a source of abundant fossils, geologic and paleontologic research, and collecting fun for over 150 years. Yet, collectors and researchers have just "scratched the surface," of its fascinating story.

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Abstracts of proceedings—
The 2011 Desert Studies Symposium

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Discerning patterns of abundance and gender expression in desert holly (*Atriplex hymenelytra*)

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In 1991, we began a long-term study of the population dynamics of desert holly (*Atriplex hymenelytra*), a member of the saltbush family (Chenopodiaceae) that is broadly distributed throughout desert areas of southwestern North America. At our study site in the Mojave National Preserve, desert holly occurs in discrete stands on gravel fans of moderate salinity that lie between the dry bed of Soda Lake and creosote-dominated bajadas. Although desert holly is considered a dioecious species in which separate individuals consistently produce either all male or all female flowers; in some (but not all) years, a subset of individuals (inconstant males) exhibit monoecy such that both male and female flowers are produced by the same individual. The extent to which environmental fluctuations affect the expression of this alternate (monoecious) gender type, as well as the abundance of plants, is currently being explored by linking biological, spatial, and meteorological data for the 17 year period extending from 1992 through 2008 and analyzing the interplay among these data using GIS (Geographic Information System) technologies. Our initial analyses suggest that temporal changes in environmental signals (principally precipitation and to some extent minimum winter temperatures) are correlated with changes in gender expression and population abundance through effects on mortality, the production of flowers, germination rates, and the survival of seedlings as new recruits to the population.

Amargosa Conservancy water study

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The Amargosa Conservancy, a non-profit land trust, is collaborating with the USGS and a private consulting firm in an attempt to gather new information about the significant springs and seeps in the Southern Amargosa area near Shoshone and Tecopa. The initial phase of the study seeks to identify and establish field parameters for basic water characteristics for several dozen surface water sites. The results of this study will be published in a report in the spring of 2011, available to anyone. Depending upon funding, the next phases of the project will include vegetation surveys and evapotranspiration data on the various sites, and eventually more detailed geochemistry work to determine the original sources of the water surfacing in the Tecopa basin. Ultimately, our goal is to provide the BLM with an accurate picture of the complex ground water plumbing in this region, which they can then use to help construct the Amargosa Wild and Scenic river management plan, as well as make decisions about possible renewable energy facilities on public lands. The presentation at the Zzyzx seminars will be an overview of the project and an opportunity for members of the science community to request a copy of the report when it is released in May 2011.

Formal definition of the Quaternary System and redefinition of the Pleistocene Series by the International Commission on Stratigraphy

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Since being established more than 40 years ago, the primary mission of the International Commission on Stratigraphy (ICS) of the International Union of Geological Sciences (IUGS) has been to establish an International Chronostratigraphic Chart with a single set of global

INTERNATIONAL STRATIGRAPHIC CHART

ICS

International Commission on Stratigraphy

IUGS

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary	Holocene		0.0117	GSSP
			Pleistocene	Upper	0.126	
				"Ionian"	0.781	
				Calabrian	1.806	GSSP
				Gelasian	2.588	GSSP
		Neogene	Pliocene	Piacenzian	3.600	GSSP
				Zanclean	5.332	GSSP
			Miocene	Messinian	7.246	GSSP
				Tortonian	11.608	GSSP
				Serravallian	13.82	GSSP
				Langhian	15.97	
				Burdigalian	20.43	
				Aquitanian	23.03	GSSP
		Paleogene	Oligocene	Chattian	28.4 ±0.1	
				Rupelian	33.9 ±0.1	GSSP
			Eocene	Priabonian	37.2 ±0.1	
				Bartonian	40.4 ±0.2	
				Lutetian	48.6 ±0.2	
				Ypresian	55.8 ±0.2	GSSP
			Paleocene	Thanetian	58.7 ±0.2	GSSP
				Selandian	~ 61.1	GSSP
				Danian	65.5 ±0.3	GSSP
	Mesozoic	Cretaceous	Upper	Maastrichtian	70.6 ±0.6	GSSP
				Campanian	83.5 ±0.7	
				Santonian	85.8 ±0.7	
				Coniacian	~ 88.6	
				Turonian	93.6 ±0.8	GSSP
				Cenomanian	99.6 ±0.9	GSSP
			Lower	Albian	112.0 ±1.0	
				Aptian	125.0 ±1.0	
				Barremian	130.0 ±1.5	
				Hauterivian	~ 133.9	
				Valanginian	140.2 ±3.0	
				Berriasian	145.5 ±4.0	

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
				(top)	145.5 ±4.0	
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	150.8 ±4.0	
				Kimmeridgian	~ 155.6	
				Oxfordian	161.2 ±4.0	
			Middle	Callovian	164.7 ±4.0	
				Bathonian	167.7 ±3.5	GSSP
				Bajocian	171.6 ±3.0	GSSP
				Aalenian	175.6 ±2.0	GSSP
			Lower	Toarcian	183.0 ±1.5	
				Pliensbachian	189.6 ±1.5	GSSP
				Sinemurian	196.5 ±1.0	GSSP
				Hettangian	199.6 ±0.6	
		Triassic	Upper	Rhaetian	203.6 ±1.5	
				Norian	216.5 ±2.0	
				Carnian	~ 228.7	GSSP
			Middle	Ladinian	237.0 ±2.0	GSSP
				Anisian	~ 245.9	
			Lower	Olenekian	~ 249.5	
				Induan	251.0 ±0.4	GSSP
	Paleozoic	Permian	Lopingian	Changhsingian	253.8 ±0.7	GSSP
				Wuchiapingian	260.4 ±0.7	GSSP
			Guadalupian	Capitanian	265.8 ±0.7	GSSP
				Wordian	268.0 ±0.7	GSSP
				Roadian	270.6 ±0.7	GSSP
			Cisuralian	Kungurian	275.6 ±0.7	
				Artinskian	284.4 ±0.7	
				Sakmarian	294.6 ±0.8	
				Asselian	299.0 ±0.8	GSSP
		Carboniferous: Penn-sylvanian	Upper	Gzhelian	303.4 ±0.9	
				Kasimovian	307.2 ±1.0	
			Middle	Moscovian	311.7 ±1.1	
			Lower	Bashkirian	318.1 ±1.3	GSSP
		Carboniferous: Missis-sippian	Upper	Serpukhovian	328.3 ±1.6	
			Middle	Visean	345.3 ±2.1	GSSP
			Lower	Tournaisian	359.2 ±2.5	GSSP

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
				(top)	359.2 ±2.5	
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	374.5 ±2.6	GSSP
				Frasnian	385.3 ±2.6	GSSP
			Middle	Givetian	391.8 ±2.7	GSSP
				Eifelian	397.5 ±2.7	GSSP
			Lower	Emsian	407.0 ±2.8	GSSP
				Pragian	411.2 ±2.8	GSSP
				Lochkovian	416.0 ±2.8	GSSP
		Silurian	Pridoli		418.7 ±2.7	GSSP
			Ludlow	Ludfordian	421.3 ±2.6	GSSP
				Gorstian	422.9 ±2.5	GSSP
			Wenlock	Homerian	426.2 ±2.4	GSSP
				Sheinwoodian	428.2 ±2.3	GSSP
			Llandovery	Telychian	436.0 ±1.9	GSSP
				Aeronian	439.0 ±1.8	GSSP
				Rhuddanian	443.7 ±1.5	GSSP
		Ordovician	Upper	Hirnantian	445.6 ±1.5	GSSP
				Katian	455.8 ±1.6	GSSP
				Sandbian	460.9 ±1.6	GSSP
			Middle	Darriwilian	468.1 ±1.6	GSSP
				Dapingian	471.8 ±1.6	GSSP
			Lower	Floian	478.6 ±1.7	GSSP
				Tremadocian	488.3 ±1.7	GSSP
		Cambrian	Furongian	*Stage 10*	~ 492 *	
				Stage 9	~ 496 *	
				Paibian	~ 499	GSSP
			Series 3	Guzhangian	~ 503	GSSP
				Drumian	~ 506.5	GSSP
				Stage 5	~ 510 *	
			Series 2	*Stage 4*	~ 515 *	
				Stage 3	~ 521 *	
			Terreneuvian	*Stage 2*	~ 528 *	
				Fortunian	542.0 ±1.0	GSSP

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

	Eonothem Eon	Erathem Era	System Period	Age Ma	GSSP GSSA
			(top)	542	
Precambrian	Proterozoic	Neo-proterozoic	Ediacaran	~635	GSSP
			Cryogenian	850	GSSA
			Tonian	1000	GSSA
		Meso-proterozoic	Stenian	1200	GSSA
			Ectasian	1400	GSSA
			Calymmian	1600	GSSA
		Paleo-proterozoic	Statherian	1800	GSSA
			Orosirian	2050	GSSA
			Rhyacian	2300	GSSA
			Siderian	2500	GSSA
	Archean	Neoarchean		2800	GSSA
		Mesoarchean		3200	GSSA
		Paleoarchean		3600	GSSA
		Eoarchean		4000	
	Hadean (informal)			~4600	

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (*www.stratigraphy.org*).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (*www.cgmw.org*).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

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units at the ranks of Stage, Series, and System with the lower boundary of each precisely defined by a Global Standard Boundary-Stratotype Section and Point or GSSP. These chronostratigraphic units are the basis for the geochronologic or time units of the Geologic Time Scale with the ranks of Age, Epoch and Period, and the GSSPs mark points in time that precisely define the beginnings of the time units. After 40 years of work, GSSPs have been selected for 61 of the 101 stages of the Phanerozoic, and a single set of global units is being established to replace the multitude of different sets of chronostratigraphic/geochronologic units that were defined for regions with greatly different stratigraphic successions and with biostratigraphies that differed due to paleobiogeographic and paleoecologic differentiation.

Recently, ICS approved and IUGS ratified the first formal definition of the Quaternary System and redefinition of the Pleistocene Series, which resulted in the Gelasian Stage being transferred to them from the Neogene System and Pliocene Series. These decisions followed established procedures of extended, open discussion and deliberation of submitted proposals, and formal voting by the relevant ICS Subcommissions, the ICS Voting Membership, and the IUGS Executive Committee. They are now established as global standards.

The ant fauna of the Mojave National Preserve

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Between 2000 and 2008 we intensively surveyed the ant fauna of the Mojave National Preserve employing a variety of sampling methods. We detected 74 native ant species including one previously unknown species. No non-native species were detected. The collection includes a number of range extensions and new state records. Most of the fauna is generally typical of the Mojave Desert and is composed of species that thrive under warm, arid conditions and relatively mild winters. Our prediction that the higher elevations in the Preserve would support cold adapted species typical of the Juniper-steppe climate of the Great Basin was not borne out. An annotated checklist summarizes these collection records and the natural history of these species.

Paleowind velocity and paleocurrents of pluvial Lake Manly, Death Valley

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Pleistocene pluvial lake deposits are found throughout the world and are frequently used to reconstruct the age and volume of past lakes. These data are then used to determine the paleoclimatic conditions that produce those lakes. At the ancient shoreline, the particle size of the deposit is directly related to wave height, which, in turn, is dependent on wind velocity. Wind velocity and direction is an indicator of storm strength and storm track. Adams (2003) developed the beach particle technique (BPT) and applied it to 14 ka Lake Lahonton deposits in Nevada. Here, we apply the BPT to several localities of 180-125 ka (Oxygen Isotope State [OIS] 6) deposits of pluvial Lake Manly in Death Valley, California. Our calculations indicate that paleowind was 15-50 m-sec-1 or greater than present-day wind velocities of 9-15 m-sec-1. Sedimentary structures and clast provenance indicate wave directions from the west to northwest with a north to south longshore drift. The northerly wind direction is likely the result of topographic funneling between the north-south trending mountain ranges and is opposite of the average modern wind direction from the south.

The archaeology at the Mirror Point site (CA-SBR-12134/H), South Range Naval Air Weapons Station, China Lake, California and its eastern connection

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This paper describes and interprets a large rock feature complex and associated artifact caches from the Mirror Point site located on the east side of Searles Lake within the boundaries of the South Range, Naval Air Weapons Station (NAWS) China Lake, California. Artifacts recovered from this site include large obsidian bifaces, glass and shell beads, a bow fragment, pottery, and several types of projectile points. Finally, these data are compared to von Werlhof's studies at similar sites near Panamint Lake, California.

A review of proboscideans from the Middle Miocene Barstow Formation of California

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Starting in the early 1900s, even after major quarrying by Frick Laboratory crews (specimens now housed at American Museum of Natural History or AMNH) and decades of prospecting by various institutions, few remains of proboscideans have been recovered from the Barstow Formation. Field work by the Raymond Alf Museum of Paleontology (RAM) has produced the largest collection of proboscidean specimens from the Barstow Formation. These include a partial skull, dentary with tusk and m3, eight isolated teeth, three carpals, and 14 occurrences of tooth or tusk fragments. The partial skull is the only one known of *Zygolophodon* from North America.

Proboscidean remains were first reported from Barstow in 1919 by J. C. Merriam from the University of California-Berkeley based on tooth fragments. In 1933, C. Frick described *Trilophodon bartonis* based on a pd3 and p4 designated as types. These teeth were later referred to *Zygolophodon*. These early discoveries were from the uppermost horizon of the Barstow Formation.

RAM field work was initiated in 1936, but it wasn't until the 1960s that proboscidean specimens were located, when the dentary with tusk/m3 and the partial skull of *Zygolophodon* were collected. Neither specimen has precise locality data, but since all proboscidean remains recovered from the Barstow Formation are from the unnamed upper member, it is assumed that the Alf Museum skull and dentary are from upper member strata as well. In 1969, a trackway was found about 120 feet above the Skyline Tuff (site relocated based on photos). Consisting of four tracks, the proboscidean trackway has been on exhibit at the RAM since the early 1970s.

Teeth collected by RAM crews over the past two decades are an m2, two P3's, two P4's, a DP4, and two dp4's. The m2 is referred to *Gomphotherium* and it is from RAM locality V98004, a site 90 feet below the tuff that underlies the "*Hemicyon* Stratum" where the then oldest specimen of *Gomphotherium* from the Barstow Formation was collected. The V98004 *Gomphotherium* tooth is now the oldest occurrence of *Gomphotherium* in the formation. RAM locality V98004 is also an important site because it is the type locality of *Megahippus mckennai* (partial skull collected in 1957) and recent collections include a shell with postcranial material of *Xerobates mohavense*, numerous specimens of *Aepycamelus, Protolabis*, and *Scaphohippus*, and hundreds of isolated elements of small birds and mammals.

The oldest *Zygolophodon* specimen is a tooth from Rainbow Quarry Prospect (AMNH site), low in the upper member. Higher in the upper member is the RAM *Gomphotherium* tooth from V98004. Thus, the RAM proboscidean trackway from strata low in the upper member was probably made by *Zygolophodon*. All proboscidean body fossils from the Barstow Formation are late Barstovian (Ba2) in age. Early Barstovian (Ba1) records of *Zygolophodon* and *Gomphotherium* are reported from northwest North America (including central California) as well as Oregon and Mexico, respectively. These areas are in relatively close proximity to the Barstow depositional basin. Why proboscidean body fossils are not known from early Barstovian strata of the Barstow Formation after 100 years of prospecting is unclear, but it is probably not a factor of sampling.

The 4 April 2010 magnitude 7.2 El Mayor-Cucapah earthquake in B.C., Mexico

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At 3:42p local time (22:40:42 UTC) on 4 April 2010, a major earthquake on the North American-Pacific plate boundary struck the region of northern Baja California, Mexico (M_W = 7.2). The epicenter was in the Sierra Cucapah at 32.259ºN, 115.287ºW at a depth of about 10 km. Direct surface ruptures along the Borrego, Pescadores, Paso Superior, and Laguna Salada faults reached for over 100 km between the northern tip of the Gulf of California to well into Imperial County, California (US). Triggered slip along many faults also occurred, especially on the nearby Laguna Salada fault. Faulting was complex, involving several stepovers between different faults. InSar imagery revealed that the Cucapah Mts and much of the Mexicali Valley dropped by over a meter. The earthquake was roughly 15 km SW of the Cerro Prieto fault, the nominal plate boundary.

Fault plane vector solutions show the motion to be oblique right lateral strike slip. Maximum measured displacement occurred along the Borrego fault (3.1 m

Rupture of the Borrego Fault in the Sierra Cucapah, B.C, Mexico. Scarp height ~1 m.

Mapping a scarp. L-R: Orlando Teran, Ramon Mendoza Borunda, Kenneth Hudnut.

strike slip, 2 m down-to-the-east dip slip, fault plane nearly vertical). Peak ground acceleration (PGA) measured by the El Centro-Array 11 was 0.59 g, and 0.54 g at the Michoacan de Ocampo MDO station.

This was the largest earthquake in the Salton Trough since the 1892 7.2–7.8 Laguna Salada quake, and only slightly smaller than the 1992 Mw 7.3 Landers quake in the Mojave Desert. Occurring only 47 km SSE of Mexicali, an estimated five hundred million dollars of damage was done in Mexico and one hundred million dollars in the US. There were two deaths in Mexico. The major impact was broken canals, irrigations channels and sewers, agricultural losses due to tilted crop fields, unemployment of farm workers, and widespread damage to structures resulting from both shaking and liquifaction.

In this talk we will present a discussion of the tectonics, rupture phenomenology, impact on the local infrastructure and the earthquakes's relevance to the plate boundary in southern California and northwestern Mexico.

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Differences in micro-topographic surface conditions effect on the distribution, establishment and survival of a serotinous desert winter annual

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Barren desert pavements and adjacent bare soil areas where sparse perennial plants occur vary significantly in their micro-topography and surface soil conditions, and thus affect desert winter annuals' distribution and establishment (Wood et al. 2002, 2005). Rain events interact with the land surface properties. For example, heavy rain storms create runoff on flat desert pavements with underlying vesicular horizons, while water quickly infiltrates on adjacent sandy areas of young alluvium with plant cover. Consequently, microtopography might play an important role in seed dispersal by rain waters (Kamenetsky and Gutterman 1994). Furthermore, the scarce and unpredictable desert rainfalls (Westoby 1972) interact with soil texture and temperature, translating into moisture pulses of different duration and infiltration depths that affect plant germination, growth and survival (Reynolds et al. 2004).

Chorizanthe rigida (Polygonaceae) is a desert annual that retains seeds after maturation (called serotiny). This species' dead spiny structures persist on the ground for several years, strongly holding its dispersal unit (i.e. involucres) that get dispersed by rainfall (Felger 2002). Field observations indicate that this species often occurs on the gravelly surfaces at the edge of desert pavements where they transition to adjacent bare areas. *C. rigida*'s distribution pattern across landscapes might result from the interaction of involucre rain-dispersal and micro-topographic ground surface characteristics.

The objective of our study is to investigate the effects of surface topographic characteristics and soil properties of different land surfaces (desert pavement, transition zone, bare soil with sparse perennials) on *C. rigida*'s seedling survival, growth, and small-scale distribution. This study will provide insight on the complex interactions between desert annuals, soil moisture, and micro-topographic surface conditions that have not been studied in detail (Wood et al. 2002; 2005). The specific questions we address in this study are: 1. Is seedling density related to surface characteristics in desert pavement/transition/bare soil areas? 2. Is seedling survival related to surface characteristics in desert pavement/transition/bare soil areas? 3. Does *C. rigida* seedling biomass production vary according to surface conditions in desert pavement/transition/ bare soil areas?

Pliocene and early Pleistocene paleogeography of the Coyote Lake and Alvord Mountain area, Mojave Desert, California

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Coarse-grained gravel and sand deposits underlie low-relief hills scattered across much of the area around Coyote (dry) Lake and Alvord Mountain, including hills whose deposits are exposed in several cuts along Interstate 15. The gravels previously have been mapped as Quaternary and Tertiary in age but few firm age assignments existed before regional mapping by USGS and subsequent detailed studies that verified that most gravel deposits are early Pleistocene and Pliocene. Relatively rare beds of tephra, some newly discovered, are early Quaternary to Pliocene in age, and improve the age constraints for these deposits.

The gravel deposits contain distinctive suites of clasts that mark source areas, including the Goldstone area of southwestern Fort Irwin for a broad sweep of gravels that lies north of Alvord Mountain, the Calico Mountains area for a wide swath of gravels that extends from the Yermo Hills to east of Manix Wash, the Alvord Mountain area for gravels that lie south of that mountain, and the Cady Mountains area for a swath of gravels that lies along the Mojave River and includes Buwalda Ridge. The gravels south of Alvord Mountain are interlayered with gravels sourced in the Calico Mountains and Goldstone, and evidently represents a long-term sink. These relations suggest that four source areas have been persistently high topographic regions for at least 4 M.y., but that other areas have changed greatly in relative topographic position. The most remarkable changes are associated with the fluvial gravels that were shed south and east from Goldstone to east of Alvord Mountain, for those deposits have been warped down into the Coyote Lake basin and warped up over Alvord Mountain. In addition, smaller pop-ups along strike-slip faults represent changes in paleogeography since the Pliocene and some pop-ups deform middle Pleistocene strata. In contrast, the area along the modern Mojave River course from Manix Wash to Afton Canyon has been a persistent topographic low. The section south of Alvord Mountain and north of Buwalda Ridge extends from underlying middle Miocene deposits of the Barstow Formation upward to active alluvial fans, in an apparently unbroken stratigraphic sequence that records shifting topographic position and changing source areas.

Tortoise time: lessons learned in three decades with *Gopherus agassizii*

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Gopherus is a genus of tortoise that has been successful in the Mojave Desert for 15 million years. *Gopherus agassizii*, the Pleistocene and recent species from the Mojave Desert, is now a federally listed threatened species. Thirty years of field research on aspects of biology and ecology show populations of the species have declined between 90 and 95%. Numerous facets of the ecological collision between humans and the desert tortoise are described—the constellation of anthropogenic effects have resulted in the steep declines seen since the 1970s. Implications of the near disappearance of the desert tortoise will be discussed as will the author's prescription for addressing the continuing decline of the species.

Ancient desert life seen through the eyes of artists

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A little under four million years ago gompotheres lived in the area now known as the Anza-Borrego Desert. In April of 2008, a family of gompotheres reappeared, much to the amazement of the community around Borrego Springs. Dennis Avery, inspired by the artwork of scientific illustrator Pat Ortega and landscape artist John Francis, in the 2006 publication Fossil Treasures of the Anza-Borrego Desert, hired another artist, Ricardo Arroyo Breceda, to interpret the works of Fossil Treasures in the form of life-size metal sculptures. These sculptures are now called the "Galleta Meadows Sky Art." Since April 2008, 125 life-size metal sculptures have been installed throughout the private, but open to the public, property owned by Dennis Avery.

Of interest is the difference in interpretation of these previously living organisms by these artists. The goal of the scientific illustrator is to depict the organisms as precisely as can be determined by careful study by paleontologists. Breceda used these illustrations to develop his sculptures, and they often depict the organism as best one might imagine it to have been like, but he also is not confined to the more precise scientific interpretation. Still, the immensity of these creatures is not lost on us by his interpretation.

Find out more in the San Diego Association of Geologists/South Coast Geological Society joint 2010 guidebook, Geology and Lore of Northern Anza-Borrego Desert. The guidebook includes a site map for locating each of the new Sky Art Sculptures plus a road log covering the "Highs to Lows of Anza-Borrego Desert State Park" field trip, and numerous papers covering stratigraphy, groundwater, geochemistry, mining, landslides, faulting, geomorphology and related subjects.

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