Breaking Up

the 2004 Desert Symposium Field Trip

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LSA Associates, Inc.

with

Abstracts from the 2004 Desert Symposium

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Breaking Up!

The Desert Symposium 2004 Field Trip Road Guide

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Introduction

D. Foster Hewett characterized the Mojave block fifty years ago (Hewett, 1954). The Mojave block is the area between the left-lateral Garlock fault on the north, the left-lateral Pinto Mountain fault on the south, the right-lateral San Andreas fault on the west, and a complex of right-lateral faults including the Soda–Avawatz–Bristol–Granite Mountains fault zone on the east (Brady, 1992). The blocks within this fault-bounded province act as an accommodation zone for forces of transtension and transpression caused by interaction of the Pacific Plate, the Continental Plate, and the surrounding Sierra, Transverse Range, and Peninsular geologic provinces. The southwestern Mojave block is cut by northwest trending right-lateral strike-slip faults that roughly parallel the San Andreas system. The northeastern portion of the Mojave Block contains northwest striking faults and east-west striking faults that roughly parallel the left-lateral Garlock fault.

The Tertiary Mojave block was probably elevated before 25 Ma (Hewett, 1954), and the first basins that could hold sediments were formed by extensional tectonics (Dokka, 1986, 1989; Nielson and Reynolds, 1996). The Eastern California Shear Zone with northwest and east strike-slip faults developed later (Dickerson, 1996; Brady and Dokka, 1989).

We will see low-angle, early Miocene faults in the Waterman Hills north of Barstow and west of Harper Lake. The early Miocene extensional style of low angle faulting is accompanied by listric normal faulting which includes block rotation around a horizontal axis and apparently clockwise block rotation around a vertical axis. The incomplete stratigraphic record of the late Miocene does not seem to show if the change to strike-slip faulting was gradual or sudden. The record indicates that the Mojave strike-slip regime was active in the Pliocene, between 5 and 3 Ma. If clockwise rotation of blocks around a vertical axis is observed in early Miocene strata, does the cause relate to a strike-slip mechanism?

The route at the start of Day 1 parallels the historically active east-striking Manix fault, and crosses segments of northwest-trending, right-lateral, strike-slip faults such as the Lenwood fault. Recently active forces have created a different stress regime that steps northward across the northwest-trending faults and created ruptures during the Landers and Hector events. On Day 2 we will see relatively fresh scarps and discuss their consequences in a more densely populated area. We will travel along the San Andreas fault rigt zone on Day 3 from Cajon Pass to Llano.

Day 1

Convene at Baker. Make sure that gas tanks are full and tires are inflated, and that you are provisioned with sun screen, hats, snacks, and water. PROCEED SOUTH to Interstate 15.

0.0 (0.0) Enter I-15 westbound.

6.2 (6.2) Cross under the Zzyzx overpass which leads south to CSU's Desert Studies Center.

12.0 (5.8) Pass Rasor Road.

14.8 (2.8) The "West Soda fault" (RLSS) is to the north

15.7 (0.9) Pass Basin Road.

24.0 (8.3) EXIT RIGHT onto Afton Road.
24.3 (0.3) Stop at overpass. TURN LEFT (south) and proceed over freeway.

24.4 (0.1) Drive south on the crest of the flat-pebble beach bar that marks the high stand of Lake Manix at elevation 1780' (Meek, this volume).

25.1 (0.8) PARK at the west toe of the hill at the intersection of Afton Road and BLM road AF2423.

STOP 1-1 To the south is the east-west trending, left-lateral Manix fault which has offset distinctive granitic gravels a distance of three miles in a left-lateral sense (Meek and Battles, 1991).

The "granitic fanglomerate" of Meek and Battles (1991) was mapped as slightly different geologic units by Danehy and Collier (1958). The railroad mapping occurred at a time before large-scale strike-slip faulting was widely accepted, and thus Danehy and Collier were probably not looking to match distant geologic units along a fault's strike. Meek and Battles (1991) discovered that the lithologic assemblage and stratigraphic layering of the offset units are nearly identical, and concluded that the units have probably been offset in a left-lateral fashion by at least 5.2 km. Because the granitic fanglomerate contains abundant Miocene volcaniclastic rocks, the offset must post-date the early Miocene age of the Cady Mountain volcanics. The granitic fanglomerate also contains some large granitic boulders from a bedrock source in the region that has yet to be identified. Deciphering the origins and transport directions of the granitic boulders will be an important key to understanding the post-middle-Miocene geologic history of this area.

Since the middle Pleistocene, significant vertical offsets on the Manix fault have occurred, rapidly uplifting the Cady Mountains in the region directly south of Afton. A thick volcaniclastic wedge has been shed to the north uncon-

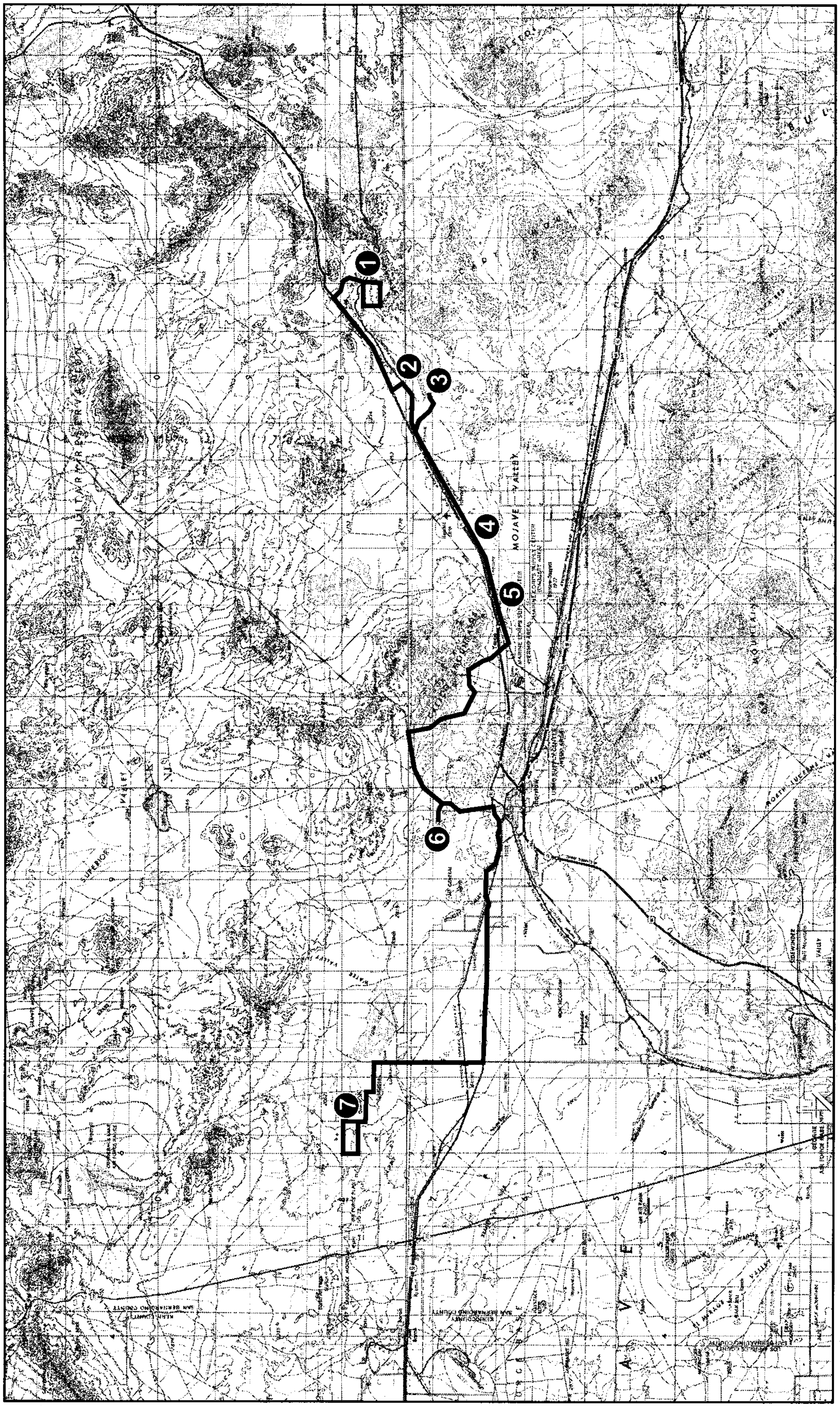

FIGURE 1

2004 Desert Symposium
Day I

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FEET

SOURCE: USGS 1:250,000 - SAN BERNARDINO, 1969 AND TRONA, 1969

PHOTO 1-1, STOP 1-3. View east along the course of the Mojave River. Apparent vertical offset on the Manix fault (center) juxtaposes the Plio–Pleistocene (2.5–1 Ma) Manix River Formation (right) against dark, older gravels on the left (north).

formably atop the highly cemented fanglomerates derived from the Cave Mountain side of the basin (Meek, 1989). This uplift along the Manix fault is probably responsible for creating the Afton topographic basin which subsequently began to accumulate Lake Manis sediments. The numerous entrenched channels that cross the Manix fault south of Afton have all incised since Afton Canyon formed and a large base-level drop occurred about 18 ka. Because the incised channels do not show significant left-lateral offsets along the Manix fault, most post-18 ka movement on this fault system may be vertical.

RETRACE to I-15.

26.0 (1.0) TURN LEFT and enter westbound I-15.

29.7 (3.7) Pass the rest stop.

33.4 (3.7) EXIT at Field Road.

33.7 (0.3) TURN LEFT (south) and cross I-15 to Yermo (frontage) Road.

33.9 (0.2) PARK at the intersection of Yermo Road and Field Road near a microwave station.

STOP 1-2. View to the south is Field Ridge (Buwalda Ridge) uplifted along the Manix fault (McGill and others, 1988) and the big bend of the Mojave River. The Mojave Desert is bordered on the north and south by left-lateral, west-trending faults, the Garlock and the Pinto Mountain, respectively. In the northeastern Mojave Desert, the most southerly east-west trending left-lateral fault is the Cady fault. The west-trending Manix fault lies north of the Cady fault and intersects it in the Harvard area.

Pleistocene Lake Manix encompassed Lake Troy and Lake Coyote to the southwest and west, respectively. PROCEED WEST on frontage road.

37.9 (7.2) TURN LEFT (south) on Alvord Road across tracks; then BEAR LEFT (southeast) toward VORE station (do not turn parallel to railroad tracks).

38.1 (0.2) TURN LEFT as the road to VORE station swings south.

39.2 (0.9) Pass under pole line.

39.4 (0.2) TURN LEFT (east) at the complex junction.

39.8 (0.4) Stop at gate, pass through, and leave the gate open or closed as you found it. Proceed to Manix Wash, but do not enter wash because of soft sand and dunes.

40.7 (0.9) PARK before entering soft sand of Manix Wash.

STOP 1-3. Hike 1000' south to a vantage point on the low ridge. Looking east you can see the trace of the west-striking, left-lateral Manix fault. This is one of a series of west-trending faults in the Mojave deset; the Cady fault runs through Hidden Valley to the southeast. The Manix fault ruptured during the (M_1) 6.2 earthquake of April 10, 1947 and produced 5 to 8 cm of left-lateral displacement. The geology of the area, including the Manix fault, was first described by Buwalda (1914). The 1947 earthquake was described by Richter (1947) and Richter and Nordquist (1951); aftershock patterns were reexamined by Doser (1990). The Manix fault zone was mapped at 1:62,500 scale by Keaton and Keaton (1977). Nagy and Murray (1991) mapped Quaternary and Tertiary deposits at the intersection of Manix Wash with the Mojave River at 1:24,000 scale. The Manix Wash area was mapped at 1:10,000 scale by McGill and others (1988). A paleomagnetic study of the Plio-Pleistocene Mojave River Formation was performed by Pluhar and others (1991). Collectively, these studies indicate that historical motion along the Manix fault has been predominantly left-lateral. However, longer-term movement on the fault may have included vertical as well as lateral motion. Aftershocks from the 1947 earthquake trend roughly perpendicular to the Manix fault and may indicate that the earthquake was on a right-lateral fault which intersects the Manix fault, with the motion along the Manix fault being only secondary. Paleomagnetic work on the Mojave River Formation indicates that roughly 8 degrees of clockwise rotation has occurred over the past two million years. RETRACE northwest to Manix Siding.

41.6 (0.9) Pass through gate.

42.0 (0.4) TURN RIGHT (north) at intersection.

43.0 (1.0) Cross under pole line.

43.8 (0.8) Join road to VORE.

44.1 (0.3) Cross to the north side of the tracks. Stop, TURN LEFT (west) onto Yermo Road and proceed west toward Minneola Road.

47.2 (3.1) Pass Harvard Road.

51.7 (4.5) Crystal Lakes Resort is to the south and the Coyote Lake overpass is north.

Pull to the right and PARK after the overpass.

STOP 1-4. Walk northwest to the freeway cut and observe an unnamed N 80°W-trending fault that places the buff sands of the Manix Formation against gray siltstones of the Barstow Formation. The strike of this fault approximates and is on line with the N 80°W strike of the western portion of the Cady fault. The strike is oriented differently than the S 80°W strike of the Manix fault and the N 25°W-striking Agate Hill fault. As we return to vehicles, we cross the Van Dyke (Yermo) ditch and a mechanically cut bench that may have supported a water pipe. These conveyances carried water from wells south of the California Inspection Station east to the agricultural fields at Harvard. PROCEED WEST.

55.5 (3.8) PARK just past Minneola Road.

STOP 1-5. Walk north to the Minneola overpass road cut to discuss the folded sediments cut by the northwest-trending Calico fault. Return to vehicles and PROCEED WEST on Yermo Road.

56.5 (1.0) To the south is the Calico Lakes Resort. Lacustrine sediments exposed by excavation here and at the Daggett Solar Sites, farther south, show that the Mojave River ponded at a higher (1902'–1938') elevation after Lake Manix drained. ^{14}C dates on charcoal from the lacustrine sediments range between 12,800 ± 900 and 9,050 ± 350 ybp. The likely candidate for damming the Mojave River is the Calico fault, and the ^{14}C dates suggest the activity was in latest Pleistocene–early Holocene time (Reynolds and Reynolds, 1985, 1991).

57.7 (1.2) Stop at Yermo Road and the freeway onramp; TURN LEFT and proceed west through Yermo.

58.9 (1.2) TURN RIGHT at Calico Road.

59.6 (0.7) Cross over I-15.

60.6 (1.0) Pass Mule Canyon Road. Borax was first discovered in California as salt marsh (playa) deposits in 1856. Deposits were found in San Bernardino County in 1865 and in Nevada in 1870 (Hildebrand, 1982). Colemanite was discovered in the Calico Mountains in 1882, prompting F. M. "Borax" Smith to launch the first hard rock underground mining for borate minerals. Colemanite ore was hauled by 20 mule team wagons, steam tractors, and the narrow gauge Borate and Daggett Railroad (Myrick, 1991; Reynolds, 1999). The town of Borate flourished from 1890 to 1907, when the entire operation was moved to Death Valley (Hildebrand, 1982).

62.4 (1.8) Pass the entrance to Calico Ghost Town. The Calico silver mines, first active in 1881, were served by the

Photo 1-2, Stop 1-4. View northwest at the I-15 road cut in the eastern Toomey Hills. The west-dipping, N80°W-trending fault, on strike with the Cady fault, places gray Lake Manix sands (left) against light-colored silts of the Barstow Formation.

Photo 1-3, MP 69.0. Chevron folds in the Barstow Formation siltstone mark the trace of a western branch of the Calico fault.

A&P railroad on the south side of the Mojave River at Calico Station, renamed Daggett in 1883 to honor John Daggett (Lieutenant Governor of California 1882-1886).

63.6 (1.2) TURN RIGHT (west) onto Yermo cut-off.

65.3 (1.7) TURN RIGHT (north) on Ft. Irwin road.

69.0 (3.7) Chevron folds in road cut mark the trace of a western branch of the Calico fault (Dibblee, 1970).

69.2 (0.2) TURN LEFT on Irwin Road.

72.5 (3.3) Continue past Copper City Road.

73.4 (0.9) Continue past Fossil Bed Road. Fossil Bed Road projects west-northwest, parallel to the trace of the Coon Canyon fault. The fault strikes east-southeast into the complex of "Calico" faults at the northwest end of the Calico Mountains, many of which cross the Barstow Formation (Dibblee, 1968). The Coon Canyon fault cuts Pleistocene and Holocene sediments southwest of elevated exposures of the Barstow Formation that are unconformably overlain by Pleistocene sediments (Dibblee, 1968). A xeric-adapted vertebrate fauna caught in a crevice along the Coon Canyon fault suggests that the fault was active in the early Holocene (Reynolds and Faye, 1989; Bell and Reynolds, 1991).

Activity on the Calico fault, south of the Calico Mountains, may have dammed the Mojave River, causing deposition of lake, pond, and marsh sediments west of the fault, from Daggett on the south to Yermo on the north (Reynolds and Reynolds, 1985, 1991). Dates of deposition between 12,000 and 9,000 ybp (Reynolds and Reynolds, 1991) are similar to activity on the Coon Canyon fault. Scarps that elevate Pleistocene and Holocene sediments on the northeast side of the Calico and Coon Canyon faults may have been active during the same period, suggesting that the "Calico" fault activity may be stepping westward (Reynolds, 1992) during Holocene time.

75.0 (1.6) Continue past a right turn to the microwave sta-

Photo 1-4, MP 73.4. View west of microwave hill in the Waterman Hills. The WHDF plane is overlain by dark red andesite and underlain by light green Waterman gneiss.

Photo 1-5, Stop 1-6. View north of the flat-lying plane of the WHDF, overlain by dark red andesite and underlain by light green Waterman gneiss. Rootless adneside vents below the towers are severed by the WHDF.

tion in the Waterman Hills. The Waterman Hills detachment fault moved 24 Ma red Miocene andesite and sediments eastward over the Waterman Gneiss about 20 Ma (Glazner and others, 1989). The microwave tower site shows relationships of the brittle upper plate (volcanics) and the ductile lower plate, and shows the fabric of the Waterman Gneiss of the lower plate increasing upward toward the plate contact (Glazner and others, 1989).

75.8 (0.8) **SLOW** through curves and TURN RIGHT as Irwin Road turns south. Pass through gravel stockpiles.

76.0 (0.2) Pass through a crossroad.

76.1 (0.1) Continue past a crossroad.

76.3 (0.2) Continue past a right turn.

76.8 (0.5) BEAR RIGHT (north) at a junction and proceed northeast.

77.1 (0.3) Take either branch as the road divides.

77.3 (0.2) PARK at gully.

STOP 1-6. View north of the Waterman Hills detachment fault. Red-brown Miocene andesite dating to 24 Ma sits in low angle fault contact with and was emplaced upon the underlying, pale greenish -gray, foliated Waterman Gneiss around 20 Ma. The Waterman Hills detachment fault can also be seen in Mount General to the southwest and we will pass the contact along Highway 58, on our way to the foliated granite at the Harper Buttes.

The Oligocene–Miocene boundary in the Mojave Desert is marked by dramatic magmatism and tectonism in the Mojave block. About 22–24 Ma, volcanic rocks erupted along an east-trending belt from the western Mojave Desert to the Whipple Mountains (Glazner, 1990; Glazner and Bartley, 1984). The magmatism accompanied extensional faulting, both moving northwest from Arizona in concert with the Mendocino triple junction (Glazner and Bartley, 1984). Volcanism began abruptly about 23 ± 1 Ma (Glazner, 1990; Glazner and Bartley, 1984), and locally produced andesitic domes up to several km thick (Glazner, 1981, 1990).

Near Barstow, magmatism and intense crustal extension were synchronous. The oldest volcanic rocks (23–24 Ma) are synkinematic with the Waterman Hills granite pluton in the footwall of the Waterman Hills detachment fault (WHDF). Extensional basin development and accumulation of the Pickhandle Formation began about the same time (Fillmore and Walker, 1993a,b; Walker and Fillmore, 1993). The most intensely extended rocks (indicated by extreme distension and tilting of upper-plate rocks) are only found from the Mitchel Range to the Buttes, roughly coincident with the areal extent of the Waterman Hills granite.

LOOK NORTH at the WHDF at the summit of the Waterman Hills where it dips south at 20.° Above us, the spectacular exposure of the footwall of the WHDF and shows progressive development of lineation and mylonitization in granodiorite as it nears the fault plain. These mylonites are well exposed in the fenster (window) above us. The WHD fault plane rings the fenster and is easily recognized by its juxtaposition of dark red rhyolites over bright green mylonites. Mylonite in the lower plate is strongly altered and resembles fault gouge.

The hanging-wall rhyolite exhibits intense hydrothermal alteration and cataclasis immediately above the WHDF surface, and is highly enriched in potassium. This style of alteration is common in extended Tertiary rocks across the southwestern United States (Chapin and Glazner, 1983; Bartley and Glazner, 1985; Glazner and Bartley, 1989), and apparently reflects hydrothermal systems that were active during extension.

Look below the microwave towers where the upper plate rhyolite intruded sedimentary rocks on the eastern side of the Waterman Hills. In contrast to ashes in the Mud Hills, tuffaceous sediments in the WHDF upper plate are highly metasomatized. Considerable slip on the WHDF is implied by the observation that nowhere are rhyolite dikes seen intruding footwall granodiorite or gneiss. Glazner and others (1989) infer these rootless plugs lie to the southwest.

Large-scale extension (tens of km) near Barstow caused a significant rearrangement of pre-Cenozoic structure and stratigraphy. Removing this extension greatly simplifies the geology of the Mojave Desert; for example, removing extension aligns the Independence dike swarm and many other pre-Cenozoic markers (Glazner and others, 1989; Martin and others, 1993).

Sedimentary rocks deposited during extension vary greatly relative to their position in the extensional basin. Fillmore and Walker (1998a) show that three main types of basins were present: (1) the intrarift Pickhandle basin, which received a thick section of coarse clastic and volcanic detritus; (2) the extrarift Tropico basin, which probably formed by flexure to the southwest of the footwall during extension; and (3) intra-hanging wall basins to the east, including the Clews basin at Alvord Mountain and the Hector basin in the Cady Mountains.

Dokka (1989) proposed that extension in the Mojave Desert originally occurred with a north-moving hanging wall, and that the current northeast orientation of extension vectors resulted from clockwise block rotation. The difference in vectors: North (Dokka group) and Easterly (Glazner group), suggests a difference in timing of tectonic events, with block rotation not occurring at the same time as the easterly translation of the upper plate containing the Independence dike swarm and Late Cretaceous dikes. The parallelism of the Mojave extension vectors to those in eastern California and Arizona (Bartley and Glazner, 1991), and the observation that vertical-axis rotations in the Colorado River extensional corridor are commonly restricted to the hanging walls of normal fault blocks (Wells and Hillhouse, 1989), suggests that further studies are necessary to define periods of Tertiary extension, block rotation and subsequent strike-slip faulting.

RETRACE to Irwin Road.

77.8 (0.5) GO LEFT (east) at the junction.

78.3 (0.5) Continue past the first crossroad. The Waterman Gold Mine is to the north.

78.8 (0.5) Stop at Irwin Road pavement, watch for fast cross-traffic, and TURN RIGHT (south).

80.7 (1.9) Pass the cemetery.

80.8 (0.1) Pass pumpkin-colored early Miocene limestone on the left.

81.1 (0.3) Stop at Old Highway 58. Go straight, but prepare for immediate right turn.

81.2 (0.1) TURN RIGHT (west) on Old Highway 58.

82.9 (0.9) Pass the Waterman Mill (site). By October, 1882, the Atlantic and Pacific Railroad (A&P) Company had completed their rail line from Mojave to Waterman's, the mill site for the Waterman Gold Mine owned by the future governor of California, Robert W. Waterman (Myrick, 1991).

84.1 (1.2) Continue past Waterman Street on the right. Waterman Gneiss is on the north, and pumpkin-colored early Miocene limestone is to the south.

85.5 (1.4) Community Boulevard is on the left. Pre-Paleozoic metamorphosed limestone (marble) is on the right within the Waterman Gneiss.

87.8 (2.3) TURN LEFT (south) on Lenwood Road.

88.1 (0.3) Highway 58. TURN RIGHT (west).

92.1 (4.0) Continue past Hinkley Road.

99.9 (7.8) TURN RIGHT (north) on Harper Lake Road. Fremont Peak is northwest, the Gravel Hills are due north, Opal Mountain is north-northeast, Black Mountain and Lane Mountain are northeast, and Coolgardie and the Barstow Formation are to the east.

101.1 (1.2) Cross the railroad tracks.

104.7 (3.6) Continue past the intersection with Santa Fe Street.

105.7 (1.0) Pass Lockhart Road and proceed north. Lockhart Ranch is to the northwest.

106.7 (1.0) TURN LEFT (west) on Hoffman Road before the Luz Solar Site. The Luz site uses concave mirrors that follow the sun from east to west, heating oil that turns water to steam that generates electricity.

108.7 (1.0) Jog north to pavement at Lockhart Road and proceed west.

109.5 (0.8) The west end of the Luz facility. The low, gravel hills to the west are the scarp of the Lockhart fault, a northwest projection of the Lenwood fault that runs toward the Rand Mountains.

109.7 (0.2) Proceed west on the section line road at the end of the pavement.

110.7 (1.0) TURN RIGHT (north) on the section line road. The low hills to the north-northeast are pre-Paleozoic metamorphosed sedimentary rocks.

111.7 (1.0) Proceed north through the intersection with the east-west section line road.

112.7 (1.0) Proceed through the intersection with the east-west section line road.

Slow for wash ahead.

113.0 (0.3) TURN LEFT (west) and proceed into the Buttes. Bear northwesterly at the junction.

113.3 (0.3) The road forks at the east end of a granitic butte. Take the branch on the south side of the butte.

113.7 (0.4) PARK.

STOP 1-7. (condensed from Dokka et al., 1994). The Buttes are remnants of a granodiorite pluton that contains evidence of ~20 Ma cooling associated with mylonitization and metamorphism. These rocks locally contain a well-developed, shallowly plunging, stretching lineation oriented NE-SW subparallel to the regional early Miocene extension direction. Based on structural and thermochronologic data, Dokka considers the superimposed brittle deformation and local mylonitization of these rocks to be the product of early Miocene detachment faulting.

Dokka concludes that metamorphism and the Early Miocene rapid cooling event recorded in metamorphic core complex rocks are manifestations of incomplete rifting of the Mojave Extensional Belt. Further, cooling of rocks of the

PHOTO 1-6, STOP 1-7. Granitic buttes west of Harper Lake. Foliation increases upward within the buttes, indicating that the WHDF passed above and move eastward.

Waterman Metamorphic Complex at ~20 Ma was the result of tectonic denudation, facilitated primarily by movements along the Mitchel and Harper Lake detachment faults and secondarily by upper plate normal faulting. Tectonic denudation is the overall vertical thinning of the lithosphere that occurs in conjunction with lateral extension (Armstrong and Higgins, 1973; Dokka et al., 1986). Tectonic denudation differs markedly from erosion in terms of the portion of the lithosphere from which material is removed. Cooling of deeper lithospheric levels as a consequence of erosion occurs at the surface, whereas tectonic denudation results in cooling of lower-plate rocks as higher structural levels are progressively thinned. In the Mojave example, first-order cooling of the footwall was most likely achieved by conductive heat transfer, developed when movement along the Mitchel and Harper Lake detachments juxtaposed shallow ("cold") hanging wall rocks against more deeply seated ("hot") footwall rocks. Dokka suggests that deformation, exhumation, and uplift of the metamorphic core complex of the west-central Mojave Desert were the result of early Miocene-age extensional orogenesis within the Mojave Extensional Belt.

Return to vehicles. PROCEED SOUTH-SOUTHWEST toward south side of third butte.

End of Day 1

Day 2

On Day 2 we will cross the pre-Miocene erosional surface of the Mojave Desert, which we will recognize by features including a flat erosional surface cut into weathered granite. On this surface are outcrops and stacks of rounded granitic boulders. Undisturbed pegmatite dikes often cut through the boulder stacks, verifying their original position. Erosion has cut back to this surface several times. We will see fresh and old northwest-trending fault scarps that cut this pre-Miocene erosional surface. Features along these scarps include springs and associated linear rows of vegetation.

The Landers earthquake scarps stepped northerly across existing northwest-trending fault zones. We will visit relatively fresh scarps from the 1992 Landers event There, fresh breaks cut granitic and sedimentary rock, pulverized fault gouge ("mole tracks"), and knocked Volkswagen-size boulders from mountain faces. Damaged roads and water systems were rapidly repaired by San Bernardino County Public Works departments, and the quake-damaged "red-tagged" houses have been dismantled. But we can still see empty foundations, scarps that produced 'split-level" front yards and elevated outbuildings from residences, and fence lines that "adjusted" property boundaries by as much as ten feet.

At the end of day two will observe the transpressional structures along the northwest flank of the San Bernardino Mountains.

0.0 (0.0) Convene at "The Buttes" northwest of Harper Lake. Retrace eastward to the north-south section line road.

0.4 (0.4) Proceed east at the east end of the butte.

0.7 (0.3) TURN RIGHT (south).

0.9(0.2) Slow for wash ahead. Proceed through the intersection with an east-west section line road.

1.9 (1.0) Proceed through intersection with east-west section line road

3.0 (2.0) TURN LEFT (east) on the section line road.

4.0 (1.0) Start of pavement. Proceed east on section line road.

4.2 (0.2) West end of LUZ facility.

4.9 (0.7) Jog in road.

6.0 (1.1) TURN RIGHT (south) on Harper Lake Road.

11.5 (5.5) Cross the railroad tracks.

12.8 (1.3) PARK at Highway 58.

STOP 2-1. Exit vehicles and look south-southwest at the low hills. These hills are anticlinal and synclinal fold pairs along the Helendale fault (Bortugno and Spittler, 1986). This portion of the western Mojave Desert lies between the left lateral Garlock fault and the right lateral San Andreas fault, and is subjected to "pull-apart stresses" (transtensional strike-slip movement with oblique extension). It is an area of low topography between two major faults that have opposing directions of movement. This low area is crossed by northwest-trending, right-lateral, strike-slip faults. As opposed to those of pure, strike-slip movement, these fault planes are often curved or exhibit braided fault strands, and topographic highs can be formed by anticlines, horsts and grabens, and "apparent" vertical displacement as topographic highs (hills) are separated. Return to vehicles; watch for cross traffic and TURN LEFT (east) on Highway 58 toward Barstow.

20.6 (7.2) Pass Hinkley Road.

22.5 (1.9) Summerset Rd. Prepare to stop on shoulder.

22.9 (0.4) Pull to shoulder and PARK.

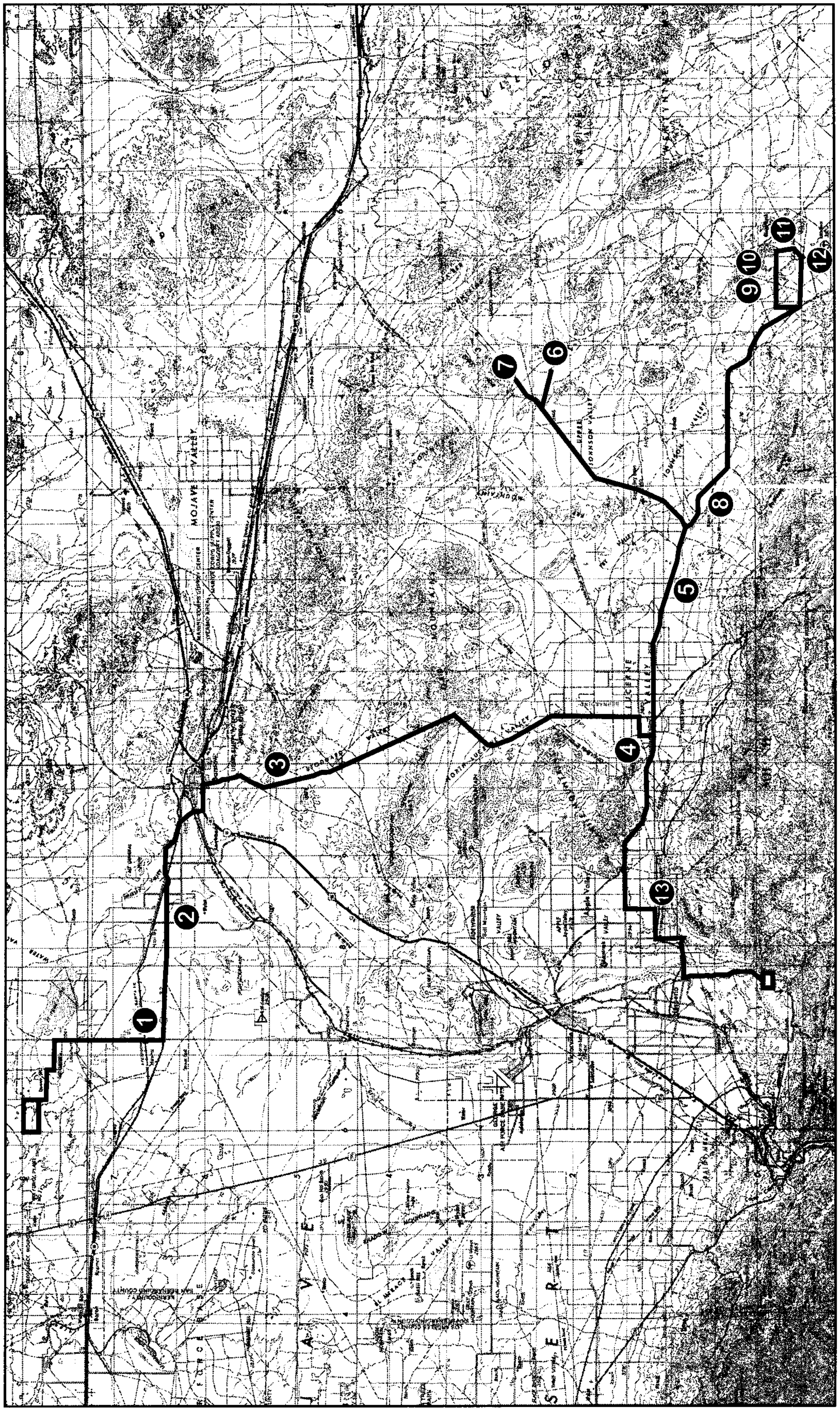

FIGURE 2

LSA

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FEET

SOURCE: USGS 1:250,000 - SAN BERNARDINO, 1969 AND TRONA, 1969

2004 Desert Symposium
Day 2

STOP 2-2 We can see Red Hill to the north-northwest and the Lenwood Anticline to the southeast. At Lenwood Road, four miles ahead, only 17 feet of sand separate the Mojave River drainage system from the Harper Lake system. Harper Lake filled at least twice during the late Pleistocene (Meek 1999), once prior to 30,000 ybp and a second time at 25,000 ybp. The fillings could have been by river meander, but it is possible that the Lenwood and Lockhart faults were active, compressing and elevating the Lenwood Anticline, which acted as a dam to force the Mojave River into the Harper Basin (Reynolds and Reynolds, 1994 ; Reynolds, Lemmer and Jordan, 1994).

24.5 (1.6) Continue past Lenwood Road.

27.3 (2.8) Continue past the exit to West Main Street in Barstow.

27.5(0.5) Bear east on I-15 toward Las Vegas.

29.3(1.8) Enter I-15 heading east.

33.1 (3.8) EXIT freeway at Barstow Road.

33.5 (0.4) Stop at traffic light. Services available, and the Mojave River Valley museum is two blocks north. TURN RIGHT (south) on Barstow Road (Highway 247).

36.6 (3.1) Reach the summit of Daggett Ridge and the entrance to a landfill.

38.0 (1.4) Continue past a right turn (west) to Stoddard Road

40.5 (1.5) TURN LEFT on a graded dirt section line road.

41.0 (0.5) TURN LEFT (north) on the road to Pink Tuff Quarry.

42.0 (1.0) PARK on low hill south of Pink Tuff Quarry.

STOP 2-3. The Pink Tuff runs from Outlet Center drive on I-15 eastward along the north flank of Daggett Ridge. We can see outcrops to the east and west. Where crossed by branches of the Lenwood fault, sections of the Pink Tuff (Dibblee, 1960, 1970) appear to be offset right-laterally a total of 3.2 km (2 miles), slightly more than the 2.5 Km (1.6 miles) of other estimates (Jachens and others, 1999). RETRACE to Highway 247.

42.9 (0.9) TURN RIGHT (west).

43.4 (0.5) TURN LEFT (south) on Highway 247.

46.3 (2.9) Pass the Slash-X Café.

47.4 (1.1) Pass a left turn to Stoddard Wash and Meridian gates.

54.3 (6.9) Cross the summit of Barstow Road at Goat Mountain Pass (el. 4148') in the West Ord Mountains. We are leaving the Mojave River drainage system and entering the internally drained Lucerne Valley drainage basin. Highway 247 bears southwest. We are driving between early Cretaceous quartz monzonite (west) and pre-Mesozoic gneiss (east).

58.2 (3.9) Barstow Road bears southeast.

63.0 (4.8) Slow for a complex junction at Peterman Hill; proceed south on Highway 247.

63.8 (0.8) Continue past Northside Road. We are at the northern margin of the Holocene playa of Lucerne Lake. Extensive Pleistocene lacustrine sediments are mapped on its southeastern margin (Bortugno and Spittler, 1986). The Lucerne drainage basin on the north side of the San Bernardino Mountains covers more than 250 square miles between the Helendale fault (west) and the Lenwood fault (east).

68.2 (4.4) Gobar Road. Slow; prepare for upcoming right turn.

68.5 (0.3) TURN RIGHT (west) at Rabbit Springs Road.

69.4 (0.9) Cross the Helendale fault scarp at Rabbit Springs. PARK off pavement.

STOP 2-4. Look at silts and groundwater discharge along the Helendale fault scarp. The Pleistocene age of the spring discharge is reinforced by the presence of a fossil horse femur (*Equus* sp. lg.). Deformation of soils along the scarp are discussed by Bryan (this vol.). We stopped at the Helendale fault at the beginning of the day, and we now are at its approximate midpoint as it strikes southeast to its terminus near Baldwin Lake. The strike-slip characteristics of the Helendale fault and the development of Lucerne Valley have been outlined in previous publications (Aksoy and others, 1986). Look north-northwest along the trace of the Helendale fault and note the deeply weathered surface on the early Cretaceous quartz monzonite east of the fault trace. This suggests apparent down-to-the-east movement on this strike-slip fault. The fault continues southeast past the source of the Blackhawk landslide to its apparent termination on the east side of Baldwin Lake in the San Bernardino Mountains. Return to vehicles, PROCEED WEST.

69.7 (0.3) Stop at Kendall; TURN LEFT (south).

PHOTO 2-1, STOP 2-4. View southeast along the trace of the Helendale fault, which projects toward a notch in the San Bernardino Mountains (skyline). Carbonaceous silts and cottonwood trees indicate groundwater discharge along the fault.

Photo 2-2, Stop 2-4. View north-northwest along the trace of the Helendale fault passing through the break on the skyline. The weathered granitic surface east of the fault (right) suggests *apparent* west-side-up movement on this right-lateral fault.

70.7 (1.0) Stop at Highway 18. TURN LEFT (east). This is a daytime headlight highway.

71.7 (1.0) Stop at the five-point intersection. Proceed east on Highway 247 to Yucca Valley. (Do not turn right on Highway 18 to Big Bear).

71.9 (0.2) Stop at Barstow Road; proceed west on Highway 247.

72.2 (0.3) Lucerne Valley Museum.

72.9 (0.7) Pass Meridian Road.

76.8 (3.9) Continue past Camp Rock Road.

78.8 (1.1) Continue past Donaldson Road.

80.9 (2.1) TURN RIGHT (south) to gravel piles at the north toe of the Black Hawk landslide.

81.0 (0.3) Stop at cable gate. PARK.

STOP 2-5. Walk to cuts in the Blackhawk landslide. Many blocks of Paleozoic limestone appear to be intact, and legend states that miners following silver veins in the limestone dug downward until they found “sand and crushed creosote.” The Blackhawk landslide event is dated to slightly greater that 17,400 ybp, based on ^{14}C dates on gastropod shells from a playa developed on top of the landslide (Stout, 1982). This period of the late Pleistocene is near the Wisconsin Glacial maximum (18,000 ybp). The source of the Blackhawk landslide is near the Blackhawk Mine (Del Mar, 1998) on the east side of the Helendale fault. It is possible that increased moisture, weight of snow pack, and activity on the Helendale fault in the source area might have triggered this massive slope failure. The Blackhawk landslide runs more than seven miles from its source to this point (Stout, 1982). Return to vehicles; retrace to Highway 247.

81.2(0.3) TURN RIGHT (east) onto Highway 247.

84.5 (3.0) Pass through a road cut into Pliocene Old Woman Sandstone in the scarp of Old Woman Springs fault. Vertebrate fossils and paleomagnetic signatures in the Old Woman Sandstone have been used to establish the date of initial uprising of this portion of the San Bernardino Mountain Range at about 3 Ma (May and Repenning, 1982.).

84.9 (0.4) TURN LEFT (northeast) at Johnson Valley OHV recreational area (Bessemer Mine Road). Four-wheel drive is not usually necessary along our route, but careful driving is imperative, and it will get bumpy.

86.9 (2.0) Drive up calichified Pleistocene old alluvium overlying Tertiary basalt.

87.6 (0.5) Drive downhill and cross the trace of the Lenwood fault. This fault showed no apparent rupture as a result of the June 28, 1992 Landers quake.

88.7 (1.2) Stay on the road as you cross Soggy Dry Lake.

89.4 (0.6) Notice dark tabular diorite bodies intruded by lighter-colored early Mesozoic quartz monzonite in hills to left (north) at 10:00, the southern tip of the Fry Mountains.

90.9 (2.5) We are driving across well-developed pavement of cobbles including Tertiary basalt developed on the southwest sloping ridge between branches of the Johnson Valley fault (Dibblee, 1964).

91.8 (0.5) Pass granitic boulders on the left. BEAR RIGHT (northeast) on Bessemer Mine Road and cross the trace of the Johnson Valley fault. This portion of the Johnson Valley fault was active during the 1992 Landers quake.

93.4 (2.0) Five miles to the north, metal powerline towers cross upper Johnson Valley. One metal tower was severely damaged when it was undercut by 3.5 m of slip on the Emerson fault, moving two of the legs approximately 9 feet relative to the other two. In this area, the Emerson fault

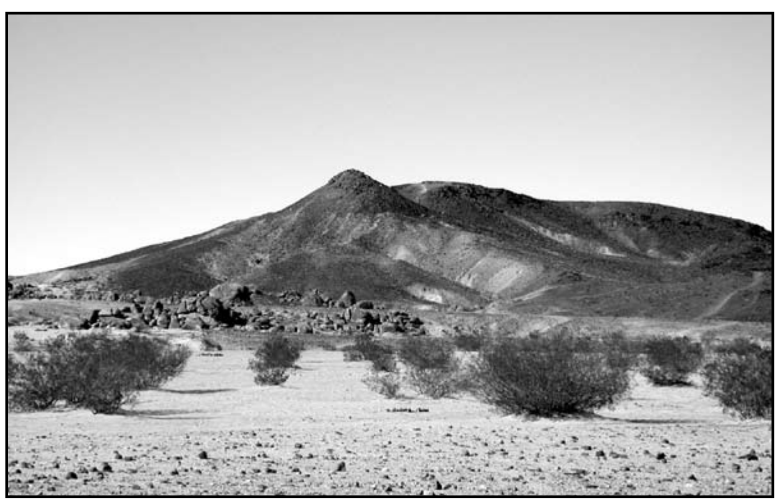

Photo 2-3, MP 91.8. View northwest of the Johnson Valley fault trace running between granitic boulder outcrops (left) and Tertiary basalt (right).

PHOTO 2-4, STOP 2-6. View north along the 1992 Emerson fault scarp, with lateral displacement of 20 + feet and vertical displacement up to 6 feet. The fault trace runs north around the granitic ridge (Stop 2-7).

joins the Camp Rock fault.

94.3 (0.9) Continue past a road through desert pavement to the southeast.

95.4 (1.1) Road junction. Notice the calichified sediments below the desert pavement in this area. We are entering a west-dipping block of uplifted Pleistocene older alluvium developed on eroded Mesozoic granitic rocks.

95.8 (0.4) Cross a dirt road junction (BLM race course route).

96.9 (1.1) TURN RIGHT on Galway Lake Road and travel toward the Emerson fault and one of the most spectacular scarps produced by the June 28, 1992 earthquake. Stay to the right along the dirt track; it's only about a mile to the turnoff.

97.9 (1.0) TURN RIGHT on the "geologists road." This well-developed track did not exist prior to 1992; it came into being as geologists visited the fault scarp; it was subsequently adopted as an off-road race course. Proceed about 0.5 mile.

98.7 (0.8) Turn around and PARK.

STOP 2-6. Emerson fault scarp near Galway Lake Road. Walk east to the fresh-appearing scarp that exhibits up to six feet of vertical slip. This feature is surprisingly undamaged from erosion and cycle travel. At this stop, Tertiary strata and overlying older Pleistocene alluvium are folded into an anticline elevated above Pleistocene alluvium to the west. The second epicenter of the Landers quake was located near this spot; it produced the largest vertical component of slip. The large vertical slip is due to a restraining bend in the Emerson fault. Elsewhere in the Landers rupture zone, the vertical component of slip is less than that of right-lateral slip.

Walk southwest to desert pavement-covered gravel fanglomerate. Fractures here were first noticed in December 1999 after the October 1999 M 7.1 Hector Mine quake. Surface ruptures show both compression and slope failure. Orientation of ruptures is approximately 60° west of the trace of the Emerson scarp.

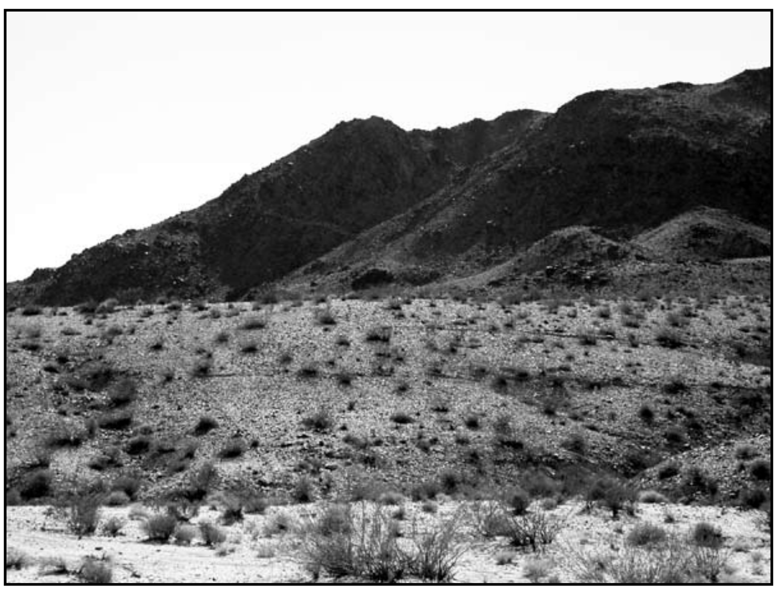

PHOTO 2-5, STOP 2-6. View southwest of dark fanglomerates west of the Emerson fault scarp. The horizontal "lines" are compression and release fracture planes that appeared after the October 1999 Hector Mine quake.

From this vantage point, follow the trace of the Emerson fault northwest to our next stop, where granitic rocks have been elevated on the west side of the fault. RETRACE to Galway Lake Road.

99.5 (0.8) TURN LEFT (west) onto Galway Lake Road. Proceed northwest to Bessemer Mine Road, staying left, out of the soft sand.

100.6 (1.1) TURN RIGHT (northeast) onto Bessemer Mine Road.

101.7 (1.1) Stay to the left (northwest); do not take right-hand road (east). Notice the fresh scarp to the left (north). Continue northeast on Bessemer Mine Road.

102.0 (0.3) TURN LEFT (north) on a dirt track.

102.2 (0.2) PARK at the Emerson fault at Bessemer Mine Road.

STOP 2-7. We are northwest of Stop 2-6 on the trace of the same fault. Walk 50 feet north to observe the scarp; then continue 500 feet north where the fault pulverized granitic bedrock, forming a

Photo 2-6, Stop 2-7. View north of a linear fault gouge featured called a mole trck on the trace of the Emerson fault.

RETRACE to Bessemer Mine Road and Highway 247.

103.8 (1.6) Junction of Galway Lake Road and Bessemer Mine Road. Continue west on Bessemer Mine Road.

109.2 (5.4) Cross the trace of the Johnson Valley fault.

112.3 (3.1) Cross Soggy Dry Lake.

113.4 (1.1) Cross the scarp of the Lenwood fault.

116.0 (2.6) Stop at Highway 247; TURN LEFT (southeast).

116.8 (0.8) Old Woman Springs is on the right (southwest).

120.0 (3.2) Continue past Lafon Road.

120.2 (0.2) Pull to the right and PARK.

"mole-track." Eighteen to 21 feet of overall lateral offset during the Landers quake has literally moved a portion of the hill, creating an appearance of vertical offset, even though right-lateral slip was predominant. Notice the fallen boulders. Also note the leisingang weathering rings on the interior of broken boulders. This is a feature developed by subaerial erosion below the pre-Miocene erosional surface, where concentric rings of iron oxide were deposited in porous, fracture-bound, granitic blocks. Return to vehicles and

Photo 2-7, Stop 2-7. Concentric leisingang rings of limonite and pyrolusite are exposed by breaks in a granitic boulder. This is a sign of deep weathering below the pre-Miocene erosional surface that allowed groundwater to precipitate metallic oxides in porous, subsurface granitic blocks.

STOP 2-8. The Lenwood fault scarp is to the east and the Old Woman Springs fault is to the west. The Lenwood fault scarp consists of elevated calichified gravels, a signature that we have seen crossing this fault and the Johnson Valley fault to the north. Look west at the scarp of the Old Woman Springs fault where granitic rocks, Tertiary basalts, and older Pleistocene fanglomerates are juxtaposed along the fault trace. Follow the trace of the scarp southeast as it bends easterly at the front of the San Bernardino Mountains. Note a similar bend in the scarp of the Lenwood fault to our southeast.

125.9 (5.7) Continue past Rock Corral Road.

129.5 (3.6) Continue past Remy Road. View south of the pre-Miocene erosional surface, a north-sloping pediment developed on granitic rocks. At upcoming stops, we will see where this surface has been cut by northwest-trending

Photo 2-8, MP 109.2. View southwest of the Johnson Valley fault scarp (in shadow) that elevates the caliche-capped erosional surface above Holocene sands.

PHOTO 2-9, STOP 2-8. View southeast of the Old Woman Springs fault trace as it bends eastward beneath the eastern San Bernardino Mountains.

faults.

133.6 (4.1) Prepare to turn left.

133.8 (0.2) TURN LEFT (east) on Linn Road.

134.0 (0.2) TURN LEFT (north) on Kickapoo Lane. We will be following the north-northeasterly trending fault of the same name. At this point, the Johnson Valley fault diverges northwesterly along the east side of the granite hills.

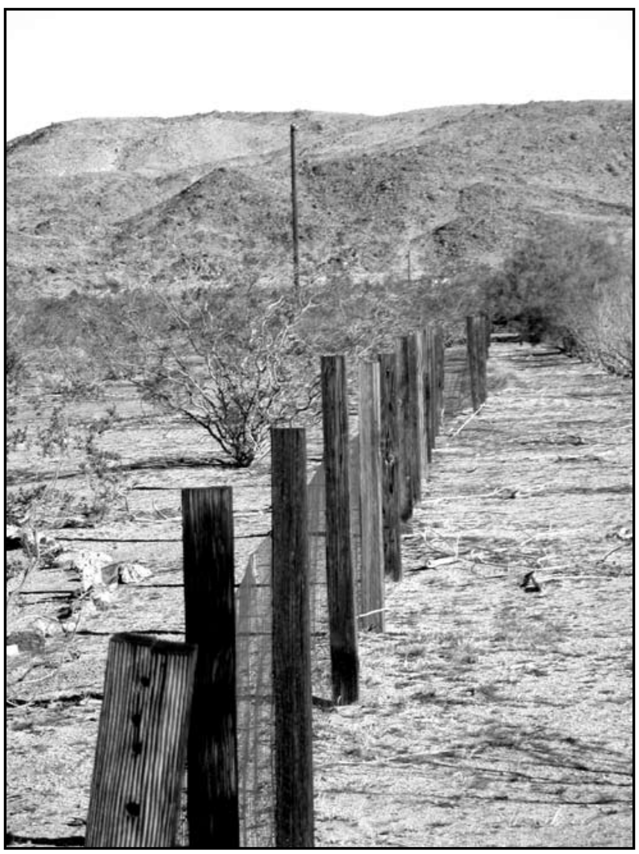

PHOTO 2-10, STOP 2-9. Property boundaries were offset as much as 20 feet along individual and cumulative Landers ruptures. The Batdorf fence shows a two-foot offset.

134.4 (0.4) The concrete foundations on the east side of the road pay testimony to structures that were damaged beyond repair. The houses were red-tagged to indicate that occupancy was not allowed, and they were subsequently demolished.

135.1 (0.7) PARK at the Batdorff residence.

STOP 2-9. The Kickapoo fault starts in this area, and the Johnson Valley fault diverges northwesterly. The Batdorff foundation and framework received significant shattering and dislocation (Lemmer and Lazart, 1993). It is one of the few structures on the Kickapoo fault that was successfully rebuilt. We can still see approximately two feet of offset in the fence line at the southern property boundary. A property line fence on Encantado Road still shows offset of more than nine feet. Return to vehicles and PROCEED NORTH.

136.0(0.9) Pass University Road.

137.0 (1.0) TURN RIGHT (east) on Bodick Road.

137.2 (0.2) PARK on Bodick Road at the Kickapoo fault scarp.

STOP 2-10. The soil profile (red paleosol over white caliche) has been elevated on the west side of the fault. The view north-northeast follows the trend of the fault toward Charles Road. Return to vehicles, PROCEED EAST to Charles Road.

137.3 (0.1) TURN LEFT (north) on Charles Road.

137.4 (0.1) PARK.

STOP 2-11. Walk west 300 feet to an escarpment of the Kickapoo fault to look at multiple, east stepping scarps. Return to vehicles and proceed.

137.8 (0.4) Drive past the Lannom residence on the left (Lemmer and Lazart, 1993). The ground on the north side of the house bulged, and the main scarp between the house and the outbuilding behind created almost three feet of vertical offset. Cumulative local right lateral displacement amounted to more than 12 inches.

137.9 (0.1) Drive past the Brown residence on the left, sitting on a low hill (old scarp?) of solid-looking gravel. The

PHOTO 2-11, STOP 2-11. View southwest along a single strand of the Kickapoo fault.

Photo 2-12, Stop 2-11. View northeast as the Kickapoo fault steps eastward, creating three scarps.

split-level front yard has seen little degradation by erosion in the last 12 years.

138.1 (0.2) TURN AROUND in the cul-de-sac and proceed south.

138.5 (0.4) Continue past Snail Trail.

139.1 (0.6) TURN LEFT (east) on Boddick Road.

139.2 (0.1) TURN RIGHT (south) on Dusty Mile.

140.2 (1.0) TURN LEFT (east) on University Road.

140.7 (0.5) Continue past Acoma Road.

141.6(0.9) Proceed slowly across wash.

141.8 (0.2) TURN RIGHT (south) on Bellfield Road (abandoned homestead on north).

142.3 (0.5) TURN RIGHT (west) toward Homestead Mountain.

Photo 2-13, MP 137.9. View northwest of the Brown residence on Charles Road. A scarp up to three feet high produced a split-level front yard. The house sits on old graels that may indicate Pleistocene(?) uplift.

142.4 (0.1) **PARK.**

STOP 2-12. Walk west to look at an extensive boulder fall generated by the Landers earthquake. After twelve years, the impact points and fractures are still visible. Boulders that fell in the San Bernardino Mountains during the contemporaneous Big Bear quake were larger and had more severe consequences in that populated area (Reeder, 1993). Return to vehicles; retrace east to Bellfield Road, then south.

142.5 (0.1) TURN RIGHT (south) on Bellfield Road.

143.2 (0.7) Do not stop on the sandy road.

143.8 (0.6) BEAR RIGHT (south) at complex intersection; continue on Bellfield Road.

144.3 (0.5) Stop at paved intersection of Linn and Bellfield Road. TURN RIGHT (west) on paved Linn Road.

144.4 (0.1) PARK**.**

STOP 2-13. The cut on the north side of Linn Road shows greenish sands overlain by dense, white, pedogenic carbonate. This sequence, from lowest to highest, suggests poorly-drained marshy ground at the base of the east facing slope. What caused the poorly drained ground? Was it the scarp of the Homestead Valley fault, now removed by erosion? The induration of the pedogenic carbonate suggests that local deposition, when compared with other carbonate deposits in the Mojave Desert, may be older than 300 thousand years. Pipes Wash might not have been present; had it been ponding would not have occurred. PROCEED west.

146.3 (1.9) Continue past Acoma Road. Ahead**,** note right lateral offset of the pavement at Dusty Mile Road.

147.6 (1.3) STOP at Highway 247. TURN RIGHT (north) on Highway 247. Retrace toward Lucerne Valley.

155.8 (8.2) Continue past Rock Corral.

158.2 (2.4) View SW at 10:00 of low scarps along east trending Lenwood fault.

164.1 (5.9) View west of cottonwood trees alignment on Old Woman Springs fault.

165.0 (0.9) Continue past Bessemer Mine Road.

168.8 (3.8) Continue past Santa Fe Road.

172.8 (4.0) Continue past Camp Rock Road.

177.7 (4.9) Stop at the intersection with Barstow Road in Lucerne Valley. Pause for fuel and snacks. Continue west on Highway 18.

180.7 (3.0) Continue past Buena Vista Road.

181.2 (0.5) Cross Rabbit Dry Lake. The alluvial fan at the base of the northern San Bernardino Mountains (left) contains scarps of thrust faults. Nearby Chimney Rock is registered California Historical Landmark # 737. Conflicts between Indians and white settlers over the rich lands of the San Bernardino Mountains culminated in the battle at Chimney Rock on February 16, 1867. Although the Indians defended themselves fiercely, they were forced to retreat into the desert. In the years following, the Indi-

PHOTO 2-14, STOP 2-12. View north-northwest of gray gravels (left) and tan sandstone (right) separated by the Homestead Valley fault. Shaking during the 1992 Landers quake caused boulders to topple from the cliff face to the west. An impact crater can be seen to the left of a toppled boulder in the foreground.

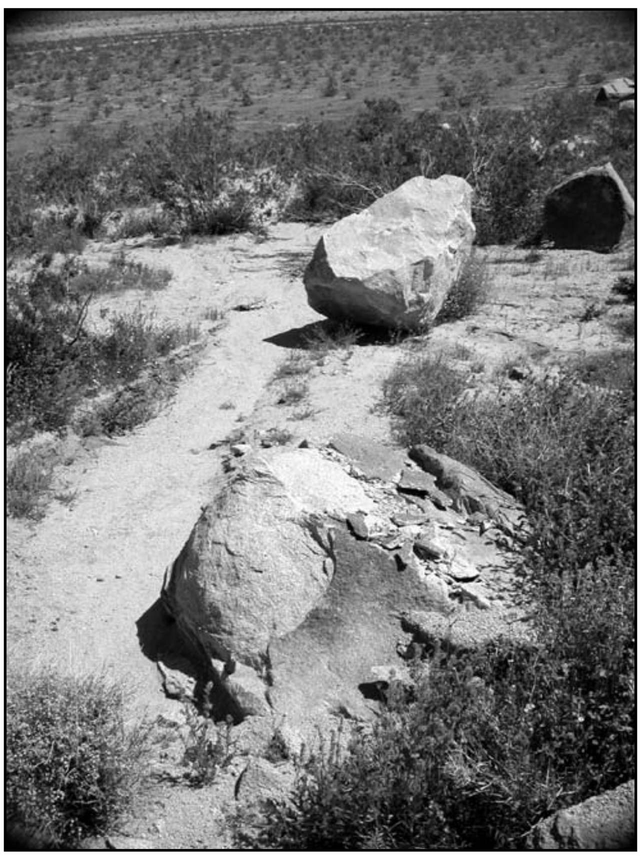

PHOTO 2-16, STOP 2-12. Dark varnished granitic boulders show fresh white scars from impacts. Impact flakes remain in position on the boulder in the foreground.

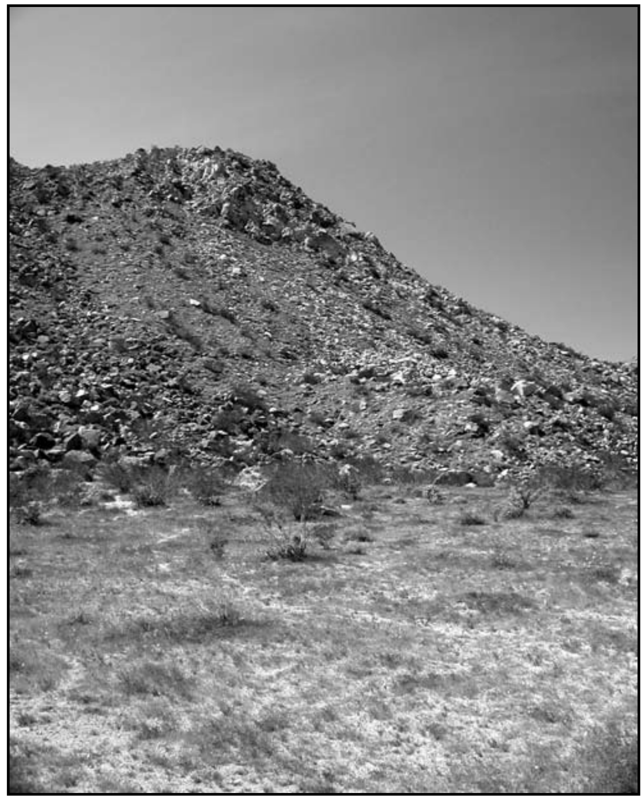

PHOTO 2-15, STOP 2-12. View northwest of the white boulder source. When the Landers quake occurred, the boulder outcrop fell on the ledge (an old landslide) and, upon impact, sent boulders east onto the alluvium.

ans' traditional mountain food gathering areas were lost to white encroachment.

183.7 (2.5) Highway 18 bears northwest.

186.6 (2.9) Highway 18 bears west.

187.1 (0.5) Pass Milpas Drive.

PHOTO 2-17, STOP 2-13. View north of a cut on eastern Linn Road. The cut shows green sandy silts overlain by think, dense pedogenic carbonate which might be more than 0.25 Ma. Greenish silty sands below suggest that drainage ponded against a north-south structure (perhaps the Homestead fault) prior to the cutting of Pipes Wash to the east.

Photo 2-18, Stop 2-14. View south-southeast of low foothills that mark the north frontal fault scarp of the northwestern San Bernardino Mountains.

188.0 (0.9) Pass Laguna Seca Drive, Prepare to turn Left (west) at Bear Valley Cutoff.

188.3 (0.3) TURN LEFT (west) at Bear Valley Cutoff

190.5 (2.2) Mesquite/Denison Roads. Prepare to turn left (south) in one-half mile.

191.0 (0.5) TURN LEFT (south) at Central Road.

192.7 (1.7) Pass Seco Road.

193.0 (0.3) TURN RIGHT at Tussing Ranch Road.

193.1 (0.1) PARK east of the intersection of Tussing Ranch and Central Roads.

STOP 2-14. The low foothills one-half mile to the south are the scarps of the North Frontal fault of the San Bernardino Mountains resulting from the compression of the mountains as they are diagonally crossed by the San Andreas fault to the west (Bortugno and Spittler, 1986). We will follow these low scarps to the southwest around the base of the mountains. The "foothills" to the south are the Ord Mountains. Proceed west on Tussing Ranch Road.

194.8 (0.9) Pass Navajo.

195.8 (1.0) Stop**,** TURN LEFT (south) on Kiowa, cross the Burlington Northern and Santa Fe Railroad branch to the limestone mines at Cushenbury. Frontal faults are to the east. Move to right lane for right turn.

197.3 (1.5) TURN RIGHT (west) on Rock Springs Road.

198.4 (1.1) Stop light at Deep Creek Road. Continue west.

198.8 (0.4) Cross the Mojave River.

200.0 (1.2) Stop at Arrowhead Lake Road/Silverwood (Main Street, Hesperia is to the right). TURN LEFT (south).

201.4 (1.4) Pass Ranchero Road.

202.1 (0.7) Hesperia Lake Park.

204.5 (2.4) View west-southwest of Mojave Forks.

205.1 (0.6) Cross the west fork of the Mojave River.

205.9 (0.3) Stop**.** TURN RIGHT (west) on State Highway 173. Slow through curves.

206.3 (0.9) TURN LEFT and enter Mojave Forks Campground. We are camped at the confluence of the West, Middle and East forks of the Mojave River. The east fork is Deep Creek, a drainage that reaches Big Bear and Holcomb Valleys.

End of Day 2

Day 3

The route of Day Three takes us along the San Andreas fault zone into the San Gabriel Mountains where we will see the Cajon Valley fault and the San Gabriel fault and how they relate to the San Andreas fault zone. The drive along the San Andreas rift will pass lakes, sag ponds, and fault-bounded valleys. We will stand on the compressional Llano escarpment and look southeast at folded rocks on the north side of the San Andreas fault. The final stop will be a view east along Cajon Valley showing Quaternary uplift and erosion along the San Andreas fault zone and the Cajon Valley fault.

CONVENE at Mojave River Forks campground.

00.0 (00) Enter Highway 173 and proceed southwesterly into Summit Valley. SLOW through curves.

1.8 (1.8) Look north to a low hill of Phelan Peak lacustrine sediments with dated volcanic ash on the eastern portion of Las Flores Ranch.

3.7 (1.9) Cedar Spring Dam.

3.9 (0.2) Spillway of Cedar Spring Dam.

4.9 (1.0) Slow for curves at the West Fork of the Mojave River.

5.9 (1.0) Stop, TURN RIGHT on Highway 138 (Highway173 ends). Silverwood Lake is to the left.

8.9 (3.0) Pass Summit Valley Road.

10.2 (1.3) Pass the Summit Railroad Siding. Railroads crossing Cajon Pass found that the faulted, soft sediments often proved problematical for tunnels and steep cuts (Myrick, 1991).

10.3 (0.1) Pass a left turn for FSR 3N22, where there is an excellent view of structural and erosional features along the San Andreas fault that have taken place during the past two million years (Kenney and Weldon, 1999).

10.6 (0.3) Summit of Highway 138. SLOWfor curves.

12.0 (1.4) Enter the buff arkosic sands of the upper Crowder Formation.

12.2 (0.2) Look south across Crowder Creek to slope failures (landslides) in the Crowder Formation.

12.3 (0.1) The pear orchard on the right is all that remains of homesteading; pioneer ranches date to the 1860s (Haen-

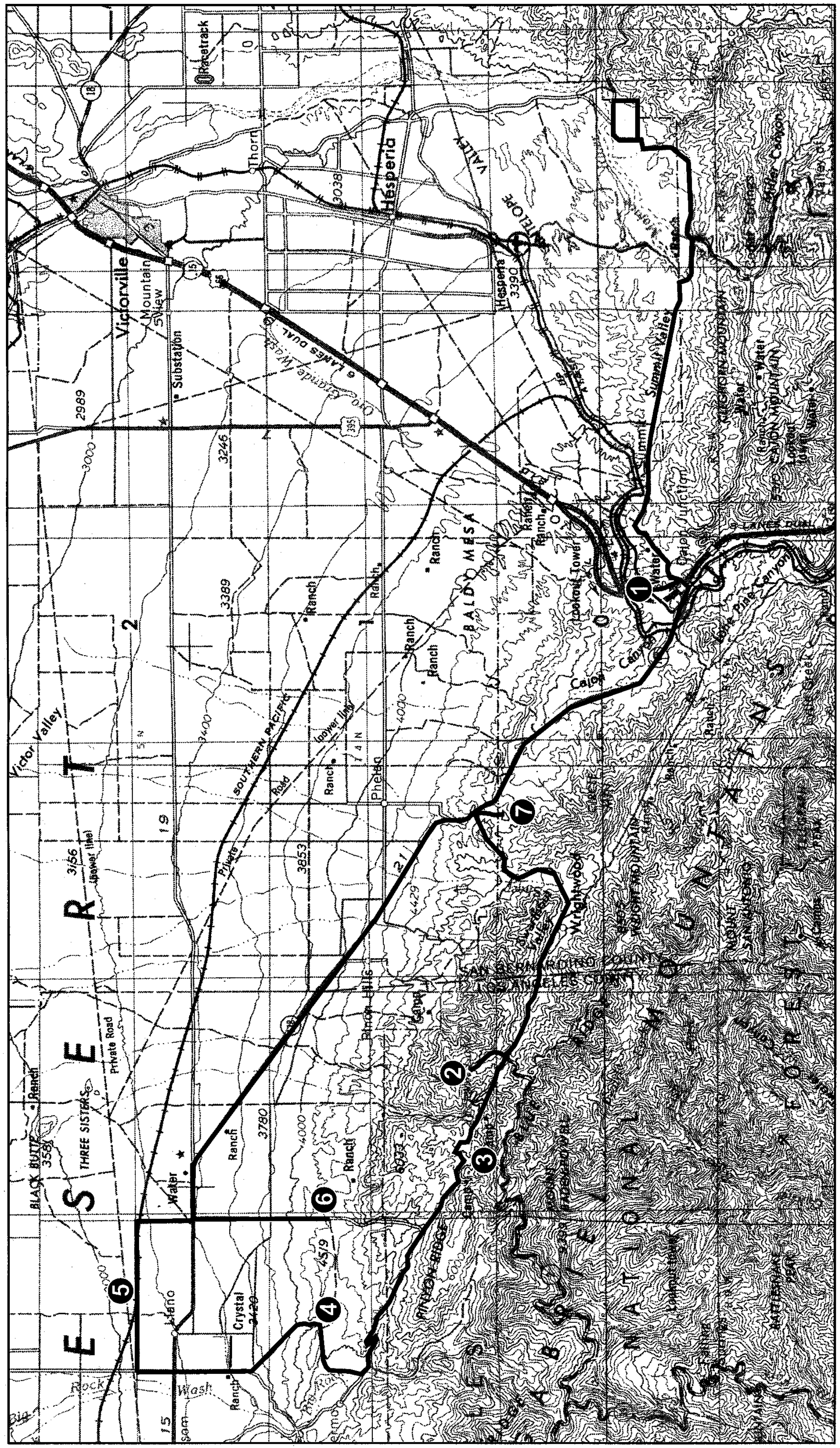

FIGURE 3

SOURCE: USGS 1:250,000' QUAD - SAN BERNARDINO, 1969

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Day 3

szel, 1976).

12.7 (0.4) Pass Sulphur Spring (Haenszel, 1976; Cataldo, 1999).

13.2 (0.5) Cross a branch of Crowder Creek and enter the lower Crowder Formation with reddish-brown paleosols that record the stratigraphic and taxonomic changes from the Hemingfordian to Barstovian land mammal ages (Reynolds, 1991).

14.1 (0.9) Stop at the intersection of Interstate15 and Highway 138. TURN RIGHT onto the dirt frontage road on the east side of I-15. PROCEED NORTH toward the railroad trestles.

14.7 (0.6) TURN RIGHT (northeast) just before reaching the first trestles.

14.9 (0.2) PARK at the site of DOSSEC “Deep Hole.”

STOP 3-1: DOSECC “Deep Hole.” The DOSECC borehole in southern Cajon Valley and west of Cajon Pass extends to a depth of 3.5 km. One of the principle scientific motivations for the borehole was to provide stress and heat flow data that would shed some light on the controversy of whether or not the San Andreas fault is a “weak” or “strong” fault (see Lachenbruch and Sass, 1992; Lachenbruch and others, 1995). The “strong” fault argument suggests that the rocks within the shear zone of the fault itself would exhibit relatively normal coefficients of friction compared to those determined for average crustal rocks. In this model, the maximum principle stress could act on the San Andreas fault at a relatively low angle (oblique). Additionally, the relatively higher coefficients of friction across the fault would lead to relatively elevated heat flow energy near the fault (see Scholz, 1980). In contrast, the “weak” fault model suggests that the coefficient of friction of the shear zone rocks at depth would be relatively low. In this scenario, the maximum principle stress would be close to normal (90 degrees) across the San Andreas fault, and the frictional head produced by numerous major events across the fault would be less than that predicted by the “strong” fault model.

Heat flow results from the DOSECC borehole indicated fairly elevated values, which were consistent with heat flow values predicted for a “strong” fault. However, these values needed to be corrected in order to incorporate the fast erosion rates of Pliocene–Pleistocene sediments during the development of Cajon Valley. Ray Weldon (see Lachanbruch papers) estimated that approximately 1.5 km of Pliocene–Pleistocene sediments were eroded from the Cajon Valley area during the past 1.2 million years. This erosion rate was faster than the rate that the geothermal gradient could acquire a new near surface equilibrium, and thus led to elevated heat flow estimates in the boring. The corrected heat flow value for the DOSECC borehole supports the “weak” fault model.

Fragments of rodent teeth from depths below 8,000 feet in the drill hole are similar to faunas of Hemingfordian Land Mammal Age, suggesting that drilling to this depth encountered the early Miocene sediments of the Cajon Beds (Reynolds and Weldon, 1988). RETRACE to Highway 138.

15.9 (1.0) Stop at Highway 138. Watch for cross traffic and PROCEED WEST.

16.0 (0.1) Cross over I-15.

16.4 (0.4) Cross over railroad trestles.

17.1 (0.7) Cross under railroad trestle, and pass a left turn to Lone Pine Canyon. The white, arkosic sandstone “hogbacks” of the lower Cajon Valley beds appear prominently on both sides of the highway.

19.5 (2.4) Cajon Pass has been used as a route of access to the San Bernardino basin by Anglo-Americans for more than 170 years. A saddle on the skyline marks the route of the Mormon Trail, pioneered by Banning teamster William Sanford in 1850. Sanford broke out this route just in time for the Mormon colonists who came from Utah and settled San Bernardino in 1851. Sanford’s Pass, another saddle about 1 mile west, was an easier wagon route established by Sanford in 1853. The Los Angeles and Independence railroad tried to breach the “Inface Bluffs” with a tunnel in this area to reach the Mojave Desert; they were not successful (Haenszel, 1976; Cataldo 1999).

22.0 (2.5) This is a steep grade; prepare to encounter slow vehicles. At Mountain Top Junction, pull into the left turn lane and prepare to turn left when oncoming traffic permits.

24.3 (1.3) TURN LEFT at Mountain Top Junction, where Highway 2 joins Highway 138.

Proceed on Highway 2 (Angeles Crest Highway)heading west toward Wrightwood.

(26.5) (2.2) Pass Desert Front Road. We are in Sheep Creek Wash which carries purplish-gray Pelona Schist from the south side of the San Andreas fault northward onto the Mojave Desert to form the dark Sheep Creek fan, visible on satellite imagery (see front and back covers).

27.3 (0.8) Enter Wrightwood and pass Sheep Creek Road. In four miles we will turn right at the ranger station.

27.9 (0.6) Pass Lone Pine Canyon Road.

29.6 (1.7) Pass the Los Angeles County line.

31.1 (1.5) Mountain High Ski Resort.

31.9 (0.8) Big Pines Forest Ranger office; prepare to turn right.

32.0 (0.1) TURN RIGHT (north) on Table Mountain Road. Proceed 1.2 miles north.

33.2 (1.2) PARK in the big parking lot at end of Table Mountain Road.

STOP 3-2 : Table Mountain: View of the Mojave Desert

- The intersection of the San Jacinto, Cucamonga and San Andreas faults is beneath our feet
- Quaternary Uplift of Table Mountain
- The subsurface restraining bend
- Development of the Table Mountain monocline
- The San Jacinto-San Andreas faults retraining bend
- Development of the San Gabriel Mountain antiform

The Subsurface Restraining Bend in the San Andreas fault

The causative agent for the uplift that has migrated from the Western San Bernardino Mountains (Cajon Valley region) to Holcomb Ridge during the past approximately 500,000 to 700,000 years is likely a subsurface restraining bend in the San Andreas fault at depth (Figure 1). The restraining bend results from the collision of the Perris Block with the Mojave Block as it is channeled downward beneath the Cucamonga fault at a dip of approximately 25 degrees in a direction parallel to the strike of the San Jacinto fault. The San Jacinto fault converges on the San Andreas fault at an angle of 15 to 20 degrees. Thus, the Perris Block comes into contact with the Mojave Block at depth where the San Jacinto and Cucamonga-Sierra Madre fault zones intersect the San Andreas fault, which occurs under Table Mountain approximately 8 to 10 kilometers. The restraining bend lifts the rocks in the Mojave Block on the north side of the San Andreas fault as it migrates northwestward. The 1.5 km vertical uplift north of the San Andreas fault has resulted in the development of a monocline that extends from Cajon Valley (now eroded away) to Table Mountain. In the Table Mountain region, the monocline (-clinal fold can be seen in?) has developed in both the Victorville Fan deposits and within the underlying crystalline basement rocks.

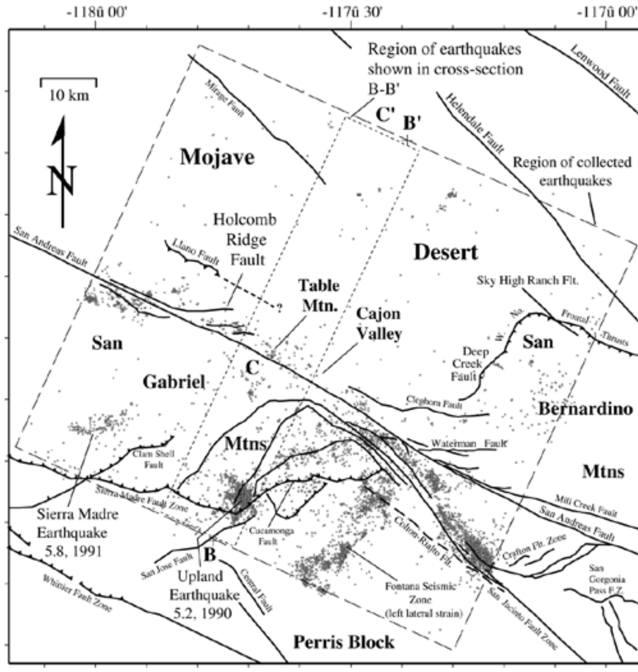


Figure 2. Map showing the final location of earthquakes, region of collected seismicity, hypocenter cross-sections B-B', and balanced cross-section C-C' (Figure 8), and Quaternary faults. Earthquakes data was collected from SCEC, and re-located utilizing a damped least squares inversion method (Kenney, 1999).

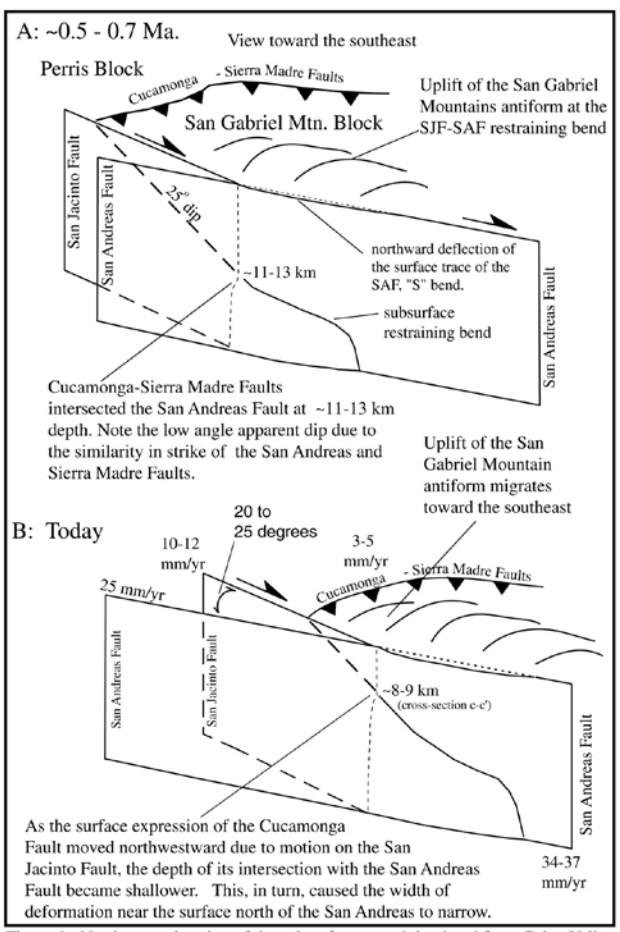


Figure 1: Northwest migration of the subsurface restraining bend from Cajon Valley to Table Mountains during the past ~700,000 years.

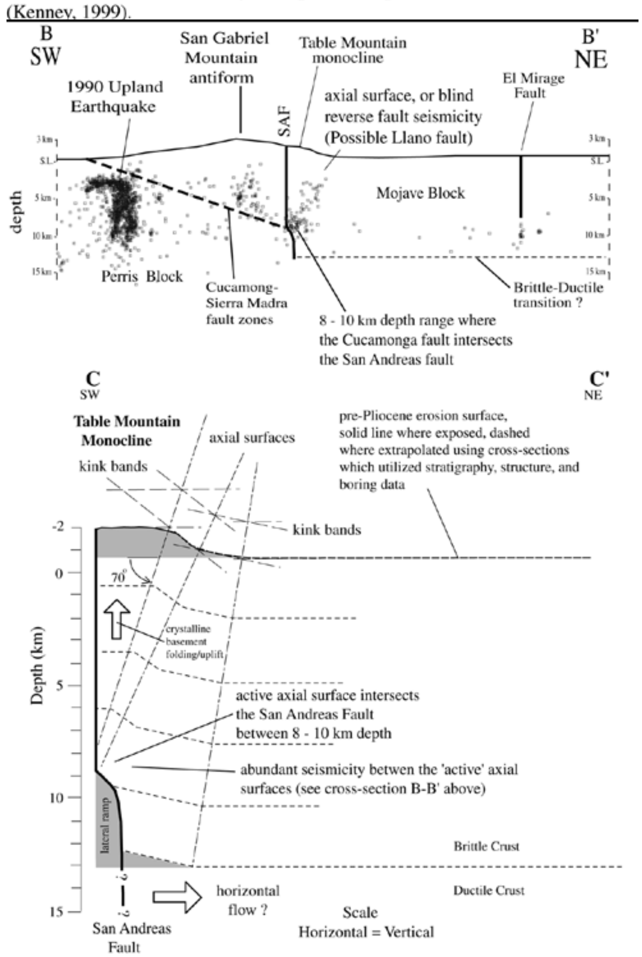


Figure 3

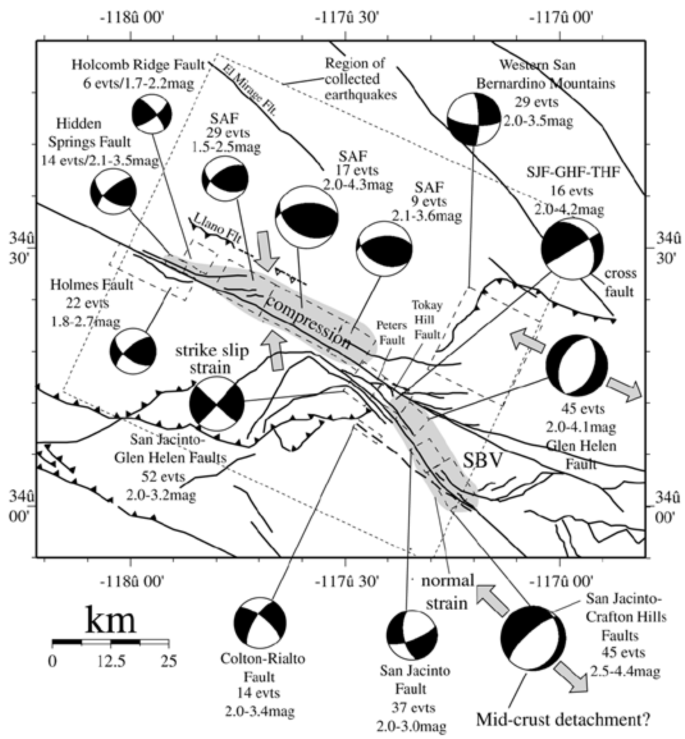


Figure 4. Focal mechanism analogues of summed moment tensors (composite moment mechanisms) near the intersection of the San Andreas and San Jacinto Faults. The number of earthquakes and the range of moment magnitudes are indicated. The region of collected earthquakes for each focal ball is within the dashed boxes. The compressional P-axis resides in the black regions, and the extensional T-axis, occur in the white areas.

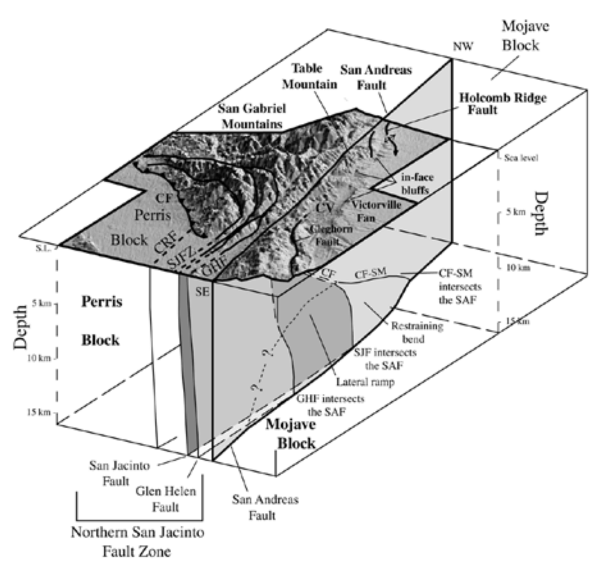
across the Cucamonga-Sierra Madre fault zone. However, in the “high peaks” area, an additional component of uplift has occurred as these rocks move through the 20 to 25 degree convergence restraining bend between the San Jacinto and San Andreas faults juncture. The deformation has resulted in the development of an antiform in the “high peaks” region with a fold axis that is parallel to the strike of the San Jacinto and San Andreas faults (Figure 6). Uplift of the anticline occurs as the rocks of the San Gabriel Mountains pass through the restraining bend at a rate equal to the slip rate of the San Jacinto fault in the San Gabriel Mountains. This slip rate is likely in the range of 5-9 mm/yr (inset diagram of Figure 6). The antiform has developed by a combination of basement rock folding and motion across a series of ‘antiformal schuppen like’ faults. The northwest-plunging antiform developed in the Vincent Thrust and underlying Pelona Schist provides additional evidence for the antiformal structure. This antiform is exposed between Mt Baden-Powell and Mt. San Antonio which strikes parallel to the San Andreas fault (Ehlig, 1975); Ehlig, 1981). Data from the LARSE seismic reflection experiment indicates that the southern limb of the Vincent Thrust dips 35 degrees toward the southwest from the fold axis, and gradually flattens to ~6 degrees along a 15 km concave-upward path toward the southwest (see Fuis et al., 1998;) Lutter et al., 1999; Ryberg et al., 1997). The diffuse seismicity shown in cross-section

Figure 2 shows approximately 7000 earthquake locations re-located from the SCEC data base utilizing a damped least squares inversion method (see Kenney, 1999). The locations of the hypocenter cross-section B-B’ and the balanced cross-section C-C’ (Figure 3) are indicated. Cross-section B-B’ shows a concentration of earthquakes at a depth of 8 to 10 km on the north side of the San Andreas fault. A steeply southwestward dipping zone of earthquakes in cross-section B-B’ under Table Mountain either represents active axial plane deformation (see cross-section C-C’), or possibly earthquakes on the Llano fault, which may be a “blind” reverse fault in this area. Additionally, summed moment tensors of focal mechanisms (Figure 4) for this region demonstrates a southwestward dipping, right-lateral reverse fault nodal plane, which is consistent with an interpretation, that this seismicity is associated with the Llano fault. Figure 5 shows an oblique cross-sectional interpretation of the upper crust in the region of Table Mountain.

The San Gabriel Mountain antiform (anticline)

Quaternary uplift of the San Gabriel Mountains southwest of the San Andreas and San Jacinto faults is the result of block uplift across the Cucamonga-Sierra Madre fault zone, and basement rock folding and faulting at the restraining bend where the San Jacinto and San Andreas faults meet. It is likely that most of the elevation associated with the San Gabriel Mountains is associated with block uplift

Figure 5. Oblique view toward the northwest of the San Gabriel Mountains, western San Bernardino Mountains, and western Mojave Desert. The figure shows the depth structure of the northern San Jacinto Fault Zone as it merges with the San Andreas Fault in the eastern San Gabriel Mountains. The subsurface restraining bend occurs where the Cucamonga-Sierra Madre (CF-SM, thrusts) Fault Zone intersects the San Andreas Fault, and the lateral ramp is located where the San Jacinto Fault Zone intersects the San Andreas Fault. CF-Cucamonga Fault; CRF-Coltan Rialto Fault; CV-Cajon Valley, GHF-Glen Helen Fault; SAF-San Andreas Fault; SJF-San Jacinto Fault.



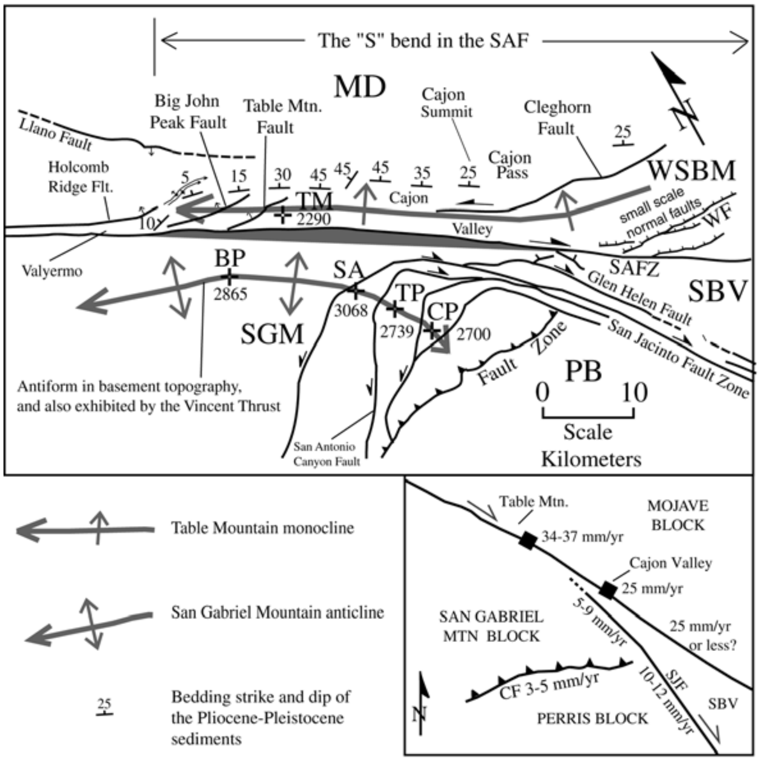


Figure 6. Map showing the locations of the San Andreas, Cucamonga, and northern San Jacinto Faults, and their associated smaller scale secondary faults, the San Gabriel Mountain antiform, and the Table Mountain monocline. The San Gabriel Mountain anticline transects the high peaks of Baden-Powell (BP), San Antonio (SA), Telegraph Peak (TP), and Cucamonga Peak (CP, elevations in meters above sea level). The antiform is also expressed in the deformed late Cretaceous to early Cenozoic Vincent Thrust exposed near peaks BP and SA (not shown). The highest exposed peak on the Table Mountain monocline is also shown, which is Table Mountain (TM). CF-Cucamonga Fault; MD- Mojave Desert; PB-Perris Block; SAF-San Andreas Fault; SJF-San Jacinto Fault; SBV-San Bernardino Valley; SGM-San Gabriel Mountains; WF-Waterman Fault; WSBM-western San Bernardino Mountains. See text for discussion.

B-B' (Figure 7) below the axis of the San Gabriel Mountain antiform suggests penetrative deformation associated with folding is occurring within the axis of the fold. The surface exposure of the Cucamonga thrust has a curvature suggesting that it too may be slightly folded.

RETRACE down Table Mountain Road to Highway 2.

34.5 (1.3) Stop at Highway 2. TURN "sharp" RIGHT onto Highway 2 and get on the Big Pines Highway (N4). Follow green sign for Palmdale/Jackson Lake. We will be driving along the rift zone of the San Andreas fault, and road-cuts will expose fault gouge and fractures. The purplish-gray, pulverized rock is Pelona Schist, restricted to the San Gabriel Mountains on the south side of the fault or caught as slices, or shutters, within the rift zone. Erosion and northward transport of the friable schist debris have deposited distinctive, sequential fanglomerates in the Mojave Desert as the source moves westward through time.

35.1 (0.6) Gray Pelona Schist outcrop. Pass a right turn to Mescal Creek

37.3 (2.1) **STOP 3-3.** Jackson Lake (sag pond). The rift zone features grabens (down-dropped block/slices) which, when filled with water, are called "sag ponds." Studies at the Lost Lake sag pond near Blue Cut in Cajon Pass (Weldon, 1987) show that the average slip rate for the San Andreas fault has been 2.45 cm (1 inch)/year for thousands of years.

37.7 (0.4) Pass Ball Road.

38.2 (0.5) Pass right turn to the Rollin N. Ranch

41.0 (2.8) Pass Mile High and the turn for Largo Vista Road.

41.2 (0.2) Pass Caldwell Lake. Views ahead (west-northwest) show a wide rift zone south of Holcomb Ridge filled with Pleistocene and Holocene alluvium, ideal for ranching and agriculture.

46.5 (5.3) BEAR RIGHT at the left turn for Holcomb Creek.

46.8 (0.3) Slow, TURN RIGHT onto the paved road before reaching the bridge over Big Rock Creek. This is Bob's Gap Road, which is unsigned.

48.0 (1.2) Bend east, passing over a low rise of the Pleistocene Harold Formation, which has produced fossils considered to be middle to early Irvingtonian (Reynolds, 1989, 1991).

48.5 (0.5) Pass Panorama Road.

50.5 (2.0) PARK on right side of the road near remains of lime kilns. Holcomb Ridge consists of Mesozoic quartzmonzonite that intruded and metamorphosed Paleozoic limestone (Bortugno and Spittler, 1986). The latter was apparently mined on Holcomb Ridge and slaked at these structures.

STOP 3-4. Holcomb Ridge Reverse Fault

- The Holcomb Ridge fault
- Anticedent Bob's Gap
- Big Rock Creek—Source of the Shoemaker Gravels.
- Look southeast toward the "nose" of the Table Mountain monocline

The Holcomb Ridge fault is exposed within the road-cut west across the road from where you have parked. Motion across the fault has folded early and late Quaternary age sediments. This fault deforms a latest Pleistocene to Holocene alluvial unit (Qoa-c, see map in pocket) approximately 2.5 miles to the east. Harold Formation (Qh) is exposed in the hanging wall rocks less than a mile to the east where it is deposited on crystalline basement. Bob's Gap is an antecedent stream that has eroded into the hanging wall rocks on the Holcomb Ridge fault as it was uplifted.

Near the intersection of Big Pines Highway and Bob's Gap road is the outlet of Big Rock Creek running north from the San Gabriel Mountains. This is the source stream for the clastic material for the mid-Pleistocene Shoemaker Gravels

Photo 3-1, Stop 3-4. View north of a lime kiln built with blocks of angular local rock.

(Qs) which are exposed near the top of the “Inface Bluffs” in Cajon Valley. Thus, it could be said that the Shoemaker Gravels are still forming in the Valyermo area.

Return to vehicles. PROCEED NORTH on Bob’s Gap Road. past Fort Tejon Road. Head north on165th Street. Stop at the signal at Highway 138 (Pearblossom Highway). This portion of Antelope Valley was used for Cattle ranching in the 1860s. The Southern Pacific Railroad completed its San Francisco and New Orleans Line through the region in 1876, and by the early 1880s government patents were being issued for land in the region (Norwood, 1993). The mid-1890s brought a severe drought that resulted in the area being abandoned for approximately a decade (Norwood,1993; Earl, 2001). Homestead grants were issued in 1916, and by 1921 it was noted that “water is obtainable at several ranches [near the Valyermo post office] 3 or 4 miles southwest of Llano” (Thompson 1921).

54.9 (4.4) Cross Highway 138, heading north.

55.2 (0.3) TURN RIGHT (east) on powerline road.

58.3 (3.1) PARK on the escarpment of the Llano reverse fault.

STOP 3-5. The Llano Reverse Fault

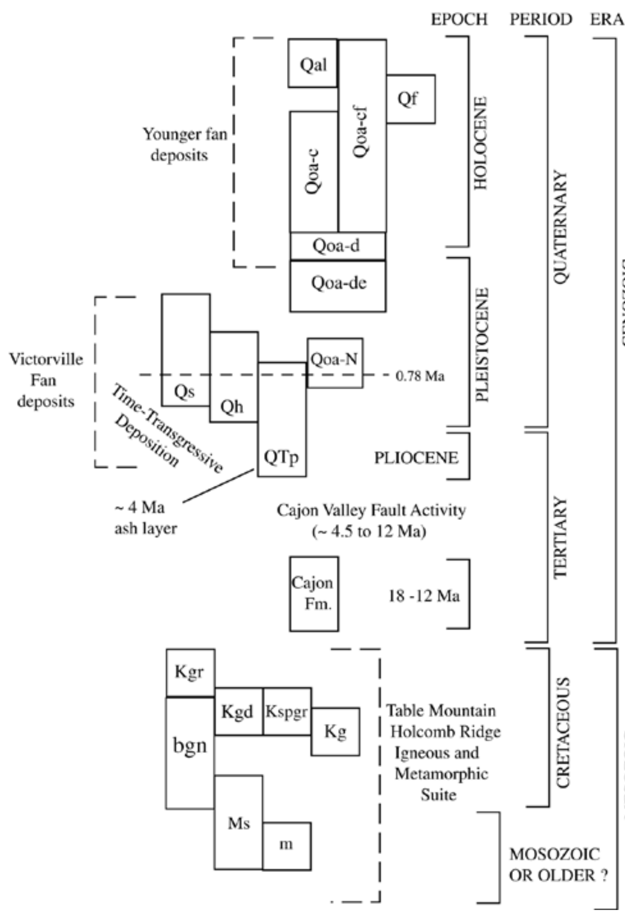
The Holocene Llano fault—a reverse fault that may extend southeastward along the north flank of Table Mountain as a “blind” reverse fault.

We are standing on a scarp associated with the Llano fault, which was named by Paul Guptil and his co-workers at Woodward-Clyde Consultants in 1978 who investigated the fault for the first time (Guptil, 1978). In their study, they identified surface folding and minor faulting that they evaluated as being associated with a buried (blind), southward dipping reverse fault. Seismicity evidence suggests that the Llano fault may extend southeastward along the northern flank of the Table Mountain monocline toward Table Mountain proper. The zone of seismicity north of the San Andreas fault in cross-section C-C’ (Figure 6) dips towards the southwest and may be associated with the Llano fault. Additionally, The summed moment tensors shown in Figure 7 in the Table Mountain region and southeast of the Llano fault also exhibit right-lateral, southwestward dipping reverse fault nodal planes. Return to vehicles, PROCEED EAST.

59.4 (1.1) Stop at Largo Vista Road. TURN RIGHT (south) toward Highway 138.

59.9 (0.5) Stop at Highway 138. Watch for cross-traffic and proceed across Highway 138, and CONTINUE SOUTH on

Figure 7. Correlation of lithologic units in the Holcomb Ridge-Table Mountian to Cajon Valley region.



Largo Vista.

63.8 (3.9) TURN LEFT(east) on a dirt road.

64.3 (0.5) PARK.

STOP 3-6 LARGO VISTA. View southeast of Plio-Pleistocene sediments tilted on the northern flank of the Table Mountain monocline. Figure 6 shows the Table Mountain monocline, dips of the Victorville fan deposits, the northward deflection of the San Andreas fault near Table Mountain, and the San Gabriel Mountain antiform. The Table Mountain, Big John Peak, and Holcomb Ridge faults represent a time-transgressive series of east-west striking reverse faults active during the past 200,000 years. The Table Mountain fault (and another in Puzzle Canyon) does not offset an older alluvial unit that is likely between 50,000 to 200,000 yeas old (Qoa-de; see map for the Cajon Valley fault, this volume), however, it does offset the lower section of the Phelan Peak Formation. The Big John Peak fault offsets the entire Pliocene-Pleistocene section (TQp, Qh, Qs) and slightly deforms the older alluvial unit and upper surface of unit Qoa-de. The Holcomb Ridge fault deforms a latest Pleistocene to Holocene Alluvial unit (Qoa-c). Thus, activity on these reverse faults has migrated toward the northwest from Table Mountain to Valyermo during the past 2 to 3 hundred thousand years. They are probably the consequence of the northwestward migration of the "nose" of the "S" bend in the San Andreas fault (Weldon, 1984), and/or compression associated with the subsurface restraining bend in the San Andreas fault. Activity on the southwest dipping Llano reverse fault is likely due to compression associated with the subsurface restraining bend as well. Return to vehicles, RETRACE northward to Highway. 138.

64.8 (0.5) TURN RIGHT (north) onto Largo Vista Road.

68.7 (3.9) Stop at Highway 138. Watch for cross-traffic. TURN RIGHT (eastward) on Highway 138, and proceed toward Pinon Hills.

70.1 (1.4) At Pearblossom Road, bear southeast on Highway 138.

71.0 (0.9) Cross the California Aqueduct.

75.6 (4.6) San Bernardino County line.

78.5 (2.9) Stop at the four-way signal at the intersection of Green and Phelan roads. Continue on Highway 138.

79.1 (0.6) Cross the Sheep Creek fan and concrete channel. Notice the gray color of gravels due to abundant Pelona schist. Like the west-moving outwash of Shoemaker Gravels (Stop 3-4, above), earlier Sheep Creek debris flows to the east show that their source at Wrightwood is traveling westerly on the south side of the San Andreas fault.

80.5 (1.4) Stop signal at Beekley Road.

82.2 (1.7) Mountain Top Junction, the intersection of Highways 2 and 138. Prepare to turn right.

82.4 (0.2) TURN RIGHT and drive up a dirt road.

82.6 (0.2) PARK at a small clearing 0.2 mile south on the dirt road.

STOP 3-7. View of Cajon Valley

- Deposition of the Victorville Fan deposits (Qoa-N, Qs, Qh, TQp)
- Quaternary uplift and erosion of Cajon Valley to Table Mountain.
- History of the Cajon Valley fault

Note: Much of what is presented here for today's stops is from Kenney, M., 1999.

From this spot we can view Cajon Valley and the western San Bernardino Mountains towards the southeast. Rapid late Quaternary erosional in Cajon Valley has exposed a cross-section of the Victorville Fan deposits along the eastern rim of the valley. Exposed at the base of the cliff below where you are standing is the orange brown, silty, lower member of the Pliocene-early Quaternary Phelan Peak Formation. This lower member of the Phelan Peak formation contains an ash layer dated at ~4 Ma. This ash layer has been identified within the lower member of the Phelan Peak formation in the Table Mountain region toward the northwest in numerous localities.

This region has experienced considerable terrestrial deposition during the late Tertiary to middle Quaternary. The Cajon Formation, which is exposed throughout much of the valley floor is estimated to have been deposited between 18 to 12.8 Ma (Liu, 1988; Reynolds, 1985; Woodburne and

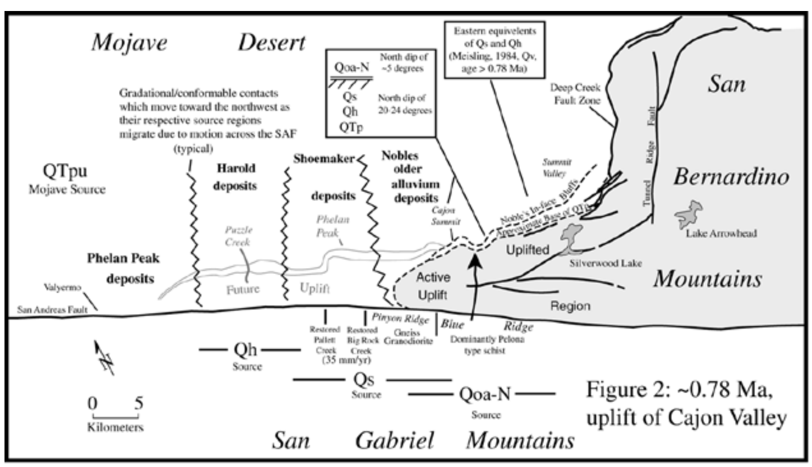


Figure 8. Paleoreconstruction of the western Mojave Desert, San Bernardino Mountains, and northeastern San Gabriel Mountains at 0.78 Ma. This scene is primarily based on radioisotopic and magnetostratigraphic data for the Pliocene to Pleistocene sediments, which indicate that the Phelan Peak Formation, Harold Formation, Shoemaker Gravel, and the older alluvium of Noble were all accumulating simultaneously at the time of the Bruhnes-Matuyama polarity reversal, 0.78 Ma (Weldon 1986; Weldon et al., 1993). An angular unconformity between the older alluvium of Noble, and the Shoemaker Gravel at Cajon Summit indicates that uplift and northward tilting had already occurred in this region.

Photo 3-2, Stop 3-7. View east-southeast of Cajon Valley. At the bottom of the photography, the red-brown paleosols are Unit 1 of the Phelan Peak formation, which contains an ash dated elsewhere at 4 Ma. This stratigraphic horizon marks the turning point of deposition flowing southwest from the Mojave Desert. The upper two units of the Phelan Peak formation and the Victorville Fan sequence record the local uplift of the Transverse Range with diagnostic San Gabriel Mountains lithologies that were shed northward into the Mojave Desert.

Golz, 1972; Reynolds written communication). Overlying the Cajon Formation in unconformity is the lacustrine lower member of the Phelan Peak Formation. Structurally above the Phelan Peak Formation (TQp), are a series of fan deposits that are collectively called the Victorville Fan. These include from oldest to youngest, the Harold Formation (Qh), Shoemaker Gravels (Qs), and the Nobel's Older Alluvium (Qoa-N). A correlation of the various units is provided in Figure 7. Unit Qoa-N started deposition approximately 780,000 years ago in the area of Cajon Valley (Weldon, 1986; Weldon et al., 1993); Figure 8).

Figure 8 shows that the source material for units Qh, Qs, and Qoa-N were from erosion of the eastern San Gabriel Mountains west of the San Andreas fault. Units Qh and Qs extend from southeastern Cajon Valley northwestward past Valyermo and both received clast material from individual areas within the eastern San Gabriel Mountains. Units Qoa-N, Qh,, Qs, and the upper two-thirds of unit TQp, were deposited time-transgressively on the north side of the San Andreas fault as their individual source areas migrated toward the northwest due to motion across the San Andreas fault during the late Quaternary. For example, at any given time, unit Qh was deposited just to the northwest of unit Qs, which was depositing concurrently as well with unit Qoa-N to the southeast.

Soon after unit Qoa-N was deposited, the region of Cajon Valley was uplifted and tilted toward the east, which produced the Table Mountain monocline. Much of the eroded material was transported down into San Bernardino Valley and Cajon Valley developed relatively quickly. The uplift in Cajon Valley around 500,000 to 700,000 years ago migrated toward the northwest at a rate close to the motion across the San Andreas fault (Weldon et al., 1993). Thus, the general geologic history of the Victorville fan at any one place between Cajon Valley and Valyermo involved deposition of units TQp, Qh, then Qs, in localized areas unit Qoa-N, then rapid uplift in a relatively narrow zone along the north side of the San Andreas fault. Today, uplift is taking place between Holcomb Ridge (Valyermo) and Jesus Creek (Figure 9). Evidence for this is provided by the older alluvium unit Qoa-de, which was likely deposited sometime between 50,000 and 200,000 years ago. The geomorphic surface of unit Qoa-de is tilted toward the northeast and dissected northwest of Jesus Creek, however, the same geomorphic surface is not deformed and extends to the mountain front southeast of Jesus Creek. Cross-section A - A' shown on Figure 9, is provided as Figure 10.

The Cajon Valley fault

The Cajon Valley fault accommodated ~27 km of right-lateral motion between approximately 4 to 10 Ma. For more information on the Cajon Valley fault (Kenney and Weldon, this volume).

Day 3 of the trip has passed through granitic and metamorphic rocks of the western San Bernardino Mountains and the eastern San Gabriel Mountains. These crystalline rocks are overlain by late Cretaceous marine sediments of the San Franscisquito Formation and the marine, late Oligocene Vaqueros Formation. Continental sandstones were subsequentially deposited, including the Miocene Cajon Valley Beds and the Crowder Formation, the Plio-Pleistocene Phelan Peak Formation, and the overlying Pleistocene Victorville Fan sequence. During the late Tertiary, debris were shed southwestward across the elevated Mojave Desert. An important change occurred in this drainage regime less than four million years ago. Lacustrine silts of the middle

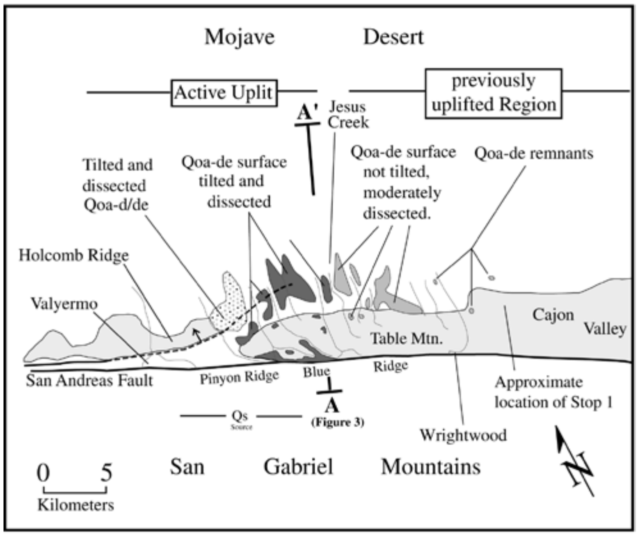


Figure 9. Generalized geologic map of Table Mountain in the northeastern San Gabriel Mountains showing deformed older alluvium surface. This figure shows the exposures, and geomorphology of the Qoa-de terrace deposit. The geomorphic surface of this unit is tilted toward the northeast and dissected northwest of Jesus Creek, however, the same geomorphic surface is not deformed and extends to the mountain front southeast of Jesus Creek. The Qoa-de unit is between 50 to 200,000 years old, and thus indicates the region currently deforming as a consequence of the subsurface restraining bend. In addition, it indicates that the subsurface restraining bend exists under the region between Valyermo and Jesus Creek.

member of the Phelan Peak Formation suggest slowing of the through-going drainage, and the upper member of the Phelan Peak Formation contains imbricated clasts indicating flow directions to the northeast with distinctive lithologies from San Gabriel sources to the southwest. This drainage reversal marks the local uplift of the Transverse Ranges, which reached their maximum height less than half a million years ago. A similar, slightly younger record of uplift for the eastern San Bernardino Mountains is recorded in the Old Woman Sandstone in southern Lucerne Valley.

As right-lateral strike slip movement continued on the San Andreas fault, the upper unit of the Phelan Peak and the Victorville fan sequence (Harold Formation, Shoemaker gravels, Nobles old alluvium) were deposited time-transgressively northward as their individual source areas in the San Gabriels to the south migrated toward the northwest during the late Quaternary. At any given time, Qh was deposited to the northwest of Qs, which was depositing concurrently with unit Qoa-N to the southeast. These sedimentary units are spectacularly exposed below us in the Cajon Valley “Inface Bluffs” that were carved by headward erosion along the San Andreas fault.

RETRACE to Highway 138.

82.8 (0.2) Stop at Highway 138. Watch for cross-traffic. Turn eastward on Highway 138, and proceed toward I-15.

91.9 (9.1) Slow for the intersection of Highway 138 with Interstate 15. Take I-15 northbound to Barstow/Palmdale, or I-15 southbound to San Bernardino/Los Angeles.

End of Day 3

Over the last three days, we have looked at faults and scarps that have occurred in southern California for the past 20 million years. The 1992 M = 7.4 Landers quake produced 20 feet of right-lateral offset (through foundations) and up to six feet of vertical offset (some in front yards). Shaking was felt from Los Angeles to Las Vegas. Only one death occurred, but the fatalities would have been higher if the event occurred in an urban area.

BE PREPARED. Gather earthquake supplies, but do not

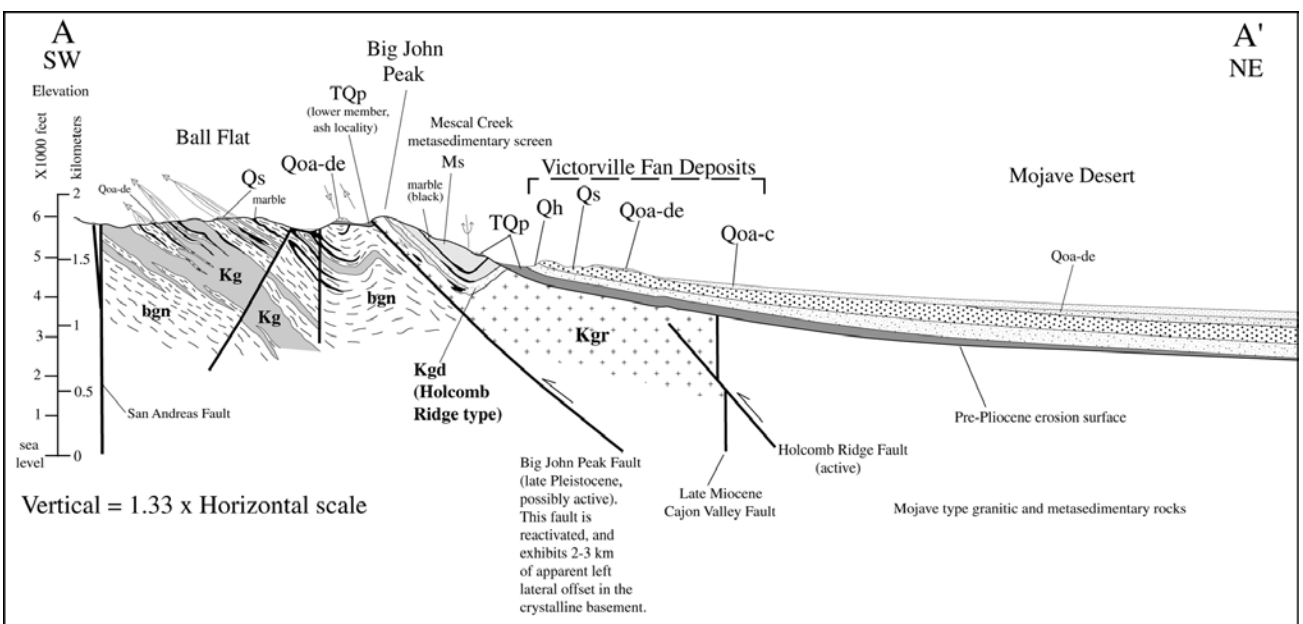


Figure 10. Cross-section of Table Mountain near Mescal Creek, northeastern San Gabriel Mountains

store them in your house, since it may collapse. Store food, propane, water, blankets, and clothing in an outbuilding or garage. Your camping gear (bag, blanket, stove and fuel, water, and canned food) are excellent supplies. Keep them readily available. Sturdy shoes and emergency supplies also belong in the trunk of your car.

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Latest Pleistocene (Rancholabrean) fossil assemblage from the Silver Lake Climbing Dune site, northeastern Mojave Desert, California

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Abstract

The Silver Lake Climbing Dune Local Fauna, with diverse small vertebrates including fish, has been recovered from aeolian sediments at the southeast end of Dolomite Mountain, one-quarter mile west of the western margin of Silver Lake in the northeastern Mojave Desert, San Bernardino County, California during construction of the Kern River 2003 Expansion Project. The presence of aeolian sand containing the remains of tui chub (*Gila bicolor*) suggest deposition after Lake Manix had drained but when fish populations were still viable in a through-flowing Mojave River ponded at Silver Lake, perhaps between post 18,000 years ago.

The fossil assemblage contains one fish, one frog or toad, eleven reptiles, birds, two rabbits, thirteen rodents, and one deer. *Gila bicolor* requires permanent water. Several of the terrestrial mammals live today at higher elevations in Nevada, and to the west, in California. The vertebrates represent a mixture of xeric and mesic adapted animals. The fauna of the Climbing Dune site is compared and contrasted with the Silver Lake Outlet sites and late Pleistocene–Holocene habitats and taxonomic ranges. Five species from the Climbing Dune site—garter snake, Mojave ground squirrel, Ord kangaroo rat, California mouse, and deer— are extra-local, existing today only in areas with chaparral and juniper scrub. Three taxa—Panamint kangaroo rat, pocket gopher, and frog or toad— may be ecologically incompatible with the arid creosote–salt brush flats of today.

Introduction

Widely scattered Pleistocene sediments are common over much of the California deserts (Hewett, 1954). Climate and weather extremes during the Wisconsinan glaciation along with tectonism have produced a complex Quaternary depositional history. Many dissected exposures in the Mojave Desert have yielded fossil assemblages that collectively provide insights into changing climatic conditions, taxonomic range fluctuations, and drainage systems during the last 20,000 years (Jefferson, 1989; Reynolds, 1989).

Silver and Soda lakes, along the Mojave River in the northeastern Mojave Desert, have long been an area of paleontologic and archaeologic interest (Orr and Warren, 1971; Warren and Schneider, 2003; Wells and Reynolds, 1990; Reynolds and Reynolds, 1991a). The Pleistocene Mojave River has a history of filling and draining Lake Manix, and subsequently filling Silver and Soda Lakes (Jefferson, 1985; Meek, 2000, this vol.; Wells and others, 1990; Brown and others, 1990). The paleontological history of lakes along the Mojave River (Jefferson, 1987; Reynolds and Reynolds, 1991a; Wells and Reynolds, 1990) prompted thorough evaluations during construction of the Kern River Gas Transmission Company's (Kern River's) original pipeline system in San Bernardino County in 1991 (Reynolds, 1991). Construction of an additional 36-inch diameter pipeline loop in 2002 and 2003 by Kern River Pipeline (Ecology and Environment, 2003) resulted in additional collection of buried dune sand containing small vertebrate fossils through implementation of a Paleontological Resource Mitigation Plan for the Kern River 2003 Expansion Project.

Methods

Large and small vertebrate fossils and Pleistocene mollusks were located on the north shore of Silver Lake near its outlet during the original excavation for the Kern River Pipeline (Dames and Moore, 1992). Environmental conditions during construction of the Kern River 2003 Expansion Project required monitoring of trench excavation in sediments where significant, nonrenewable vertebrate fossils were anticipated. This requirement applied to a two mile section of right-of-way at the north end of Silver Lake. Invertebrate fossils were found sporadically below the shoreline of Silver Lake, and within a seven meter segment of the pipeline that passed through the dune. With assistance from Kern River environmental inspectors and contractor equipment operators, paleontologists from LSA Associates, Inc. (LSA) removed three feet of overburden from fossiliferous dune sands near Silver Lake and collected two samples, one on initial discovery and the other during trench backfill. The volume of sand was reduced in the field by dry screening through one-eighth mesh and twenty mesh screen. Vertebrate fossils were removed in the LSA lab. The Climbing Dune site was backfilled and restored, including contour and slope restoration in accordance with Kern River's reclamation plans.

Fossil specimens were compared with modern osteological collections at the LSA lab, the Riverside Municipal Museum, the University of Arizona Laboratory of Paleontology (Czaplewski, p. c. 2004; Lindsay, p. c. 2004) , the George C. Page Museum of Rancho La Brea Discoveries, and with osteological literature. The specimens are curated into the Riverside Municipal Museum repository.

Geologic setting

Silver Lake is located north of Soda Lake along the Mojave River where it flows northward through the Soda–Avawatz Fault Zone. The late Pleistocene (Rancholabrean LMA, Jefferson, 1991) flow of the Mojave River terminated at

Table 1. Occurrence and Geographic Range of Taxa from Silver Lake Climbing Dune

Taxa	Common name	Climbing Dune	Outlet Sites	Wedlands	Contempory	Questionable habitat	Extra-local
Gastropods	snails		•	•			
Pelecypods	bivalves		•	•			
Ostracodes	ostracodes		•	•			
Gila bicolor	tui chub	•	•	•			
Anura	frog and/or toad	•		•		•	
Sauromalus? sp	chuckwalla	•			•		
Sceloporus sp.	spiny lizard	•			•		
Dipsosaurus dorsalis	desert iguana	•			•		
Uta stansburiana	side-blotched lizard	•			•		
Phrynosoma sp.	horned lizard	•			•		
Crotophytus? sp.	collared lizard	•			•		
Cnemidophorus tigris	whiptail	•			•		
Thamnophis sp.	garter snake	•		•			W, N-E
Pituophis sp.	gopher snake	•			•		
Masticophis sp.	coachwhip snake		•		•		
Crotalus sp.	rattlesnake	•	•		•		
C. cerastes?	sidewinder	•			•		
Fringillidae	small birds	•			•		
Sylvilagus sp.	cottontail	•	•		•		
Lepus sp.	jack rabbit	•	•		•		
Spermophilus sp.	squirrel	•			•		
S. (sm) nr. *tereticaudus*	round-tailed ground squirrel	•			•		
cf. *Spermophilus mojavensis*	Mojave ground squirrel	•					W
Perognathus sp. (lg)	pocket mouse		•				
Perognathus sp. (sm)	pocket mouse		•		•		
Perognathus sp. (sm) nr. *longimembris*	little pocket mouse	•			•		
Dipodomys sp. (sm)	kangaroo rat	•	•		•		
Dipodomys sp. nr. *panamintinus*	Panamint kangaroo rat	•				•	
Dipodomys sp. cf. *ordii*	Ord kangaroo rat	•					N-E
Dipodomys sp. cf. *merriami*	Merriam kangaroo rat	•	•		•		
Dipodomys sp. cf. *deserti*	desert kangaroo rat	•			•		
Thomomys sp. cf. *bottae*	Botta pocket gopher	•	•	•?		•	
Peromyscus sp. (lg)	deer mouse	•					
Peromyscus sp. (lg) nr. *californicus*	California mouse	•					W
Peromyscus sp. (sm) nr. *maniculatus*	deer mouse	•			•		
Neotoma sp.	wood rat	•					
Microtus sp	meadow mouse (vole)		•	•			W, N-E
Odocoileus sp.	deer	•	?			•	W/E

Lake Manix (Meek, 1987). Lake Manix sills were breached at the Wisconsin glacial maximum, post 18 ka (Jefferson, 1985; Meek, 2000). This breach ran through Soda Lake and filled Silver Lake. Silver Lake backed up into Soda Lake, creating Lake Mojave in latest Rancholabrean time (Meek, this volume; Wells, and others, 1990; Warren and Schneider, 2003). Soda Lake also receives water from Kelso Wash, which drains the north side of the New York Mountains.

The north end of Silver Lake is surrounded by hills of quartz diorite and gabbro (Dolomite Mountain of Grose, 1959) and Proterozoic? dolomite and limestone. Coarse fanglomerates and braided stream deposits of middle Pleistocene to Holocene time fill the valleys between these crystalline outcrops. Silver Lake recorded a sequence of latest Pleistocene sediments and shoreline features in the last 15,000 (Wells and others, 1984, 1985; Orr and Warren, 1971) since it began receiving major flow from the Mojave River.

This part of the Mojave Desert receives strong winds, predominantly from a westerly direction (Laity, 2000; Lancaster, 1995). When Lake Manix drained, sand from the shoreline, beach bars and from the broad Mojave River delta became available for aeolian transport (Lancaster, 1995). Linear sand alignments in the western Cady Mountains, climbing dunes like those at Red Pass, falling dunes on Cat Mountain, and dune complexes like those at Kelso are all the result of windblown dry sand from Lake Manix and the Mojave River bed (Lancaster,1995). A reduction in dune building as a result of lack of sand replenishment is suggested after 9,700 years (Lancaster, 1995).

Aeolian features

The north shore of Silver Lake exhibits lake shore features such as shoreline benches, beach bars (Wells and others,1984), *Anodonta* valve accumulations, and tufa-coated cobbles (Orr and Warren,1971; Warren and Schneider,2003). The ridges of Dolomite Mountain show scour and flutes from strong westerly winds. These winds have also laid blankets of dune sands that climb up ridges and interfinger with coarse fanglomerates, and have carried sand over ridges, where arenaceous aeolian deposits fill hollows and gullies of those ridges. Climbing and falling dunes on slopes of crystalline ridges interfinger with gravels from those sources. The alternating coarse–fine sequence may reflect cycles of heavy rain followed by strong, dry winds.

Paleontology

The Kern River pipeline construction project (Dames and Moore, 1992) recovered vertebrate fossils from the outlet at the northern end of Silver Lake. A composite faunal list from is given in Table 1, where Outlet sites are compared to the faunal list from the Silver Lake Climbing Dune. Taxa have been referred to extant species, indicating whether the taxa are currently extralimital and if habitat might preclude them from being present in the Holocene.

Mollusks. No mollusks were recovered from the Climbing Dune site, although aquatic and terrestrial gastropods, pelecypods, and ostracodes were recovered from the Silver Lake Outlet sites (Dames and Moore, 1992).

Fish (Osteichthyes). *Gila bicolor* (tui chub) is a small fish known to occur in sediments of Pleistocene Silver Lake. The Climbing Dune site containing the fish is west of Silver Lake, in a direction opposite of prevailing winds, suggesting that it was transported westward by predators.

Frog and Toad (Anura). Frog or toad remains were recovered from the Climbing Dune site. The area is not within the current range of the spadefoot toad (*Scaphiopus* sp.) or any frogs (Stebbins, 1966). The range for the red-spotted toad, *Bufo punctatus*, covers the area, but the described habitat, "desert oases....and floodplains of rivers," (Stebbins, 1966) suggests that it requires water when active.

Lizards (Iguanidae and Teiidae). The iguanid lizards and the whiptail are known from the area today, and from cave deposits on Kokoweef Peak (Goodwin and Reynolds, 1989; Reynolds and others, 1991c) 35 miles east.

Snakes (Serpentes). Colubrids (whipsnake and gopher snake) and crotalids (rattlesnakes and sidewinder) are known from the area. The garter snake, *Thamnophis* sp., frequents meadows and streams. It is not known from the eastern Mojave Desert today and suitable Holocene habitat is questionable in the area (Stebbins, 1966).

Birds (Fringillidae). Small birds such as finches are common in the area today.

Rabbits (Lagomorpha). Jackrabbits and cottontail rabbits are currently found in the area.

Squirrels (Sciuridae). Size and morphology separate specimens of round-tailed ground squirrel (*S. tereticaudus)* from specimens that compare with the Mojave ground squirrel (*Spermophilus mojavensis*). Both are found in the fossil record at the Climbing Dune site. The round-tailed ground squirrel is present in the area today; the Mojave ground squirrel is restricted to the western Mojave Desert (Ingels, 1965).

Pocket Mice (Heteromyidae). Pocket mice are found in the Pleistocene deposits of Silver Lake, and range through the area today.

Kangaroo Rats (Dipodomyiidae). Merriam's kangaroo rat (*Dipodomys merriami*,) and the desert kangaroo rat (*Dipodomys deserti*) currently inhabit the area (Ingels, 1965). Silver Lake is not within the Holocene habitat for the Panamint kangaroo rat (*Dipodomys panamintinus*). The identification of the Ord kangaroo rat *(Dipodomys* sp. cf. *ordii*) is based on the distinctive morphology of the deciduous lower premolar (Fig. 2, Wood, 1935). The current range of the Ord kangaroo rat *(Dipodomys ordii*) is in northwestern Nevada and Oregon (Hall, 1981).

Gophers (Geomyiidae). The range of the Botta pocket gopher *(Thomomys bottae*) is within the eastern Mojave

Desert (Ingels, 1965). The Holocene habitat is given as "All of California except ...sagebrush area, and parts of the dry deserts." Because of habitat, the Holocene record of the gopher is questioned at Silver Lake; however, the Pleistocene climatic conditions with abundance of wetlands suggests a favorable environment for the species.

Deer Mice (Cricetidae). The deer mice recovered from the Climbing Dune site include the California mouse (*Peromyscus* sp. (lg) nr. *californicus*), and the deer mouse (*Peromyscus* sp. (sm) nr. *maniculatus*). The current range of the deer mouse is throughout the eastern Mojave Desert, but the California mouse is restricted to the western Mojave Desert (Fig. 4; Hall, 1981; Ingels, 1965).

Woodrats (Cricetidae). The desert woodrat (*Neotoma lepida*) currently ranges in the Silver Lake area (Ingels, 1965). The fossil remains do not permit identification to a specific level.

Voles (Microtinae). The meadow mouse (*Microtus californicus*) was not found at the Climbing Dune site, but it was recovered from the Silver Lake Outlet site (Reynolds, 1991). The meadow mouse requires "upland meadows and grassy places"(Ingels, 1965), and its current range is the western Mojave Desert and along the California coast (Fig. 6; Hall, 1981; Ingels, 1965). Its presence at Silver Lake Outlet indicates contemporary perennial water and wetlands east of the Climbing Dune site.

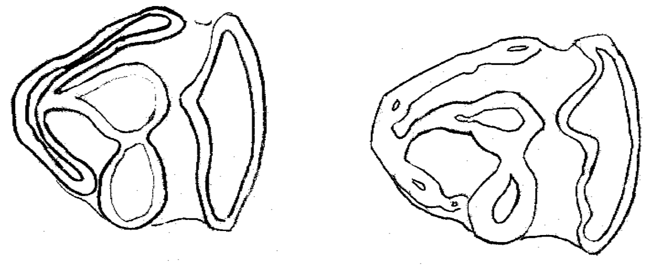
Herbivores (Artiodactyla). The partial femur of a deer (*Odocoileus* sp.) was the first fossil located from the Climbing Dune site. Fragments of a large deer-size artiodactyl were recovered from the Outlet site, and from Pleistocene cave deposits to the east (Reynolds and others, 1991c). Deer are not recorded from the eastern Mojave Desert during the Holocene, but were re-introduced to the Mid Hills in the early 20th century (Johnson and others, 1948).

Habitat and range

The elevation and position of the Outlet sites and the Climbing Dune site differ relative to the present-day and Pleistocene margins of Silver Lake. The former produced a suite of aquatic mollusks, a fish, gopher, and meadow mouse. The Climbing Dune fauna represents an assemblage of xeric reptiles, sciurids, heteromyids and cricetids, fish, and toad or frog.

All taxa found at the Climbing Dune site are extant in the southwestern United States. The vertebrates from the site include 19 taxa that currently occur near the site and six taxa that do not. The California mouse and the Mojave ground squirrel occur today to the west. The Ord kangaroo rat occurs to the northeast. Both deer and garter snake are found in wooded or wet lands outside the area to the west and east. The dry, Holocene habitat would generally be unsuitable for fish, frogs and toads, gophers, Panamint kangaroo rat, and deer.

The Climbing Dune site contains a cosmopolitan fauna of 28 vertebrate taxa. During the Holocene, the ranges of certain taxa were reduced to the west and east, away from the low corridor along the Mojave River into Death Valley. The optimum time for the presence of (1) available sand to form climbing dunes (Lancaster, 1995), (2) the presence of fish and frogs/toads, (3) mesic/wetland dwellers such as deer, gopher, meadow mice and garter snake, and (4) extra-local taxa such as the Mojave ground squirrel, California mouse, and the Ord kangaroo rat would be in latest Pleistocene time after Lake Manix drained (17,000 ybp) and before the end of the Pleistocene (10–9,000 ybp) when climatic extremes had not proscribed habitat and geographic limits to extra-local vertebrate populations.



Dipodomys ordii deciduous lower third molar. Left: from Wood (1935). Right: from Climbing Dune site.

Methods of vertebrate accumulations

The Silver Lake Outlet sites are at or below elevation 930 feet, lower than the 970 foot sill at the north end of Silver Lake. Localities include concentrations of articulated *Anodonta* valves in gray, silty sand. Deposition was lacustrine with local concentrations of fossils due to wave action and current.

The Climbing Dune site is at elevation 950 feet, near the late Pleistocene high shoreline of Silver Lake. The well-sorted, cross-bedded aeolian sands interfinger with gravels shed from the adjacent ridges of crystalline rock. The respective elements (such as vertebra) within the groups of lizards, snakes and rodents all appear to be similar in size. This suggests concentration at the site by small avian predators. The presence of rabbits at the site also suggests presence of a larger raptor that was able to carry prey of greater weight. The prey would subsequently be disarticulated and reworked up and down the slope by wind and water. The fragmentary proximal deer femur suggests the presence of a mammalian carnivore.

The lack of taxa in common between the Outlet sites and the Climbing Dune site is in part due to the lacustrine habitat and current accumulation at the former, and by selective predation at the latter.

Discussion and conclusions

The availability of sand to form aeolian deposits and the presence of aquatic animals (fish, toads, garter snakes) suggest vertebrate accumulation at the Climbing Dune site in latest Pleistocene time, after the breach of Lake Manix at 17,000 ybp. The taxa that require mesic or well-watered, vegetated land suggest that deposition was before the end of the Wisconsinan pluvial period, around 10,000 ybp.

The taxa collected from the site provide a much more

Table 2. Habitat distribution of taxa from Silver Lake Outlet and Climbing Dune

Locality	Taxa	Wetlands	Contemporary	Non-Contemporary	Questionable habitat	Extralocal west	Extralocal north-east
Climbing Dune	28	4n 14%	19 n 68%	9n 32%	5n 18%	4n 14 %	2n 7%
Outlet sites	15	6n 40%	7n 47%	8n 53%	3n 20%	2n 13%	2n 13%

comprehensive picture of the fauna during that period than was previously available. The abundance of taxa suggests that the habitat around Silver Lake was able to support a greater abundance of species of certain genera than are present today. For instance, two species of kangaroo rat, large and small, are recorded in the area today (Ingles, 1965) but the latest Pleistocene Climbing Dune site contains four species. The site also contains taxa that have been extirpated from the area, and are currently found in the western Mojave Desert and to the east in Nevada and Arizona.

The small vertebrates of the Climbing Dune site are extremely diverse, ranking with the Daggett Solid Waste site (Reynolds and Reynolds, 1991b) for faunal diversity along the Mojave River. The only Mojave Desert sites that are more diverse are the caves on Kokoweef Peak (Reynolds and others, 1991c). The large number of species of certain genera (*Dipodomys*, *Peromyscus*, *Spermophilus*) suggests that the diverse local topography contained a very favorable spectrum of habitat niches.

Summary

Excavation monitoring and salvage of fossils produced a new local fauna from the vicinity of Silver Lake in the eastern Mojave Desert. The accumulation of vertebrates and their deposition in the climbing dune differs from previously known faunas at the Silver Lake Outlet sites. When compared to the Outlet sites, the Climbing Dune site exhibits a greater number and diversity of taxa. These taxa provide habitat data and suggest a greater range of certain species in the latest Pleistocene, with contraction of those ranges during climatic extremes of the Holocene.

Acknowledgements

The faunas at Silver Lake Outlet and the Climbing Dune were unknown prior to 1991, when the first Kern River pipeline was constructed through the area. The recovery of new taxa, along with significant new temporal and range data, during the Kern River 2003 expansion exemplifies the important data provided through implementation of an environmentally conscientious construction plan. The specimens and their data would not be available had the pipeline not been constructed.

Special acknowledgments are extended to Kern River for the design and implementation of construction plans that incorporated provisions of the Paleontological Resource Mitigation Plan, for the commitment and support demonstrated by Kern River in implementing this plan, and the cooperation and compliance demonstrated by its contractors. Mr. Dan Beisner, Environmental Inspector, coordinated equipment and recommended safety procedures during the fossil salvage. Pre-construction "paleontological awareness training" by the author resulted in mechanic Steve Hoadly finding the first fossil specimen. LSA crew members Heidi Sellers, Tyler Hare, and Brooks Smith recovered fossiliferous matrix in the field and processed it to remove specimens at the LSA lab in Yermo.

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Harper Dry Lake Marsh: past, present, and future

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History

The Harper Dry Lake Area of Critical Environmental Concern (ACEC) Wetland Creation and Restoration site is five miles north of Highway 58 on Harper Lake Road, and two miles east on Lockhart Road. The site is on the south side of Harper Dry Lake, in San Bernardino County, California. The town of Hinkley lies ten miles to the southeast. The site is in the western Mojave Desert and receives an annual rainfall of approximately 4.5 inches.

This area of Harper Dry Lake has had a high water table historically, and seasonally had additional water supplied by winter rain events that helped to support wetland vegetation. Agriculture began in the region surrounding Harper Dry Lake during the 1930s and 1940s. During the 1960s, 1970s, and 1980s alfalfa farming was a major component of the land use on private lands adjacent to this section of Harper Lake. Runoff from these fields began to supply water to the marsh on a consistent basis, which allowed for the development of extensive marsh vegetation and open water that was utilized by a wide variety of avian and mammalian species. As pumping costs increased, local alfalfa farms went out of business. Seventy years of farming in the area had left the water table depleted, so even natural ponding was less frequent. By the end of the 1990s, runoff from these farms had ceased, and the marsh dried up.

There was not a clear way for the BLM to obtain water to restore the marsh until a mitigation proposal from the LUZ Solar Company and the California Energy Commission materialized in 1999. A formal agreement between the California Energy Commission, Harper Lake Solar Company and LUZ Solar Partners, and approved by the Mojave Water Agency, was completed. This agreement involved Bureau of Land Management (BLM) accepting a wetland maintenance mitigation obligation from a state-permitting requirement for the Harper Lake Solar Company Solar Electric Generating Systems (SERGS) VIII and IX. Specifically, BLM agreed to continue to manage the public lands occurring within the Harper Dry Lake ACEC for wetland values and would install a well and wetland hydration piping system in exchange for the solar company transferring title to the adjudicated annual rights of 75 acre-feet of water in perpetuity and funding ($60,000) to install a well and necessary piping for water delivery to the ACEC.

Work on the well, piping system, ponds, and containment dikes was completed in January of 2003. The construction involved the drilling of a 50ft well, and the installation of two pipes that transfer water from the well to ponds on the eastern and western ends of the marsh area. These ponds were widened and made deeper in order to help provide better open water habitat for waterfowl. Low dikes were also constructed on the lake bed that tied in with previously constructed dikes to contain any overfill water from the ponds themselves. In February of 2003 the pump was turned on, and additional water from a larger nearby well, owned by members of the "Friends of Harper Lake," was used to augment this water supply until the ponds had been filled. Once filled, the current pond depth was maintained until June with water from the smaller pump. The pump was then turned off, and the ponds were allowed to dry for the summer. This drying of the ponds during the summer helps in conservation of critical water resources in the area because it would take a tremendous amount of pumping to keep up with evaporation rates during that time of the year. It also helps to regulate salinity levels in the pond because salts left in the ponds following the drying are exposed to winds that can carry them away. Drying of the ponds also helps to control the extent of bulrush and cattail vegetation, so that it does not choke out all of the open water habitat that is necessary to maintain a diverse array of habitats.

Vegetation at Harper Lake: past and present

Vegetation during the alfalfa farming period was split into upland shrub and lowland marsh communities. A desert saltbush scrub vegetation community, similar to the one seen today, consisting of allscale, spinescale, shadscale, saltgrass, and some honey mesquite dominated the upland areas with scattered creosote bushes intermixed. Lowland areas consisted mostly of saltgrass patches near the water's edge and large areas of bulrush and cattail marshes. Tamarisk invasion was a problem at this time with seed sources from adjacent private land making it difficult to achieve a saltcedar-free marsh. When the marsh went dry in the late 1990s, all of the saltgrass patches and bulrush and cattail marshes died, leaving no vegetation in these lowland areas. Much of the dead cattail marsh is still present. Much of the tamarisk in the area has been removed over the years, and the current marsh area does not have a tamarisk infestation, but infestations on adjacent private lands continue to be a problem. The adjacent disturbed and abandoned agricultural lands have probably also allowed for invasion of other weed species into the Harper Dry Lake Marsh. An extensive infestation of five-hook bassia that began in the abandoned farmlands has taken hold in both upland and lowland areas of the Harper Dry Lake Marsh. This exotic species from Asia is highly salt tolerant and perfectly adapted to take over areas of the Harper Lake Dry Marsh, especially following disturbances. With the addition of water to the wetland, bulrush vegetation has begun to return along the shores of the ponds, and a few large saltgrass patches have returned. With the addition of water, however, the bassia infestation has become more intense and saltcedar has begun to reinvade.

Wildlife at Harper Lake: past and present

Since the overflow from the alfalfa farms began to enhance marsh habitat at Harper Lake, birds have been using this area. With the loss of wetland, riparian, and marsh habitat all over the region, the marsh at Harper became exceedingly important to migrating and resident birds. The area may have been at its peak wetland extent through the 1970s and 1980s in the heyday of the alfalfa farming. Observations from the early portion of this peak are rare, but in the late 1970s the BLM began to monitor the avian fauna at this site. Some of the informal records are astounding. In 1987, Larry Foreman, former Lead Wildlife Biologist for the California Desert District of the BLM, recalls seeing 16 species of raptors before noon and, on another day, approximately 150 short-eared owls. The bird list for the site stands at approximately 250 species, with over 100 riparian obligate species. Sensitive and listed species, such as western snowy plovers and Yuma clapper rails, were also seen at this site during this period. Following the drying of the marsh in the late 1990s, however, the richness of avifauna at the marsh dropped off precipitously until only species common to upland areas of the western Mojave Desert remained.

During the spring of 2003, following the addition of water to the marsh, many bird species began to return. Species seen at the marsh during monitoring in the spring of 2003 included: killdeer, great egrets, American avocets, western sandpipers, spotted sandpipers, western meadowlarks, black-necked stilts, long-billed dowitchers, western snowy plovers, semipalmated plovers, common ravens, black terns, mallards, western kingbirds, white-faced ibises, ring-billed gulls, nighthawks, cinnamon teals, Wilson's phalaropes, least sandpipers, red-tailed hawks, turkey vultures, Wilson's warblers, mourning doves, sage sparrows, and horned larks. Of these species, American avocets, western snowy plovers, and killdeer were confirmed to nest and fledge young at the site. During the fall of 2003 and the winter of 2003/2004 species seen at the marsh included: great egrets, snowy egrets, Say's phoebes, pied-billed grebes, killdeer, horned larks, American avocets, western meadowlarks, savannah sparrows, sage sparrows, western sandpipers, marsh wrens, northern shovelers, northern harriers, prairie falcons, green-winged teal, mallards, common ravens, American wigeons, loggerhead shrikes, American pipits, and a LeConte's thrasher. The spring of 2004 has the potential to be a very good season for nesting wading and shorebirds at Harper Lake. As vegetation and habitat conditions improve over time with the maintenance of water levels, species richness will improve further and Harper will become a more important stopover site for waterfowl during the winter.

The importance of a large stopover site for migrating birds in this area should not be underestimated. On the Eastern Sierra flyway and on the Pacific Coast, there have been significant losses of habitat for migrating waterfowl, wading birds and riparian-associated songbirds. This site provides a much-needed respite for migratory birds in the region. Habitat varies from marsh to playa to open water, both deep and shallow.

Although birds immediately come to mind, the wetland construction at Harper provides habitat for many other animal species. Many animals are naturally drawn to the water and food associated with this wetland environment. Most species seen currently at the marsh are common western Mojave upland reptilian and mammalian species. Historically the marsh present at Harper Lake supported the Mojave River vole (*Microtus californicus mohavensis*). It is not known how this species came to inhabit the marsh at Harper Lake, but following the drying it is certain that it no longer exists at the site. Other rodent species requiring regular intake of water, such as the common house mouse, also inhabited this marsh.

Future plans for Harper Lake:

Harper Dry Lake Wetland is in the very early stages of its restoration. Adding water was the first major step, but there is much work left to be done. A potential mitigation project on the horizon may provide funding for the expansion of the current wetland, which will provide even more habitat for wintering waterfowl and spring nesting wading and shorebirds. Cooperation with adjacent private landowners may lead to removal of tamarisk stands that serve as seed sources for invasion into the Harper Dry Lake Wetland area. Current steps are being taken to remove five-hook bassia at the site, including a controlled burn planned for a monoculture near the western pond. Transplants of saltgrass and plantings of honey mesquite are also planned for the area in an attempt to replace the bassia that is removed with native vegetation. If native vegetation can succeed in these areas, it will decrease the likelihood of reinvasion of these sites by non-native weeds. These active restoration projects will increase species richness at the site by increasing the diversity of habitats located in the area. If the before mentioned mitigation project can provide for a sustainable year round wetland, the reintroduction of the Mojave River vole may be a possibility in the future. If this reintroduction is successful, Harper Dry Lake Marsh can serve as a refugium for this sensitive species. Amphibian species found along the Mojave River may also be translocated if the future project leads to a sustainable year round wetland. Species such as the western toad (*Bufo borealis)*, red-spotted toad (*Bufo punctatus)*, and California treefrog (*Hyla cadaverina)* could be introduced, either as adults, or if identifiable, as tadpoles. However, salinity may prove to be too high to effectively introduce these species. If established, these species in adult and larval forms would provide significant food for birds and mammals. The introduction of nonnative species by the public will be combated through signs and education programs. It will be made clear that bullfrogs, crayfish, or game fish should not be added to the Harper Lake ecosystem. Harper Lake is now supporting migrating waterfowl and nesting shorebirds, and future restoration efforts and habitat improvements promise to increase the amount of diverse wildlife habitat and species richness at the site. One day Harper Dry Lake Marsh will be a diverse ecosystem that supports a wide array of faunal taxa that can provide viewing enjoyment to the public for many years to come.

Mojave River history from an upstream perspective

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Abstract

Several interpretations of Mojave River history by Enzel et al. (2003) in GSA Special Paper 368 appear to lack solid evidence or realistic conceptualization. Before their geomorphic and stratigraphic interpretations are accepted, researchers working on the history of the Mojave River should consider some serious problems regarding Enzel et al.'s (2003) latest revision of Mojave River geomorphic history.

Introduction

Issues will inevitably arise when scientists attempt to reinterpret the work of their peers, and this is especially true when little or no communication exists between the scientists. Because I was not provided a chance to conduct a peer review of the Enzel et al. (2003) article prior to publication, and no opportunity exists for a "comment and reply" in the Special Paper series of the Geological Society of America, this article is meant to review some mistakes and misinterpretations of Enzel et al. (2003) and to challenge evidence in the Silver/Soda basin for the first time.

How quickly do recessional shorelines vanish?

Fifteen years ago I published a paper suggesting that the final lake in the Afton sub-basin of Lake Manix drained quickly, forming upper Afton Canyon in the process (Meek, 1989a). Since then, researchers under the guidance of Stephen Wells who have worked downstream in the Silver/Soda basin have maintained that Lake Manix drained slowly and therefore that all of Afton Canyon formed in a time-transgressive manner over thousands of years (e.g., Wells and Enzel, 1994; Enzel et al. 2003).

Recently, Enzel et al. (2003, p. 68) have made a claim that is critical to understanding the Afton Canyon controversy: "In addition, we observe recessional shorelines in the Afton basin at elevations below the highest level of Lake Manix, suggesting a longer period of downcutting." Future researchers of the Mojave River and any reviewer knowledgeable about Afton Canyon should realize that this is THE most important issue in the whole debate. All other conflicts are side bars. It is the absence of recessional shorelines that has been the primary basis for my claim of a rapid upper canyon incision (e.g., Meek, 1989a). No evidence of recessional shorelines was presented by Enzel et al. (2003). None has ever been noted by any prior researcher in Afton basin (e.g., Buwalda, 1914; Ellsworth, 1932; Blackwelder and Ellsworth, 1936; Keaton and Keaton, 1977; Jefferson, 1985, 2003). It is difficult to understand why none of the reviewers of Enzel et al. (2003) demanded that the location and evidence for the recessional shorelines be provided. If Enzel et al. (2003) cannot produce unequivocal evidence of recessional shorelines, their claim about the time-transgressive formation of upper Afton Canyon is untenable and their latest stratigraphic interpretations of the Silver basin cores are suspect. Alternatively, if Enzel et al. (2003) truly have unequivocal evidence of recessional shorelines, I will have to reevaluate my interpretations of the history of the Mojave River, Afton Canyon, and the Manix basin.

Consequently, in November 2003 I sent E-mail requests to each of the authors (Enzel, Wells and Lancaster) to provide the location(s) of the recessional shorelines in Afton basin. As of March 2004, no responses have been received. Replication is a foundation of science, and if readers are not permitted to view and evaluate vital evidence for themselves, there can be no trust between author and reader.

No one other than Enzel et al. (2003) has recognized or reported significant depositional features in Afton basin that formed as the final stand of Lake Manix receded. The basin floor of the last stand of Lake Manix is preserved for long distances below each of the large beach ridges in eastern Afton basin. This floor can be recognized by remnants of "tufa" coatings (i.e., some of the oncoids described by Awramik et al., 2000), but this surface was undoubtedly buried in green lake clays when the lake drained. Surprisingly, the wave energy that was sufficient to construct the beach ridges composed of large cobbles did not leave any strandlines of even gravel-sized sediments downslope from the beach ridges in the basin. My belief in a rapid cutting of upper Afton Canyon rests on my assumption that some evidence of strandlines would be visible if the lake drained over a period of years. Thus, the absence of strandlines is the best (albeit negative) evidence that the lake drained rapidly.

I searched the literature and the field widely for evidence of recessional shorelines in Afton basin with the following results: a) there is a tufa-coated bench north of South Afton beach ridge, but U/Th dating indicates that this bench is an exhumed shoreline of an Oxygen Isotope Stage 4 lake stand (Meek, 2000, p. 33); b) west of the Afton Exit beach ridge there are features I once described as "cobble lineations," but these are mining scars from when the interstate was built (Meek, 1990, p. 71-73); and c) there is potential evidence of a recessional shoreline in the form of a subtle shoreline platform on the western slope of Buwalda Ridge beneath the high shoreline platform (Meek, 1990, p. 70), however, shoreline platforms are long-lived erosional features in bedrock that could have been created by numerous earlier stands of Lake Manix. In this case, the subtle wave-cut platforms likely formed at or near the most common lake level in the basin over its long history. Nothing requires that the subtle shoreline platform was formed by the final lake stand, and there are no depositional strandlines that correspond to its elevation in other parts of Afton basin.

Until Enzel, Wells and Lancaster publish specific evidence of recessional shorelines and disprove other explanations, one must suspend judgment on the alternative history they propose.

The Afton Canyon straw man

Enzel et al. (2003, p. 68) claim three types of evidence prove that Afton Canyon incised slowly: 1) the slow upstream migration of the nickpoint formed by the incision; 2) the existence of marsh and lacustrine conditions in the Mojave River delta in western Lake Manix as late as 12–9 ka; and 3) the existence of pronounced Holocene terraces within the canyon. They follow the last point with this statement: "...indicating that the incision of Afton Canyon to its present form was not a continuous, but episodic and a relatively long process." On page 67, Enzel et al. (2003) make the following claim: "The rapid-incision idea was based mainly on the lack of recessional shorelines in the Afton basin, the lack of terraces within the canyon, and the presence of deeply incised tributary channels into the canyon (Meek, 1989a). Wells and Enzel (1994) analyzed the geomorphology of Afton Canyon, including these specific observations, and concluded that an alternative hypothesis such as time-transgressive incision during at least a few thousands of years is a more realistic explanation." Since this section of their paper is meant to challenge my interpretation of a rapid canyon incision, one might reasonably assume that I have claimed that all, or nearly all, of Afton Canyon formed in a single flood event.

Such is not the case. Careful reading of the Meek (1989a) article includes the following statements: "*At elevations above the lake floor*, no resistant rock units that may have once extended across the canyon, forming long-lived spillways, are evident in either wall of Afton Canyon," and "No river terraces (strath or fill) are present in the canyon *at elevations above the lake floor*. Had canyon cutting been episodic, some evidence of terraces might remain, given the late Wisconsin age of the canyon cut" (Meek, 1989a, p. 10). Note that both statements include the phrase "above the lake floor" and it is clear that I was making the case that the portion of Afton Canyon above the floor of Lake Manix, not the whole canyon, was eroded in the draining event. Subsequently, I explicitly stated that "the upper half of the canyon could have eroded rapidly as Lake Manix drained" (Meek, 1990, p. 95).

To clarify the issue again after Wells and Enzel (1994) made the claim that the whole canyon formed in a time-transgressive manner, I wrote (Meek, 2000, p. 33): "Sometime about 18 ka, water overtopped the lowest rim of the Manix basin immediately above Afton Canyon, and the water spilled out, removing that part of the canyon above the lake floor in as little as 10 hours. Some people who have read my 1989 paper and accompanied me to the area have told me that they thought I suggested in the paper that the entire canyon was eroded in this event. There is no evidence that this happened. Rather, a series of strath terraces on the meander bend and upstream of the canyon indicate that the *lower half* [italics in original] of the canyon was incised over much longer periods."

Large late Wisconsinan and Holocene terraces do exist in the Afton Canyon vicinity, but they all lie far below the reconstructed floor of Lake Manix, and thus have no bearing on the speed at which the lake drained. Further proof that my interpretation has been misstated is found in my written response to Wells' peer-review of the manuscript where I proposed the rapid incision of upper Afton Canyon. In my direct response (written communication to Wells, 2 June 1988), I wrote: "Comment 20, p. 7: Statement: 'I have observed fluvial terraces and fan surfaces 35 m above the canyon floor; are these insignificant?'" To which I responded: "At 35 m above the canyon floor at ANY location in Afton Canyon you are significantly below the bottom of the Lake Manix basin floor. Therefore, I would conclude that these features, if they are indeed terraces, probably have little relevance to the draining of the lake."

In a related matter, Wells and Enzel (1994, p. 178-179) have claimed that: "a topographically high fluvial terrace (>45 m above the canyon floor) has been observed at the mouth of Afton Canyon.... This terrace occurs as isolated remnants on bedrock ridges along the north wall of the canyon, sloping downstream and away from the canyon. These terrace remnants are topographically much higher than early Holocene alluvial fans near Basin railroad siding at the mouth of Afton Canyon.... These field observations imply that an ancestral Mojave River was debauching from Afton Canyon prior to the deposition of early Holocene alluvial fans." An important observation here is that they did not present any evidence that the terrace is older than the breaching of Lake Manix, and they also failed to provide sedimentary evidence that the terrace was formed by overflows from Lake Manix or an ancestral Mojave River.

Wells and Enzel (1994) and Wells et al. (2003, p. 111) have also argued that the Mojave River once flowed down Baxter Wash and "offer the hypothesis (Wells and Enzel, 1994, p. 181) that the lower part of Afton Canyon formed by progressive headcutting as Baxter Wash valley served as the outlet for Lake Manix. Eventually stream piracy along the headward migrating Afton Canyon diverted flow from Baxter Wash." First, no evidence yet presented indicates that overflows from Lake Manix have flowed down Baxter Wash. However, if Baxter Wash hosted such flows, its gradient is very steep, especially when one realizes that the lower reaches have been deeply buried. The steep gradient would have been sufficient to allow the flows to rapidly erode the weak Miocene deposits that can be found near the rim of Afton Canyon throughout the area (Meek, 1990, p. 101-107). Unequivocal evidence is needed to assert the bizarre geomorphic alternative that a hypothetical stream without substantial flows in the Afton Canyon vicinity could have eroded headward to pirate a stream in Baxter Wash that would have had a very steep gradient and substantial flows.

In summary, future researchers should not confuse the straw-man argument that most or all of Afton Canyon was carved by the draining of Lake Manix with the need of Enzel and Wells to provide valid evidence that: 1) the terraces in lower Afton Canyon pre-date the rapid incision of Afton basin, 2) Baxter Wash once carried Mojave River water, and 3) stream piracy by headward incision has indeed occurred here.

Age of Afton Canyon

My retraction of the 14,230 radiocarbon date required me to revise the maximum age of Afton Canyon to the next limiting radiocarbon date of 18.1 ± 0.4 ka (Meek 1999, 2000). Enzel et al. (2003, pp. 65, 68, 69) discuss this revision in their article. Yet they go on to write: "We ask again the key question: When did the Afton basin of Lake Manix drain (i.e., the beginning of the lowering of its highest stand from 543 m by spillway incision)? Catastrophically ca. 13 ka (Meek, 1989)? Or after 18 ka (Meek, 1999)? Was it in fact a catastrophic event, or was it a time-transgressive process that continued into the early Holocene (Wells and Enzel, 1994)? Specific answers to these questions will require additional research."

There is no confusion based on reliable limiting radiocarbon dates. Upper Afton Canyon must have formed after about 18.1 ± 0.4 ka because Afton basin was intact and contained a lake near the sub-543 m level until that time. There is no reliable evidence of lakes younger than this in Afton basin, or additional limiting radiocarbon dates younger than 18.1 ka, but since this is an erosional basin, the best evidence has been removed. Because of the absence of recessional shoreline features, I believe the breach was catastrophic. Exactly when it formed after 18.1 ± 0.4 ka is unclear, but the best place to determine the date is not in Afton basin, but downstream from Afton Canyon.

Some difficulties interpreting lake history in eroding basins

The Silver/Soda basin where Wells and Enzel have worked is a closed basin preserving a nearly complete record of upper Quaternary sediments. By drilling cores in such a setting, both shoreline features and basin sediments can be used to construct the lake basin's history.

The Afton basin is much different. When the final lake drained, the lake clays from all of the Wisconsinan stands of Lake Manix were highly vulnerable to erosion because they rested on top of the sedimentary sections. In fact, I have estimated that more than 99% of such clays have been removed from Afton basin (Meek and Douglass, 2001, p. 200), including all(?) of the clays from the eastern three-fourths of the Afton basin. Lake clays from the highest lake stands might remain in the lagoon subsurface at the Afton exit, but to my knowledge that small playa has never been cored. Many casual observers in Afton basin do not realize that all or nearly all of the green clays that they see rest stratigraphically below the Sangamon interpluvial (ca. 125 ka) fanglomerates that have protected them from erosion, and thus have no bearing on the Late Wisconsinan history of lakes that occupied the basin.

Enzel et al. (2003, p. 65) wrote: "Because the sequence of events represented by the various shore features is based on the ages of the shore features and not on stratigraphic relations, this curve [referring to the lake history curve] is subject to modifications with additional ages, different ages, and whether or not the varnish ages are included.... Based on two additional age determinations, the 15-14 ka stand was recently discarded (Meek, 1999) and the same beach ridge from which the earlier age came is now dated at ca. 29 ka (Meek, 1999). This change emphasizes the problem of using ages without a clear stratigraphic context; a beach ridge once considered the youngest in the sequence is now considered older than other late Pleistocene lacustrine features."

Reading this passage, a neutral observer might assume that the present writer does not understand or use basic stratigraphic principles. Yet, in the unique setting of Afton basin, my procedures are fully understandable. Without lake clays from the final lake stand, the only practical way to interpret the Wisconsinan stands of Lake Manix is from the remaining evidence, which in this case means the large porous beach ridges, a few wave-cut platforms and the tufa-coated floor of the lake basin. Nothing else remains from the final lake stands in Afton basin except for the coarse-grained (i.e., gravel, pebbles, granules and sand) braid delta at the western end of the basin. Unlike the small beach complexes in Silver basin, the Lake Manix beach ridges consist mostly of sandy gravel and large cobbles. The beach ridges were built in storms when large waves capable of easily moving cobbles overtopped the ridges. At first glance, one might assume that conventional stratigraphic principles apply—the highest beach ridge deposits are consistently the youngest; but, because multiple stands of Lake Manix reached the same elevation owing to the overflows across an internal spillway into Coyote basin, the beach ridges appear to be composed of a complex assortment of overwash deposits and therefore should produce an assortment of radiocarbon dates from the various lakes. Unlike the much smaller Silver Lake beach deposits, few shell fragments remain in the Lake Manix beach ridges because the wave energy obliterated them. When I was fortunate enough to find a few (extremely rare) fragments of shells in the ridges, I dated them not knowing from which lake stand they came. Interestingly, the beach deposits that contain the most *Anodonta* shells (usually dating to the 21.5 ka to 18.1 ka lake stand) can be found more than 4 m below the beach ridge crests on the foreslopes of the beach ridges, whereas the rare shell fragments within the beach ridges have so far dated to the 31 to 28 ka lake stand.

Someone wishing to decipher the Wisconsinan stands of Lake Manix history further could carefully map the complex mix of beach ridge layers and then radiocarbon date materials from each of the zones if sufficient datable material could be found. But I can make an educated guess as to what they will find: Lake Manix reached the sub-543 m level multiple times, including 21.5 to 18.1 ka, 31 to 28 ka, and probably a few earlier times. I welcome such a detailed site-specific study to test my interpretation.

Harper basin

Enzel et al. (2003, p. 69) also challenge my interpretations by claiming: "This large volume of water and the nonoverlapping ages discussed above led him [Meek] to conclude that Harper Lake was not contemporaneous with late Wisconsinan highstands of Lake Manix. He interpreted that the gaps in the Manix dates could be explained by dates from Lake Harper suggesting to him that Lake Harper was filled when Lake Manix was low." Without providing any new evidence, Enzel et al. (2003, p. 70) then proceed to propose two new interpretations: "...one or more of the following scenarios: (1) shifting of the river between basins on millenial time scales (Meek, 1999), (2) the river feeding both basins all the time, and/or (3) frequent shifting of the river on its delta resulting in a permanent but shallow body of water in each basin." The primary impetus for their claim is that "the Mojave River was able to support Lake Manix and Lake Mojave at the same time" (Enzel et al., 2003, p. 70), and thus it is possible that the river could have once supported both Lake Harper and Lake Manix at the same time.

Whether the Mojave River could have supported both Lake Manix and Lake Mojave at the same time rests on the assumption that the age control and extrapolated deposition rate in the Silver/Soda basin prior to 18 ka are reliable, and prove conclusively that Lake Manix and Lake Mojave existed at the same time. At best, this assumption is a tenuous one (see below).

I have asked several knowledgeable physical geographers if they can name a location on the Earth where a single river, flowing across a broad sandy plain, splits and *simultaneously* terminates in two different lake basins. No one has yet been able to identify a place where this happens. Except in the most extraordinary of circumstances, the two basins would probably have different base levels and hypsometries, and consequently the hypothetical river would have a difficult time maintaining multiple, continuous flows in different directions at the broad interfluve between the basins. For example, when the Colorado River began to flow directly into the Salton Trough in 1905 to eventually form the Salton Sea, and despite heroic efforts to return the Colorado River to its channel, "the main canal was carrying 87% of the total flow of the river, and the water was deepening and widening the Alamo River, along which the canal extended, to a great gorge. Strong efforts by the Southern Pacific Railway Company resulted in the control of the Colorado in the early fall of 1906, but it broke out again on December 7, and was only closed finally in February, 1907" (Freeman and Bolster, 1910, cited in Bowman, 1911, p. 241; see also de Stanley, 1966, pp. 28-38). Since there seem to be no known examples of rivers *simultaneously* flowing into two different terminal lake basins across a broad, sandy plain, I believe that the second hypothesis of Enzel et al. (2003, p. 70) where they claim it happened for lengthy periods of time is unrealistic.

Finally, the third hypothesis (frequent back-and-forth channel avulsions maintaining two separate shallow lakes) directly conflicts with the likely time and paleodischarges needed to fill the large volumes of Lake Manix at 28 and 21.5 ka, and Harper Lake at 25 ka. Each lake was at its *maximum* stage and surface area at these times, and no evidence yet exists for major lakes simultaneously in both basins. Shallow lakes probably existed in the alternate basin periodically, but the presence of shallow lakes does not warrant the proposition that the Mojave River changed flow directions near Lenwood several more times than the lake evidence currently indicates.

In a related matter, the fact that rivers do not normally split to flow to multiple lake basins simultaneously makes the claim that the Mojave River was "capable of delivering water simultaneously to Coyote Lake and, through an incising Afton Canyon, to Lake Mojave" (Enzel et al., 2003, p. 69) quite unlikely.

Coyote basin

Enzel et al. (2003, p. 69) cite written communication from me in 1990 in order to make it appear that I argued for the following baseless claim "(1) Coyote Lake basin could have received Mojave River water only as an overflow from the Afton and Troy basins after these basins reached a sill elevation of 543 m, and (2) only after Coyote Lake also filled to that elevation could the joint Lake Manix have risen to higher levels. Therefore, Meek (1990, written commun.) suggested that the lakes in the Coyote Lake basin after 13 ka (i.e., after his proposed draining of Afton basin ca. 13.5 ka) are residual water bodies that were trapped as remnants of the larger Lake Manix after the formation of Afton Canyon. However, the retraction of the 14.5 ka age means that all the ages from Coyote Lake are < 18.1 ka, which is the youngest age from Afton basin (Meek, 1999). We postulate that simple calculations will show that even for lowest estimations of latest Pleistocene evaporation rates, Coyote Lake would dry up within a few to tens of years were it not being fed continuously by discharge of the Mojave River." Enzel et al. (2003, p. 69) then go on to propose that the Mojave River flowed directly into Coyote basin multiple times after Lake Manix drained.

Enzel et al. (2003) chose to cite personal communication not intended for publication rather than (1) my dissertation (Meek, 1990, p. 146) where I wrote: "Following the draining of Lake Manix, the Mojave River delta remained active throughout a long mesic interval which continued to about 9 or 8 ka. Until 12.3 ka, and possibly 11.3 ka, the delta shifted into Coyote basin, and was responsible for one or more deep lakes in Coyote basin long after the remainder of the Manix basin had drained and was dry."; or (2) the detailed discussion of the deltas in Coyote basin that accompany the different lake stands in Coyote basin in an article titled: "The geomorphology of Coyote basin" (Meek, 1994, p. 6-7); or (3) the map and statement: "...several radiocarbon dates from the topographically intact subbasins of Lake Manix indicate that lakes continued to exist in the Coyote and Troy subbasins long after Afton Canyon had formed and the Afton subbasin was permanently drained. Major lakestands produced by a shifting Mojave River occurred in Coyote basin about 17,500, 13, 600, 12,900 and 11,800 years B.P" (Meek, 1999, p. 115-116).

There is no evidence requiring that the maximum stand of Lake Manix (cresting on the beach ridges at 543 m but normally remaining more than 3 m lower) was maintained by an overflow sill in the Afton Canyon region that carried water towards Lake Mojave (e.g., Weldon, 1982; Enzel et al., 2003, p. 65). The salient point of my 1990 written communication was to notify Wells of the huge increase in surface area and volume of Lake Manix at elevations just below 543 m, and to point out that the Coyote and Afton (and probably Troy) subbasins could each have independent lake histories that reached the same maximum elevation depending on the flow direction of the Mojave River. Only after all three subbasins were filled to the internal overflow sill elevation between Coyote and Afton basin would the level of Lake Manix rise above the sub-543 m stage. Clearly, when the rim of Afton basin failed and Afton basin drained, any water in Coyote basin would be residual until the Mojave River shifted course to flow into the basin—something it appears to have done more than once.

Is the Mojave River deltaic plain a braid delta or a fan delta?

Since I labeled the Mojave River deltaic plain between Yermo and Camp Cady a braid delta (Meek, 1989a, p. 7), Wells and his students have found it necessary to attempt to correct me by incorrectly terming it a fan delta. For example, Enzel et al., (2003, p. 66) title a section of their paper "The Mojave River fan delta" and then, to emphasize their point, write: "The large delta that is observed at the surface and termed 'Mojave River braid delta' (e.g. Meek, 1990) is of late Quaternary age." They also label the landform a fan delta on two figures in their article.

I based my terminology on a paper published in the *Geological Society of America Bulletin* titled "Fan-deltas and braid deltas: varieties of coarse-grained deltas" (McPherson et al., 1987). The purpose of the article is to differentiate between the two types of coarse-grained deltas (see Figure 1), and the article provides 16 criteria to differentiate the two. The Mojave River deltaic plain meets all relevant criteria for a braid delta, but few of the requirements for a fan delta. The first five sentences of the McPherson et al. (1987) article explain the differences: "Two types of coarse-grained deltas are recognized: fan-deltas and braid deltas. Fan deltas are gravel-rich deltas formed where an alluvial fan is deposited directly into a standing body of water from an adjacent highland. They occupy a space between the highland (usually a fault-bounded margin) and the standing body of water. In contrast *braid deltas* (here introduced) are gravel-rich deltas that form where a braided fluvial system progrades into a standing body of water. Braid deltas have no necessary relationship with alluvial fans, as exemplified by fluvioglacial braid deltas." After reviewing McPherson et al. (1987), I have no doubt that the reader will consider the Mojave River deltaic plain in Troy, Afton and Coyote basins to be a braid delta.

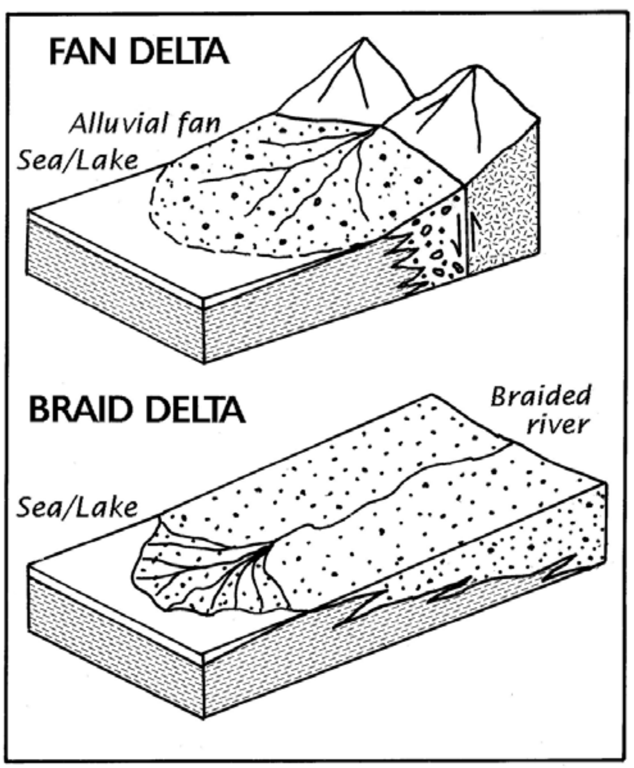


Figure 1 Caption: Fan delta vs. Braid delta (after McPherson et al., 1987, p. 332)

Challenging the Silver Lake work

It should be appreciated that a strong bias exists in the Silver Lake research of Wells and his students, because extrapolated deposition rates and other key assumptions of their research program would be overturned by the rapid draining of Lake Manix. In spite of multiple written invitations, no member of their active research group has ever been on one of the many field trips I have led to the Manix basin, including the multiple advertised trips for organizations such as the Association of American Geographers (Meek and Dorn, 1992), the International Association of Geomorphologists (Dorn and Meek, 1993) the Mojave Desert Quaternary Research Symposia (e.g., Reynolds et al., 2000) or the recent National Association of Geology Teachers meeting in 2003. Thus, I have not had the opportunity to show them the field evidence supporting my interpretations in the Manix basin or Harper basin.

On the other hand, I attended the Friends of the Pleistocene trip that visited the Silver basin in 1985 that was partially led by Wells, and also Wells' field trip in the Manix, Troy and Silver basins associated with the 1994 Cordilleran GSA meeting. In October 1985 I witnessed their interpretation of soil pits and shoreline evidence in the Silver basin after having worked in the Manix basin since January 1985. In was obvious that Wells et al. (1985) were attempting to interpret the Silver Lake stratigraphy without detailed knowledge of Late Wisconsinan hydrologic events upstream from Afton Canyon (nothing concerning Afton Canyon or Lake Manix appears in the Wells et al. 1985 or 1987 articles), and since they were suggesting that "an increase in effective moisture between 15,500 and 10,500 yr B.P. was probably necessary to maintain this lake [meaning Lake Mojave]" (Wells et al., 1987, p. 140), this led directly to my efforts to point out the significance of Lake Manix to their studies (Meek, 1989a).

Since then, I provided new empirical radiocarbon evidence that dismissed the 14 ka lake stand in the Manix basin (Meek, 1999, p. 115). In 1990 I discussed my suspicions that the 14 ka lake stand might be erroneous because of conflicting varnish dates, the absence of tufa, and the fact that I could not find the inflow delta associated with this lake stand (Meek, 1990, p. 135-137). I was also aware that it did not fit the downstream record that was richly supported with radiocarbon dates on shells after 16.3 ka (Meek, 1990, p. 137; 140). To try and resolve the issue, I collected new shell fragments from the same beach ridge overwash deposit that had been dated at 14.23 ka and submitted them to two different radiocarbon labs (Meek, 1999, p. 115), fully believing that they should produce an older age, either from the 19 or 29 ka lake stands. This is exactly what happened.

Today, I don't believe that the 21.5 to ~18.1 ka stand of Lake Manix will see significant (i.e., more than 1 ka) revisions because there are eight radiocarbon dates from this interval, some of which are from the coarse-grained braid delta associated with this lake stand.

Enzel et al. (2003, p. 67) report that the Silver basin has evidence of a deep lake beginning sometime around 22 ka or earlier, and Wells et al. (2003, p. 111) have now concluded that the waters of a lower Lake Mojave rose to inundate the Silver basin starting at ca. 22.6 ka. Assuming that the radiocarbon chronologies are reliable, an obvious question that arises, then, is how a large quantity of Mojave River water made its way downstream to Lake Mojave several thousand years prior to ~18.1 ka when radiocarbon evidence on *Anodonta* shells suggests that the Lake Manix basin was still intact. Three possibilities exist: 1) there was once an overflow sill at an elevation of about 543 m in the vicinity of Afton Canyon that is close to the height of the present overflow sill between Coyote and Afton basin (Wells and Enzel, 1994; Wells et al., 2003); 2) groundwater leaked from the Manix basin through the Cave Mountain/Afton Canyon/Cady Mountain barrier because of its large hydraulic head and the fracture zones associated with the Manix fault system; or 3) the evidence for major lake stands in the Silver/Soda basin prior to 18.1 ka is problematic. Because of extensive erosion, the first two possibilities are impossible(?) to examine today (unless one believes that Baxter Wash was the overflow channel), but the last option—the Silver/Soda basin chronology—can be investigated.

The Silver/Soda lake chronology prior to 16.3 ka has been based primarily on extrapolated average deposition rates in cores (Enzel et al., 2003, p. 67, Wells et al., 1989, p. 86), but recently Wells et al. (2003, p. 105) added inferred correlations of aeolian deposits to support the age control. *In 1990, I pointed out that the average deposition rate of clays in the downstream Silver/Soda basin should have rapidly changed after Afton Canyon formed* (Meek, 1990 , p. 137), *regardless of when Afton Canyon formed, because erosion of vast quantities of sediments from the Manix basin started then*. Wells et al. (2003, p. 104-105) continue to claim that average deposition rates in the Silver/Soda basin have remained between 1.08 and 1.16 m/1000 yrs from ~22 ka to ~9 ka, and they have developed an elaborate history of lake fluctuations and drying events based partly on those assumptions (e.g., Wells et al, 1989; Enzel et al., 2003; Wells, 2003). A long history of Silver/Soda lake research, then, would have to be substantially reinterpreted if Lake Manix drained rapidly after ~22 ka.

Assuming that there is reliable evidence that Lake Manix drained after ~18.1 ka, the most obvious explanations for the constant clay accumulation rates in the Silver/Soda basin after their inferred inferred 22 ka horizon are: 1) because all of the layers starting with at least the "intermittent lake 1" in SIL-1 of Wells et al. (1989, Fig. 23) accumulated after the rim of Lake Manix failed, and 2) because the age control and extrapolated deposition rates in the Silver/Soda basin prior to at least 16.3 ka are invalid. What is surprising is that Wells et al. (2003, p. 79-80) admit that *"...the beginning of Lake Mojave II appears to have coincided with the incision of Afton Canyon and subsequent draining of Lake Manix, an event which significantly increased sediment loading..."* yet despite this, the graphs of Wells et al. (2003) show no change in the sediment accumulation rates about this time.

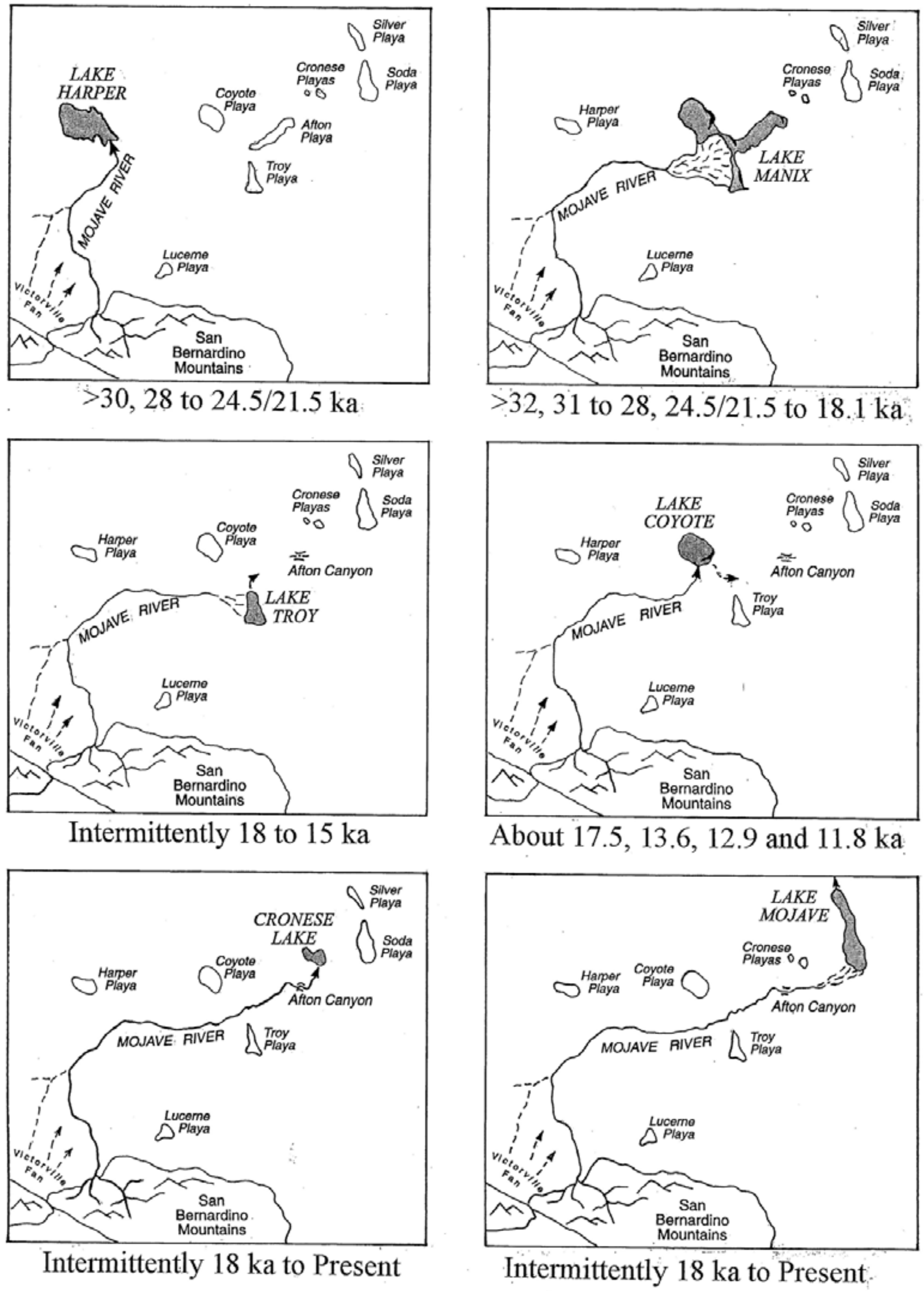
It is noteworthy that the sole radiocarbon date that constrains the Enzel et al. (2003) chronology in the Silver/Soda basin prior to 16.3 ka is a single 20.3 ka date on "disseminated organic matter" which they use to infer essentially constant sediment accumulation rates in Silver basin before and after Afton Canyon formed (Enzel et al. 2003, p. 67; Wells et al., 1989, p. 86). Three such radiocarbon dates were produced from their deep core (SIL-I), but one was discarded as "suspect" because it failed to fit their model of sediment accumulation independently developed by study of the nearby beach ridges (Wells et al., 2003, p. 104).

Another of their disseminated organic matter dates is just as "suspect" as the one that they discarded. It is possible that the disseminated organic material dated at 20.3 ka washed into the Silver basin from the Manix basin amid the massive influx of clays and sediments from Lake Manix that began when it drained rapidly, perhaps about 18 ka. There was a substantial lake in the Manix basin from >21.5 to 18.1 ka, and based on similar beds in Coyote basin from this interval, the contemporaneous lake in Afton basin contained abundant clays and organic matter. I would caution researchers to be suspicious of the existing (or any future) "disseminated organic matter" dates on the clayey sediments in the Silver/Soda basin until macrofossils (i.e., shell beds) that could not have washed in from the Manix basin are found in the layers. Researchers should also be aware that without (multiple) reliable disseminated organic matter dates in the cores, much of the detailed climate record in the Silver basin is not constrained temporally, but is based on inferred correlations with the beach ridge strata.

If the assumption of near-constant deposition rate in the Silver Lake cores is erroneous, the timing of events in the Silver basin is subject to change. In spite of my warnings (Meek, 1994, p. 7; Meek, 1999, p. 116) for workers to be wary of interpreting the stratigraphy of any terminal basin as a record of paleoclimates until proof is provided that the Mojave River was continuously flowing into that basin, Wells et al. (2003, p. 113) have claimed that a major drying event indicates that the Silver Lake region experienced a major drought about 15.5 ka. They made this interpretation even though the Mojave River was migrating laterally across its plain upstream of Camp Cady during this time, periodically terminating in Coyote and Troy basins (Meek, 1999). If one presumes that the timing of their drought is subject to change, then it is possible that the "drought" is simply the result of the Mojave River terminating in another basin such as Coyote or Troy for some unknown interval, perhaps at one of the times already identified (see Fig. 2).

Until solid evidence is provided that a substantial stand of Lake Mojave coincides with a deep stage of Lake Manix, I believe the conclusion of Enzel et al., (2003, p. 69) that "Lakes Manix and Mojave coexisted during the last glacial

Figure 2: Late Wisconsinan flow directions of the Mojave River. Because of river avulsion across the broad intervening plains, the river has terminated sedimentologically in at least six different terminal basins during the Late Wisconsinan (Modified from Meek, 1999).



maximum, at least for a short period, to form a joint lake area that could have reached up to ~500 km² that was supported by the Mojave River" is a speculative proposition, possibly invalidating the paleoclimate analyses that are built on this assumption.

A final point to keep in mind when considering whether evidence of a near catastrophic flooding event should appear in the Silver Lake record is that the Silver Lake basin was not the lowest large basin downstream from Afton Canyon during the Late Wisconsinan (Wells et al., 1994, p. 184), and thus Silver Lake was neither the primary depocenter nor the first place downstream from Lake Manix to record hydrologic changes during the Late Wisconsinan. A massive influx of sediments from Afton basin has infilled the large basin that once existed in the Crucero and southern Soda Lake vicinities. Thus, the elevated paleogeographic position of the Silver Lake record means that similar facies probably record larger hydrologic changes in the region at 18 ka than they did at 13 ka or than they do today, and that much or all of the water from the rapid breach of the Manix basin could have been contained in the larger and deeper basin upstream of the Silver Lake basin that has yet to be studied at the same level of detail.

A different perspective on Mojave River history

From the preceding review, it should be apparent that the Enzel et al. (2003) article is in error in several respects. Having read their critique, a reasonable question is whether and how I would alter my latest graphic presentation of Mojave River history (Meek, 1999, p. 116). The answer is that I would widen the caption listing 21.5 ka as the time of avulsion between Lake Harper and Lake Manix to a broader 24.5 to 21.5 ka interval because I am uncertain when it actually occurred. Nothing else would change based on evidence presented by Enzel et al. (2003). Moreover, given all of the evidence I am aware of from this region, I believe Figure 2 summarizes Late Wisconsinan Mojave River history upstream of Afton Canyon in the most straightforward manner and without the many unsupported assumptions of Enzel et al. (2003).

However, I want to mention two new thoughts about Mojave River history that I have not discussed in previous publications:

1) Enzel et al. (2003, p. 69) claim that "very slow nickpoint propagation" of the Mojave River upstream of Afton Canyon occurred "through unconsolidated sediments." I once made a similar mistake by analyzing constant nickpoint recession rates and not taking into account the lithologic resistance of the different reaches (Meek, 1990, p. 110-113). For anyone who drives to the Afton Canyon campground it is apparent that the river upstream of the canyon is entrenched in highly cemented fanglomerates. Numerous tributaries in this area have major nickpoints (atop the cemented fanglomerates) that are impassable without ropes, and some large strath terraces are evident along the Mojave River. Thus, it is likely that nickpoint recession of the Mojave River in the two-mile region upstream from Afton Canyon would have proceeded very slowly (i.e., probably taking thousands of years) before reaching the weakly consolidated sediments in the badlands south of Dunn. Moreover, once the nickpoint migrated farther upstream of the Buwalda Ridge area, it would have encountered resistant fanglomerates again, this time associated with Buwalda Ridge and the Mojave River formation (Jefferson, 2003). These fanglomerates might have again slowed nickpoint recession upstream from Buwalda Ridge for thousands of years, allowing the Mojave River to migrate laterally across its braid delta into the Holocene.

2) The resistant fanglomerate barriers in the Buwalda Ridge area might have ponded Mojave River water locally long after Afton Canyon formed. However, because this region has been deeply eroded, the existence of such a sub-basin is speculative. However, in several iterative computer analyses recreating the stepwise erosion of Afton basin based on lithologic resistance and local stream gradients, Kempton (2001, Plates 3-5 and 9-11) discovered that one or two small subbasins remained in the Buwalda Ridge vicinity long after Afton Canyon formed.

If these sub-basins existed, they would provide an additional explanation as to why the Mojave River was belatedly transporting unusually large quantities of green clays into the Afton basin after the tributaries in the Afton area had partially incised in resistant fanglomerates. These green clays were interpreted by Blackwelder and Ellsworth (1936) as evidence for a third lake in Afton basin that developed after Afton Canyon formed, but I have interpreted the sediments as possible slackwater or levee-ponded deposits that accumulated in tributary canyons as the Mojave River incised (Meek 1989b, 1992).

Some concluding thoughts for future researchers

This paper outlines a case example of how science should NOT work. Instead, whenever possible:

1) scientists should visit their peer's field sites in their peer's company before writing major critical reviews of their work;
2) scientists should conduct thorough literature reviews and/or attempt timely communications rather than use obsolete letters and correspondence that were not intended for publication;
3) scientists should provide the specific locations of field evidence in their publications and if requested by colleagues;
4) scientists should be able to find analogues somewhere on the Earth for processes they invoke;
5) scientists should realize that it is in their best interest to use peer reviewers intimately familiar with the field evidence and differing interpretations in a region;
6) scientists should beware of conflicts of interest and biases, for it is now apparent that a presumed solid research program could be in danger of being washed away by a flood originating upstream.

Acknowledgments

This paper has benefitted tremendously from the comments and wisdom of five veteran reviewers who have toured the Manix basin and are very knowledgeable about the region.

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Non-brittle fault deformation in trench exposure at the Helendale fault

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Introduction

Geotechnical study of potentially active and active faults in California, as required by the Alquist-Priolo Special Studies Zone Act (Hart, 1985; p. 5-6) generally includes a trenching program to evaluate recency of surface rupture. Inherent in this approach is the assumption that trenches, crossing and oriented perpendicular to the average strike of the fault zone, will expose evidence of activity if the fault has ruptured the surface during the time frame covered by the sediments exposed in the trenches. We excavated a trench across the Helendale fault in the western part of the Mojave geomorphic province in Lucerne Valley with the intent of characterizing the faults' Holocene behavior. The Helendale fault is one of many of the Mojave faults that were zoned by the State of California as active and requiring further study (Figure 1). We trenched across a scarp along the mapped tract of the fault near Rabbit Springs within the A-P zone (Figure 2). The trench exposed a sequence of highly plastic, early Holocene clays overlain by coarser silty sand alluvium. No brittle deformation was observed in the clayey units, although significant warping (plastic deformation) can be attributed to recent faulting. The absence of surface faulting may have led many consultants to question the presence of an active fault at this site, with the possible outcome of direct construction across the fault. The purpose of this paper is to present the results of our trenching study of the Helendale fault and discuss some of the problems associated with trenching faults in materials that behave in a non-brittle fashion.

The Helendale fault extends from the Mojave River area southeastward through Lucerne Valley into the San Bernardino Mountains (Jennings, 1975; Manson, 1986). The fault is the westernmost of a series of subparallel, northwest-striking, dextral faults in the central Mojave Desert (Figure 2). South of Interstate 15, the Helendale fault can be traced as a zone of discontinuous scarps, tonal and vegetation alignments, right-laterally offset drainages and ridges, linear drainages, sidehill benches, breaks-in-slope, and shutter ridges. In Lucerne Valley, the fault locally is shown to offset alluvium of undifferentiated Pleistocene and Holocene age (Dibblee, 1964a) or Holocene age (Hollenbaugh, 1968; Rzonka and Clark, 1982). In the area around Rabbit Springs, the fault is expressed as a low northeast-facing scarp, and there are several seasonally active artesian springs along the fault trace.

Methods

A detailed examination of USDA aerial photographs (1952, series AXL) and field mapping at a scale of 1:2000 revealed an approximately 0.5–1 meter high scarp in the Rabbit Springs area along a portion of the fault previously mapped by Dibblee (1964a). A detailed topographic map was created (2 foot contour interval) along the scarp using a WILD TC-2000 total station. Several small-diameter bor-

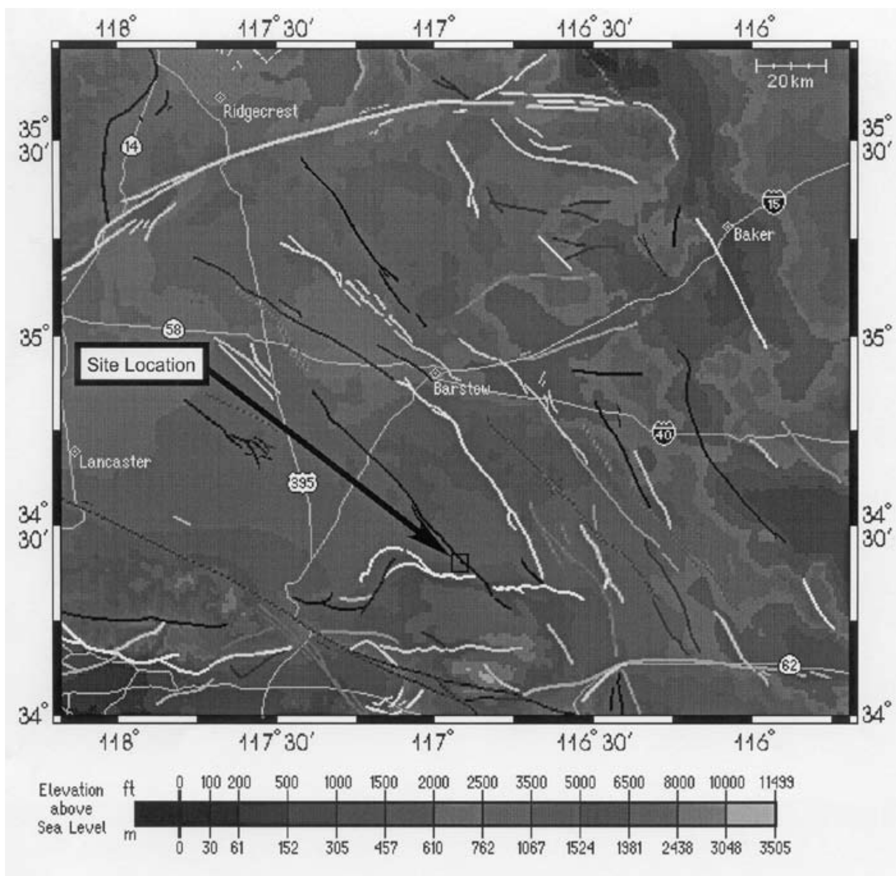

Figure 1. Location Map showing the major faults of the Mojave Province
Source: http://www.data.scec.org/faults/mojfault.html

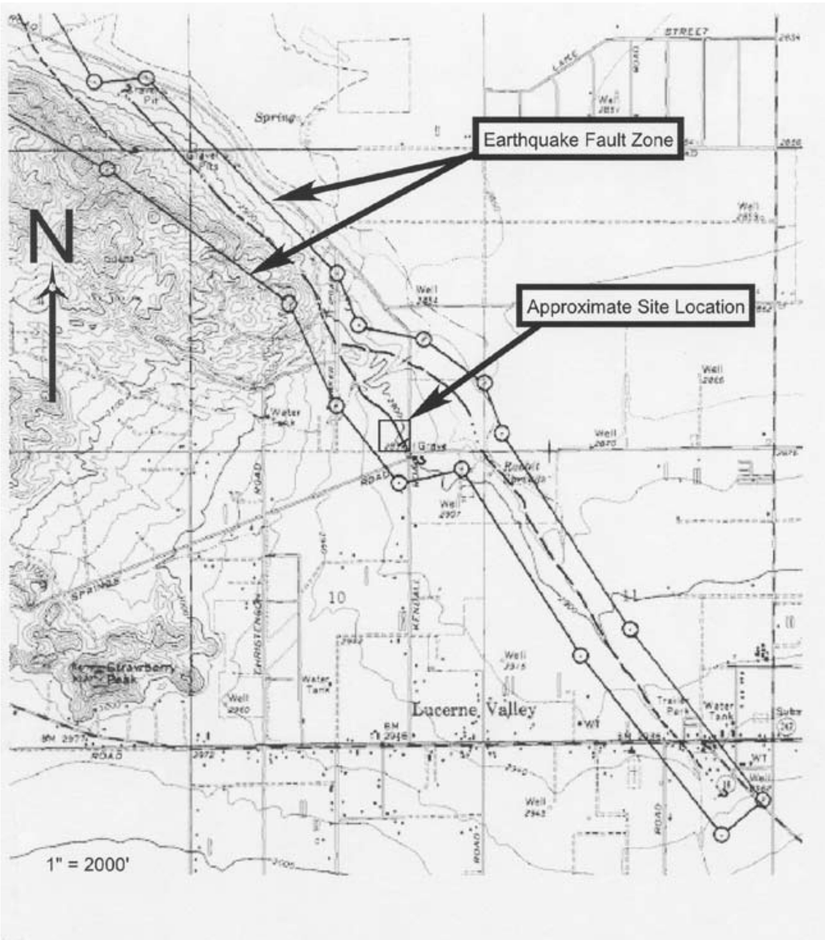

Figure 2. Site location map showing a portion of the Alquist-Priolo Special Studies Zone for the Helndale Fault

ings were completed with a hand auger on either side of the scarp to test for stratigraphy and ground water conditions. The primary purpose of these borings was to correlate stratigraphy across the scarp and to obtain a sample of the sediments in the near surface. The presence of fine-grained sediments in the upper 3 meters and a very dense greenish clay near the base of the borings, all of which appeared vertically displaced across the scarp, suggested that this site would be a prime location for a trench. A 20 meter long exploratory trench was excavated by backhoe to a maximum depth of about 4.5 m, the approximate depth of groundwater, to evaluate the history of surface rupturing events along this segment of the fault. A one meter grid was placed on the southwest wall of the trench to facilitate logging of the stratigraphy.

Site stratigraphy

The 4.5m-deep trench exposed a sequence of lacustrine and alluvial units that probably record deposition over much of the Holocene. The lower 1.5 m of section exposed in the trench is a massive olive-green, damp to wet, dense, "fat" or highly plastic clay with minor carbonate as 1–2 mm diameter nodules (Unit 1). This unit is interpreted to represent deposition under lacustrine conditions in that: 1) the trench site is located on the margins of Lucerne dry lake, and 2) all alluvial fan and fluvial deposits examined in this part of the Mojave are devoid of "clean" clay deposits except those around the margins of late Pleistocene lakes, and 3) similar appearing deposits are known from other lacustrine sites in the Mojave region (Herzberg and Rockwell, 1993; Padgett and Rockwell, 1993).

Unit 1 grades upward into Unit 2, a 1.5 to 2.5 meter thick, greenish gray (lower) to light brown (upper), blocky, fine to coarse sandy, silty clay with scattered pebbles. Unit 2 is also interpreted to be lacustrine in origin. The porosity and sand content increase upward, as does the gravel content. Clay is visible as linings in tubular pores and as discontinuous stains on ped faces in the upper part of Unit 2. This unit effervesces mildly when dilute (10%) hydrochloric acid is applied. We interpret the upper part of Unit 2 as a weakly expressed argillic horizon developed through the upper portion of the lacustrine section.

Overlying the clayey lacustrine units is a 2-m-thick section of alluvial fan and spring deposits. A 0.5–1 m-thick chalky white to light gray, crumbly to blocky, sandy silt immediately overlies the lacustrine section (Unit 3). State II to stage III carbonate development is locally expressed in this unit, although much or most of this carbonate appears to be related to spring activity rather than soil development. The upper portion of Unit 3 is a sequence of stratified light brown to charcoal gray sandy silt. These silty units comprise a series of colluvial strata that thin across the scarp and are discontinuous along the length of the exposure.

The upper meter of section exposed at Rabbit Springs (Unit 4) consists of massive, light brown, loose, silty fine to medium pebbly sand interpreted to be primarily of colluvial and debris flow origin. It is continuous across the scarp, although this unit also thins at the scarp.

Charcoal was recovered from several of these non-lacustrine colluvial strata, and ^{14}C dates are pending. Correlation of the lacustrine section to other, well-dated lacustrine units in the area (Padgett and Rockwell, 1993; Herzberg and Rockwell, 1993) suggests that the entire section exposed in our trench may be Holocene with the basal lacustrine unit being about 9.5–10 ka in age. Further studies will confirm or modify our preliminary age estimates.

Non-brittle Deformation and Fault Activity

The clay of lacustrine units 1 and 2 is highly plastic and was found to be moist or wet at the time of trenching

(April). Standing water formed at the base of our trench at a depth of about 4.5 m, indicating the position of top of the water table. Thus, it is safe to assume that at least the lower part of the lacustrine section is saturated or close to saturation most of the time.

Two zones of open fractures, some as wide as 1.5 cm and up to a meter in height, are present in the clay (Figure 3). The base of the fractures generally occur near the top of unit 1 (saturated most of the time) and continue upward to the top of unit 2 (oxidized and therefore unsaturated most of the time). The fractures opened more or less perpendicular to the bedding attitude and are generally aligned along the average strike of the Helendale fault. They occur only below the scarp and are apparently related to the formation of the scarp itself. No brittle shears or faults were expressed in the lacustrine clay, however.

Understanding the origin of the open fractures as well as the scarp itself are critical to assessing whether or not this site is crossed by an active fault in the absence of brittle shearing or faulting in earliest Holocene strata. We explore the possible origins of the fractures and scarp in the following section.

Scarp Formation

There are several possible ways in which a scarp may have formed at this site. Several processes can lead to the formation of a tectonic scarp. Strike-slip faults that have even a minor dip-slip component and rupture to the surface can lead to the formation of a scarp. Vaughan (1922) noted a slight uplift of the southwestern block in Lucerne Valley as evidence for faulting. Given the continuity of some of the strata across the scarp and the warping of the lacustrine clay units, this process could be the cause of the low scarp that we see in the Rabbit Springs area. However, pure strike-slip motion can also lead to the formation of a scarp if local topographically high areas are juxtaposed against topographically low areas. The scarp that we excavated is located in a relatively flat area, although there are several minor channels and other topographic features that could produce vertical separations with lateral displacement. Another possibility is that the warping is caused by a fault that doesn't rupture brittlely to the surface. Oblique displacement on such a fault at depth might cause the overlying saturated and partially saturated sediments to be warped, thereby causing the formation of a scarp. Finally, the scarp may be accentuated by the formation of a mole track, or linear zone of localized uplift due to minor transpression along a strike-slip rupture.

Several non-tectonic processes can also lead to the formation of a scarp. One cause often overlooked in undeveloped areas such as the western Mojave is that the scarp may be man made. Discussion with local long-time residents revealed that a nearby depression (and low scarp) was the site of a garbage dump in the late 1930s and early 1940s. A hand dug test pit at that location did turn up a variety of rusted cans and scrap metal just below the surface. However, our field observations and excavation did not reveal any features that would suggest that the trench site had been altered prior to our work. The absence of cultural material does not support the possibility of a dump site at our trench. Another possibility is that the trench site was used as a borrow pit. However, borrowing of sediment is not a likely cause for the scarp in that most or all units

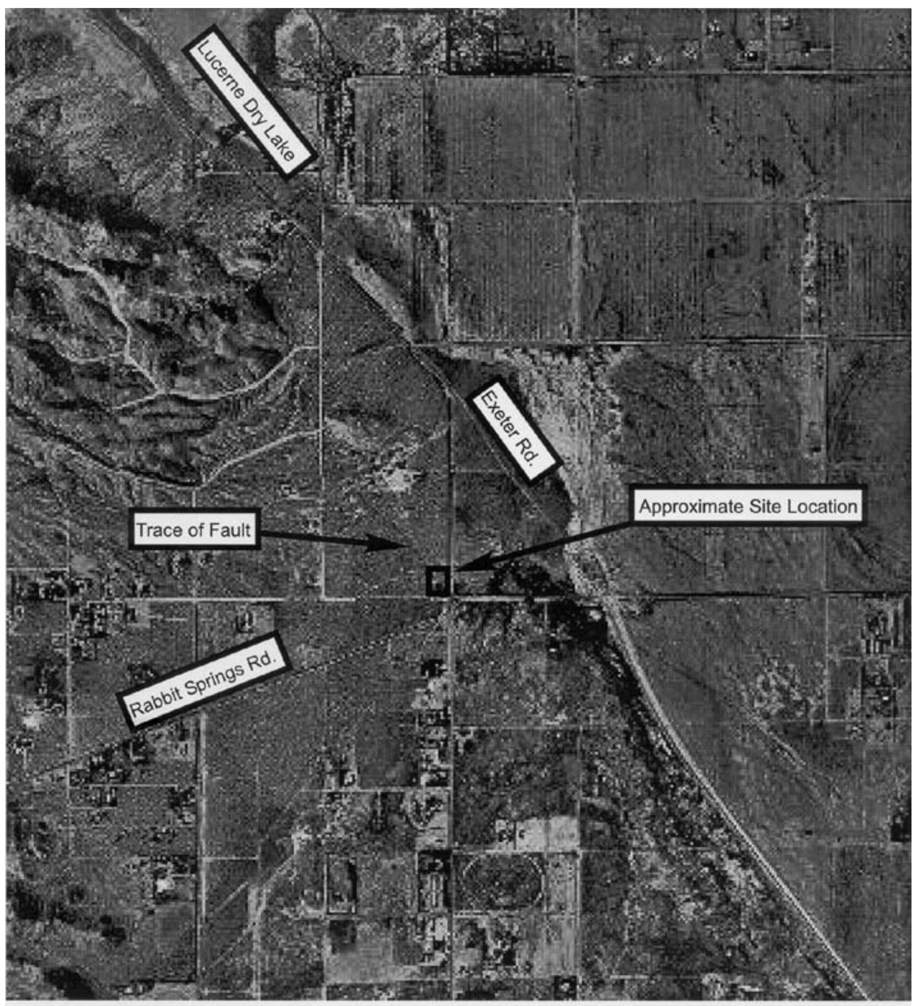

Figure 3. Aerial photograph showing trace of the Helendale fault in the Rabbit Springs area. Source: http://www.terraserver.com

crossed the scarp as opposed to being removed on the downthrown, eastern side. Furthermore, the scarp is long, linear, and parallel to the Helendale fault, a feature that would not be expected for a dump or borrow area.

Erosion and subsequent re-deposition by a stream can also be the cause of a scarp. Detailed logging of exposure did not reveal the pres3ence of any erosional features or fluvial deposits that would lead us to believe that this was the case. Another possibility is that the presence of a flowing spring along the fault caused hydroconsolidation of the fine grained sediments on the topographically lower northeastern side of the fault as water from the spring ponded in the deepening depression, thereby causing the formation of a low scarp. It is doubtful, however, that the clay of units 1 and 2 would allow substantial transfer of water, thereby allowing collapse. Furthermore, the shallow water table does not support the notion of hydroconsolidation. The fact that many of the strata associated with the spring deposits are continuous across the scarp would suggest that they were deposited prior to the formation of the scarp and were subsequently warped during its formation.

Sapping at the spring could also have removed material and thereby caused a scarp to form, but this would also have required truncation of some units northeast of the scarp, a possibility not borne out by the trench stratigraphy. We conclude from the above observations that the most likely cause of the scarp is tectonic movement on the Helendale fault.

Fracture Formation

The formation of the open fractures that are visible beneath the surface scarp are interpreted to be a result of extension as the scarp formed. Striations are visible on some of the ped faces within the fractures but appear to be randomly oriented and can be attributed to either fault movement or expansion and contraction of the clayey material. The fact that the fractures are not infilled implies that they are a relatively young feature and were not exposed to the surface during the formation of the scarp. The fractures may have formed due to differential settlement across the scarp due to the spring activity. If this is the case, then the scarp should only be present where springs have been active. In reality, the scarp is apparent for kilometers along strike of the fault.

The other most plausible explanation is that the scarp is tectonic and formed from movement on the Helendale fault. If this is the case, then the scarp should be co-linear with the fault, as it is. Furthermore, other geomorphic features indicative of active faulting should be present along the scarp if it is due to surface rupture. Analysis of stereo-paired aerial photographs shows that the scarp has formed along a very distinct vegetation lineament that joins two pressure ridges, or areas of transpressive uplift. Deflected streams are also present along this lineament.

Based on the above observations, we conclude that the scarp has formed along the surface trace of the Helendale fault and that the most likely interpretation is that the scarp is produced from tectonic movement along the fault. The absence of brittle shear in the clay is interpreted to be the result of ductile deformation within the clay rather than the actual absence of surface rupture.

Discussion

We conclude that the scarp is the direct result of movement along the Helendale fault. It is this conclusion that is important to future geotechnical studies because it provides an example of an active Holocene fault that does not display brittle shear at the depths most commonly encountered during a typical geotechnical fault evaluation. This study has shown that the absence of brittle shearing in the near surface does not necessarily preclude the presence of active (Holocene) faulting that could disrupt foundations. Consequent deformation of structures built overlying the scarp would probably have been similar whether or not the fault ruptured in a brittle fashion to the surface.

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Re-evaluation of flash flood risk following the wildfires of October 2003, using space and airborne imagery

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Virtually all parts of Southern California were touched by some aspect of the regional scale fires of October 2003. In a 10 day period, 14 people were killed and 2,232 homes destroyed as fires spread across an area in excess of 750,000 acres.[1] Much of the area burned, especially the areas of San Bernardino County along roughly 40 miles of the San Gabriel and San Bernardino mountain fronts, is extremely steep. Along these mountain fronts are numerous canyon floors having average gradients of 15 to 30 degrees and many are locally steeper. Between 6PM on December 24, 2003 and 9PM on the 25th, Devore (a residential community at the entrance to Cajon Pass) received 6.55 inches (16.63 cm) of rainfall, with a significant portion falling in a 2 hour period around 4PM on the 25th. Localized flash floods with mud and debris flows burst out from several canyons, causing significant damage to property and 16 fatalities, two more than those killed in all the October fires. Significantly, the damage along Greenwood Avenue in Devore, (figs.1-3*) resulted from discharge from a small canyon only draining a catchment area of less than 160 acres.[2] Both residents and, from their comments, local officials were stunned by the magnitude of the damage caused by runoff from this small basin. Flood risk maps existed, but risk analysis was only modeled for heavy rain on vegetated slopes, and did not anticipate total denudation by fire followed with intense rain,[3] and it appears all present planning disregards the worst credible risk of extreme rain from an El Niño on the burned mountain front.

December 25, 2003 saw a heavy winter storm saturate topsoil in a region just denuded by a virtual repeat of the November 1980 firestorm, with this rainstorm terminated by trailing thunderstorms pounding the mountain front with locally intense micro-bursts. In the 2003–04 rainfall season, the Christmas Day flood represents the major storm to date, and probably for the season. Several subsequent storms have been totally or partially deflected by high pressure systems, so the flood disaster has not been repeated—yet. As bad as this disaster seems, rainfall rates equal to or exceeding the volume measured on Dec. 24–25 were a typical daily rate measured at my home station in Devore during the El Niños of the 1990s, when Devore's annual rainfall (fig. 4)exceeded 50 inches three times in 10 years (1992–93: 70.38", 1994–95: 54.69", 1997–98: 50.17"). During these periods, winter storms typically brought six to eight inches of rain in one to two days, analogous to the Christmas Day 2003 storm, and in the Devore area during these El Niño storms, intense rainfall bursts with sustained inch+ per hour rainfall rates were common.

If the November 1980 Panorama fire is used as a model, post-fire regrowth of vegetation cannot be expected to reach sufficient density to significantly mitigate this flood risk for three to four years, and with the ongoing drought, possibly much longer. If the present drought period ends by a shift to an El Niño focused on this area, this worst case potential for flood events would mean that damage and flooding exceeding that typically associated with a 100 year storm could literally become weekly events for one to two months. The communities of Devore and Lytle Creek are in special peril, as long term studies of discharge in these areas by Southern California Edison have shown these areas to have the highest volume of runoff discharge per unit of rainfall collection area in Southern California (J. Short, SCE retired, pers. comm.). Recognizing that residential development has encroached into extensive areas adjoining 100 year floodplains, if the next few years sees the arrival of an El Niño, this will place a large number of residents in the urban foothill areas, as well as downstream low areas, in serious peril, even with the risk that residents may have neither time or route available for evacuation.

To help clarify this worst case risk model which the area may realistically face within the next two to three years, I requested a post-fire satellite image of the burn area from NASA-JPL. Dr. Robert Crippen, of the JPL Earth and Space Sciences Division, was kind enough to integrate a multi-spectral image (ASTER[4]) obtained just after the fire with a digital elevation model from Space Shuttle imaging radar to create an analglyph image showing both the burned area as well as the down slope flood risk area in 3-D (figs. 5,6). With the image having a ground resolution of 75–100 feet, detailed drainage analysis of the burn area with the emphasis on defining small basins with temporarily enhanced risk was undertaken. Comparing this with 1930s vintage air photos (fig. 7) it could easily be seen that most of the houses along Greenwood Ave. that were damaged were built in an area prone to sheet wash from a poorly channelized stream. It quickly became clear that several flood control channels are totally lacking in capacity for the present risk situation. Maps of flood hazard areas in San Bernardino, distributed by the City of San Bernardino as preparation for the 1997 El Niño, showed the 100 year flood risk areas to be basically contained by the county's flood control channel system, yet the 2003 Christmas Day flood filled several channels below Devore to capacity, even though the rainfall rate had only peaked around the 1.12 inch per hour rate, the volume of rainfall used by the U.S.G.S.[5] (OFR-03-475) to define a 25 year storm in this area. Work continues on trying to help emergency response agencies and the community understand the real possibility that repeated runoff, typically only seen with 100 year storms, will regularly happen if a major El Niño arrives in the next few years. Even failing that, Cajon Pass and Lytle Creek both have experienced local microbursts from summer storms which

* Figures for this paper are in the pocket at the end of this volume.

have produced local flash floods, from the same canyons active on Dec. 25, 2003. These floods are typically the result of monsoonal type flow of moisture left over from tropical storms, between June and mid-September, so disaster preparedness, including public education, must be ongoing all year. The extreme storm that caused the flood in Mill Creek Canyon in 1997 was such a summer thunderstorm and damage from that flood was not associated with any major burned areas.

It is unfortunate when disasters of this type occur unexpectedly, but the Christmas Day flood was a totally predictable event. The Waterman Canyon and Cable Canyon mudflows are larger scale versions, but otherwise very similar to the 1980 Harrison Canyon flash flood[6,7] that involved a basin about 1/2 mile east of Waterman Canyon. The key difference was that the Harrison Canyon flood event was preceded by what was, in 1980, the sixth rainiest period on record. In the 2003 Christmas Day flood the rainfall of that day was heavy but seasonally typical. The lack of precursor rainfall appears to have been compensated for by the larger basins that included higher elevations, which are subject to significantly higher rainfall rates. El Niño storm cycles have repeatedly occurred in the last 25 years, and rainfall data for the City of San Bernardino from 1871 to 1986 (fig. 8) show that seasonal rainfall in excess of 20 inches typically occurs at about five to seven year intervals. Devore typically receives two to three times the rainfall of San Bernardino in a typical season (fig. 9), and so it can be safely estimated that in those periods local flooding occurred. Given the well documented extent of damage associated with the winter floods of February 1980, January–February 1969, March 1938, and the winter of 1861–1862, as well as the many more frequent smaller floods, this suggests the statistical risk of a "worst case" flood in the next five years probably approaches 50%.

The ongoing failure of land use planners to appreciate the magnitude and danger of foothill floods associated with fire and deluge periods is dismaying, as we now have clear evidence the 1980 Harrison Canyon flood was not an isolated event. The eastern portion of the San Bernardino Mountains will burn in the next few years, as more than 60% of the north and east forks of the Santa Ana River and roughly 80% of the Mill Creek drainage systems are covered with dead trees and at risk for massive fire denudation. It is easy to visualize the effect of a 1997 scale thunderstorm over the same area, but with no vegetation. It appears only luck and the present prolonged drought stands between us and the next disaster.

Notes

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The Holcomb Ridge–Table Mountain fault slide: ramifications for the evolution of the San Gabriel fault into the San Andreas fault

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Abstract

The Holcomb Ridge-Table Mountain (HR-TM) fault slice in the northeastern San Gabriel Mountains is a Late Cretaceous and older igneous and metamorphic suite (IMS) structurally bounded by the modern San Andreas fault toward south and the Cajon Valley fault toward the north. Six piercing lines (lithologic contacts-thus dipping-planes) within the HR-TM fault slice correlate with an IMS in the western San Bernardino Mountains (WSBM) indicating 27 5 km of apparent right-lateral motion. The offset was accommodated by the Cajon Valley fault, which is exposed for 13 kilometers in Cajon Valley in the northeastern San Gabriel Mountains, and can be extrapolated more than 20 km parallel to the SAF toward the northwest. Age constraints on the Cajon Valley fault indicate that it was active between approximate 4.1 and 9.5 to possibly 13.5 Ma. The Cajon Valley fault was likely the northern strand of the northwestern extension of the SGF, which likely accumulated somewhere between 40 to 60 kilometers of right-lateral motion between 4.5 to 5 and 12 Ma. If the Cajon Valley fault did not accommodate all the offset attributed to the San Gabriel fault, then a "southern" strand fault bounding the southern side of the HR-TM fault slice likely existed. The southern strand may have been reactivated as it grew into the modern San Andreas fault. A paleo-reconstruction of the Cajon Valley-San Gabriel fault system is presented which requires that the San Bernardino strand of the modern San Andreas fault developed after the HR-TM fault slice had been 'removed' (~ 4 Ma), and that the late Miocene Squaw Peak-Cedar Springs fault system did not accrue several tens of kilometers of offset. Additionally, that the modern San Andreas fault as far south as Cajon Valley may have participated in the San Andreas fault system prior to activity on the San Gabriel Fault.

Introduction

Total dextral motion between the North American and Pacific Plates during the late Tertiary has primarily been accommodated by a broad zone of offshore and continental shearing on strike-slip faults, Basin and Range extension, and transrotation of crustal blocks (Dickinson and Wernicke, 1997; Hornafius et al., 1986; Luyendyk et al., 1980). Total right lateral motion between the North American and Pacific plates may be as high as 1,100 to 1,500 km during the past 30 Ma (Atwater, 1970; 1989; Stock and Molnar, 1988). The San Andreas fault system (*sensu stricto* in central California, and including the SGF system and San Francisquito-Fenner-Clemens Well system (SF-F-CW; Joseph et al., 1982; Powell, 1981; 1986; 1993) in southern California has likely contributed between 300 to 340 km of this total slip (Ehlig, 1981; 1982; Ehlig and Dillon, 1993; Graham et al., 1989; Huffman, 1972; Joseph et al., 1982; Matthews, 1973; Nilsen, 1984; Powell, 1993; Revenaugh and Reasoner, 1997; Ross, 1970; Stanley, 1987; Turner et al., 1970). For example, although the 300 km of dextral motion on the San Andreas fault north of the Transverse Ranges took place essentially across a relatively narrow zone since the early Miocene and possibly Late Eocene (Matthews, 1973; Ross, 1970), numerous strands and fault systems have accommodated the motion within and south of the Transverse Ranges in southern California during the same time period (Crowell, 1952; 1975; 1982; Ehlig, 1968; 1975; Joseph et al., 1982; 1999; Kenney and Weldon, 1996; Matti and Morton, 1993; Powell, 1981; 1986; 1993; Smith, 1977). Therefore, reconstruction of the Late Cenozoic San Andreas fault system in southern California involves estimating the timing and magnitude of slip across active strands and inactive strands which were subsequently abandoned and often truncated by younger faults. The cumulative 300 to 340 km of dextral motion on the San Andreas fault system in southern California has been distributed to principally three fault systems: 155 ± 5 km on the modern San Andreas fault during the past 4.5 Ma (Frizzel et al., 1986; Matti et al., 1986; Matti and Morton, 1993; Weldon, 1986); 40 to 60 km on the SGF system between 12-5 Ma (Crowell, 1952; 1982), 100 ± 10 km on the SF-F-CWF system likely between 18 and 13 Ma (Powell, 1981; 1986; 1993; Powell and Weldon, 1992).

A number of reconstruction models for the San Andreas fault system have proposed right lateral slip on the Cajon Valley fault and used it to provide a northern extension for the San Gabriel fault (Powell and Weldon, 1992; Matti and Morton, 1993; Powell, 1993). In these models, the entire right lateral slip of 42–44 km on the San Gabriel fault is placed on the Cajon Valley fault, which aligns similar rocks of the HR-TM fault slice with those north of the fault at Liebre Mountain (Figures 2 & 3). However, based on thin section petrographic analysis, detailed field mapping and review of data provided in published reports of basement rocks north of the San Andreas fault from the WSBM to Holcomb Ridge, the Cajon Valley fault likely accrued a total of 27 ± 5 km of right lateral offset. This value indicates that either the total right lateral offset across the San Gabriel fault was only 27 ± 5 km, or that the additional slip lies south of the HR-TM fault slice. The latter case is more likely because most estimates of total slip on the San Gabriel fault typically larger than 35 km (Crowell, 1952; 1982; see Powell, 1993, for a thorough review of slip estimates for the San Gabriel fault). The modern San Andreas fault may have followed, or reactivated this older southern fault.

Age and style of the Cajon Valley fault

The Cajon Valley fault juxtaposes crystalline basement on the south and middle Miocene sediments deposited on crystalline basement to the north, and is overlain by Pliocene to Pleistocene sediments. A minimum age constraint for the Cajon Valley fault is provided in Sheep Creek where the Pliocene to early Pleistocene Phelan Peak Formation is deposited across the fault. Magnetostratigraphy and an absolute age of an ash within the basal lacustrine member of the Phelan Peak Formation indicates that it was deposited approximately 4.1 Ma (Meisling and Weldon, 1989; Weldon et al., 1993).

A maximum age for activity on the Cajon Valley fault is indicated by the nonmarine Cajon Formation (the Cajon facies of the Punchbowl Formation of Dibblee, 1967; Foster, 1980; Noble, 1954; Woodburne and Golz, 1972) which the Cajon Valley fault offsets. Based on fossil evidence, structural relationships with other sedimentary units, and magnetistratigraphy, the Cajon Formation was likely deposited between 18 to approximately 12.8 Ma (Liu, 1988; Reynolds, 1985; Reynolds and Weldon, 1988; Woodburne and Golz, 1972). Additionally, this is suggested by the conformable contacts and similar magnitude of deformation exhibited by member units of the Cajon Formation, and that the lower half of the formation likely extended across the current trace of the San Andreas and Cajon Valley faults (Woodburne and Golz, 1972).

Woodburne and Golz (1972) suggested that the Cajon Valley fault may have been active, and with a vertical component, during deposition of member 5a (unit 1 oldest). This conclusion was based on their observation that unit 5a is wedge-shaped (alluvial fan), contains more angular clasts than is typical of the Cajon Formation, and that the clasts were dominantly composed of rocks similar to those currently exposed across the fault to the south (granodiorite gneiss and marble). However, several lines of evidence suggest that the Cajon Valley fault was not active during deposition of the majority of the Cajon Formation (members structurally above unit 5a). The crystalline basement rocks immediately south of the Cajon Valley fault do contain granodiorite gneiss and marble, however, quartzite is rare which is common in members of the Cajon Formation above unit 5a. The Cajon Valley fault truncates a NW-SE trending doubly plunging antiform equally involving all members of the Cajon Formation. Unit 5a is conformable with overlying unit 6, which is compositionally very similar to the other units of the Cajon Formation.

Additional constraints for the maximum age of the Cajon Valley fault are provided by the upper Crowder Formation which is approximately 9.5 million years old (Reynolds and Weldon, 1988). The Crowder Formation was deposited prior to activity on the Squaw Peak compressional faults in Cajon Valley (Figure 3; Meisling and Weldon, 1989). These faults have been correlated across the SAF to the Liebre Mountain faults located within and bounding the northern edge of Ridge Basin (Figure 1; Alexander and Weldon, 1987; Meisling and Weldon, 1989; Weldon et al., 1993). Activity on the Liebre Mountain fault was contemporaneous with activity on the SGF (Crowell, 1975, 1982; Ensley and Verosub, 1982). Therefore, if the Liebre Mountain thrusts in Ridge Basin correlate with the Squaw Peak thrusts of Cajon Valley, then the CVF was active after the deposition of the upper Crowder Formation dated at 9.5 Ma.

Timing and development of late Cenozoic structures and

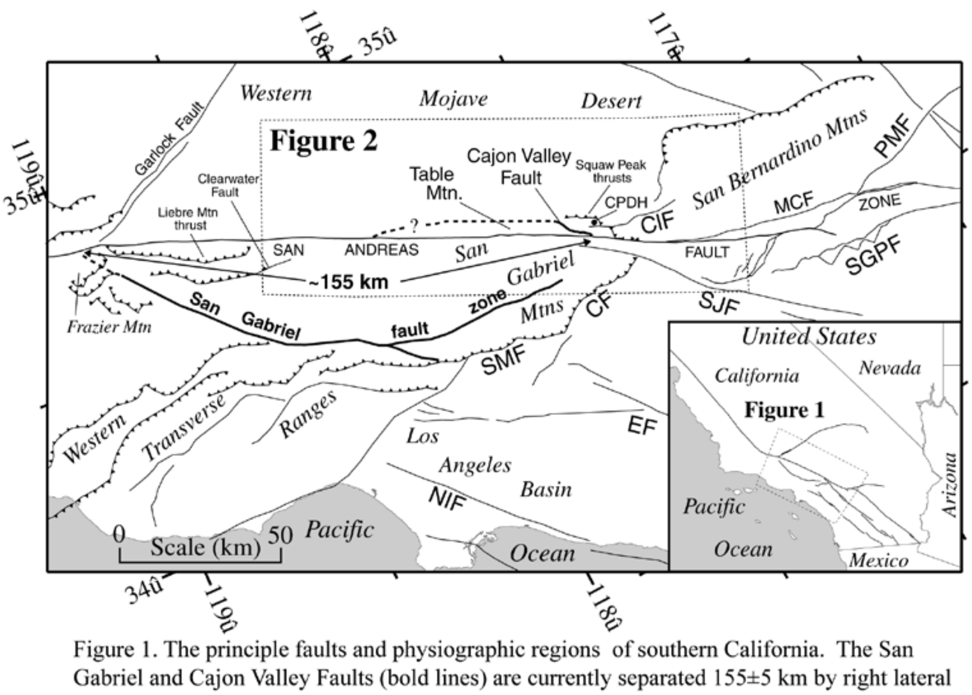

Figure 1. The principle faults and physiographic regions of southern California. The San Gabriel and Cajon Valley Faults (bold lines) are currently separated 155±5 km by right lateral displacement on the modern San Andreas Fault since 4.5-5 Ma. Gravity data and distribution of rocks types indicate that the Cajon Valley Fault continues northwest (bold dash line) beneath younger undeformed sediments to connect with the San Andreas Fault to possibly one of the faults indicated. CF, Cucamonga Fault; ClF, Cleghorn Fault; CPDH, Cajon Pass Drill-Hole; EF, Elsinore Fault; MCF, Mill Creek Fault; NIF, Newport-Inglewood Fault; PMF, Pinto Mountain Fault; SGPF, San Gorgonio Pass Fault; SJF, San Jacinto Fault; SMF, Sierra Madre Fault (figure made using GMT, 1995).

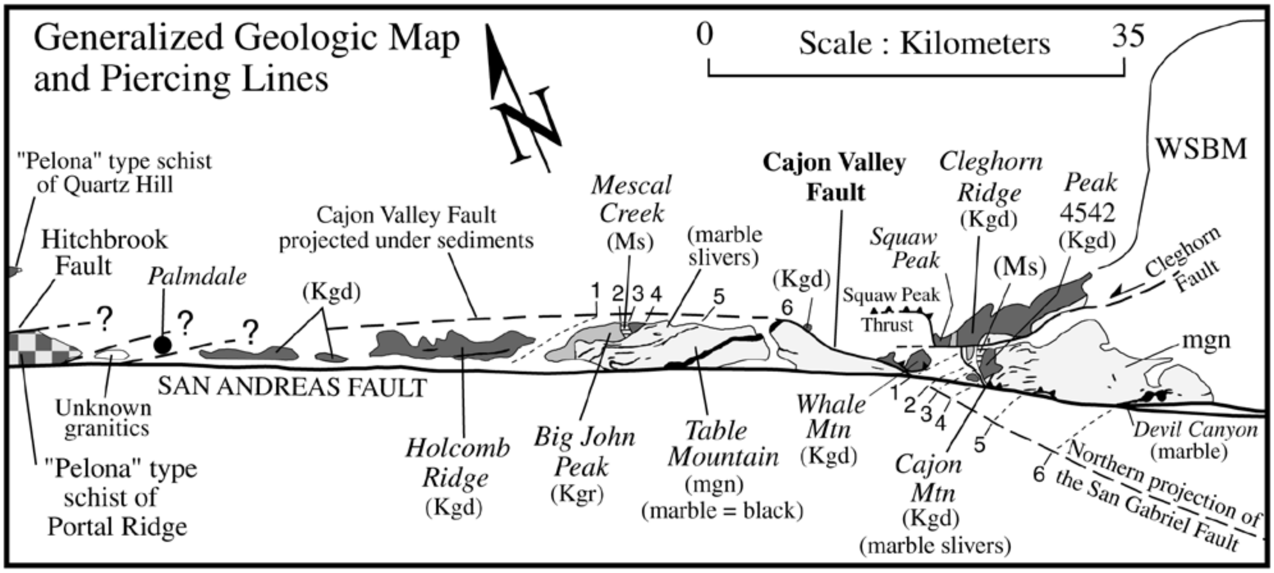

Figure 2. Geologic map of the crystalline rocks in the northeastern San Gabriel Mountains (Table Mtn) and Western San Bernardino Mountains (WSBM) which are correlated across the Cajon Valley Fault. Piercing lines 1-6 are indicated on both sides of the Cajon Valley Fault and projected by thin dashed lines if concealed by younger alluvium or projected across a fault. Kgd (dark gray) - Holcomb Ridge granodiorite; Kgr (medium gray) - Big John Peak granite; mgn (light gray) - mixed gneiss; marble (black); Ms (horizontal line pattern) - Mescal Creek metasedimentary rocks.

ages of sedimentary rocks in the Cajon Valley region, (see Weldon 1984, 1986), indicates that the Cajon Valley fault was contemporaneous with motion across the SGF, and may represent early activity on the SAF system. Matti et al. (1986) suggested that the Cajon Valley fault represented the northern extension of the SGF because the two faults align once their proposed ~160 km of right lateral slip across the modern San Andreas fault is restored (also see Frizzel et al. 1986). Alternatively, Noble (1954), Dibblee (1975), Woodburne and Golz (1972), and Foster (1980), mapped in the Cajon Valley region with an emphasis on the stratigraphy of the Miocene to Pleistocene sedimentary rocks, and indicated that the Cajon Valley fault experienced dominantly dip-slip motion. This seems unlikely, however, because 25–35 km of dip-slip motion would be required to produce the 27 km of apparent right lateral offset observed in the correlated igneous and metamorphic suite across the fault, which is not reflected in the current topography or sedimentary record.

Rock descriptions and correlated piercing lines

The geologic map of Figure 2 indicates the relative locations of the 6 piercing lines within the igneous and metamorphic suite in the HR-TM fault slice and WSBM. The rocks consist of syntectonicaly emplaced and intercalated late Cretaceous intrusives, relatively older banded (mixed) gneiss of likely late Cretaceous age, and metasedimentary strata separated dominantly by gradational contacts (Kenney, 1999; Ehlig, 1988). The mixed gneiss (mgn) consists of sections of relatively older banded gneiss dominantly composed of tonalite and granodiorite with relatively minor marble, and quartzite (paragneiss). The paragneiss is intercalated with relatively younger granodiorite intrusives (orthogniess), which were syntectonicaly emplaced. Andrew Barth (personal communication) determined a U/Pb age of 79 Ma for the relatively younger granodiorite orthogneiss.

Units of the IMS typically exhibit east-west striking foliation, axial planes, and contacts with surrounding units, all of which dip moderate to steeply northward. Thus, Piercing line 1 is structurally the highest, and Piercing line 6 is structurally deepest. The late Cretaceous plutons in HR-TM fault slice (Kgr and Kgd) and WSBM were emplaced as relatively long but narrow tabular structures most likely as a result of syntectonic emplacement. The IMS grades northward from primarily a mixed banded gneiss containing both paragneiss and orthogneiss (U/Pb date of ~79 Ma, Andrew Barth, personal communication), to dominantly late Cretaceous intrusives up section. This deeper to shallower compositional progression is also observed in the 3.5 km deep Cajon Pass drill-hole (Figure 1; Silver et al., 1988) and in the rocks of the western San Bernardino Mountains.

Piercing line 1 (Figures 2 and 3) represents the gradational and foliated contact between Titanite (sphene) hornblende biotite granodiorite (Kgd, dark gray), and leucocratic biotite granite (Kgr, medium gray). The correlation of the Kgd of Whale Mountain, Squaw Peak, western Cleghorn Ridge, and samples from the Cajon Pass drill hole has been suggested by Ehlig (1988), Silver and James (1988), and Silver et al. (1988). Silver et. al. (1988) determined Zircon and Sphene U-Th-Pb apparent ages within the range of 75 to 81 Ma for the Kgd rocks in the western San Bernardino Mountains (Whale Mountain, Squaw Peak, Silverwood

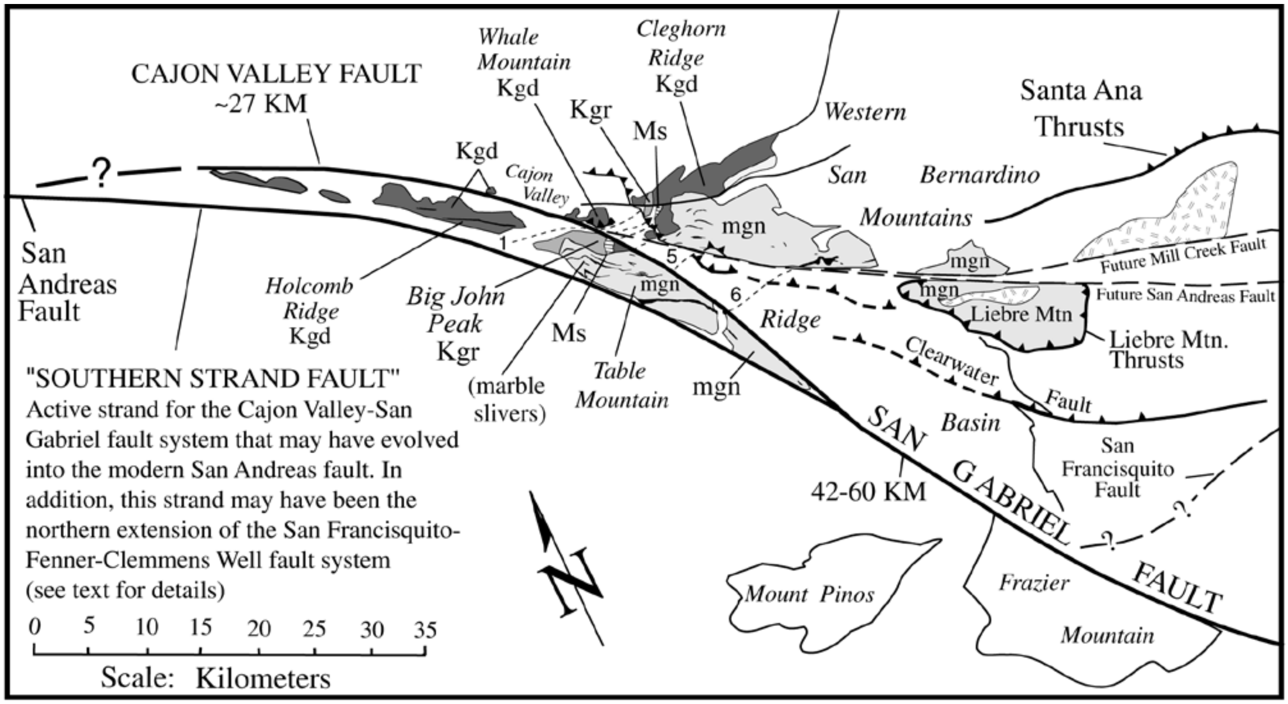

Figure 3. Reconstruction Holcomb Ridge-Table Mountain fault slice and the western San Bernardino Mountains prior to their offset on the San Gabriel, Cajon Valley and "Southern Strand" faults, which occurred between 4.1 and 9.5-12.8 Ma. Alignment of the San Gabriel fault and Cajon Valley fault is based on Matti et. al. (1986). 27 km of right lateral offset is restored on the Cajon Valley - San Gabriel fault stystem. The proposed "Southern Strand Fault" accommodates the additional slip attributed to the San Gabriel fault not observed to have occurred on the Cajon Valley fault, and may have evolved into the modern San Andreas fault. Units correlated across the Cajon Valley fault from the Holcomb Ridge-Table Mountain area to the western San Bernardnino-Cajon Valley area include: Kgd (dark gray) - Granodiorite of Holcomb Ridge, Whale Mountain, and Cleghorn Ridge; Kgr (medium gray) - Granite of Big John Peak and western end of Cleghorn Ridge; mgn (light gray) - mixed gneiss; marble (black) - marble typically in mixed gniess; Ms (horizontal line pattern) - Metasedimentary rocks. Megaporphyritic monzogranite (double stipple pattern), is correlated across the San Andreas fault (Frizzel et al., 1986).

Lake, and Cajon Pass deep borehole). All the Kgd outcrops exhibit similar appearance, composition, orientation and degree of foliation (moderate to strong), petrography (see Ross, 1972), structural position, and the existence of relatively thin transposed layers of marble and mixed gneiss (mgn, light gray in Figure 2). Petrographically, this unit contains distinctive euhedral titanite containing opaque metallic inclusions (Kenney, 1999; Ehlig, 1988; Ross, 1972). Un-deformed aplite dikes occur in the Kgd at Whale Mountain, Squaw Peak, westernmost portion of Cleghorn Ridge (Ehlig, 1988), and Holcomb Ridge (Figure 2). The dikes are more common where they structurally overlie the Kgr and uncommon in the underlying mgn. Based on structural position, relative age, and similarity of hand samples, the Kgr is the likely source for some of the aplite dikes found in the Kgd.

Kgr outcrops at Big John Peak, 0.5 km southeast of Squaw Peak, and northwest of peak 4542 (NW 1/4, section 6, Cajon 7.5 minute quad; Figure 2). Similar to the Kgd, this unit was likely emplaced as a tabular-tongue shaped pluton, which pinches out toward the east in the WSBM. Compared with other units in the IMS, the Kgr is distinctive by its low mafic content, absence of hornblende, relatively weak foliation within the pluton, homogeneity, and youngest relative age. In addition, some of the contacts between unit Kgr and surrounding units are relatively sharp and distinct as compared to contacts between other units within the IMS.

Piercing line 2 is the contact between Kgr and metasedimentary rocks (Ms, horizontal line pattern in Figure 2). In the SGM, at Big John Peak and Mescal Creek, the Ms represents a recently discovered screen ~1 km thick, which contains pyroxene and amphibole schists, quartzite, marble, and an abundant locally distinctive intercalated igneous suite (Kenney, 1999; Kenney and Weldon, 1998). In the WSBM, hand sample and reconnaissance mapping indicates that similar schist exists on the northwest slope of peak 4542 (Cajon 7.5-minute quad).

Piercing line 3 represents the contact between units Ms and Kgd, which is exposed near the mouth of Mescal Creek in the SGM, and on the western slope of peak 4542 in the WSBM.

Piercing line 4 delineates the contact between units Kgd and mixed gneiss (mgn, light gray in Figure 2).

Piercing line 5 represents a 1-2 km wide zone within the mgn (Figure 2) that contains a series of coarse grained transposed marble layers of variable thickness resulting from thickening near fold axis and thinning along fold limbs associated with the development of the gneiss and syntectonic igneous intrusions. The marble sliver zone trends EW through Mescal Creek and Table Mountain proper (Kenney, 1999; Kenney and Weldon, 1998), and identified on the SE flank of Cajon Mountain in the WSBM by mapping by the authors (unpublished) and by Dibblee (1967), Morton and Miller (1975), and Weldon (unpublished maps). Structurally below and south of piercing line 5 is a 1-2 km thick zone of mgn that contains very few marble layers, which also correlates into the WSBM.

Piercing line 6 represents a 100 to 300 meter thick coarse-grained marble layer within mgn (Figure 2). Piercing line 6 is clearly delineated across Table Mountain toward Sheep Creek in the San Gabriel Mountains, and in Devil's Canyon (Miller, 1979) in the WSBM.

Interpretation and discussion

Figure 3 represents the configuration of the San Andreas, Cajon Valley and San Gabriel faults approximately 10-12 Ma which is considered the period of time in which the SGF system likely initiated movement (see Matti and Morton, 1993). The paleogeographic map of Figure 3 indicates the alignment of the 6 piercing lines (planes) in the IMS units reconstructed across the aligned Cajon Valley and San Gabriel faults (northern extent) after 27 km of right-lateral motion is restored. It also restores ~155 km of right-lateral motion on the SAF (past 4 – 5 Ma) and 42-60 km on the SGF. In the reconstruction, the map aerial extent of Ridge Basin was not changed due to complexities regarding magnitudes of various styles of deformation within Ridge Basin. Thus, it is possible that the rocks of the HR-TM slice may have resided further toward the northeast and tucked closer to the WSBM than indicated which provides a better alignment to the piercing line data.

If the Cajon Valley fault represented the northern extension of the SGF, then either the San Gabriel fault only accrued 27 ± 5 km of right lateral offset, which is less than most estimates (60 km: Crowell, 1982; 44 km: Matti and Morton, 1993; 42 km: Powell, 1993; 38-43 km: Nourse, 2002), or the additional slip of 15-33 km was placed on a fault that lie south of the HR-TM fault slice. The southern fault must have branched off of the San Gabriel fault between the southeastern tip of the Table Mountain fault slice, and northeast of the Mount Piños and Frazier Mountain rocks which have experienced the total 300 km of offset on the San Andreas fault system (Figure 3; Powell, 1993). During motion on the proposed southern strand, Cajon Valley, and San Gabriel faults, the southern strand fault would have rotated counterclockwise and into an alignment approximating the location of the modern San Andreas fault. Therefore, the southern fault might have been reactivated or 'captured' by the modern San Andreas fault, which subsequently severed the Cajon Valley fault from the San Gabriel fault and offset them right laterally 155 5 km during the past 4-5 Ma (Figure 1).

The reconstruction indicates that the majority of offset on the Cajon Valley, San Gabriel and southern strand faults occurred prior to the development of the San Bernardino strand of the modern San Andreas fault because the rocks of the HR-TM fault slice had to be 'removed' prior to its activity (Figure 3). In addition, because the basement rocks correlate across the Squaw Peak-Cedar Springs fault system, it is likely that these faults did not accrue several tens of kilometers of offset as proposed by Meisling and Weldon (1989).

The SF-F-CWF system has been proposed to be a main strand of the early San Andreas fault system which accommodated 100+ km of right lateral offset between 18 to 17 and 13 Ma (Powell, 1981, 1993). The configuration of the rocks and faults in Figure 3 represent their location at the end of faulting on the SF-F-CWF system and initiation of the San Gabriel fault approximately 10-13 Ma (Figure 3). Reconstruction models of the San Andreas fault system (Matti and Morton, 1993; Powell, 1993; Powell and Weldon, 1992) have correlated the Mount Piños and Frazier Mountain rocks with those of the San Gabriel Mountains, which requires that the SF-F-CWF system be located northeast of these rocks, but southwest of the HR-TM slice. Therefore, the northern extension of the SF-F-CWF system needed to reside in close proximity to the northern San Gabriel and southern strand faults of Figure 3, and, thus, may have used these faults as well. This indicates that the modern San Andrea fault as far south as Cajon Valley may have participated in the SAF System during the past 18 Ma.

After motion on the Cajon Valley and modern San Andreas faults is restored, both the HR-TM fault slice and Liebre Mountain rocks were located southwest of the WSBM (Figure 3). This indicates that at ~4.5 Ma, a group of correlated terranes (IMS) were located south of the modern trace of the SAF which had not been offset by prior strike-slip faults associated with the San Andreas fault system (Figure 3). Thus, all major strike-slip faults of the SAF System needed to be located south of this group of correlated terranes prior to ~4.5 Ma and indicates that the San Bernardino strand of the modern San Andreas fault likely formed sometime during the past ~4.5 million years.

Conclusions

The revised total dextral slip for the Cajon Valley fault of 27 ± 5 km places the rocks of the HR-TM fault slice adjacent to the WSBM between approximately 4 to 12 Ma. Assuming that the Cajon Valley fault was the northern extension of the San Gabriel fault, which was first proposed by Matti et. al. (1986), structural arguments provided by the 27 km cumulative Cajon Valley fault offset indicates a number of temporal and special constrains on various faults in the region. First, that a southern strand fault likely existed along the southern boundary of the HR-TM fault slice, which we argue evolved into the modern San Andreas fault as far south as Cajon Valley. In addition, dextral faults associated with the San Andreas fault system older than the San Gabriel fault system are constrained westward of the HR-TM and WSBM rocks, which suggests that the proposed SF-F-CWF system may have also utilized the southern strand fault. This interpretation indicates that the modern San Andreas fault north of Cajon Valley may have existed for the past 17 to 18 million years, and that the San Bernardino strand of the San Andreas fault likely formed approximately 4 to 4.5 million years ago. Correlation of basement rocks across the late Tertiary Squaw Peak-Cedar Springs fault system indicate that these faults likely did not accrue several tens of kilometers of offset as proposed by Meisling and Weldon (1989).

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Abstracts from The 2004 Desert Symposium

Patterns of genetic differentiation in Mojave and Great Basin desert populations of the western fence lizard, *Sceloporus occidentalis*

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The western fence lizard, *Sceloporus occidentalis*, has a restricted distribution in the Mojave and Great Basin deserts where it is found primarily in intermediate to high mountain ranges in association with pinyon-juniper habitats. In some areas, however, the species is found associated with permanent, intermittent, and historical streambeds at relatively low elevations. Genetic differentiation between these isolated and semi-isolated populations is expected to reflect historical patterns of vicariance, however, current isolation events may be too recent to be reflected in genetic differentiation. We sampled lizards from approximately 85 isolated and semi-isolated populations throughout the Mojave and Great Basin deserts. Single lizards from each population were sequenced for approximately 900bp of the mtDNA NADH4-Serine region. Sequences differed between populations by up to 5%. Haplotypes belonged to one of four distinct and geographically non-overlapping clades: 1) eastern Great Basin (north and east of the Shepard Range); 2) Central Great Basin (from the Monitor to the Egan Range and north to the Ruby Range); 3) western Great Basin and Western Mojave (from the Avawatz Mountains to the eastern edge of the Sierra Nevada north into western Oregon and east along the Humboldt River to Elko); and 4) eastern Mojave including the Clark, Providence, Kingston (CA), and Spring Mountains (NV) plus haplotypes from the LA Basin. Patterns of differentiation within clades varied substantially with some (e.g., clade 3) indicating very recent dispersal across a broad geographic area. Levels of differentiation between clades indicate that they have been present in the region of at least 1 million years.

On the use of Weights-of-Evidence analysis for predicting the incidence of prehistoric archaeological sites in unsurveyed areas

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It is often desirable to predict the incidence of prehistoric archaeological sites in unsurveyed areas based on data derived from limited systematic surveys. A quantitative method for combining lines of evidence in support of various hypotheses has been used to prepare "predictive models" of relative prehistoric site incidence in the Antelope Valley. This quantitative method is known as Weights-of-Evidence Analysis. The Weights-of-Evidence method is a probability-based technique for mapping site incidence potential using the spatial distribution of known locations, in this case, of prehistoric evidence. A location potential map predicting the relative incidence of sites as high, medium, and low sensitivities can be generated from geological, soils, botanical, and hydrological data.

Weights-of-Evidence Analysis is based upon Bayes' Rule of Probability. Bayesian theory assigns equal probability to any number of outcomes conditional upon the actual outcome over a period of time. That is to say, Bayesian theory assumes an element of learning or teaching by the subject. In this case, the subject is a software program (ArcView GIS ARC-SDM), which has a series of training points integrated within it. More particularly Bayesian theory integrates new evidence with existing knowledge.

Paleoseismic investigation on the Pinto Mountain fault at the Oasis of Mara, Mojave Desert, California

Ana Cadena*, Pat Flanagan, Paul Smith

Preliminary results from the first paleoseismic investigation across the Pinto Mountain fault reveal evidence for at least three and probably five events in the last 14,000 years. The left-lateral Pinto Mountain fault bounds the Eastern Transverse Ranges and the Mojave Desert block of the eastern California shear zone. We excavated just west of the Oasis of Mara, along trend with a subdued Holocene scarp. A fault-perpendicular trench exposes chiefly alluvial and lacustrine deposits, as well as highly liquefied silt, sand and pebble gravel that define the main fault zone. North of the main fault zone, massive to moderately bedded holocene alluvium unconformably overlies the oldest exposed units that consist of locally tilted, highly sheared, massive to weakly-bedded, indurated silty clay, sand and pebble gravel. Analysis of stratigraphic relations in Holocene alluvium indicates two events in the northern fault zone. Strata overlying the penultimate event horizon are faulted and folded to the south in the main fault zone. South of the primary bounding fault the lowermost unit consists of silt to pebble gravel characterized by dominantly vertical, liquifaction-induced fabric. The liquefied units are juxtaposed with the indurated silty clay, sand and pebble gravel exposed to the north.

We acquired seven radiocarbon dates on detrital charcoal and peat that provide initial stratigraphic age constraints. The oldest dated unit exposed south of the main fault zone is 13,350 to 14,050 years B.P. The base of the lacustrine sediment is 9,270 to 9,500 years B.P. corresponding to the early Holocene wet period (pluvial). Events that pre-date the pluvial deposit may be constrained by further analysis of cross-cutting relations of liquified units. The pre-penultimate, penultimate, and most recent event horizons

lie stratigraphically above the lacustrine sediment, and are consequently younger than 9,500 years old. Luminescence dating methods are required to constrain the timing of these three events.

Biology implications (Pat Flanagan)

Desert naturalist Pat Flanagan is now analyzing the vegetative pattern around the Oasis of Mara. She observes that an oasis wetland formed by the fault fracture zone is dominated by salt tolerant vegetation. This pattern is reflected at the oasis and indicates that the size of the wetland (pond or lake) was at least a mile across, although no precise measurements have yet been made. In recent times there have been four distinct ponds present at the oasis. The last remaining large pond must now be supplemented by a well supply due to aquifer declines, probably from regional overdrafting.

Historical implications (Paul Smith)

Early man sites in nearby desert regions date back to 9,000 BP, at places such as Pinto Basin, Silver Lake, and Soda Lake. Early work in this area was done by William and Elizabeth Campbell and published by the Southwest Museum in the 1930s. The clear but unsubstantiated implication is that the Oasis of Mara at Twentynine Palms was a likely early man site. A long term presence has been substantiated by the large presence of artifacts.

**Geologists: Ana Cadena, Principal Investigator (Central Washington University), Charles Rubin (Central Washington University), Chris Walls (Earth Consultants International), Faten Khatib (San Diego State University), Thomas Rockwell (San Diego State University), Scott Lindvall (William Lettis and Associates), and Christopher Madden (Earth Consultants International)*

Common raven roosting behavior at the Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, California

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As human communities in California deserts have grown, common ravens (*Corvus corax*), making use of anthropogenic resources, have experienced precipitous increases. Ravens and other members of the Corvid family (crows and jays) roost nocturnally in trees, abandoned buildings, cliffs, power lines, and even on the ground amidst dense vegetation. The behavior is thought to be an adaptation for predator avoidance and to help locate food sources. At MCAGCC, common ravens have formed a nocturnal roost on power lines near the Exercise Support Base at Camp Wilson, a concern to natural resource managers on the base because aggregations of ravens may lead to increased predation pressure on juvenile desert tortoises (*Gopherus agassizii*), a federally threatened species. In addition, the roost represents a Bird Aircraft Strike Hazard (BASH) because of its proximity (< 3 km) to the Base's Expeditionary Airfield. We monitored attendance at the roost on a monthly basis from December 2002–present, examining daily and seasonal patterns of roost attendance. Monitoring efforts consisted of counting roosting ravens at 5-minute intervals as they arrived at the roost in the evening and departed in the morning. Roost attendance ranged from 53 to approximately 2100 ravens, varying significantly by season, with more ravens present in the fall and winter than in the spring and summer. Seasonal differences were consistent with other studies of Corvid roosting and may be a reflection of the birds' loyalty to nesting territories at these times of year. Alternatively, the pattern may reflect changes in human activity on the base, as Marine deployments led to suspended training activities from February until October, 2003. Results of surveys in 2004, with the resumption of normal training schedules, will determine whether roosting patterns are seasonal or are tied to Marine activities. Predictable patterns were observed in the timing of raven arrival and departure on a daily basis. Most ravens settled onto the roost by about 30-45 minutes after sunset and departed from the roost by about 30-45 minutes before sunrise. Ravens frequently passed directly over or very close to the airfield. Based on these observations, we suggest that, to avoid BASH problems, Marine pilots should be cautious during peak periods of raven arrival and departure from the roost, especially during the fall and winter months when the greatest numbers of ravens are present in the area. In addition, we suggest a region-wide effort to control raven access to human subsidies to help alleviate other problems associated with raven overpopulation, especially predation on desert tortoises.

Further observations on the Joshua tree, *Yucca brevifolia*, as a source of water for small desert mammals

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

Beginning in 1998 I noticed unusually intense browsing on Joshua tree (*Yucca brevifolia*) leaves at seven study sites in the Mojave Desert of California. In most cases browsing was confined to one or two branches of individual adult trees. Browsing was noted as high as 5 meters above the ground. In a few instances young trees under 0.5 meters in height were killed by browsing.

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

Unlike many other desert rodent groups such as the Heteromyids (kangaroo rats, pocket mice) and Cricetids (white-footed mice) known to survive in deserts without constant access to succulent foods, woodrats are dependent upon the free water found in cacti, agave, and other succulent desert plants (Schmidt-Nielsen, 1964). Over broad areas of the Mojave Desert Joshua trees are the only succulent plant present that could provide a reliable, year-round supply of moisture. Thus, the woodrat's existence in many areas may be permitted only by the local presence of Joshua trees. This dependency may be particularly critical in years of unusually low precipitation.

This research has been made possible by a grant from the Garden Club of The Desert.

Recent carbonate deposits in the Mojave Desert: Indicators of wet conditions 8000-9000 years ago

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The occurrence of stratigraphic sequences of interbedded mud, sand, and carbonate within large drainage areas in the Mojave Desert could not have formed in the climatic and hydrologic settings that exist today. Deposits at Archer Station, 11 km southeast of Cadiz, are located in the lower reaches of the 3200-km^2 Fenner Valley drainage, and those at Kelso Sands, 28 km west of Kelso, on the lower reaches of the ~1500-km^2 Kelso Wash drainage. The Archer Station deposit is 0.8+ m thick and consists of 62% massive, fine-grained silty sand with root casts of vascular plants; 33% carbonate; and 5% cross-bedded, medium-grained sand. The Kelso Sands deposit is 5+ m thick and consists of 68% massive mud; 20% silty, fine-grained sand; 10% carbonate; and <1% medium-grained, faintly cross-bedded sand. No root casts were observed in this sequence. Both deposits are capped by thick (10-25 cm), porous carbonates that contain abundant molds of plant fragments. The environment in which these fine-grained sequences were deposited must have been significantly different from the arid, coarse-grained fluvial washes that now dominant these areas. The abundant plant fossils and fine-grained sediment are like those found in a marshy wetland formed where the water table is at or near the land surface.

Diamond Tooth Lil and the tontine of fame

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Tales of Diamond Tooth Lil—usually rich in bawdy humor but lacking in historic detail—appear in stories from the Alaskan Klondike to the Florida beaches, and can be found as far away as Zimbabwe and as close to home as Death Valley's copper camp of Greenwater. Mae West's notorious portrayal of Diamond Lil in the early 1930's made an icon of this Western madam.

But what, really, do we know about Diamond Tooth Lil? Precious little. While a considerable number of women used the name Diamond Lil or Diamond Tooth Lil during the western boom years, few of them ever merit more than a brief mention in the history books. But one of them, the one who plied her trade in boom camps all over the Mojave desert, stands apart from the rest.

Perhaps it was because she lived to the ripe old age of 82, despite statistics that predicted otherwise for a woman of her profession, or that she never denied her history while her 'frail' sisters carefully hid their pasts as they grew old. Perhaps it was her long-time association with Diamondfield Jack Davis, a Nevada gunman and gold miner in the boom town of Goldfield, that made her noteworthy. Whatever the case, in her later years the woman known as Evelyn Hildegard received plenty of media coverage. But even so, her story was distorted—partially by Hildegard herself in an effort to protect her conservative family back home in Youngstown, Ohio, and partially by reporters and writers who were more interested in a good story than in the truth.

Through a variety of sources found in archives spanning several western states, as well as interviews with a rare few people who still remember her (including the nurse who recorded Lil's last words), I have pieced together the real story of Diamond Tooth Lil—the one she did not tell while she was alive. But this is not just the story of the life and times of a Death Valley madam, which is fascinating in its own right. This is also the story of the creation of a legend, of how a variety of characters combined to create that hazy icon known as Diamond Lil, a name widely recognized but a personality little known.

Tectonics of a portion of the northern Kit Fox Hills, Death Valley, California

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The Kit Fox Hills, Death Valley, California are the highest and most continuous pressure ridge formed along the Quaternary right-lateral Northern Death Valley fault zone (NDVFZ). The northern Kit Fox Hills are composed of the Quaternary–Tertiary Furnace Creek Formation, which consists of alternating beds of sandstones and mudstones with sparse breccias and tephra beds overlain by alluvial-fan deposits of four different ages. Geologic mapping and structural data identify folds with trends sub-parallel and near the NDVFZ; normal faults, found toward the northeastern margin of the hills away from the NDVFZ, have a curvilinear strike, which is consistent with simple shear deformation. The deformation of the Kit Fox Hills fits neither a simple nor a pure shear model perfectly. Structural data are consistent with low shear strength rock in the earliest stages of simple shear deformation. The Kit Fox Hills lack the right lateral Riedel shears found in the Confidence Hills of southern Death Valley; however, there are structurally similarities suggesting that a possible flower structure formed by the joining of the NDVFZ (southwest side) and an unnamed fault (northeast side) exists at depth. Several problems remain unresolved, including the trace of the folds and faults at a larger scale and the lack of information on the unnamed fault in the north.

A fresh look at Newberry Cave and its paintings

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Newberry Cave is home to some of the most unusual rock art in the Mojave Desert. Its pictographs are composed of green, red, black, white, and an undocumented color that is more blue than green. This is the only rock art site with green paint known in the Mojave Desert. In 1981, C. Alan Davis wrote his Masters thesis on Newberry Cave which helped organize and document artifacts collected from the cave by Gerald Smith's volunteer crew in the 1950s. Davis and Smith mentioned the rock art, but no complete record of the paintings has been made. There are more paintings than previously thought, many difficult to discern on blackened surfaces in the dark of the cave. Davis wrote about a green handprint that he suspected was destroyed by vandals. Subsequent papers quote this remark, but the handprint is indeed still there. Also, marked along an interior wall is a series of vertical blue lines, evenly spaced, but of varying lengths. These lines seem to have gone unnoticed and we can only speculate about their origin and purpose.

The inventory of artifacts from Newberry Cave is fascinating. It includes quartz crystals, a sheep dung pellet wrapped in sinew, sandals, a fire drill set, and pigment stones that match the pictographs on cave walls and the paint on some artifacts, and much more. These artifacts, linked with the lack of food processing features, point to ceremonial use rather than occupation of the cave according to Davis and Smith. Projectile points, split twig figurines (one with a chalcedony flake in its chest), shafts and their decorations, as well as the inventory of the artifact assemblage can be compared to those of other cave sites that have yielded split twig figurines. Such a comparison could give us more detail about the complex civilization that extended into the Mojave Desert about 1500 BC.

Electromagnetic methods used to identify fractures and unconformities in Paleozoic carbonate rock

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Noninvasive, electronic testing helps improve the efficiency and accuracy of interpreting subsurface structural geology. Graphic results from electronic tests will be shown; including mapping of magnetic gradients, earth resistance, induced polarization and time-domain pulse detection. Topographic highlands in the northern Ivanpah Range and Mescal Range are composed of fractured Paleozoic carbonate rock, and the fractures have been subject to groundwater dissolution since Pleistocene and probably Miocene time. The carbonate rocks are bounded on the east by the Clark Mountain fault, which separates the carbonates from pre-Cambrian metamorphic rocks. To the west a series of Paleozoic sediments is stacked in an older-over-younger sequence of Mesozoic thrust faults that have been disrupted by Miocene extensional tectonics. Electromagnetic tests in this fractured area have been used to help locate and map variations in magnetic and electrical gradients. The test results have been helpful in identifying fault structures, mineral locations, and subterranean vacuities.

Hell along the edge of Death Valley: lack of nourishment among the emigrant '49ers along the route from Las Vegas to the Mojave River

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In late 1849, as the California gold rush emigration approached its peak, some 3000 to 5000 anxious overland travelers concluded to turn southwest at Salt Lake City and head for the Los Angles area. These argonaughts had not reached the Great Basin until August and were fully aware of the fate of the Donner Party three years previously. It was assumed that travel could continue over this Southern Route not possible through the snow-filled Sierra Nevada Mountains. They hoped to then make their way up the California coast before the gold mining season commenced in the spring.

Unfortunately, many of these travelers did not possess sufficient provisions to make this journey comfortably. Many of these people suffered immeasurably during this ordeal, although virtually none starved to death. We will discuss their experiences, including descriptions of their diet, which was mainly the tough meat of exhausted draft animals barely alive, sometimes called "carrion." This is a fascinating story for present desert visitors to hear and try to empathize with.

Mojave River history from an upstream perspective

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Several interpretations of Mojave River history by Enzel et al. (2003) in GSA Special Paper 368 appear to lack solid evidence or realistic conceptualization. Before their geomorphic and stratigraphic interpretations are accepted, researchers working on the history of the Mojave River should consider some serious problems regarding Enzel et al.'s (2003) latest revision of Mojave River geomorphic history.

Flora of the Mojave Desert

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

Last spring Hilburn started taking digital photographs of every flower he encountered. Peggy Miles, who loves plants as well as nature as a whole, went to the works of Edmond Yeager, Milt Stark, Adrian Knute, Tom D.Whitson and Frank D.Venning. She researched the classification of the plants and pointed out the hazards of certain plants that would be of interest to people who own livestock.

Source List:

Poisonous Plants of California by Thomas C. Fuller and Elizabeth McClintock.

Plants of the East Mojave National Preserve by Adrinenne Knute

A Flower Watchers Guide to the Wild Flowers of the Western Mojave Desert by Milt Stark

Weeds of the West by Tom D.Whitson.

Wildflowers of North America by Frank D.Venning

A perspective on the recent earthquake predictions by Keilis-Borok et al. (UCLA Inst. of Geophysics and Planetary Physics)

Robert Mortimer, *Wyo. prof. geol.#1721*

Much recent interest has been generated in the press regarding the prediction of a potential M6.5 to M7.5 earthquake to strike somewhere in the area of the Mojave Desert, generally between Barstow and south of Imperial, California (Keilis-Borok, et al. UCLA press release). The area of the prediction encompasses key active portions of the San Andreas and San Jacinto faults, as well as the area of the Mojave generally including the epicenters of the Landers (M7.3), Hector Mine (M7.1), and Big Bear earthquakes. Previous evaluations have evaluated risk along several of these faults, and the combined risk of a seismic event in the predicted range just on the known active faults has been estimated by several working groups to be of the order of 50% in the next five years.

Studies of "mean time between failure" (MTBF) for these same faults suggest that several segments in the prediction area are *approaching, at* or *exceeding* their MTBF. For an earthquake prediction to be meaningful it must be sufficiently specific that the approximate magnitude, time frame, and location are sufficiently well defined that the prediction methodology can be distinguished from chance. It appears that the current prediction may be based on valid criteria, but the present level of seismic risk within the prediction area is so high that its lack of specificity undermines its credibility.

A speculative model for a trans-tensional relation between the San Andreas fault and the western San Bernardino Mountains

Robert Mortimer, *Wyo. Prof. Geol. #1721, Texas Prof. geoscientist #5026*

Landslide scars and slumping are common features throughout the San Bernardino Mountains. The southerly scarp, facing the San Andreas fault, has numerous landslide scars, as does the eastern flank, and the landslides on the north face of the mountains are "text book classic" in form. It is obvious from basic principals that when scarps of the magnitude of those around the San Bernardino Mountains are attacked by weathering, time and gravity; landslides and block slumping are to be expected. But there are some aspects of the largest scale elements of these slumps that may also be critical to differentiating processes by which the San Bernardino Mountains are being formed.

Previously (DRS 2001) it was pointed out that the mountain front between Cajon Pass and Running Springs is controlled by land sliding, with water erosion being merely a secondary geomorphic factor. Further, it was suggested that the rate of change in elevation along the skyline front of the San Bernardino Mountains, from Cajon Pass to Running Springs, is directly proportional to the distance between the San Andreas Fault and the crest of the ridge. Recent supportive evidence for this model has just become available, allowing recognition that this style of block motion also includes larger slabs moving towards the San Bernardino basin along listric faults miles wide in scale. After these were seen in 3-D SRTM synthetic aperture satellite imagery, (courtesy of R. Crippen, NASA-JPL), an examination of the literature showed some of these listric faults were mapped, but most appear to have been overlooked. Field examination clearly showed why. From the ground, most of these faults were obscured by vegetation, and they simply appear as minor topographic relief along the crest of the frontal scarp. Even where mapped, their true nature as part of a complex network of landslide scarps only becomes obvious when the entire system can be seen. Topographic profiles perpendicular to strike support the apparent offset seen on the satellite imagery.

It appears that the western portion of the range is almost wholly composed of large scale blocks that are slumping and tilting towards the un-supported scarp front above the San Andreas Fault Zone. Tectonically, this would be consistent with the adjacent portion of the Mojave crustal block being tilted to the NNE, such that the front along the San Andreas represents the uplifted end of the slab, with the San Bernardino Mountains resulting from local rotations and slumping of a detaching slice along the interface between the tilting slab and the strike slip fault. This model is fully consistent with the previously discussed relation between the crest elevation and mountain front slump zone width, resulting from differential shear across the mountain front pulling apart of the San Bernardino basin, and published COCORP results that have suggested the western portion of the range is not in isostatic equilibrium, with the mountain range, at least in the area of Cajon Pass, rootless.

Given the complex history of the front of the range prior to its uplift and deformation, it is not totally unexpected that the boundary would be prone to such slumping, reflecting the effects of adjacent blocks sliding past a thin crustal block of complex metamorphic and intrusive rocks. Shear with extension and tilting, rather than transpression, may be the predominant factor involved in the present dynamics of the western half of the San Bernardino Mountains.

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The Cryo-Genie gem pegmatite mine: a vision of gemstones for the new millennium

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Discovery of a major gem tourmaline pocket at the Cryo-Genie Pegmatite Mine, San Diego County, in September, 2001, prompted the author to suggest to the mine owner that Ground Penetrating Radar (GPR) might be a useful tool to assist in the exploration efforts at the mine. Previous investigations at other San Diego County gem pegmatite mines demonstrated the efficacy of GPR for delineating pegmatite orientation and finding gem pockets. However, not all gem pegmatites are amenable to the use of GPR. High clay contents in the overburden and wet clay seams within a dyke limits the depth of penetration and reduces the GPR signal quality. Poor understanding of the mineralization sequence and internal structure of a pegmatite hampers interpretation. Therefore, this study was undertaken to establish whether GPR would be as effective a geophysical exploration tool at the Cryo-Genie Pegmatite Mine as it has been at other San Diego County mines. So far, we have been able to discern small pockets, although the correct interpretation of larger structures is still somewhat inconclusive. As more of the pegmatite is explored, we hope to improve the geologic model and improve our interpretive skills. In any event, the amount of new gem and specimen material recovered by the Gochenour team should provide substantial material well into this new millennium.

The Cryo-Genie Mine is located in northern San Diego County, about 2 miles north-northwest of the village of Warner Springs. The locale was mentioned in the first geologic investigation of San Diego County by Blake in 1854, as part of the railroad surveys near the 32nd parallel. Blake reports lithia mica in the sediments of the canyon near *Agua Caliente*. This particular site was later prospected as the Lost Valley Truck Trail Prospect in 1904 for gem tourmaline and beryl by Bert Simmons with little success. The claim was located as the Lindy B Mine by the San Diego Mineral and Gem Society in 1962 and as the Cryo-Genie in 1974 by Bart Cannon. Since 1994, Dana Gochenour has held the claim to the mine. A complete history of the current mining operations and mineralogy is given at the Cryo-Genie Website at http://home.earthlink.net/~goke/Cryo-Genie.htm. A complete copy of this paper and a mining diary of activities in 2002 can also be found on the MSA Pegmatite Interest Group website at http://www.minsocam.org/MSA/Special/Pig/PIG_articles/PIG_articles.html.

Between 6 January, 2002 and 29 July, 2003 GPR data were collected with GSSI SIR type GPR units. A 300 MHz, central frequency, broadband antenna was selected for use on the surface and a 900 MHz antenna was used underground to provide reasonable images of the near surface region (less than 5 m). On the surface the antenna is pointed down, but underground the antenna can be pointed in any direction and is usually positioned sub-parallel to the vertical walls. This allows us to image pockets and fracture zones in or near the direction of mining.

Geologically, the majority of the pegmatite consists of a first pulse, which appears to be a high temperature orthoclase, quartz, oligoclase, schorl, and muscovite phase. Plagioclase, (oligoclase), is contained within the perthitic microcline and graphic granite of the upper 1 m and portions of the lower sections. Very little, if any, albite was observed in this upper central zone of the pegmatite. The emplacement of the second pulse brought in a lower temperature albitic phase and the initial lithium mineralization, as evidenced by graphic albite-quartz intergrowths in the bottom of several pockets and the epitaxial rim of lepidolite on muscovite. It also lifted the lower contact into the middle portion of the pegmatite and re-crystallized this biotite border zone to a schorl and garnet rich aplite band. A third pulse appears to have brought in an extremely hydrous salic, lithium, boron, beryllium, phosphate rich melt, that crystallized as the giant quartz crystals, large polychrome elbaite tourmalines, the massive compact lepidolite masses, and the montebrasite pods. A post-emplacement, probably Elsinore Shear Zone time, clay-filled fracture can generally be followed from pocket to pocket along the current main drift.

The interpreted GPR scans from the surface match very well the underlying mine workings. Both open drifts or declines and geologic features are clearly visible on the recorded scans. The scans of the underground workings are very impressive, given that we have had a 100% positive correlation with our interpretations so far. As mining progresses, and we are able to closely measure the exact distances of the working face to the anomalies, we should be able to improve the accuracy of our interpretation and complete a detailed geologic mapping of the complex features of the Cryo-Genie Pegmatite.

In our opinion, GPR is proving to be a useful geophysical prospecting tool at the Cryo-Genie Pegmatite Mine. A 3-D survey, using our current technology recording equipment, would provide a complete image of the sub-surface. The preliminary complete underground survey appears to have revealed several pocket anomalies. The GPR method was successful in finding pockets at the Himalaya Mine, and it appears that it is also successful at the Cryo-Genie.

Acknowledgements. The author would like to thank the mine owner, Dana Gochenour for the opportunity to continue our GPR research on his claim and for providing geological and mineralogical samples for analyses. Financial support was provided by the Natural Sciences and Engineering Research Council of Canada in the form of a Research Grant to my advisor at the University of Calgary, Frederick A. Cook, Ph.D., Department Geology & Geophysics.

Silver Lake Climbing Dune Local Fauna, Northeastern Mojave Desert, California

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The Silver Lake Climbing Dune Local Fauna, with diverse small vertebrates including fish, has been recovered from a climbing dune at the southeast end of Dolomite Mountain, one-quarter mile west of the western margin of Silver Lake in the northeastern Mojave Desert, California. The aeolian sand of the site is interbedded with gravels derived from adjacent bedrock ridges. The presence of aeolian sand containing the remains of tui chub (*Gila bicolor*) suggest deposition after Lake Manix had drained but when fish populations were still viable in a through-flowing Mojave River ponded at Silver Lake, perhaps between 17,000 and 10,000 years ago.

The fossil assemblage contains one fish; frog or toad; eleven reptiles; birds, two rabbits; thirteen rodents; and one deer. Some of these taxa are present locally today, while others are extra-local. *Gila bicolor* requires permanent water. Several of the terrestrial mammals live today at higher elevations in Nevada. The vertebrates represent a mixture of xeric and mesic adapted animals. The fauna of the Climbing Dune site are compared and contrasted with the Silver Lake Outlet site and late Pleistocene– Holocene habitats and taxonomic ranges. At least six species from the Climbing Dune site are extra-local, existing today only in areas of upper Sonoran habitat or transitional habitats with chaparral and juniper scrub. Two taxa may be ecologically incompatible today with the arid creosote - salt brush flats.

Age constraints on Miocene stratigraphy and volcanism the southeastern Calico Mountains, central Mojave Desert, California

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New $^{40}Ar/^{39}Ar$ dates from the southeastern Calico Mountains provide age brackets on Miocene lacustrine sedimentation and volcanism. The ~300 m thick lacustrine section in the Calico Mountains, previously correlated to the Barstow Formation in the Mud Hills (Reynolds, 2000), conformably overlies the Pickhandle Formation, is intruded by numerous andesitic domes and is capped by andesitic breccias. A dacite dome at the base of the lacustrine section near Old Borate yielded $^{40}Ar/^{39}Ar$ plateau ages of 19.13 ± 0.04 Ma and 19.15 ± 0.1 Ma on biotite and plagioclase, respectively. Clasts of this dome are present in the base of the lacustrine section, indicating that lacustrine rocks in this area are younger than ca. 19.1 Ma. A mean age of 17.0 ± 0.3 Ma (plagioclase and whole rock) on an andesite dome that clearly intrudes the upper part of the lacustrine section provides a reliable upper age limit on lacustrine sedimentation. A clast from andesite breccia that caps the lacustrine section yielded a plateau age of 17.2 ± 0.2 Ma (plagioclase). This particular breccia layer contains clasts of baked shale and was deposited on soft sediment, suggesting that lacustrine sedimentation had ended by ca. 17 Ma. South of the Calico fault, an andesite dome yielded a plateau age of 17.3 ± 0.1 Ma (plagioclase).

These new $^{40}Ar/^{39}Ar$ ages demonstrate that the lacustrine section in the Calico Mountains is distinctly older than the lacustrine section of the Barstow Formation in the Mud Hills, which is bracketed from ca. 17 Ma to 13 Ma (MacFadden et. al, 1990). In the southeastern Calico Mountains, andesitic rocks that appear to be younger than the lacustrine section cover ~10 km^2, suggesting that the area was a center of significant volcanism ca. 17 Ma. Prior to this study, it was thought that most volcanism in the Barstow area was predominantly between 24-20 Ma and had ceased by ca. 18 Ma (Glazner et. al, 2002).

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Do springs leave behind geochemical markers of drought-wet cycles in the Holocene lake record of the Great Salt Lake, Utah?

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Springs on the northern, southern, and eastern margins of the Great Salt Lake, Utah, are major contributors of total dissolved solids (TDS) to the lake. During drought periods, when the contribution from springs relative to rivers is high, concentrations of trace elements and isotope ratios from springs should increase in the lake and be incorporated into carbonate minerals, forming “drought markers” in the Holocene sedimentary record. In order to help test this hypothesis, the character and chemistry of the springs must be determined. Water samples were collected from eight cold, seven warm, and six hot springs in the vicinity of the Great Salt Lake. Temperature, pH, and TDS were measured in the field. The cold springs have a temperature range of 16-20°C (average 18°C), pH range of 7.3–7.9 (average 7.6) and TDS range of 0.9–21 ppt (average 7.6 ppt). The warm springs have a temperature range of 21–27°C (average 24°C), pH range of 7.3–9.7 (average 8.5) and TDS range of 1.9–7.5 ppt (average 3.7 ppt). The hot springs have a temperature range of 34–51°C (average 43°C), pH range of 6.3–7.3 (average 6.7), and TDS range of 4.8–31.5 ppt (average 15.1 ppt). The large ranges in temperature and TDS of the springs indicate that the hydrogeology of the springs is highly varied, even for springs that are geographically close. The highly concentrated hot springs are the most likely sources to impact the lake chemistry and leave geochemical markers during periods of drought.

A seismic gap south of the Manix fault

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The Manix fault of the eastern Mojave is a roughly east-west trending fault with a component of strike-slip motion. A compilation of aftershocks from the Hector Mine and Landers earthquakes, which had epicenters south of the Manix fault, suggest the presence of a seismic gap to the south of the Manix fault. A $M_L = 6.2$ earthquake in 1947 produced 5 to 8 cm of left-lateral displacement along approximately 6 km of the Manix fault. The epicenter of the main shock was about 2 km north of the Manix fault. In the subsequent three years, approximately 140 aftershocks occurred south of the Manix fault. The aftershocks form an alignment that is roughly perpendicular to the Manix fault and along the northern projection of the right-lateral Pisgah fault to the south. Aftershocks from the 1947 earthquake are coincident with some aftershocks from the Hector Mine and Landers earthquakes. The aftershock patterns suggest that displacement along the Manix fault accompanying the 1947 earthquake was secondary and that the earthquake and aftershocks occurred on the Pisgah fault. The northern extension of the Pisgah fault may have been reactivated during the Landers and Hector Mine earthquakes, and motion along the Pisgah fault was truncated by the Manix fault following these earthquakes.

Native Americans of the Mojave Desert: ancient migrations, surviving and expanding

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Over 5,000 years ago a group of Native Americans came from north central Mexico and migrated into the western part of the Mojave Desert. For 250 generations these people survived in the Mojave Desert. We know these migrants spoke a Uto-Aztecan Language and that some of their relatives migrated down to as far as Panama, and that a group developed into the great Aztec Empire of central Mexico. Those who came to Mojave expanded and later divided into four language groups and occupied southern Owens Valley–Indian Wells Valley, southern Sierra Nevada, Antelope Valley and the Victor Valley. Then these four groups expanded and migrated and colonized thousands of miles of what became the United States, from Catalina Island to eastern Oregon, parts of Idaho, Wyoming, Utah, most of Nevada, Colorado, northern Arizona, and expanded to become the Comanche of the southern Great Plains.

What is happening to these Native Americans today? Some groups want to come back to the desert to open casinos. Clifford J. Walker will discuss what is known about these early migrants of the desert, and what is not known, such as what kind of people were here for maybe 10,000 years before the Uto-Aztecan folks. He will cover their survival techniques, their adaptive abilities as the desert became dryer, and how it led to their expansion.