SAN BERNARDINO COUNTY
MUSEUM
ASSOCIATION

The west-central Mojave Desert:

Quaternary studies between Kramer and Afton Canyon

a special publication of the
San Bernardino County Museum Association

prepared in conjunction with the
1989 Mojave Desert Quaternary Research Center Symposium
May 19 - 21, 1989

The west-central Mojave Desert:
Quaternary studies between Kramer and Afton Canyon

compiled and edited by

Robert E. Reynolds, Division of Earth Sciences
San Bernardino County Museum, Redlands, California 92374

a special publication of the
San Bernardino County Museum Association
2024 Orange Tree Lane, Redlands, California 92374

prepared in conjunction with the
1989 Mojave Desert Quaternary Research Center Symposium
May 19 - 21, 1989

Cover. View east along Afton Canyon. The Manix Fault separates light-colored Cady Mountains gravels from darker Miocene volcanics and gravels of the Hector Formation. (R.E. Reynolds photo)

The west-central Mojave Desert: Quaternary studies between Kramer and Afton Canyon

The west-central Mojave Desert: Quaternary studies between Kramer and Afton Canyon

Field trip road log:

Robert E. Reynolds, Division of Earth Sciences, San Bernardino County Museum, Redlands CA 92374
Allan Glazner, Department of Geological Sciences, University of North Carolina, Chapel Hill NC 27599-33315
Norman Meek, Department of Geography, University of California, Los Angeles CA 90024

INTRODUCTION

This guide will lead us from the San Bernardino Valley over the Transverse Ranges and into the west-central Mojave Desert, from Victorville to Jim Grey, east of Kramer; through the Waterman Hills and Mud Hills; and along the Calico Fault and Manix Fault to Afton Canyon. Because we will follow paved roads and good graded dirt roads, the trip is passable for ordinary passenger vehicles, but be certain that you start off with a full tank of gas and adequate water for emergencies.

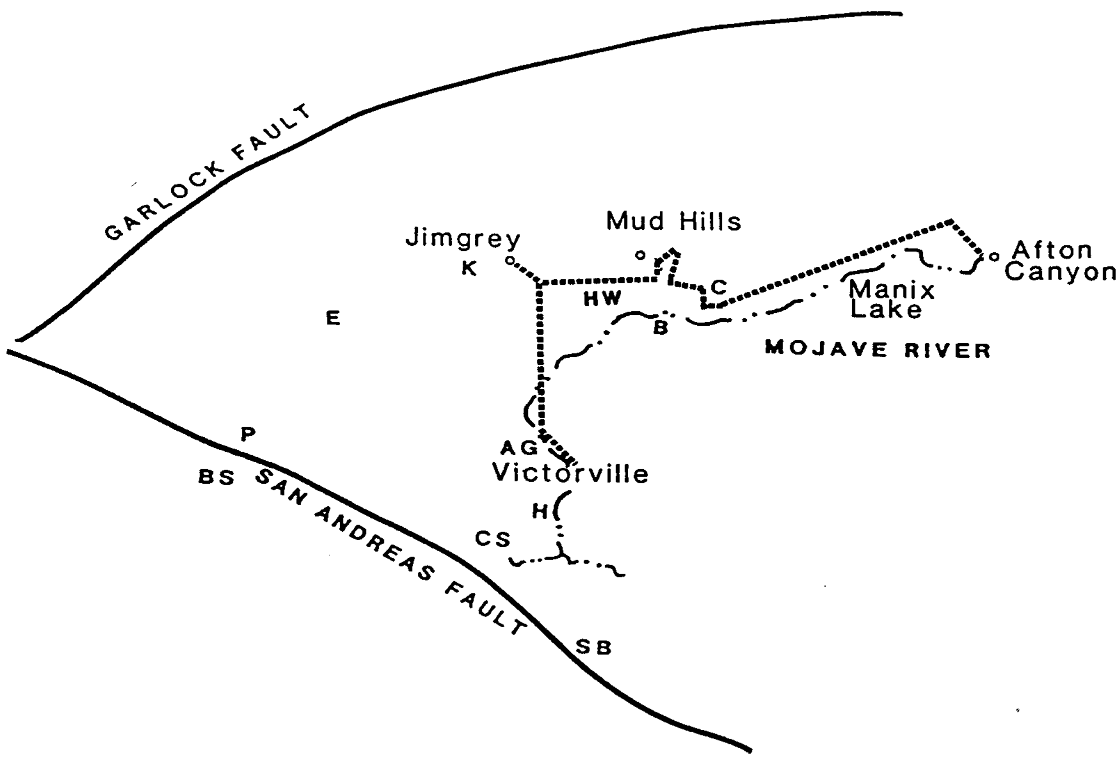


Figure 1. Field Trip Route Map. The route is from the San Bernardino County Museum to Victorville, north on Harper Lake Rd, west on Hwy 58 to Jimgrey Playa, east on Hwy 58 and Irwin Rd to Waterman Hills, Mud Hills, and past Calico Ghost Town to I-15. Traveling east on I-15, exit at Afton Rd and travel midway through Afton Canyon. Letters refer to localities discussed in text: AG = Adelanto/George AFB; B = Barstow; BS = Barrel Springs; C = Calico Ghost Town; CS = Cajon Summit; E = Edwards AFB; HW = Hawes; H = Helendale; K = Kramer; P = Palmdale; SB = San Bernardino.

Leaving the San Bernardino Valley, we will pass through Cajon Pass. Areas of interest are noted in the guide; for a more complete tour, see Geological investigations along Interstate 15, Cajon Pass to Manix Lake (Reynolds, 1985). The Transverse Ranges are an integral part of the Quaternary history of the west-central Mojave Desert; not until the mountains were uplifted in late Tertiary times did the Quaternary and recent topography of the desert take form. Once in the Mojave Desert, we will visit localities that have provided specific evidence for the theories surrounding its Pleistocene geography, geology, and paleoenvironment. Many of these areas are discussed in special papers published in this volume. Allan Glazner provided information for the road log for the Waterman Hills segment; Norman Meek provided data for the Afton Canyon segment. This guide was prepared for the 1989 Mojave Desert Quaternary Research Symposium, May 19-21 at the San Bernardino County Museum in Redlands. Abstracts of the Proceedings of this meeting have been published as a San Bernardino County Museum Association Quarterly (1989).

MILEAGE LOG

00.0	(0.0)	LEAVE the parking lot of the San Bernardino County Museum, turn west (right) on Orange Tree Lane to California Street; turn south (left) on California.
00.3	(0.3)	ENTER I-10 freeway west using the California Street onramp, heading toward Los Angeles.
02.5	(2.2)	We are crossing the trace of the Loma Linda Fault between the Tippecanoe/Anderson offramp and the Waterman offramp (Bortugno and Spittler, 1986). Prepare to turn off I-10 and enter I-215 to the right, following the signs to Barstow.
03.7	(1.2)	TURN ONTO I-215 toward Barstow and go north. We are crossing the trace of the San Jacinto Fault at the interchange of I-215 and I-10. The fault runs northwest to Lytle Creek (Ehlig, 1975; Elders, 1973; Morton, 1975; Rogers, 1967; Sharp, 1972) west of Cajon Pass. Cajon Pass is the low point on the horizon to the northwest.
8.0	(4.3)	At Baseline, look due east to see Mount San Bernardino (elevation 10,624'). South of Mt. San Bernardino is Mt. San Gorgonio, at elevation 11,502' the highest peak in southern California.
9.5	(1.5)	At Highland Avenue, look northwest to see Cucamonga Peak, elevation 8,859'; Mt. San Antonio (Mt. Baldy) is behind it at an elevation of 10,084'. Left-lateral movement along the San Andreas Fault caused the San Gabriel Mountains to move northwesterly relative to the San Bernardino Mountains; the steep southern face of the San Bernardino Mountains is a reflection of the shearing movement of the San Gabriel Mountains along the fault.
11.6	(2.1)	At State University Parkway, the hills on the east (right) are the Shandin Hills of Mesozoic Pelona Schist; the highest point is Little Mountain. They, and the low hills to the north, are on the uplifted side of Barrier K (Wiggins Hill) Fault, which lies northeast of and parallel to the freeway (Dutcher and Garrett, 1963; Eckis, 1934; Morton, 1976).
14.3	(2.7)	Cross the trace of Barrier K Fault at the Palm Avenue/Kendall Drive offramp. The fault thrusts Pelona Schist over older (Pleistocene?) alluvium and creates a groundwater barrier (Dutcher and Garrett, 1963).
15.3	(1.0)	To the northeast (right), the trace of the San Andreas Fault is above the red hills at the upper edge of the terrace.

17.3	(2.0)	Devore. Glen Helen Regional Park is to the west; the Glen Helen Fault (Sharp, 1975) parallels the San Andreas Fault and the freeway. Springs rise along the fault at the Regional Park.
18.7	(1.4)	Junction of I-215 and I-15.
21.8	(3.1)	The view west (left) from the crest on I-15 is along Lone Pine Canyon, the San Andreas Fault rift zone. Lost Lake is a sag pond developed on the fault trace (Crowell, 1975; Dibblee, 1980a; Weldon, 1983; Weldon and Sieh, 1984).
22.7	(1.9)	Quaternary gravels exposed in the gravel pit to the east are about 40 m thick and were deposited between 14,400 and 12,400 years before present (BP)(Weldon, 1986).
24.3	(1.6)	The freeway follows the trace of the Cleghorn Fault from the Cleghorn offramp to the junction of Highway 138 (Weldon and others, 1981).
25.2	(0.9)	Highway 138 offramp; continue on I-15. Squaw Peak is at the northeast corner of the intersection. The Squaw Peak Fault runs west from the peak and separates the Cajon Formation (west) from the Crowder Formation (east).
27.5	(2.3)	Cross the trace of the Squaw Peak Fault. Inface bluffs were formed by the headward erosion of Cajon Creek capturing streams that once ran northward from the San Gabriel Mountains.
28.5	(1.0)	The alternating coarse gravels and red-brown paleosols to the left are the Phelan Peak Formation (Weldon, 1985; Meisling and Weldon, 1989); the last of the paleosols marks its top. In Cajon Basin the Phelan Peak Formation represents the first evidence of halting of the drainage southwest from the Mojave Desert and the start of ponding and then erosion that suggests the first uplift of the San Bernardino Mountains, approximately 4 million years BP (Foster, 1980a, 1980b, 1982; Weldon, 1985). Other sedimentary evidence for the age of uplift in the San Bernardino Mountains is presented in Dibblee (1975), May and Repenning (1982), Meisling and Weldon (1982, 1989), Neville and Chambers (1982), Sadler (1982a, 1982b), and Strathouse (1982).
28.9	(0.4)	The Phelan Peak Formation is overlain by the middle Pleistocene Shoemaker Gravels (Weldon, 1985).
30.4	(1.5)	Cajon Summit, elevation 4,190'. To the west, across the freeway, the Summit Safety site (SBCM 01.103.080) yielded Pleistocene fossils of probable late Irvingtonian Land Mammal Age (see Reynolds, 1985b and herein). The Brunhes/Matuyama magnetic reversal event, 700,000 BP, has been identified in the underlying Shoemaker Gravels (Meisling and Weldon, 1989; Harland and others, 1982).
30.7	(0.4)	View west (left) of beheaded drainage that ran northeast across fans during Pleistocene times.
33.6	(2.9)	Intersection of Highway 395.
39.8	(6.2)	Bear Valley Road. Six miles east of the freeway along Bear Valley Road is Hesperia Road. Several localities along Hesperia Road have produced Irvingtonian Land Mammal Age (LMA) faunas in sediments mapped by Power (herein). Faunas are discussed by Reynolds (herein). Sigmodon sp., the cotton rat, was recovered from Irvingtonian LMA deposits on Hesperia Road (Reynolds, 1987a).

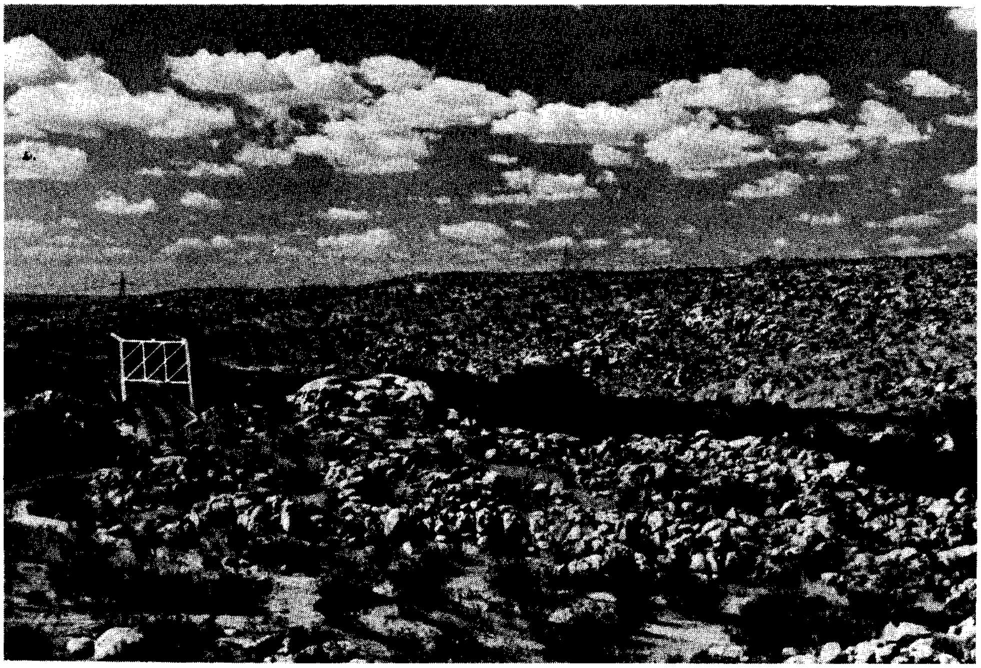


Figure 2. Pediment developed on granitic rocks at the Lower Narrows of the Mojave River, north of Victorville on National Trails Highway. Pleistocene sediments are to the west. (Milepost 47.2) (R.E. Reynolds photo)

Figure 3. A thick Pleistocene section is west of the Mojave River. (Milepost 55.0) (photo courtesy of Harris Aerial Services, Yermo)

Since Cajon Summit, we have been in the Victorville Fan Complex (Meisling and Weldon, 1989). These Pleistocene conglomerates reflect the accelerated uplift of the San Bernardino Mountains and the movement of the San Gabriel Mountains past the San Bernardino Mountains along the San Andreas Fault. The fan complex was derived from the Transverse Ranges as a result of uplift of the mountains and was accompanied by a change in drainage northerly into the Mojave Desert. Uplift of the San Bernardino Mountains began less than 9 million years BP (Weldon, 1985). A change in depositional regime that began approximately 4 million BP is seen in the Phelan Peak Formation. Northeastward deposition was in progress in the upper Phelan Peak Formation about 2 million years BP (Reynolds, 1985a; Weldon, personal communication to author, 1985). Upwarping on the northeast side of the San Andreas Fault may have been accompanied by filling of the Victorville Basin with shallow lake and pond sediments (see Power, herein).

44.5	**(4.7)**	Mojave Drive offramp. Light-colored sediments are exposed in road cuts to the left for one-half mile from this point to milepost 46.2. These sediments represent lake or pond horizons (Power, herein).
45.2	**(0.7)**	Prepare to exit freeway at Oro Grande/Silver Lakes exit.
45.5	**(0.3)**	EXIT on D Street offramp to Oro Grande/Silver Lakes; as you go down the offramp, notice granitic outcrops to the east. TURN LEFT and go under the freeway.
46.0	**(0.5)**	TURN NORTH (left) onto National Trails Highway, proceed north.
46.2	**(0.2)**	The bluffs on the west are Pleistocene sediments consisting of fairly well sorted sands and gravels interfingering with light-colored, sometimes tuffaceous lacustrine sediments (Bowen, 1954; Power, herein).
47.2	**(1.0)**	Note pediment (Bowen, 1954) at 2:00 to the northeast. Very few Pleistocene sediments remain on the east side of the Mojave River in this area, in contrast to significant thicknesses of the Pleistocene section on the west side of the river (Figs 2,3).
47.8	**(0.6)**	Air Base Road leads to the Adelanto/George faunas discussed by Reynolds (herein). Continue on National Old Trails Highway.
48.4	**(0.6)**	Cross the Mojave River at the Lower Narrows. The west side of the river has a thick section of relatively undissected Pleistocene sediments.
51.3	**(2.9)**	Past the town of Oro Grande, go under the railroad bridge. The entrance to the Riverside Cement Company is just east of the underpass.
54.4	**(3.1)**	View at 10:00 of bluffs on west side of the river, showing sedimentary section with white lacustrine sediments overlain by red soil horizons.
56.2	**(1.8)**	View at 10:00 of unconformity in sediments on the west side of the Mojave River.
60.0	**(4.8)**	TURN LEFT onto Vista Road (sign reads "to Silver Lakes") just past the Helendale Market.
60.2	**(0.2)**	Cross railroad tracks and bear north (right) on Vista Road.

60.7	**(0.5)**	Bear west (left) on Vista Road, again crossing the Mojave River.
61.1	**(0.4)**	TURN RIGHT onto Helendale Road at its intersection with Vista Road.
62.0	**(0.9)**	The Vitrlite Quarries appear as white sediments on the horizon at 2:00, to the northeast.
62.9	**(0.9)**	TURN RIGHT onto Wild Road.
63.4	**(0.5)**	Road (temporarily named Smithson Road) continues but turns left (north). The trace of the Helendale Fault is at this bend to the north; the fault runs southeast-northwest (Aksoy and others, 1986). Lacustrine sediments are mapped as being on both sides of the Helendale Fault (Bowen, 1954; Rogers, 1967).
64.2	**(0.8)**	Road is renamed Wild Road again as turns easterly.
64.8	**(0.6)**	Road turns northeasterly
65.0	**(0.2)**	Road turns easterly.
65.1	**(0.1)**	TURN LEFT onto dirt track and drive north 0.2 miles to Vitrlite Quarry.
65.3	**(0.2)**	PARK at the Vitrlite Marl Quarry.

STOP 1. The Vitrlite Marl Deposits of the Mojave Marl Company were active in the late 1920s and the 1930s (Bowen, 1954; Wright and others, 1953). Fanglomerates thin rapidly to the north and give way to and are overlain by a section of green and brown marly lacustrine siltstones which in turn give way to pinkish marly playa siltstones with locally thick, dense layers of lake tufa and bedded lacustrine opalite, perhaps derived from tuffs. Quarrying at this site mined the lacustrine limestone for use as soil additives.

The sedimentary sequence, from the base of the section, includes brown playa silts and marls interfingered with sands and river channel conglomerates. The sequence is overlain by gray silts and a 14-foot thick sequence of white siliceous marl. These lie on the southwest side of the Helendale Fault (Bowen, 1954; Bortugno and Spittler, 1987).

RETURN to Wild Road. As you drive back down the dirt road, the view southeast is along the trace of the Helendale Fault toward Lucerne Valley (Aksoy and others, 1986). The fault passes through the saddle on the horizon. Stoddard Mountain is at 11:00; Ord Mountain at 10:00 (Fig. 4). Wood rat (<u>Neotoma</u> sp.) middens from the Ord Mountain area provide evidence that pinon pine and juniper survived here until 7,800 BP (King, 1976; Weber, 1963).

65.5	**(0.2)**	TURN RIGHT (westerly) onto Wild Road; return to Helendale Road (which, at or near this junction, is renamed Harper Lake Road).
67.6	**(2.1)**	TURN RIGHT (north) at the stop sign and follow Helendale (Harper Lake) Road north. Pavement will eventually become good graded dirt surface.
69.6	**(2.0)**	Cross from fine-grained orange fluviatile sediments into white lacustrine sediments that we saw at the Vitrlite Quarry.
70.2	**(0.6)**	View at 11:00 of lacustrine sediments that appear to dip to the southeast; at 10:00 they appear to dip to the southwest. This suggests the presence of an anticlinal structure.

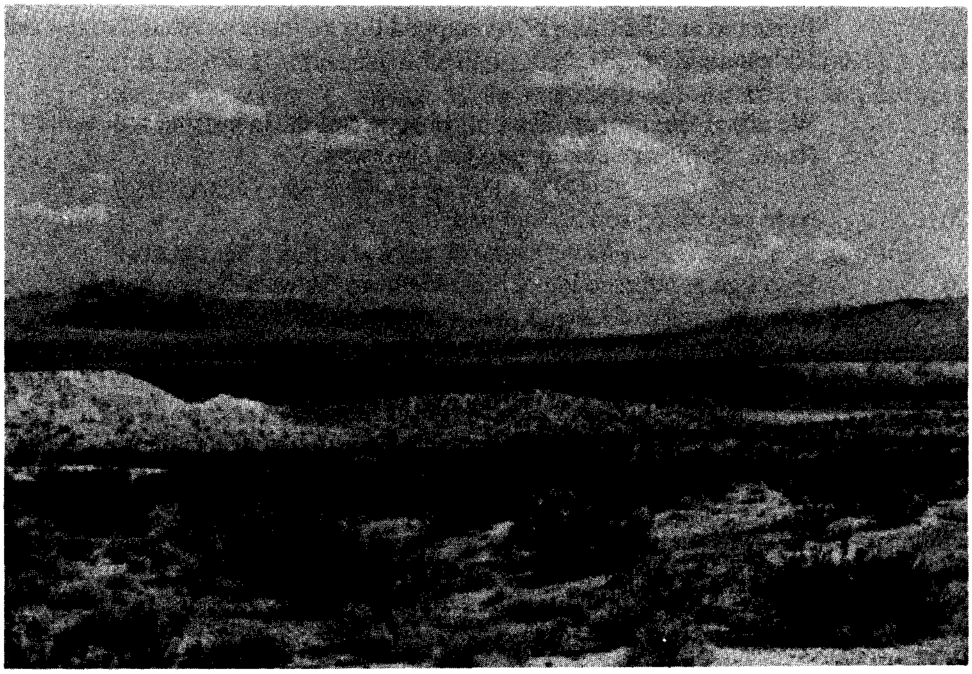


Figure 4. View southeast toward Lucerne Valley along trace of the Helendale Fault. The fault passes through the white Vitrlite marl beds in foreground. (Milepost 65.3) (R.E. Reynolds photo)

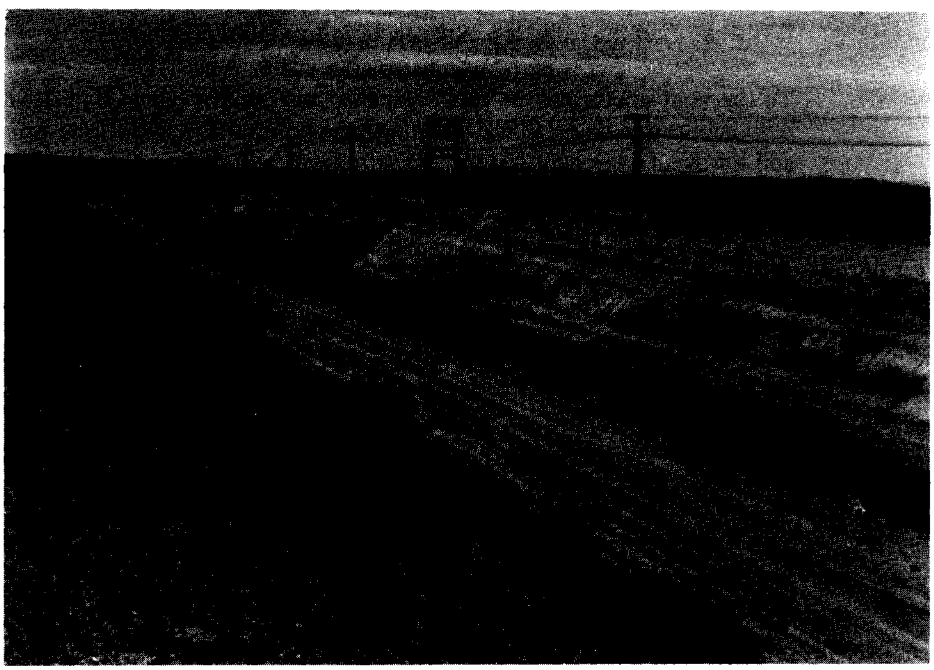


Figure 5. Portions of the west-central Mojave Desert are characterized by relatively flat erosional surfaces and well-developed soil profiles, as exposed here in the railroad cut at Jimgrey. (Milepost 86.7) (R.E. Reynolds photo)

Bortugno and Spittler (1986) mapped this anticline as related to the axis of the Helendale Fault.

72.8 (2.6) We are at the northern limit of exposures of the lacustrine sediments along Harper Lake Road. Sediments continue to the northwest.

75.1 (2.3) Note calichified soil in road bed.

78.4 (3.3) Stop sign at intersection of State Highway 58; we will turn west (left). At 10:30 see Red Mountain, east of Johannesburg. The pointed peak at 11:00 is Fremont Peak. The Gravel Hills are the light-colored deposits between Fremont Peak and Black Canyon. Black Canyon cuts the basalt flows of Black Mountain at 1:00 (Dibblee, 1968). Fossil Canyon and the Barstow Fossil Beds can be seen at 2:00.

TURN NORTH (left) and proceed on Highway 58.

85.5 (7.1) TURN RIGHT onto Jim Grey playa, located on the west (down) side of a fault that may relate the Helendale Fault to the Lockhard Fault (Bortugno and Spittler, 1986). Drive along the edge of the playa to a dirt road leading from the northeast edge of the playa toward the railroad tracks.

86.0 (0.5) TURN onto dirt road leading east at north edge of the playa.

86.3 (0.3) TURN LEFT toward railroad, crossing an old railroad grade; TURN LEFT on the railroad frontage road.

86.7 (0.4) PARK at a high point along the railroad frontage road.
STOP 2. Soil horizons are exposed in railroad cut (Fig. 5).

To the west-northwest the Luz Solar Site mirrors are visible slightly southerly of a line between us and Saddleback Butte. At the Kramer Junction Solar Site, deeply-weathered soil horizons were exposed by excavation. A fauna of presumed Irvingtonian land mammal age was recovered during excavation within thick, well-developed soil horizons (Reynolds, 1987b).

Further west along Highway 58 the Mojave Cogeneration Site is being constructed at Boron. On Edwards Air Force Base, southeast of Boron, older Pleistocene sandstones and fanglomerates occur on slopes of low ridges above elevation 2325' such as Leuhman Ridge. These sediments yield assemblages of vertebrate fossils of middle Pleistocene Irvingtonian Land Mammal Age (Reynolds, 1988b and herein). Sediments of Lake Thompson deposited below its high stand of 2325' contain a late Pleistocene assemblage (Jefferson, herein).

The Kramer Hills are to the south and southwest. The Kramer Hills contain sediments of late middle Miocene age which are probably the same age as those exposed in the Boron Open Pit mine which yielded the Boron Local Fauna of Hemingfordian land mammal age (Whistler, 1985). Dokka and Baksi (herein) discuss the age of the Kramer Hills.

The railroad cut, at elevation 2400', exposes about 8 feet of deeply-weathered brown arkosic sediments with a calcareous cap. The well-developed soils may be correlative with the Tylerhorse sequence described by Ponti (1985) in the Antelope Basin near Palmdale, to the southwest.

It is notable that these middle Pleistocene soil horizons are visible in artificial cuts rather than in outcrops. This suggests that tectonism and related erosion has been limited in the western Mojave Desert since the middle Pleistocene.

RETRACE route to Highway 58.

87.5	**(0.8)**	TURN LEFT onto Highway 58 after checking carefully for cross-traffic.
95.0	**(7.5)**	Intersection of Harper Lake Road. Continue east on Highway 58.
98.9	**(3.9)**	The Hawes paleontologic localities are located one-half mile south of the highway. White sands and greenish-gray silty sands were exposed during excavation for the All American Pipeline which yielded a vertebrate assemblage including one Irvingtonian taxon (Reynolds, 1988a and herein).
103.1	**(4.2)**	Intersection of Hinkley Road at the trace of the Lenwood/Lockhart Fault. Continue along Highway 58.
105.0	**(1.9)**	Sommerset Road intersection.
107.0	**(2.0)**	Lenwood Road. Continue on Highway 58. To the south-southeast on both sides of the highway, the Lenwood Anticline exposes a sequence of fluviatile sediments with soil horizons grading upward into tuffaceous lacustrine sediments, playa sediments, and playa silts.
111.0	**(4.0)**	Waterman Gneiss crops out on the north (left).
113.0	**(2.0)**	TURN LEFT at the intersection of Irwin Road.
113.1	**(0.1)**	Highway 58 goes east; we go north on Irwin Road.
114.3	**(1.2)**	As we drive north, up the fan, the Waterman Hills and the Mitchel Range loom prominently in the foreground. The reddish area in the Waterman Hills, at 12 o'clock, is the Waterman Mine (Stop 4 of Glazner et al., 1988). The near base of the Mitchel Range, at 12 to 3 o'clock, is bounded by the northwest-trending, right-lateral Harper Lake-Gravel Hills fault system (Dibblee, 1960, 1968, 1970). This fault forms a prominent topographic linear along the southwestern margins of the Mitchel Range, Waterman Hills, and Gravel Hills. Although direct evidence of right-lateral movement on this fault is lacking, fold axes in metamorphic rocks of the Hinkley Hills and Mitchel Range are bent in a right-lateral sense (Dibblee, 1960, 1970). Dibblee (1961) showed that prominent northwest-striking faults in the Mojave Desert are dominantly right-lateral strike-slip faults. The age of this fault system is not well constrained. Geomorphic evidence such as the fault scarp in front of you indicates that many of the northwest-trending faults are currently active, and there is no evidence that they were active during early or middle Miocene time. A careful sedimentologic study of middle Miocene rocks in the Barstow basin, to our north, might provide information that could be used to constrain the age of inception of faulting in this area.
115.0	**(0.7)**	SLOW DOWN through curves in road.

As we head into the pass between the Mitchel Range (to the right) and the Waterman Hills (to the left), the character of the Waterman Gneiss is better shown. The greenish, layered rocks are dominantly chloritic gneisses. Foliation strikes northeast but has quite variable dips. Prominent white bands are layers of felsite (variably mylonitic) and marble within the gneiss.

116.8 (1.8) TURN LEFT onto the prominent graded dirt road that leads to the microwave towers. Drive 1.7 miles to the parking area at the bend in a sharp switchback, and park.

118.5 (1.7) PARK at base of steep driveway to microwave towers.
STOP 3. Waterman Hills detachment fault (WHDF) at the summit of the Waterman Hills. We will view spectacular exposures showing Tertiary faulting that resulted in profound structural changes influencing Quaternary topography.

The objectives of this stop are: (1) to see outstanding exposures of the WHDF; (2) to study the progressive development of lineation and mylonitization in footwall granodiorite as we approach the fault; (3) to see brittle overprinting of ductile fabrics in footwall rocks; (4) to see cataclasis and intense hydrothermal alteration of hanging-wall rhyolites near the WHDF.

At this parking area we are standing on intensely shattered rhyolite in the hanging wall of the WHDF. The rhyolite under our feet is only a few meters thick; below it are mylonites developed in granodiorite of the footwall. These mylonites are well exposed in the fenster in front of you. The WHDF rings the fenster and is easily recognized by its juxtaposition of dark red to buff rhyolites with bright green mylonites (Fig. 6). Mylonite within the fenster is badly altered and resembles fault gouge. Rhyolite immediately above the fault is cut by numerous low-angle shears that are subparallel to the main fault, as is mylonite a short distance below the fault.

Upper-plate rocks of the WHDF are everywhere 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. Potassic alteration results in partial to total replacement of plagioclase by adularia, pervasive oxidation, and widespread shattering. All these features are evident in rhyolites around the parking area. Oxidation imparts a distinctive dark-red color to the rhyolite lavas and plugs. Lithic tuffs in the upper plate of the WHDF are also highly metasomatized, in sharp contrast to lithologically similar tuffs in the Mud Hills (Walker et al., submitted).

It is apparent from this location that the WHDF is a complex, corrugated surface. The portion of the fault exposed around the fenster dips to the south at about 20°. At the parking area the fault surface is relatively horizontal, but the parking area is a culmination from which the fault surface dips in all directions. It is not clear if this corrugation reflects original irregularities in the fault surface, or resulted from folding of an initially planar surface. Because S-C fabrics indicate top-to-northeast shear, the fault surface initially must have dipped to the northeast.

The rhyolite that underlies the towers was intruded into sedimentary rocks now exposed on the eastern side of this set of hills. Considerable slip on the WHDF is implied by the observation that nowhere in the area are rhyolite dikes or plugs seen intruding footwall granodiorite or gneiss. We infer that the bodies of these "decorpitated" plugs lie somewhere under the vast sea of alluvium to the southwest.

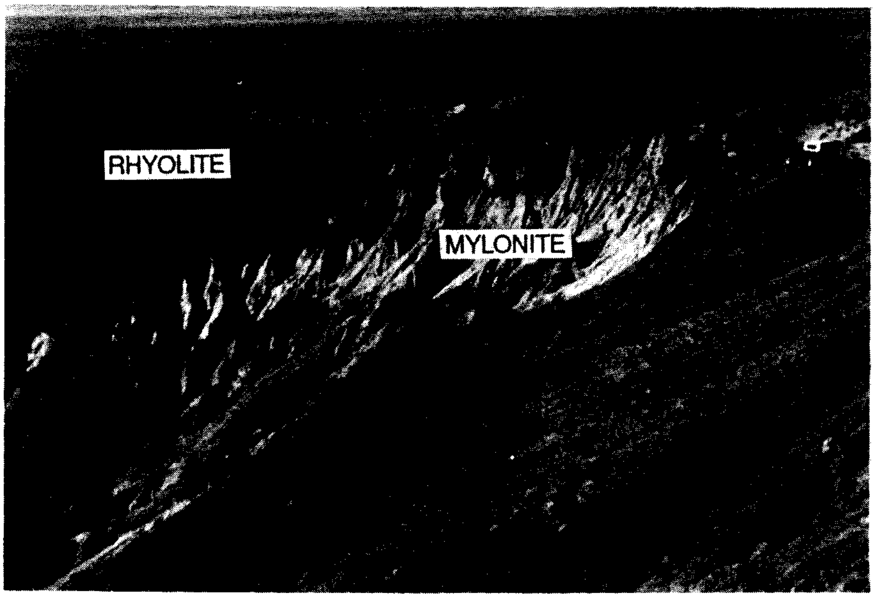


Figure 6a. The Waterman Hills Detachment Fault juxtaposes dark red to buff rhyolites (above the fault) with green mylonites (below the fault). (Milepost 18.5) (A.F. Glazner photo)

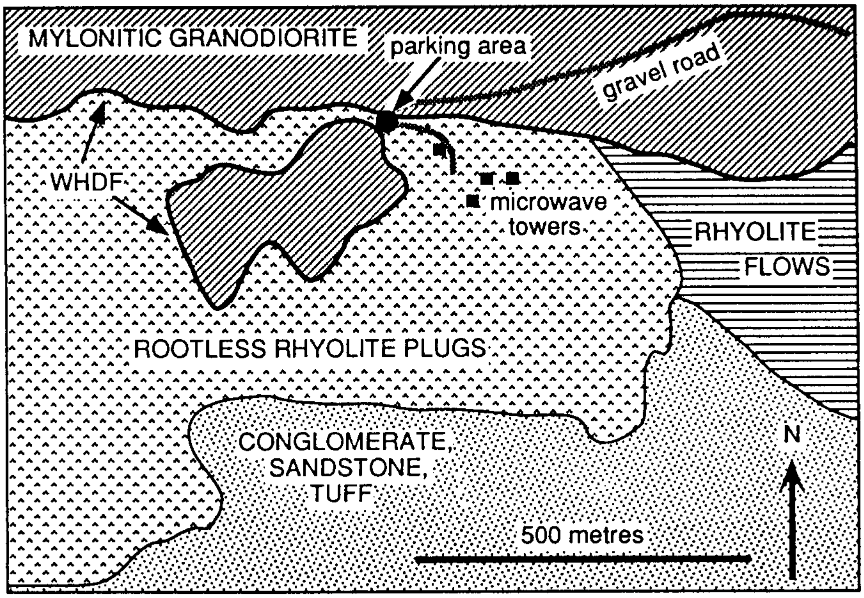


Figure 6b. Simplified geologic map of the area around the microwave towers at the summit of the Waterman Hills.

At this stop we will make a traverse to the north and study the progressive development of biotite lineation and mylonitic lineation as we approach the WHDF. Many of the mylonites exposed in this area are pure L-tectonites. We will also see how the lineation is disrupted by brittle faults near the WHDF and how S-C relations indicate a top-to-northeast sense of shear. Excellent exposures of the mylonites are found in the roadcuts east of the parking area, and in gullies leading north from the rhyolite outcrops at the parking area. Take any gully leading north from the rhyolites near the parking area, and watch how the mylonitic fabric dies into a simple lineation away from the WHDF.

For geographic reference, the Tehachapi Mountains lie at 9 o'clock; the pointed gray peak at 10:30 is Fremont Peak; the reddish, rounded peak to the right of Fremont Peak is Red Mountain, which lies just south of the Garlock fault; Black Mountain (basalt) is at 10:30 and Opal Mountain (rhyolite and silicic tuff) is at 11 o'clock; the Mud Hills lie at 11:30 to 1 o'clock; and the Calico Mountains lie at 2:30 to 3 o'clock.

RETRACE route to Irwin Road. Directly ahead as you drive toward the intersection is a red klippe on white and green mylonitized lower plate rocks.

120.1 (1.6) TURN LEFT (north) on Irwin Road at the end of the dirt microwave road.

121.7 (1.6) TURN LEFT onto Fossil Bed Road (graded dirt).

124.6 (2.9) Continue on Fossil Bed Road.

Entrance to Rainbow Loop Road is at right. If time permits, turn right into this ONE-WAY loop for a **SIDE TRIP** through the type section of the Barstow Formation in the Mud Hills which produced fossils which define the Barstovian LMA (see Woodburne and Tedford, and Woodburne and others in Reynolds, 1985).

125.3 (0.7) The exit from Rainbow Loop Road is at right.

125.7 (0.4) **STOP 4**. Discussion stop for the Coon Canyon Fault Crevice (CCFC) locality (see Reynolds and Fay, herein). Abundant latest Pleistocene or early recent fossils are preserved in crevices in Tertiary sediments, suggesting that faulting was active into recent times.

Turn around and RETRACE ROUTE to Irwin Road.

At Irwin Road, RESET TRIP METER TO 0.0

0.0 (0.0) TURN LEFT (east) on Irwin Road at the intersection with Fossil Bed Road.

01.0 (1.0) Copper City Road intersection. Continue along Irwin Road.

04.3 (3.3) TURN RIGHT at the stop sign at the intersection of Irwin Road and Fort Irwin Road (the road sign indicates "to Barstow").

05.3 (1.0) View south of Ord Mountain on skyline, with Daggett Ridge in front (Lander and Reynolds, 1985; Dokka and Glazner, 1982).

08.6 (3.3) TURN LEFT at Yermo Cutoff. Continue on Yermo Cutoff Road.

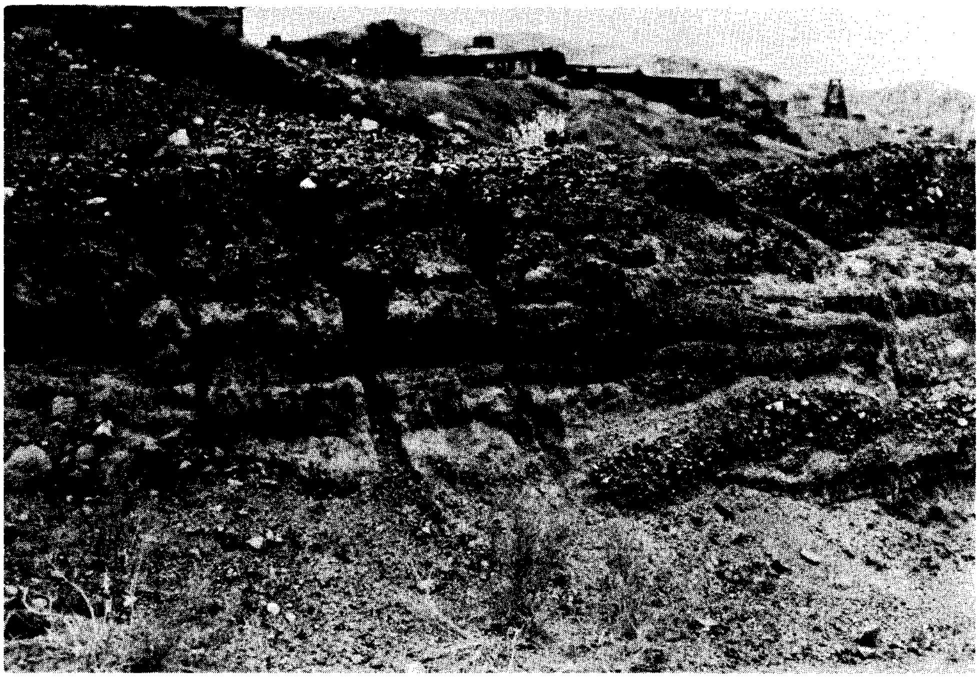


Figure 7. Weathered silty sandstones are interbedded with gravels in terraces below the historic town of Calico. (Milepost 12.5) (R.E. Reynolds photo)

Figure 8. Equus conversidens skull weathering from Calico Ghost Town terrace sediments. (Milepost 12.5) (R.E. Reynolds photo)

09.0	(0.4)	The Waterloo gold mine workings are visible to the north in the West Calico Mining District. Originally called the "Burcham Formation" by McCulloh (1952), sediments contain fossils suggesting an early Barstovian land mammal age (Lander, 1985).
10.1	(1.1)	TURN LEFT at stop sign at intersection of Ghost Town Road and proceed north and then east toward Calico Ghost Town. [If needed, gas is available at the I-15 freeway intersection by turning right on Ghost Town Road].
11.3	(1.2)	Burcham mine workings
12.5	(1.2)	Entrance to Calico Ghost Town. The townsite and present-day bus parking are located on terraces which contain Irvingtonian LMA fossils discussed by Reynolds (herein) and Lander and Reynolds (1985)(Figs 7,8).
12.9	(0.4)	Duran Drive is to the left. Continue on pavement of Ghost Town (Calico) Road.
14.4	(1.5)	Mule Canyon Road. The playa to the right is the site of Marion, the processing plant for borate minerals mined from Borate, to the east along Mule Canyon Road. Marion was connected by a narrow-gauge railroad to Daggett via the old Waterloo mine railroad (Reynolds, 1967; Weber, 1966).
15.5	(1.1)	CROSS OVER FREEWAY and ENTER Interstate 15 eastbound (sign says "I-15 North").
17.5	(2.0)	The Calico Lakes development is to the south (right). Excavation here recovered a Rancholabrean fauna and a radiometric date of 12,800 +900 BP (Geochron GX-10417) which indicate that the Calico Fault was active at that time, allowing lacustrine sediments to accumulate upstream from fault trace (Reynolds and Reynolds, 1985).
18.5	(1.0)	EXIT on Minneola Road.
18.9	(0.4)	TURN RIGHT at end of offramp onto Minneola Road, going south.
19.0	(0.1)	TURN RIGHT onto Yermo Road; PARK on the road shoulder. **STOP 5**. Walk back to road cut on Minneola Road and look at deformed river gravels interfingered with lacustrine sediments deformed along the Calico Fault. Sedimentary strata exposed in the road cut have been folded by the Calico Fault. The interaction of the northwest-trending Calico Fault and the east-west Manix Fault at their junction may have caused a structural depression (Hamilton, in Jefferson and others, 1982; Reynolds and Reynolds, 1985). Walk back to vehicles and RETRACE route to freeway.
19.2	(0.2)	ENTER eastbound freeway ("I-15 North").
22.1	(2.9)	Cross the trace of the Manix Fault (Jefferson et al, 1982; Keaton and Keaton, 1977; McGill and others, 1988). In the road cut on the north side of the freeway the tan sands of the Manix Formation are in contact with light green Miocene siltstone. The fault trace runs through the hills to the southeast at approximately 1:00 (Fig. 9).

Figure 9. The Manix Fault places Miocene sediments (white, on left) against Pleistocene sediments (tan, on right) along Interstate 15. (Milepost 22.1)(R.E. Reynolds photo)

26.6	**(4.5)**	Coyote Lake is to north at 9:00 (Hagar, 1966; Reynolds 1985c, 1985d). Coyote Lake is the northernmost extent of Manix Basin and, based on radiometric dates on Anodonta shell, may have contained fresh water significantly later than when the Manix basin was drained (G.T. Jefferson, Page Museum, personal communication to Reynolds, 1986).
26.8	**(0.2)**	Harvard Road.
29.3	**(2.5)**	We are crossing the divide between Coyote and Manix basins.
31.4	**(2.1)**	Look south to Manix Wash and the classic exposures of the lacustrine section described first by Buwalda (1914) and subsequently by Ellsworth (1932), Blackwelder and Ellsworth (1936), Jefferson (1985, 1987), Meek (1988 and herein), and McGill and others (1988).
34.1	**(2.8)**	Field Road
42.1	**(8.0)**	EXIT at Afton Road, turn right.
42.4	**(0.3)**	PARK just south of freeway to look at beach ridge at the Afton exit. **STOP 6**. This beach ridge has been greatly disturbed by highway construction. The best remnants lie northwest of I-15. A tombolo/ridge is exposed east of hill 1935. Notably, the ridge lacks significant varnish.
		DRIVE SOUTH on Afton Road, which follows the beach bar.
44.0	**(1.6)**	Pole line, with road immediately to the south. Continue only 0.1 mile to the next track, which is the turnoff for a side trip.

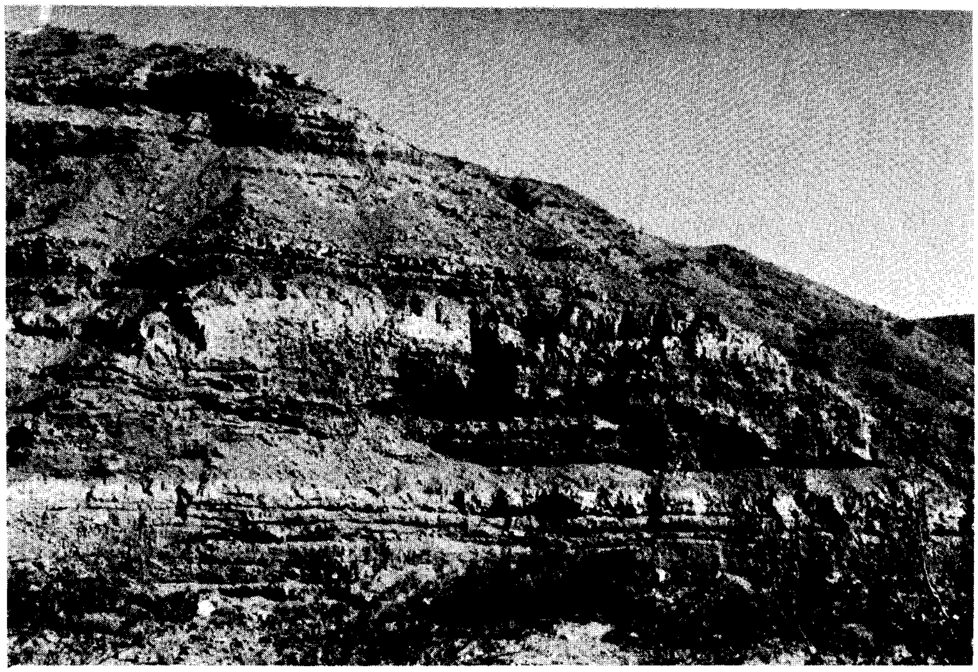


Figure 10. Calichified sands and gravels that underlie the Manix Formation are exposed along Afton Road. (Milepost 44.6)

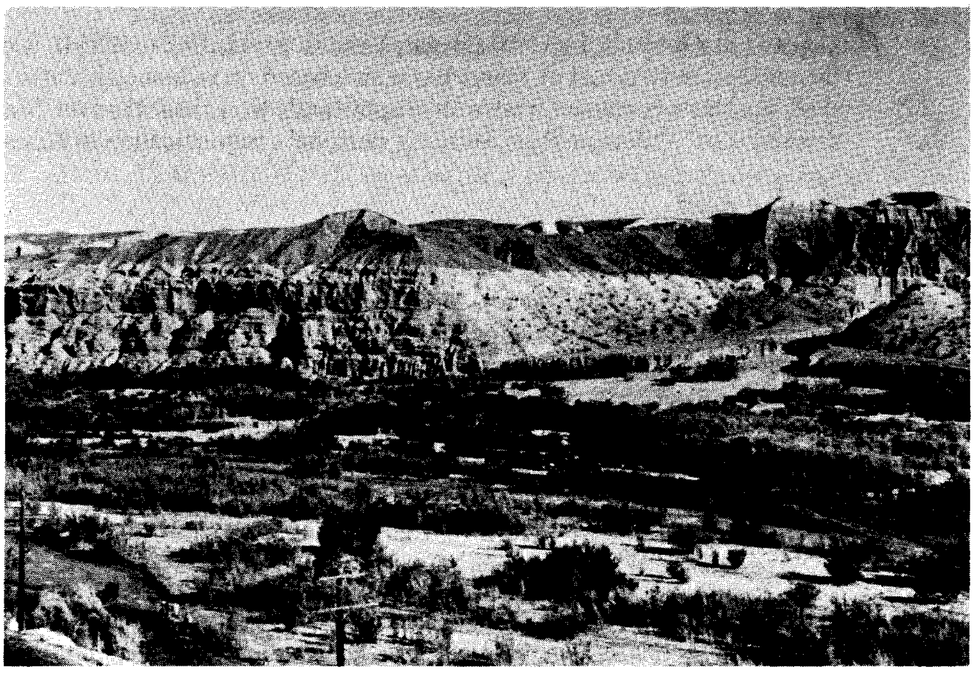


Figure 11. On the south side of the Mojave River in Afton Canyon, light-colored, resistant, calichified gravels are overlain by gray fanglomerates derived from the Cady Mountains. These sediments interfinger with light green silts of Lake Manix. (Milepost 45.3) (R.E. Reynolds photo)

44.1 (0.1) **SIDE TRIP** to north Afton beach ridge.
Drive east across a major sandy wash, then double back on a road up the east side of the beach ridge. Drive on the ridge to the south, but not too far. Several vehicles have been stuck on the irregular, dissected ridge crest.

The crest of the north Afton beach ridge has been dated at about 14 ka by AMS radiocarbon on varnish and conventional age estimates on shells. Outcropping shells and tufa below the crest have provided older Wisconsinan dates. Superposed beach ridge deposits and cross-cutting fanglomerate layers can be viewed in this beach ridge. Shoreline hill can be seen to the east (see Meek, herein).

If you have taken the Side Trip, return to Milepost 44.1.

44.6 (0.5) Afton Road leaves beach terrace and enters calichified paleosols and fanglomeratic gravels that were filling the Manix Basin prior to filling by fresh water of Lake Manix (Fig. 10).

45.3 (0.7) Road dips through wash and up onto terrace. In the view south and east across Mojave River, notice the dark fanglomerate of the Cady Mountains which interfingers with the light green silts of Lake Manix (Fig. 45.3).

45.9 (0.6) PARK near the railroad bridge west of Afton near the campground entrance.
STOP 7. HIKE to south Afton beach exposures. (Remember to take plenty of water).

Walk across the Mojave River and hike up the trail on the ridge immediately west of the large wash entering the river at the bridge. This is the only passable path in this area to the south Afton beach exposures. Climb up the section, passing south of the lake clay outcrops. About 200? meters beyond the final outcrop of lake clays, watch the ground for a change in cobble roundness and pavement texture. This is the high shoreline. Shells have been discovered and are being dated which were found in this beach two canyons to the west. The crest of this beach is 1.6 m lower than the crest of beach ridges north of the Mojave River (see Meek, herein).

Return to the cars via the canyon to the east. Note the Gray and Brown Fanglomerate sections, and the post-lacustrine fault. This is not the Manix Fault, just a minor splinter? fault. The Manix Fault can be viewed less than 1 km farther south (beyond south Afton beach) at the fanglomerate-bedrock contact.

DRIVE EAST toward Afton Canyon.

47.2 (0.2) PARK near the railroad bridge underpass at turnout to south. We can see Cady Mountains gravels against Miocene red gravels and Miocene black volcanics.
STOP 8. HIKE. Afton Canyon meander knob crest.
Climb to the top of the ridge immediately to the east. This point provides a good view of Afton Canyon. The meander knob crest lies >50 m below the lake bottom in this area. The initial canyon cut may have been to approximately this level. New (unpublished) dating of varnish on this crest is only slightly younger than the age of the highest shoreline. Note the soil profile and pavements on the crest (not the exhumed paleosol/carbonate layers on the meander-knob walls).

Resume vehicles and CONTINUE EAST.

49.0 (1.8) Meander scour is located on north side of railroad. Drive east through the canyon on the railroad access road. The road dips into some left-bank tributary channels adjacent to small railroad bridges.

49.5 (0.5) At first bridge east of meander scour you can cross under the railroad and enter an entrenched tributary. In the area where a large fanglomerate section crops out on the north, stop at the first tributary channel.

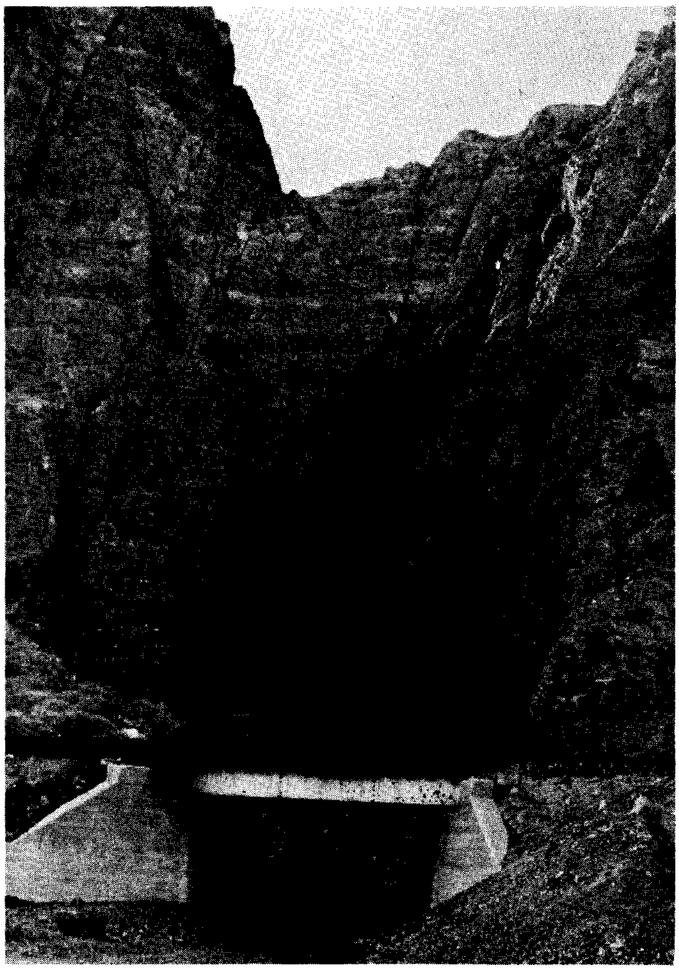


Figure 12. Entrenched drainage in Afton Gorge cuts through resistant gravels, indicating downcutting. (Milepost 49.5) (R.E. Reynolds photo)

STOP 9. HIKE. Walk up the channel into the narrow canyon on the north. Note the exposed fanglomerate section, fractures, and piping features. The canyon suggests that a rapid base level drop has occurred.

RETRACE route to Interstate 15.

57.3 (7.8) Interstate 15, and the end of this guide.

REFERENCES CITED

Aksoy, R., P.M. Sadler, and S. Biehler, 1986. Gravity anomalies over sedimentary basins on the Helendale Fault trend. Redlands, Inland Geological Society Publications, 1:121-228.

Bartley, J. M., and Glazner, A. F., 1985, Hydrothermal systems and Tertiary low-angle normal faulting in the southwestern United States: Geology, v. 13, pp. 562-564.

Blackwelder, E. and Ellsworth, E.W., 1936. Pleistocene lakes of the Afton basin, California. American Journal of Science 31:453-463.

Bortugno, E.J. and T.E. Spittler, 1986. Geologic map of the San Bernardino quadrangle, scale 1:250,000. Regional Geologic Map Series, Map No. 3A, California Division of Mines and Geology.

Bowen, O.E. Jr., 1954. Geology and mineral deposits of the Barstow quadrangle, San Bernardino County, California. California Division of Mines Bulletin 165:1-85.

Buwalda, J.P., 1914. Pleistocene beds at Manix in the eastern Mojave Desert region. University of California, Department of Geological Sciences Bulletin, 7(25):443-464.

Chapin, C.E., and Glazner, A.F., 1983, Widespread K_2O metasomatism of Cenozoic volcanic and sedimentary rocks in the southwestern United States: Geological Society of America Abstracts with Programs, v. 15, p. 282.

Crowell, J.D., 1975. San Andreas Fault in southern California. California Division of Mines and Geology Special Report 118: 272 p.

Dibblee, T. W., Jr., 1960, Geologic map of the Barstow quadrangle, San Bernardino County, California: United States Geological Survey Map MF-233, scale 1:62,500.

_____ 1961. Evidence of strike-slip movement on northwest-trending faults in Mojave Desert, California. United States Geological Survey Professional Paper 424-B:197-198.

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

_____ 1970. Geologic map of the Daggett quadrangle, San Bernardino County, California. U.S. Geological Survey Miscellaneous Geologic Investigations Map I-592, scale 1:62,500.

_____ 1975. Late Quaternary uplift of the San Bernardino Mountains on the San Andreas and related faults, IN San Andreas Fault in southern California, J.D. Crowell, ed. California Division of Mines and Geology Special Report 118:127-135.

_____ 1980a. Geologic structure of the Mojave Desert, IN Geology and mineral wealth of the California desert, D.L. Fife and A.R. Brown, eds. Santa Ana, South Coast Geological Society:69-100.

Dokka, R.K. and A.F. Glazner, 1982. Field trip road log: Late Cenozoic tectonic and structural evolution of the central Mojave Desert, California, IN Geologic excursions in the California Desert, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran Section, Anaheim:1-30.

Dutcher, L.C. and A.A. Garrett, 1963. Geologic and hydrologic features of the San Bernardino area, California, with special reference to underflow across the San Jacinto Fault. U.S. Geological Survey Water Supply Paper 1419.

Eckis, R., 1934. Geology and ground-water storage capacity of valley fill, South Coastal Basin investigation. California Department of Water Resources Bulletin 45.

Ehlig, P.L., 1975. Basement rocks of the San Gabriel Mountains, south of the San Andreas Fault, IN San Andreas Fault in southern California, J.D. Crowell, ed. California Division of Mines and Geology Special Report 118:177-186.

Elders, W.A., 1973. Geological investigations of the San Jacinto fault zone and aspects of the socio-economic impact of earthquakes in the Riverside-San Bernardino area, California. University of California Riverside, Campus Museum Contributions,3.

Ellsworth, E.W., 1932. Physiographic history of the Afton basin: Ph.D. Dissertation. Palo Alto, CA, Stanford University: 99 p.

Foster, J.H., 1980a. Late Cenozoic evolution of Cajon Valley, southern California [PhD diss.]. University of California, Riverside, Department of Geological Sciences: 238 p.

_____ 1980b. Late Cenozoic tectonic evolution of Cajon Valley, southern California, IN Geology and mineral wealth of the California desert, D.L. Fife and A.R. Brown, eds. Santa Ana, South Coast Geological Society:430-440.

_____ 1982. Late Cenozoic tectonic evolution of Cajon Valley, southern California, IN Geologic excursions in the California Desert, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran Section, Anaheim:76-84.

Glazner, A.F., and Bartley, J.M., 1988, Early Miocene dome emplacement, diking, and faulting in the northern Marble Mountains, Mojave Desert: Geological Society of America Abstracts with Programs, v. 20, p. 163-164.

_____ 1989, Source of potassium in potassium-metasomatized, extended Tertiary rocks of the Mojave Desert: International Association of Volcanology and Chemistry of the Earth's Interior Meeting, Santa Fe, in press.

Hagar, D.J., 1966. Geomorphology of Coyote Valley, San Bernardino County, California, [PhD. diss.]. Department of Geology, University of Massachusetts.

Harland, W.B., A.V. Cox, P.G. Llewellyn, C.A.G. Pickton, A.G. Smith, and R. Walters, 1982. A geologic time scale. Cambridge, Cambridge University Press.

Jefferson, G.T., 1985. Stratigraphy and geologic history of the Pleistocene Lake Manix Formation, central Mojave Desert, California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:157-170.

Jefferson, G.T., 1987. The Camp Cady Local Fauna: paleoenvironment of the Lake Manix basin. Redlands, San Bernardino County Museum Association Quarterly XXXIV(3,4):3-35.

Jefferson, G.T., J.R. Keaton, and P. Hamilton, 1982. Manix Lake and the Manix Fault. Redlands, San Bernardino County Museum Association Quarterly XXIX(3,4):47 p.

Keaton, J.R. and R.T. Keaton, 1977. Manix fault zone, San Bernardino County, California. California Division of Mines and Geology, California Geology, 30(8):177-186.

King, T.J. Jr., 1976. Archaeological implications of the paleobotanical record from Lucerne Valley area of the Mojave Desert. Redlands, San Bernardino County Museum Association Quarterly XXIII(4): 208 p.

Lander, R.B., 1985. Early and middle Miocene continental vertebrate assemblages, central Mojave Desert, San Bernardino County, California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:127-144.

Lander, E.B. and R.E. Reynolds, 1985. Fossil vertebrates from the Calico Mountains area, central Mojave Desert, California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:153-156.

May, S.R. and C.A. Repenning, 1982. New evidence for the age of the Old Woman Sandstone, Mojave Desert, California, IN Geologic excursions in the Transverse Ranges, southern California, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran section, Anaheim:93-96.

McCulloh, T.H., 1952, Geology of the southern half of the Lane Mountain quadrangle, California [Ph.D. thesis]: Los Angeles, University of California, 180 p.

McGill, S.F., Murray, B.C., Maher, K.A., Lieske, J.H. Jr., Rowan, L.R., and Budinger, F., 1988. Quaternary history of the Manix Fault, Lake Manix Basin, Mojave Desert, California. Redlands, San Bernardino County Museum Quarterly XXXV(3,4):3-20.

Meek, N., 1989. Geomorphic and hydrologic implications of the rapid incision of Afton Canyon, Mojave Desert, California. Geology 17:7-10.

Meisling, K.E. and R.J. Weldon, 1982. The late Cenozoic structure and stratigraphy of the western San Bernardino Mountains, IN Geologic excursions in the Transverse Ranges, southern California, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran section, Anaheim:75-82.

_____ 1989. Late Cenozoic tectonics of the northwestern San Bernardino Mountains, southern California. Geological Society of America Bulletin 101:106-128.

Morton, D.M., 1975. Synopsis of the geology of the eastern San Gabriel Mountains, southern California, IN San Andreas Fault in southern California, J.D. Crowell, ed. California Division of Mines and Geology Special Report 118:170-176.

_____ 1976. Geologic, fault and major landslide and slope stability maps, IN Geologic hazards in southwestern San Bernardino County, California, D.L. Fife and others, eds. California Division of Mines and Geology Special Report 113.

Neville, S.L. and J.M. Chambers, 1982. Late Miocene alkaline volcanism, northeastern San Bernardino Mountains and adjacent Mojave Desert, IN Geologic excursions in the Transverse Ranges, southern California, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran section, Anaheim:103-106.

Ponti, D.J., 1985. The Quaternary alluvial sequence of the Antelope Valley, California, IN Soild and Quaternary geology of the southwestern United States, D.L. Weide, ed. Geological Society of America Special Paper 203:79-96.

Reynolds, R.E., 1967. Exploring the Calico mining district. Bloomington, San Bernardino County Museum Association Quarterly XV(2):1-24._____ 1985b. Paleontologic salvage, Summit Safety site, Cajon Pass, San Bernardino County, California. Redlands, San Bernardino County Museum: 51 p.

_____ 1985c. Paleontologic salvage, Intermountain Power Project geotechnical testing, ground electrode, Coyote Lake, San Bernardino County, California. Redlands, San Bernardino County Museum.

_____ 1985d. Paleontologic salvage, Intermountain Power Project southern ground electrode, Coyote Lake, San Bernardino County, California. Redlands, San Bernardino County Museum: 182 p.

_____ 1987a. Paleontologic salvage, Southern California Edison Company Victor Valley branch office, Victorville, San Bernardino County, California. Redlands, San Bernardino County Museum: 54 p.

_____ 1987b. Paleontologic mitigation, Kramer SEGS sites, San Bernardino County, California. Redlands, San Bernardino County Museum: 30 p.

_____ 1988a. Paleontologic monitoring and salvage, Federal lands along the All American and Celeron pipeline project, California section. Redlands, San Bernardino County Museum: 428 p.

_____ 1988b. Paleontologic resource overview and management plan for Edwards Air Force Base. Redlands, San Bernardino County Museum: 199 p.

Reynolds, R.E. and Reynolds, R.L., 1985. Late Pleistocene faunas from Daggett and Yermo, San Bernardino County, California, IN Geological Investigations along Interstate 15, Cajon Pass to Manix Lake. Redlands, San Bernardino County Museum:175-191.

Rogers, T.H., 1967. Geologic map of California, San Bernardino sheet, 1:250,000. California Division of Mines map sheet series.

Sadler, P.M., 1982a. An introduction to the San Bernardino Mountains as the product of young orogenesis, IN Geologic excursions in the California Desert, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran Section, Anaheim:57-66.

_____ 1982b. Provenance and structure of late Cenozoic sediments in the northeast San Bernardino Mountains, IN Geologic excursions in the California Desert, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran Section, Anaheim::83-92.

Sharp, R.V., 1972. Map showing recently active breaks along the San Jacinto fault zone between the San Bernardino area and Borrego Valley, California. U.S. Geological Survey Miscellaneous Investigations Map I-675.

_____ 1975. En ecelon fault patterns of the San Jacinto fault zone, IN San Andreas Fault in southern California, J.D. Crowell, ed. California Division of Mines and Geology Special Report 118:147-154.

Strathouse, E.C., 1982. The Santa Ana Sandstone (Miocene, in part) and evidence for late Cenozoic orogenesis in the San Bernardino Mountains, IN Geologic excursions in the Transverse Ranges, southern California, J.D. Cooper, ed. Geological Society of America, 78th Annual Meeting, Cordilleran section, Anaheim:97-102.

Walker, J.D., Bartley, J.M., and Glazner, A.F., Large-magnitude Miocene extension in the central Mojave Desert: Implications for Paleozoic to Tertiary paleogeography and tectonics: submitted to Journal of Geophysical Research.

Weber, F.H., Jr., 1963. Geology and mineral deposits of the Ord Mountain district, San Bernardino County, California. California Division of Mines and Geology Special Report 77.

_____ 1966. Silver mining in old Calico. California Division of Mines and Geology, Mineral Information Service, 19(5):71-80.

Weldon, R.J., 1983. Climatic control for the formation of terraces in Cajon Creek, southern California. Geological Society of America, Cordilleran Section, Abstracts with Programs, 15:429.

Weldon, R.J., 1985. Implications of the age and distribution of the late Cenozoic stratigraphy in Cajon Pass, southern California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:59-68.

Weldon, R.J., 1986. Fill terrace formation in Cajon Creek, southern California. Geological Society of Amerca, 82nd Annual Meeting, Cordilleran section, Abstracts with programs, 18(2):196.

Weldon, R.J., K.E. Meisling, C.R. Allen, and K.E. Sieh, 1981. Neotectonics of the Silverwood Lake area, San Bernardino County. Report of the California Department of Water Resources: 22 p.

Weldon, R.J. and K.E. Sieh, 1984. Holocene rate of slip and tentative recurrence interval for large earthquakes on the San Andreas Fault in Cajon Pass, southern California, IN Guidebook for the San Andreas Fault--Cajon Pass to Wrightwood, R.L. Hester and D.E. Hallinger, eds. Los Angeles, Pacific Section American Association of Petroleum Geologists: 120 p.

Woodburne, M.O., Miller, S.T., and Tedford, R.H., 1982. Stratigraphy and geochronology of Miocene strata in the central Mojave Desert, California.IN Geological investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:79-104.

Woodburne, M.O. and R.H. Tedford, 1982. Litho- and biostratigraphy of the Barstow Formation, Mojave Desert, California, IN Geological investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:111-126.

Wright, L.A., R.M. Stewart, T.E. Gay, Jr., and G.C. Hazenbush, 1953. Mines and mineral deposits of San Bernardino County, California. California Journal of Mines and Geology, 49(1,2):49-192.

Late Pleistocene and earliest Holocene fossil localities and vertebrate taxa from the western Mojave Desert

George T. Jefferson, George C. Page Museum, Los Angeles County Museum of Natural History, 5801 Wilshire Blvd, Los Angeles, CA 90036

INTRODUCTION

Within the western Mojave Desert and the adjacent, southwestern-most Great Basin region (MD/GB), late Pleistocene (Rancholabrean) and earliest Holocene vertebrate fossil localities occur in sediments that usually reflect three distinct depositional environments: fluviatile, lacustrine/paralimnitic, and caves.

Most of the fossiliferous fluviatile sediments are exposed along the course of the ancestral Mojave River and its tributaries. Isolated, large mammalian skeletal elements occur in fluviatile deposits like those that overlie the Manix Lake beds east of Camp Cady (Appendix 1) (Jefferson, 1985a). Fluviatile deposits may also yield microvertebrate remains. Fossil assemblages recovered from exposures of fluviatile and associated pond sediments like those near Daggett (Reynolds and Reynolds, 1985) are rich and diverse with respect to herpeto taxa, small birds, and mammals (Appendix 1).

Near-shore lacustrine depositional environments provide loci for the accumulation and burial of the disarticulated remains of large mammals and the articulated skeletal remains of fish, freshwater turtles and waterfowl. As an example of this paleoenvironment, the China Lake local faunule (Fortsch, 1978; Davis, 1982) (Appendix 1) was recovered from aeolian blowouts and exposed sediments located around the margin of a dry lake playa. The Camp Cady local fauna of Lake Manix (Jefferson, 1985a, 1985b) was recovered from lacustrine sediments that crop out in eroded banks along the lower Mojave River Valley.

Schuiling Cave (Downs and others, 1959; Jefferson, 1983) and Newberry Cave, both located in the Newberry Mountains, have produced assemblages that contain a mixture of large and small late Pleistocene and early Holocene vertebrates (Appendix 1).

Vertebrate faunal assemblages from the MD/GB document a continental ecosystem. During the latest Pleistocene and earliest Holocene, there were biotic differences between interior desert areas and more mesic coastal southern California (Jefferson, 1988). Many species ranged widely throughout southern California. However, the distribution of rare, locally endemic or extralocal taxa (such as Gerrhonotus, Pheuticus, Sorex, Mammut, or Tapirus) and the relative abundance of common taxa (such as Equus, Camelops, and Bison), reflect local paleoecologic conditions and habitat patterns that contrast with the more modern xeric environment (common names of taxa in the MD/GB paleofauna are listed in Table 1).

DISCUSSION

Most late Pleistocene fish, amphibians, and reptiles of the MD/GB are still present in the area (Table 1). Although no late Pleistocene lower vertebrates from the region are extinct, some have extralocal geographic ranges.

The range of Gila bicolor mohavensis has been drastically restricted since the disappearance of pluvial lakes and rivers (Snyder and others, 1964). Gasterosteus aculeatus is locally extinct (Roeder, 1985). This species presently inhabits the greater Los Angeles Basin river systems, and has been recently reintroduced by humans into the Mojave River (C. Swift, LACM, personal communication to Jefferson, 1989).

Fossil amphibians are known only from Daggett-Yermo localities (Reynolds and Reynolds, 1985) (Appendix 1). Scaphiopus, Bufo, and Rana are today restricted to the Mojave River drainage and other local perennial waters. Hyla species do not range into the MD/GB, but occur in mountains along its western and southern margin (Stebbins, 1966).

Reynolds and Reynolds (1985) have discussed the paleoecologic aspects of the Daggett-Yermo faunas, and they separate the reptiles into groups indicative of lacustrine, terrestrial mesic, and/or xeric conditions. Clemmys marmorata is locally extinct, but occurs in lakes and rivers west of the Sierra Nevada and in coastal southern California (Stebbins, 1966). Of the lizards and snakes, only Gerrhonotus exhibits an extralocal distribution. It presently inhabits the Panamint Mountains west of Death Valley (Stebbins, 1966).

The late Pleistocene avifauna represents several paleoenvironments. Most of the taxa that are still extant are either endemic or are migratory visitors to the region. The avifauna includes many waterfowl, including extant and extinct species (Table 1). Evidently, the extinct forms were unable to survive the disappearance of pluvial lakes in western North America (Snyder and others, 1964).

Paleoenvironmental aspects of the Lake Manix avifauna, which includes taxa from China Lake, were described as follows (Jefferson, 1985b):

> All of the extant species represented in the Lake Manix avifauna are at least seasonally present in southern California. Most taxa are found along the California coast during the winter or are winter visitors on inland lakes, such as the Salton Sea, or along the Colorado River. Pelicanus is a summer visitor most common at the Salton Sea. Only Oxyura and Fulica are wide ranging throughout the year. Cygnus is rare in southern California and found in winter on inland lakes or reservoirs to the north (Cogswell and Christman, 1977; Garrett and Dunn, 1981).
>
> All extant, migratory species leave southern California in the spring. They travel northward along the coast or follow inland portions of the north-south Pacific Coast flyway. During Pleistocene pluvial periods, this inland route would have been over the lakes of the Mojave Desert, the lakes east of the Sierra Nevada Mountains including China Lake, the western part of Lake Lahontan, and the lakes of southeastern Oregon, including Fossil Lake (Snyder and others, 1964)....
>
> The Lake Manix assemblage samples a complex of freshwater lake and lake margin habitats. Judging from food preferences, procurement methods, and nesting habits (Cogswell and Christman, 1977) of the extant forms represented, open water, sandy beach flats, and extensive reedy marshlands must have been persistent lacustrine features. An extensive lacustrine environment is confirmed by lithostratigraphy and reconstructions of the depositional environments...

The avifauna recovered from the fluviatile, overbank and pond sediments deposited in the ancestral Mojave River channel near Daggett and Yermo (Reynolds and Reynolds, 1985) (Appendix 1) includes species that presently inhabit local desert lowland areas, forms that prefer desert mountain woodlands, and extralocal taxa. Problems in the identification of many small passerines (song birds) below subfamily or generic levels preclude detailed paleogeographic or habitat analyses.

The largest carnivores and herbivores in the MD/GB paleofauna are extinct, a continent-wide pattern which is addressed by Martin and Klein (1984). Extinct and extant mammalian carnivores are rare as fossils. Like modern forms, the large extinct carnivores exhibit broad, regional geographic ranges. Ursus is the only extant carnivore whose range does not presently extend into the desert. Although some extinct large herbivores were restricted mainly to coastal regions, most ranged widely throughout southern California. No small mammals in the MD/GB paleofauna are extinct, and almost all presently inhabit the desert. Only a few forms exhibit extralocal ranges (Table 1).

Fossil mammalian assemblages in the MD/GB region are typified by an abundance of Camelops. A large extinct species of Equus and Hemiauchenia are well-represented. Compared with assemblages from coastal and intermontane southern California (Jefferson, 1988), a small extinct species of Equus is common, and an extinct species of Bison is generally rare. However, Bison is moderately well-represented in southern Great Basin assemblages and Hemiauchenia is relatively rare (Jefferson, 1988).

Throughout the western desert region, ground sloth taxa (Megalonyx, Nothrotherium, and Glossotherium) are rare. Historic records of abundant Antilocapra in Antelope Valley (Stickle and others, 1980) document an apparent post-Pleistocene phenomenon. Antilocapra, Capromeryx minor, Cervidae, and Ovis canadensis inhabit upland habitats in the area today, but are poorly represented in the earlier record.

The occurrence of Mammut in the late Pleistocene record of the region has not been confirmed. It is present in the Irvingtonian assemblage from Edwards Air Force Base (Reynolds, this volume). Mammut also has been recovered from the Shoemaker Gravels near Oro Grande, which are probably latest Irvingtonian in age (Jefferson, 1986). The identification of this taxon from Black Butte (Appendix 1) is questioned. Tapirus (tapir), Platygonus (extinct peccary), and the Ovibovini (musk oxen) have not been reported from the region.

Within the MD/GB, most late Pleistocene or earliest Holocene small mammalian taxa are known only from the Daggett-Yermo assemblages and cave deposits in the Newberry Mountains (Appendix 1). Some small mammal species exhibit extralocal geographic ranges. These taxa presently inhabit montane environments that border the region.

In southern California, the geographic distribution of Sorex ornatus, Scapanus latimanus, Sylvilagus bachmani, and Eutamias merriami is from the coast to the eastern edges of the mountains that border the western Mojave Desert. A single population of Microtus californicus is established along the Mojave River near Victorville; otherwise, this animal occurs in the mountains west and south of the desert. The southernmost distribution of Sorex palustris and Eutamias minimus presently includes the Sierra Nevada and mountains in central Nevada. In the Tehachapi and southernmost Sierra Nevada, Marmota flaviventris is not found below 2154 m (7,000 feet) elevation. Its southernmost range in the central Great Basin includes mountains of similar altitude. Thomomys monticola is presently restricted to the Sierra Nevada range.

Differences in faunal composition between assemblages may result from changes in glacial or interglacial environmental conditions. This is observed between some coastal California localities (Jefferson, 1988) but has not been recognized within the MD/GB. Local environmental factors may also account for some variation between assemblages. The proximity of seasonally-favorable montane habitats to the China Lake local faunule may account for the larger number of Bison there in comparison to sites in the Mojave Desert. Mammuthus is widespread throughout the region but not abundant in any assemblage. Apparently, taphonomic factors of the local depositional environment control the observed abundance of these very large mammals.

ACKNOWLEDGEMENTS

I thank the following vertebrate paleontologists who provided information about and/or allowed me to examine collections under their care: W. Daily and M. Woodburne, University of California, Riverside; T. Demere, San Diego Society of Natural History; H. Hutchison, University of California, Berkeley Museum of Paleontology (UCMP); E. Lindsay, University of Arizona, Tucson; C. Repenning, United States Geological Survey, Denver; R. Reynolds and R. Simpson, San Bernardino County Museum. S. McLeod accessed information from the Los Angeles County Museum of Natural History (LACM) and UCMP Taxonomic Information Retrieval (TAXIR) data base. LACM colleagues are thanked for their comments and review of the manuscript.

REFERENCES CITED

Agenbroad, L.D., 1984. New world mammoth distribution, IN Quaternary extinctions, a prehistoric revolution, P.S. Martin and R.G. Klein, eds. Tucson, University of Arizona Press.

American Ornithologists' Union, 1957. Check-list of North American Birds, 5th edition. Baltimore, American Ornithologists' Union.

Bischoff, J.L., R.L. Shlemon, T.L. Ku, R.D. Simpson, R.J. Rosenbauer, and F.E.

Budinger, 1981. Uranium-series and soil-geomorphic dating of the Calico Archaeological Site, California. Geology, 9:576-582.
Brattstrom, B.H., 1958. New records of Cenozoic amphibians and reptiles from California. Southern California Academy of Sciences Bulletin, 57(1):5-13.
Brattstrom, B.H., 1961. Some new fossil tortoises from western North America with remarks on the zoogeography and paleoecology of tortoises. Journal of Paleontology, 35(3):543-560.
Budinger, F.E., Jr., 1983. The Calico Early Man Site. California Geology, 36(4):75-82.
Cogswell, H.L. and G. Christman, 1977. Water birds of California. Berkeley, University of California Press, California Natural History Guides.
Davis, C.A. and G.A. Smith, 1981. Newberry Cave. Redlands, San Bernardino County Museum Association.
Davis, E.L., 1982. The geoarchaeology and history of China Lake, California, IN Peopling of the New World, J.E. Ericson, R.E. Taylor and R. Berger, eds. Ballena Press Anthropological Papers, 23:203-228.
Downs, T., H. Howard, T. Clements and G.A. Smith, 1959. Quaternary animals from Schuiling Cave in the Mojave Desert, California. Los Angeles County Museum of Natural History Contribution in Science, 29:1-21.
Fortsch, D.E., 1978. The China Lake Local Faunule, IN The ancient Californians, Rancholabrean hunters of the Mojave lakes country, E.L. Davis, ed. Natural History Museum of Los Angeles County, Science Series, 29:173-184.
Garrett, K. and J. Dunn, 1981. Birds of southern California, status and distribution. Los Angeles Audubon Society.
Hall, E.R. and K.R. Kelson, 1959. The mammals of North America. New York, Ronald Press.
Harris, A.H., 1985. Late Pleistocene vertebrate paleoecology of the west. Austin, University of Texas Press.
Howard, H.H., 1955. Fossil birds from Lake Manix, California. United States Geological Survey Professional Paper 264-J:199-205.
Jefferson, G.T., 1971. New Pleistocene vertebrate sites on the Mojave Desert: a reconnaissance report. Geological Society of America Special Papers, Abstracts to Meetings in Riverside, California, 3(2):140.
_____________, 1983. A fragment of human skull from Schuiling Cave, Mojave Desert, California. Southern California Academy of Science Bulletin, 82(2):89-102.
_____________, 1985a. Stratigraphy and geologic history of the Pleistocene Lake Manix Formation, central Mojave Desert, California, IN Geological investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:157-169.
_____________, 1985b. Review of the late Pleistocene avifauna from Lake Manix, central Mojave Desert, California. Natural History Museum of Los Angeles County Contributions in Science, 362:1-13.
_____________, 1986. Fossil vertebrates from late Pleistocene sedimentary deposits in the San Bernardino and Little San Bernardino Mountains, IN Geology around the eastern San Bernardino Mountains, M. Kooser and R.E. Reynolds, eds. Redlands, Inland Geological Society Publications I:77-80.
_____________, 1987. The Camp Cady local fauna: paleoenvironment of the Lake Manix Basin. Redlands, San Bernardino County Museum Association Quarterly 34(3,4):3-35.
_____________, 1988. Late Pleistocene large mammalian herbivores: implications for early human hunting patterns in southern California. Southern California Academy of Sciences Bulletin, 87(3):89-103.
Jefferson, G.T., P. Ennis, L. Payne, P. Slota, Jr., R. Taylor, D. Donahue, A. Jull and T. Linick, 1987. Accelerator mass spectrometry 14C determination on human remains from Schuiling Cave, Mojave Desert, California. Southern California Academy of Sciences Bulletin, 86(3):156-158.
Kurten, B. and E. Anderson, 1980. Pleistocene mammals of North America. New York, Columbia University Press.
Martin, P.S. and R.G. Klein, 1984. Quaternary extinctions, a prehistoric revolution. Tucson, The University of Arizona Press.
McDonald, J.N., 1981. North American bison, their classification and evolution. Berkeley, University of California Press.

Meek, N., 1989. Geomorphic and hydrologic implications of the rapid incision of Afton Canyon, Mojave Desert, California. Geology, 17:7-10.

Peterson, R.T., 1947. A field guide to the birds. Boston, Houghton-Mifflin Company.

______________, 1961. A field guide to western birds. Boston, Houghton-Mifflin Company.

Reynolds, R.E. and R.L. Reynolds, 1985. Late Pleistocene faunas from Daggett and Yermo, San Bernardino County, California, IN Geological investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:175-191.

Roeder, M.A., 1985. Late Wisconsin records of Gasterosteus aculeatus (threespine stickleback) and Gila bicolor mojavensis (Mojave tui chub) from unnamed Mojave River sediments near Daggett, San Bernardino County, California, IN Geological investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:171-174.

Simpson, G.G., 1945. The principles of classification and a classification of mammals. New York, Bulletin of the American Museum of natural History, 85:1-350.

Snyder, C.T., G. Hardman and F.F. Zdenek, 1964. Pleistocene lakes in the Great Basin. United States Geological Survey, Miscellaneous Geological Investigations Map I-114.

Stebbins, R.C., 1966. A field guide to western reptiles and amphibians. Boston, Houghton-Mifflin Company.

Steinmetz, J.J., 1988. Biostratigraphy and paleoecology of limnic ostracodesa from the late Pleistocene Manix Formation [MS thesis]. Pomona, California State Polytechnic University, Department of Biological Sciences.

Stickle, E.G., L.J. Weinman-Roberts, R. Berger and P. Hopa, 1980. An overview of the cultural resources of the western Mojave Desert. Bureau of Land Management, California, Cultural Resources Publications, Anthropology-History.

APPENDIX 1

Late Pleistocene and Earliest Holocene Fossil Vertebrate Localities and Taxa from the Western Mojave Desert and Southwestern Great Basin

Appendix 1 systematically lists vertebrate taxa from late Pleistocene through earliest Holocene localities in the western Mojave Desert and southwestern Great Basin. It has been compiled from published records, technical reports, unpublished manuscripts, communications and inspection of paleontologic collections. Pertinent data are arranged in the following format.

Locality name (synonyms): geologic formation: institutional locality number(s); age: radiometric date(s): (publications and information sources)
systematic taxonomic list

Localities are listed alphabetically by county and locality name. Equivalent names for a site, either published or used by some institutions, are enclosed in parentheses. Following the locality name(s), geologic formation names are included when known. Institutional locality number(s) are then listed.

An age assessment follows the locality name, and is based on published estimates or the age of the listed geologic formation. Assemblages that may be in part Holocene are indicated. An assemblage that is probably late Pleistocene but lacks age determinate taxa or definitive geologic context is labeled as "age uncertain." Published radiometric dates are listed after the age assessment. Where numerous radiometric determinations have been made, a range is given. Holocene dates less than 8000 years BP are not reported.

Principal references and other information sources follow each locality entry. These include publications that describe a locality, provide an age or discuss recovered and identified taxa.

Vertebrate taxa are listed in systematic order. Nomenclature follows Simpson (1945), the American Ornithologists Union Check List (1957) and subsequent published revisions. Botanical and invertebrate taxa are included where reported or identified in collections. The molluscan taxonomy was revised by R. Lamb (personal communication to Jefferson, 1987).

Locality information and taxonomic lists for the University of California, Museum of Paleontology (UCMP) were compiled from the Taxonomic Information Retrieval (TAXIR) computer data base. Locality and taxonomic data from the Vertebrate Paleontology collection at the Los Angeles County Museum of Natural History were recovered from TAXIR and revised following examination of the collection. The note "specimen(s) not listed in TAXIR" refers to described UCMP localities where no speciemsn were collected or localities with no specimens cataloged and recorded into the TAXIR system.

Institutional acronyms are as follows: LACM = Los Angeles County Museum of Natural History; LACM(CIT) = Los Angeles County Museum of Natural History, California Institute of Technology; SBCM = San Bernardino County Museum; SDSNH = San Diego Society of Natural History; UALP = University of Arizona Laboratory of Paleontology; UCMP = University of California Museum of Paleontology; UCRV = University of California Riverside; USGSM = United States Geological Survey Museum.

Inyo County

Bedelle: UCMP V37025
(specimen/s not listed in TAXIR)

Lone Pine: (Hay, 1927)
Mammuthus ?columbi

Lone Pine, southeast: LACM (no locality number): (Whistler pers. comm. 1981)
Felidae (medium-size)
Proboscidea
Equus sp.
Camelops sp.

Owens Lake, north: LACM 4691
Proboscidea
Felis sp.
Equus sp.
Camelidae

Owens Lake, east: SBCM 6.6.3--6.6.4
Equus sp.
Camelops sp.
Bison sp.

Panamint Crater: UALP 49
Gopherus agassizi
Lepus sp.
Neotoma sp.
Rodentia
Canidae
Equus sp. (large)
E. sp. (small)
Hemiauchenia sp.
Antilocapridae

Panamint Valley Sinkhole (= ? UALP 49): (S. Winslow pers. comm. 1988)
condor
Equus sp.
Camelops sp.

Kern County

China Lake, China Lake Local Faunule: LACM(CIT) 266, LACM 1543, 3659, 7013: 18,600 +450, 11,800 +800: (Fortsch, 1978; Kurten and Anderson, 1980; McDonald, 1981; Davis, 1982; Agenbroad, 1984)
Gila bicolor mohavensis
Anura
Chelonia
Aechmophorus sp.
Phalacrocorax sp.
Anas sp.
Aythya sp.
Branta sp.
Cygnus sp.
Oxyura sp.
Aquila cf. A. chrysaetos
Haliaeetus sp.
Fulica sp.
Grus sp.
Edentata
Microtus sp.
Canis sp.
Smilodon sp.
Felidae gen. sp.
Mammuthus cf. M. columbi
Camelops cf. C. hesternus
Hemiauchenia sp.
Odocoileus sp.

Bison antiquus antiquus
B. sp. (large)

Dove Springs: UCMP V67225
(specimen/s not listed in TAXIR)

Dove Springs Wash: LACM 4708-09: (Whistler and Stewart pers. comm. 1989)
Pisidium sp.
Lymnaeidae
Hydrobeiidae
Vallonia cyclophorella
Vertigo berryi
Physidae
Succineidae
Discus crokhitei
Deroceras sp.
Anura
Sceloporus occidentalis
Phrynosoma sp.
Gerrhonotus sp.
Lampropeltis zonata
Pituophis melanoleucus cantenifer
Passeriformes
Sorex palustris
Pipistrellus hesperus
Sylvilagus sp.
Ammospermophilus sp.
Eutamias minimus
Thomomys monticola
Dipodomys sp. (a)
D. sp. (b)
Perognathus longimembris
Chaetodipus penicillatus
Reithrodontomys sp.
Peromyscus sp.
Neotoma sp. (cf. N. fuscipes or N. cinerea)
Microtus californicus

Edwards Air Force Base, Rogers Lake: SBCM 1.155.8, 1.155.11, 1.155.24--25, 1.155.51, 1.155.151, 1.155.245--46, 1.155.251, 1.155.254, 1.155.282 (major localities only): ?in part Holocene
Physa sp.
Gastropoda (sp. a)
Gastropoda (sp. b)
Ostracoda
Osteichthys
Reptilia
Aves
Homo sapiens
Lepus sp.
Sylvilagus sp.
Dipodomys sp.
Neotoma sp.
?Mammuthus
Equus sp.
?Camelops
cf. Hemiauchenia
?Antilocapra

Goler Gulch: LACM 3721
Equus cf. E. conversidens

Los Angeles County

Palmdale, on San Andreas Rift: LACM(CIT) 589: age uncertain
(material not in collection)

San Bernardino County

Awl Site, west Drinkwater Basin: (Cottrell pers. comm. 1989)
Mammuthus sp.

Bedford Road: SBCM 1.76.77
Equus sp.

Bitter Springs Playa, Rodgers Ridge (OPKC): SBCM 1.72.10
Gopherus sp.
Lepus californicus
Sylvilagus audubonii
Spermophilus nr. S. tereticaudus
Dipodomys sp.
Canis latrans
Perognathus sp.
Neotoma sp.
Microtus sp.
C. dirus
C. (lupus-size)
Felis atrox
Smilodon sp.
Arctodus simus
Mammuthus sp.
Equus cf. E. conversidens
E. sp. (large)
?Camelops
Hemiauchenia sp.
Antilocapra americana

Black Butte: SBCM 37, 1.76.14
?Mammut
Mammuthus sp.
Camelops sp. (large)
Artiodactyla (small)

Calico Early Man Site: Yermo Gravels: SBCM 1.128.5: 200,000 +20: (Bischoff and others, 1981; Budinger, 1983)
Proboscidea

Calico Lakes: SBCM 1.76.35
Camelops cf. C. hesternus

Calico Road: SBCM 1.76.18--1.76.28
Chelonia
Lepus sp.
Equus sp.
Camelops sp.

Camp Cady Bluffs #1-3: SBCM 1.76.7--1.76.9
Mammalia

Daggett, Calico Lakes Project: SBCM 1.76.25, 1.76-35a--1.76.37: 12,800 +900, 9050 +350: (Reynolds and Reynolds, 1985)
Pisidium sp.
Heliosoma sp.
Planorbula sp.
Physa sp.
Pupilla sp. (a)
P. sp. (b)
Succinea sp.
Ostracoda
Teleostei
Rana sp.
Xantusia cf. X. vigilis
Colubridae
Crotalinae
Aves
Scapanus latimanus
Lepus cf. L. californicus
Sylvilagus sp.
Spermophilus mohavensis
Thomomys bottae
Dipodomys sp.
Perognathus sp.
Peromyscus sp.
Neotoma lepida
Microtus cf. M. californicus
Equus cf. E. occidentalis
Camelops cf. C. hesternus
Hemiauchenia macrocephala
Ovis canadensis

Daggett, Cool Water Coal Gassification Site: SBCM 1.76.31--1.76.32: (Reynolds and Reynolds, 1985)
Gopherus agassizi
Lepus cf. L. californicus
Sylvilagus sp.
Mammuthus sp.
Equus cf. E. occidentalis

Daggett, Cool Water Coal Gassification Solid Waste Site: SBCM 1.76.33: 12,210 +430: (Reynolds and Reynolds, 1985)
Anodonta sp.
Pisidium sp.
Heliosoma sp.
Planorbula sp.
Physa sp.
Vallonia sp.
Succinea sp.
Insecta
Ostracoda
Gila bicolor
Gasterosteus aculeatus
Scaphiopus sp.
Anura
Sceloporus sp.
Crotophytus xislenzenii
Phrynosoma platyrhinos
Xantusia cf. X. vigilis
Cnemidophorus sp.
Gerrhonotus sp.
Colubridae
Crotalinae
Callipepla sp.
Geococcyx californianus
Caprimulgidae
Colaptes sp.
Eremophila alpestris
approx. Troglodytes
cf. Turdus
cf. Mimus
Vireonidae
Dendroica sp.
Emberizinae sp. (small)
Emberizinae sp. (large)
nr. Zontrichia
nr. Junco
nr. Sturnella
Icterus nr. I. cucullatus

cf. Xanthocephalus xanthocephalus
nr. Pheuticus
Fringillidae
Carduelinae
Sorex ornatus
Notiosorex crawfordi
Scapanus latimanus
Antrozous pallidus
Lepus sp.
Sylvilagus audubonii
S. bachmani
Spermophilus mohavensis
S. sp. (small)
Thomomys sp.
Dipodomys sp.
Perognathus sp.
Peromyscus sp.
Neotoma lepida
Microtus sp.
Vulpes macrotis
Proboscidea
Equus sp. (large)
Hemiauchenia macrocephala

Daggett, Luz Solar Trough Site: SBCM 1.76.34: 10,910 +425: (Reynolds and Reynolds, 1985)
Anodonta sp.
Lymnaea sp.
Gyraulus sp.
Planorbula sp.
Menetus sp.
Physa sp.
Vallonia sp.
Succinea sp.
Ostracoda (sp. a)
Ostracoda (sp. b)
Teleostei
Dipsosaurus dorsalis
Sauromalus obesus
Sceloporus sp.
Phrynosoma platyrhinos
Cnemidophorus sp.
Lichanura trivirgata
Colubridae
Crotalinae
Trogloditidae
Fringillidae
Lepus cf. L. californicus
Sylvilagus sp.
Spermophilus mohavensis
S. tereticaudus
Thomomys bottae
Dipodomys sp.
Perognathus sp.
Peromyscus sp.
Neotoma lepida
Microtus cf. M. californicus
Vulpes cf. V. macrotis
Equus cf. E. occidentalis

Daggett, Luz Foundation: SBCM 1.76.34: (Reynolds and Reynolds, 1985)
Anodonta sp.
Pisidium sp.
Planorbula sp.
Vallonia sp.
Succinea sp.
Ostracoda (sp. a)
Ostracoda (sp. b)
Teleostei
Anura
Sceloporus sp.
Xantusia cf. X. vigilis
Colubridae
Crotalinae
Aves
Notiosorex crawfordi
Sylvilagus sp.
Thomomys bottae
Dipodomys sp.
Perognathus sp.
Peromyscus sp.
Neotoma lepida
Microtus cf. M. californicus

Daggett, Solar One Generating Station: SBCM 1.76.11--1.76.13: in part Holocene: (Reynol and Reynolds, 1985)
Anura
Gopherus agassizi
Dipsosaurus dorsalis
Sauromalus obesus
Crotophytus sp.
Uta stansburiana
Phrynosoma platyrhinos
Cnemidophorus sp.
Gerrhonotus sp.
Colubridae
Crotalinae
Strigidae
Tyrannidae
Icteridae
Fringillidae
Homo sapiens
Lepus cf. L. californicus
Sylvilagus sp.

Spermophilus tereticaudus
Ammospermophilus cf. A. leucurus
Thomomys bottae
Dipodomys sp.
Perognathus sp.
Neotoma lepida
Mammuthus sp.
Equus cf. E. occidentalis
Camelops cf. C. hesternus

Daggett, United Energy Solar Ponds: SBCM 1.76.38: (Reynolds and Reynolds, 1985)
Heliosoma sp.
Equus cf. E. conversidens

Harper Valley: LACM 1345: ?Holocene
Lepus sp.

Kramer, SEGS III-VII: SBCM 1.137.3-9:
Gopherus sp.
Lepus californicus
?Sylvilagus
Equus sp.
Hemiauchenia sp.
Antilocapra sp.

Lake Manix (Manix Lake Beds), Camp Cady Local Fauna: Manix Formation: LACM(CIT) 540-542, 582, LACM 1093, 3496, 4032-39, 4054-61; SBCM 528, 1.59.2-23, 1.59.30; UCMP V676, V791;UCRV 6709-64, 6767, 6769, 6852, 69100-124, 7019-24, 7049-65, 7101-15, 7129-46; USGSM (field locality numbers only): numerous radiometric dates, 350+ to 14 kyr BP: (Brattstrom, 1961; Kurten and Anderson, 1980; Jefferson and others, 1982; Harris, 1985; Jefferson, 1985a, 1985b, 1987; Steinmetz, 1988; Meek, 1989)
Spermophyta
Anodonta californiensis
Pisidium compressum
Valvata humeralis
Fossaria modicella
Planorbella ammon
P. subcrenata
P. ?trivolvis
Carinifex newberryi
Gyraulus vermicularis
Physa sp.
Vorticifex effusa
Cyprinotus incongruens
L. ceriotuberosa
L. platyforma
L. robusta
Gila bicolor mojavensis
Gasterosteus aculeatus
Clemmys marmorata
Gopherus agassizi (presence not confirmed)
Gavia cf. G. arctica
Podiceps cf. P. erythrorhynchos
Aechmophorus occidentalis
Pelecanus aff. P. erythrorhynchos
Phalacrocorax auritus
P. macropus
Ciconia maltha
Poenicopterus minutus
P. copei
Cygnus cf. C. columbianus
Branta canadensis
Anas cf. A. platyrhynchos
Aythya sp.
Mergus cf. M. merganser
Oxyura jamaicensis
Haliaeetus leucophalus
Aquila chrysaetos
Fulica americana cf. F. a. minor
Grus sp.
cf. Actitis
Phalaropodinae
Larus cf. L. oregonus
L. sp.
Bubo virginianus
Megalonyx sp.
Nothrotheriops cf. N. shastense
Glossotherium sp.
Lepus sp.
Cricetidae
Canis cf. C. dirus
C. latrans
Arctodus sp.
cf. Ursus
Homotherium sp.
Felis sp.
Mammuthus sp.
Equus cf. E. conversidens
E. sp. (large)
Camelops cf. C. hesternus
C. aff. C. ?minidokae
Lamini gen. et sp. nov.
Hemiauchenia macrocephala
Antilocapra sp.
Bison cf. B. antiquus
Ovis canadensis

Lake Manix, Coyote Lake IPP Electrodes: Manix Formation: SBCM 1.75.11: (Roeder, 1985; Steinmetz pers. comm. 1987)

Limnocythere bradburyi
L. ceriotuberosa
L. robusta
L. platyforma
Heterocypris sp.
Moina ephippia
Gila bicolor
Gasterosteus aculeatus

Lake Manix, Mojave River Bluffs: Manix Formation: SDSNH (no locality number)

Gila sp.
Equus sp. (small)

Lake Manix, Stevens' Lake: Manix Formation: SBCM 830

Clemmys marmorata
Edentata
Mammuthus sp.
Equus conversidens
Camelops sp. (large)

Lucerne Dry Lake, Rabbit Springs: SBCM 1.107.1

Equus sp.
?Camelidae

Lucerne Valley, Silver Creek Canyon: UCMP V59030: ?Holocene

(specimen/s not listed in TAXIR)

Ludlow Cave: P. Reeves Collection: (P. Reeves pers. comm. 1988)

Gopherus agassizi
? cf. Capromeryx
Artiodactyla (?Hemiauchenia)

Minneola Road: SBCM 1.76.30: age uncertain

Mammalia

Newberry Condor Road: SBCM 1.76.15: age uncertain

Mammalia

Newberry Cave: SBCM 102: in part Holocene: (Davis and Smith, 1981)

Larrea tridentata
Eriogonum inflatum
Encilia farinosa
Ferocactus acanthodes
Opentia basilaris
Yucca sp.
Curcurbita sp.
Insecta
Sauromalus obesus
Crotalus sp.
Gopherus agassizi
Gymnogyps californicus
Buteo jamaicensis
Fulica americana
Bubo verginianus
Nothrotheriops shastense
Lepus californicus
Sylvilagus audubonii
Marmota flaviventris
Spermophilus spp.
Ammospermophilus leucurus
Thomomys bottae
Dipodomys sp.
Neotoma lepida
Microtus californicus
Taxidea taxus
Canis latrans
Urocyon cinereoargenteus
Felix concolor
Equus sp. (E. caballus reported)
Ovis canadensis nelsoni

Schuiling Cave: LACM 1123; SBCM 1.77.1; in part Holocene: 12,500 +150: (Brattstrom, 1958, 1961; Downs and others, 1959; Kurten and Anderson, 1980; Jefferson, 1983; Harris, 1985; Jefferson and others, 1987).

Gopherus agassizi
Sauromalus obesus
Crotalus cf. C. atrox
Anas cf. A. platyrhynchos
A. cf. A. carolinensis
Mareca americana
Nyroca cf. N. americana
Oxyura jamaicensis
Gymnogyps amplus
Aquila chrysaetos
Buteo jamaicensis
Fulica americana
Recurirostra americana
Zenaidura macroura
Otus cf. O. asio
Bubo verginianus
Colaptes cafer
Corvus corvax
Homo sapiens
Lepus sp.
Sylvilagus sp.

Spermophilus sp.
Thomomys sp.
Dipodomys sp.
Perognathus sp.
Neotoma sp.
Taxidea cf. T. taxus
Canis cf. C. lupus
Urocyon sp.
Procyon sp.
Felis cf. F. concolor
F. sp. (small)
Equus sp. (large)
E. sp. (small)
Camelidae (?Camelops hesternus)
Hemiauchenia sp.
Capromeryx minor
Ovis sp.

Superior Dry Lake: SBCM 1.134.1; UCRV (no locality number): ?in part Holocene: (Jefferson, 1971)
Leporidae
Camelidae

Vitrlite Marl Quarry, Helendale: LACM 1184
Phrynosoma sp.
Zenaidura macroura
Lepus sp.
Sylvilagus sp. (small)
Perognathus sp.
Dipodomys sp.
Thomomys sp.
Neotoma sp.

TABLE 1

Late Pleistocene and early Holocene vertebrate taxa from the western Mojave Desert

Explanation: EL = extralocal range, no longer inhabits the region; RR = range restricted since late Pleistocene; XT = extinct. Geographic ranges of extant taxa are from Garrett and Dunn (1981), Hall and Kelson (1959), Peterson (1947, 1961), and Stebbins (1966).

CLASS OSTEICHTHYES

Order Cypriniformes
Gila bicolor mojavensis, Mojave tui chub, RR
Order Gasterosteiformes
Gasterosteus aculeatus, threespine stickleback, EL

CLASS AMPHIBIA

Order Anura
Scaphiopus sp., spadefoot toad, RR
Bufo sp., toad, RR
Rana sp., frog, RR
cf. Hyla, tree frog, EL

CLASS REPTILIA

Order Chelonia
Clemmys marmorata, western pond turtle, EL
Gopherus agassizi, desert tortoise
Order Squamata
Dipsosaurus dorsalis, desert iguana
Sauromalus obesus, chuckwalla
Sceloporus occidentalis, western fence lizard
Crotophytus wislenzenii, leopart lizard
Uta stansburiana, brown-shouldered lizard
Phrynosoma platyrhynos, desert horned lizard
Xantusia cf. X. vigilis, yucca night lizard

Cnemidophorus sp., whiptail lizard
Gerrhonotus sp., alligator lizard, EL
Lichanura trivirgata, rosy boa
Crotalidae, rattlesnakes
Pituophis melanoleucus cantenifer, Pacific gopher snake

CLASS AVES

Order Gaviiformes
Gavia cf. G. arctica, arctic loon
Order Podicipediformes
Podiceps cf. P. nigricollis, eared grebe
Aechmophorus occidentalis, western grebe
Pelecanus aff. P. erythrorhynchos, American white pelican
Phalacrocorax auritus, double-crested cormorant
P. macropus, large-footed cormorant, XT
Order Ciconiiformes
Ciconia maltha, brea stork, XT
Phoenicopterus minutus, minute flamingo, XT
P. copei, Cope's flamingo, XT
Order Anatidae
Cygnus cf. C. columbianus, tundra swan
Branta canadensis, Canada goose
Anas cf. A. crecca, green-winged teal
A. cf. A. platyrhinchos, mallard
Aythya sp., greater scaup or canvasback
Mergus cf. M. merganser, common merganser
Oxyura jamaicensis, ruddy duck
Order Accipitriformes
Haliaeetus leucophalus, bald eagle
Aquila chrysaetos, golden eagle
Gymnogyps amplus, condor, XT
G. californicus, California condor, EL
Buteo jamaicensis, red-tailed hawk
Order Galliformes
Callipepla sp., quail
Order Gruiformes
Fulica americana cf. F. a. minor, small American coot, XT
Grus sp., crane
Order Charadriiformes
Recurvivostra americana, avocet
cf. Actitis sp., sandpiper
Phalaropodinae, phalarope
Larus cf. L. oregonus, Oregon gull
L. sp. (large), gull
Order Columbiformes
Zenaidura macroura, mourning dove
Order Cuculiformes
Geococcyx californianus, roadrunner
Order Strigiformes
Otus cf. O. asio, screech owl
Bubo virginianus, great horned owl
Order Caprimulgiformes
Caprimulgidae, goatsuckers
Order Piciformes
Colaptes sp., flicker
Order Passeriformes
Tyrannidae, flycatchers
Eremophila alpestris, horned lark
Corvus corax, common raven
approx. Troglodytes, wrens
cf. Turdus, robin, EL
cf. Mimus, mockingbird
Vireonidae, vireos
Dendroica sp., warbler
Emberizinae ap. (small), sparrow
Emberizinae sp. (large), sparrow
nr. Zontrichia, sparrow
nr. Junco, junco
nr. Sturnella, meadowlark
cf. Xanthocephalus xanthocephalus, yellow-headed blackbird
Icterus sp. nr. I. cucullatus, hooded oriole
nr. Pheuticus, grosbeak
Carduelinae, finches

CLASS MAMMALIA

Order Insectivora
Sorex ornatus, ornate shrew, EL
S. palustris, northern water shrew, EL
Notiosorex crawfordi, gray shrew
Scapanus latimanus, California mole
Order Primates
Homo sapiens, human
Order Chiroptera
Pipistrellus hesperus, western pipistrel
Antrozous pallidus, pallid bat
Order Edentata
Megalonyx sp., ground sloth, XT
Nothrotheriops cf. N. shastense, Shasta ground sloth, XT
Glossotherium sp., large ground sloth, XT
Order Lagomorpha
Lepus cf. L. californicus, California jack rabbit
Sylvilagus audubonii, desert cottontail

S. bachmani, brush rabbit, EL

Order Rodentia

- Marmota flaviventris, yellowbelly marmot, EL
- Eutamias cf. E. merriami, Merriam's chipmunk, EL
- E. minimus, least chipmunk, EL
- Spermophilus mojavensis, Mojave ground squirrel
- S. tereticaudus, roundtail ground squirrel
- Ammospermophilus cf. A. leucurus, whitetail antelope squirrel
- Thomomys bottae, valley pocket gopher
- T. monticola, Sierra pocket gopher, EL
- Dipodomys cf. D. merriami, Merriam's kangaroo rat
- D. sp., kangaroo rat
- Perognathus longimembris, little pocket mouse
- Chaetodipus penicillatus, desert pocket mouse
- Reithrodontomys sp., harvest mouse
- Peromyscus sp. (cf. P. maniculatus or P. crinitus), white-footed mouse
- Neotoma lepida, desert woodrat
- N. sp. (cf. N. cinerea or N. fuscipes), woodrat, EL
- Microtus californicus, California vole, RR

Order Carnivora

- Taxidea taxus, badger
- Canis cf. C. dirus, dire wolf, XT
- C. latrans, coyote
- Vulpes macrotis, kit fox
- Urocyon cinereoargenteus, gray fox
- Arctodus sp., short-faced bear, XT
- cf. Ursus, bear
- Homotherium sp., scimitar cat, XT
- Smilodon sp., sabertooth cat, XT
- Felis concolor, mountain lion
- F. sp. (F. onca agusta size), jaguar, XT
- F. sp.(small), bobcat

Order Proboscidea

- Mammuthus cf. M. columbi, columbian mammoth, XT
- ?Mammut, mastodon, XT

Order Perissodactyla

- Equus cf. E. conversidens, small horse, XT
- E. cf. E. occidentalis, large horse, XT

Order Artiodactyla

- Camelops cf. C. hesternus, large camel, XT
- C. aff. C. ?minidokae, small camel, XT
- Lamini gen. et sp. nov., large llama, XT
- Hemiauchenia macrocephala, large-headed llama, XT
- Antilocapra sp., pronghorn antelope, RR
- Capromeryx minor, small pronghorn antelope, XT
- Bison antiquus antiquus, antique bison, XT
- B. sp. (large), large bison
- Ovis canadensis, mountain sheep

Episodic lake bed formation in the Victorville area, California

Jeanne D. Power, Department of Earth Sciences, University of California, Riverside, CA 92521

Previous reconnaissance studies of the Victorville area described fluviatile and lacustrine sediments of late Pleistocene age (Fig. 1). The fossils found in the area by Reynolds and others (1981) are Irvingtonian in age. The finer-grained sediments have been correlated to the Shoemaker Gravels, and the coarser-grained fluviatile sediments have been correlated to the Older Alluvium (Bowen, 1954; Dibblee, 1967; Noble, 1954a, 1954b; Reynolds, 1980, and herein); Rogers, 1967; Woodburne, 1978; Woodburne and Golz, 1977).

Mapping was done on a composite of portions of the Adelanto and Apple Valley 7.5 minute quadrangles and all of the Victorville 7.5 minute quadrangle. The field mapping indicates that there is a series of lacustrine deposits that alternate with a series of fluviatile deposits. All of the beds mapped were flat-lying. Within the 300 ft measured section, nine fossil-bearing lake beds were described. The lower part of the stratigraphic section, from the base 2726 ft to 2890 ft, was measured on the National Trails Highway in a bluff across from the cement plant. The rest of the section was measured along Green Tree Boulevard at the intersection with Hesperia Road and continued along Yates Road. The lacustrine beds are all laminated to thinly-bedded silty claystone to clayey siltstone. The fluviatile beds are fine- to coarse-grained sandstones and conglomerates which are commonly cross-bedded. A brief description of the beds may be found in Figure 2.

There have been several interpretations as to the origin of the lacustrine deposits in the Victorville area. Bowen (1954, p. 89) attributes the lacustrine deposits to uplift and consequent damming on the Victorville Fault. However, the broad distribution of the lake deposits versus the limited extent of the Victorville Fault would indicate that his interpretation is incorrect. Another interpretation (Rogers, 1967) suggests that both the Victorville Fault and the local damming of the Mojave River occurred in response to uplift parallel to the Helendale Fault, subsequent to the San Andreas Fault and possibly along an unmapped southeasterly section of the Mirage Valley Fault (Fig. 1). Thus from Rogers' (1967) interpretation, multiple uplifts parallel to the Helendale Fault have resulted in the episodic production of lake beds in and around Victorville.

In the Fall of 1987, the map was expanded and photo updated using U2 imagery at a scale of 1:32,500 and satellite imagery. Air photointerpretation suggests that the areal extent of some of the beds of the Victorville lacustrine sequence may extend as far as the Shadow Mountains to the west and as far east as Lucerne Valley. The exact determination of these lake beds is under investigation by the author.

The possible areal extent of some (all?) of the lacustrine deposits based on the satellite imagery may be so vast that other interpretations (or interpretations in addition to damming of the Mojave River) may be needed to explain the formation of such widespread lacustrine deposits.

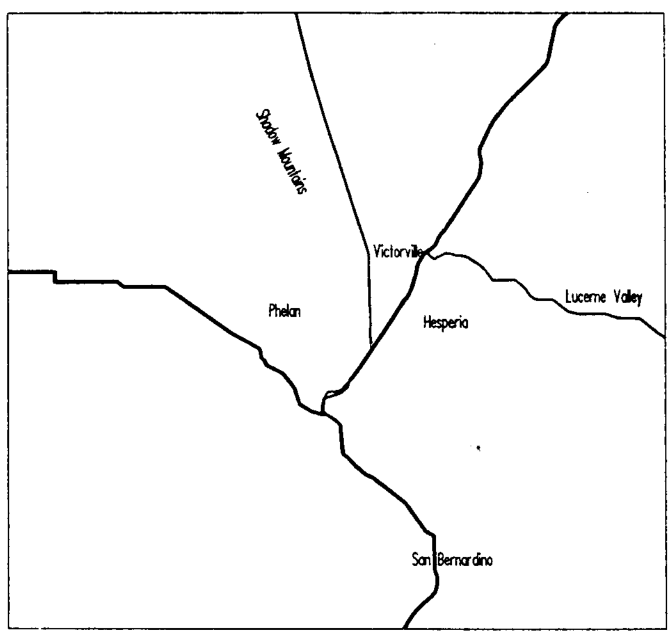
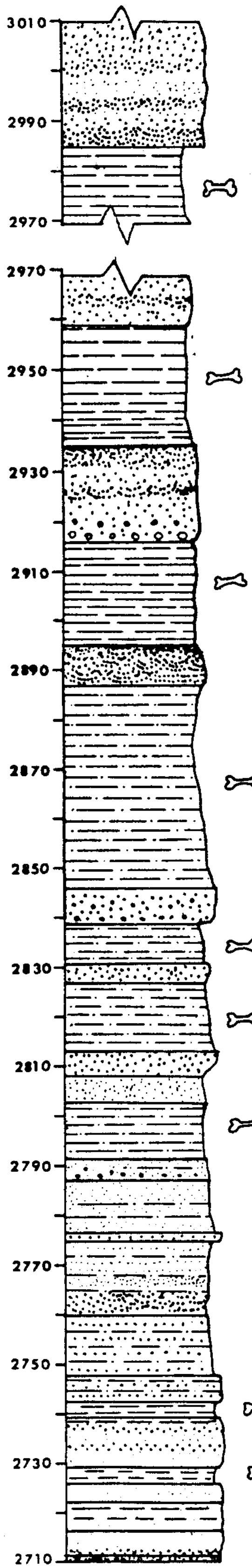


Figure 1. Index Map.

Section continues outside of mapped area



Very fine-grained to coarse-grained sands interbedded with conglomerates and with siltstone stringers. Colors of the sands very from orange-brown to pink to purple, the siltstone stringers are tan in color, the sands are commonly crossbedded.

Silty-claystone, yellowish orange-gray in color, the top 1 to 3 ft. are light orange-gray, caliche is commonly found along the upper surface of the bed, fossiliferous, massive.

Interbedded and crossbedded sandstones and siltstones and occasional conglomerates, the sandstones range in color from orange-brown to pink to purple, the siltstones are brown to to tan in color.

Silty-claystone, light grayish green in color, the top 3 ft. are light yellow to white in color, fossiliferous, massive.

Interbedded medium- to coarse-grained sandstones and conglomerates, the sandstones are commonly crossbedded and orange-brown in color with streaks of purple.

Claystone, grayish yellow-green in color, massive, fossiliferous.

Coarse-grained crossbedded sandstone with cobble clasts, calcite cement, light gray in color, becomes finer upward.

Siltstone, fossiliferous, poorly bedded, beds with calcite nodules. Light gray-green at base, center of unit is white, top portion very light brown.

Very coarse-grained sandstone-cobble conglomerate.

Fossiliferous siltstone, light brown to light green in color.

Coarse-grained poorly sorted sandstone, orange in color.

Siltstone, light brown to yellow-gray in color, fossiliferous.

Interbedded fine- to coarse-grained sandstone, light brown in color

Siltstone, fossiliferous, light brown to light green-gray in color.

Interbedded and crossbedded coarse to fine grained sandstones and silty-sandstones. Colors vary from light brown to orange to purple.

Silty-claystone, fossiliferous, greenish-gray.

Interbedded siltstones and sandstones, yellow-gray in color.

Silty-claystone, greenish-gray in color, fossiliferous

Interbedded and crossbedded sandstones and silty-claystones, orange-brown to light brown in color.

FIGURE 2, COLUMNAR SECTION

REFERENCES CITED

Bowen, O.E. Jr., 1954. Geology and mineral deposits of the Barstow quadrangle, San Bernardino County, California. San Francisco, California Division of Mines Bulletin 165.

Dibblee, T.W. Jr., 1967. Areal geology of the western Mojave Desert. Washington, D.C., U.S. Geological Survey Professional Paper 552.

Noble, L.F., 1954b. The San Andreas fault zone from the Soledad Pass to Cajon Pass, California. San Francisco, California Division of Mines Bulletin 170, Chapter IV.

__________, 1954a. Geology of the Valyermo quadrangle and vicinity, California. Washington D.C., U.S. Geological Survey quadrangle map series.

Power, J.D., 1985. Geologic map of the Bear Valley Road Redevelopment Area. City of Victorville.

Reynolds, R.E., 1980. Cultural resources assessment, Baldy Mesa water lines, County Services Area 70, Improvement Zone J, San Bernardino County, California. Redlands, San Bernardino County Museum Association.

____________, 1981. Paleontologic survey, Bear Valley Road Redevelopment Area near Thorn, San Bernardino County, California, IN Cultural Resource Survey of Bear Valley Road Redevelopment Project Study Area, Victorville, San Bernardino County, California. Larry Seaman Associates, Environmental Impact Report.

Rogers, T.H., 1967. Geologic map of California, San Bernardino Sheet, scale 1:250,000. San Francisco, California Division of Mines and Geology.

Woodburne, M.O., 1978. Fossil vertebrates in the CDCA. ms prepared for Desert Planning Staff, Bureau of Land Management, Riverside.

Woodburne, M.O. and Golz, D., 1972. Stratigraphy of the Punchbowl Formation, Cajon Valley, southern California. Los Angeles, University of California Press, University of California Publications in Geological Sciences 92.

Mid-Pleistocene faunas of the west-central Mojave Desert

Robert E. Reynolds, Division of Earth Sciences, San Bernardino County Museum, Redlands CA 92374

ABSTRACT

Mid-Pleistocene mammal faunas from the west-central Mojave Desert have been recognized on the basis of temporally restricted taxa that represent the Irvingtonian Land Mammal Age (LMA), more than 450,000 years before present (BP)(Repenning, 1987). Other localities have a stratigraphic relationship with those containing Irvingtonian taxa. Still others fossil assemblages occur in sediments mapped as mid-Pleistocene or Older Quaternary Alluvium, or are within well-developed soil horizons attributed to a middle Pleistocene age; they are also referred to the Irvingtonian LMA. The relatively undeformed and undissected nature of the sediments suggest that the Mojave Desert west and north of the Mojave River between Hesperia and Yermo has been structurally stable over the last half-million years.

BACKGROUND

Previous geologic mapping in the western and central Mojave Desert has been published by Noble (1953, 1954), Bowen (1954), and Dibblee (1958, 1959, 1960a, 1960b, 1963, 1964, 1967, 1968) and Bowen (1954). They recorded Quaternary continental sediments such as alluvium (undifferentiated) (Q), older alluvium (undifferentiated) (Qo), older fan deposits (Qof), windblown sand (Qs), well-dissected alluvial fans (Qod), and terrace gravel (Qot). These lithologic units are, in part, referred to a middle Pleistocene age and in several specific cases contain fossils that can be referred to the Irvingtonian LMA.

Mapping of these sedimentary units has been summarized on the San Bernardino sheet (Bortugno and Spittler, 1986), the Trona sheet

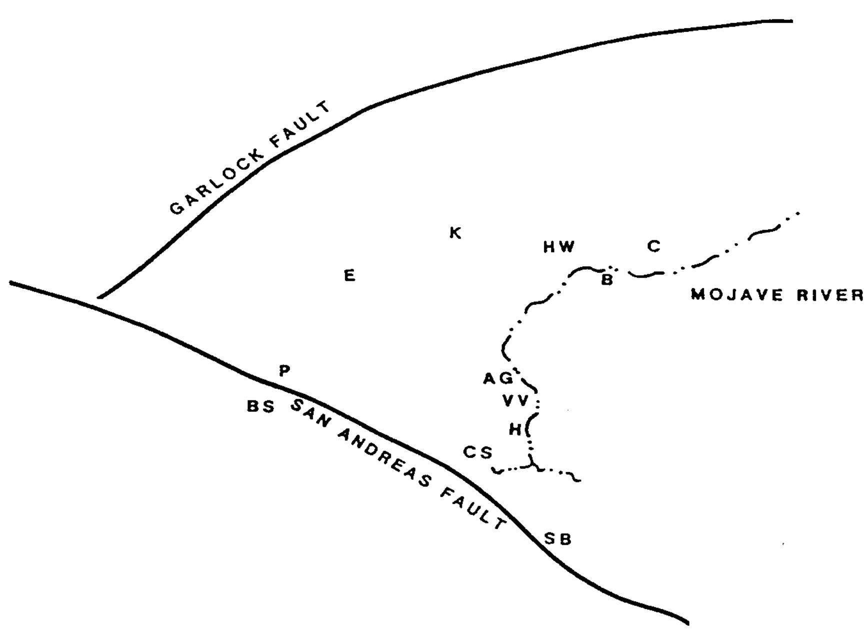


Figure 1. Index map of Irvingtonian LMA localities in the west-central Mojave Desert; cities indicated for reference. AG = Adelanto/George AFB; B = Barstow; BS = Barrel Springs; C = Calico Ghost Town; CS = Cajon Summit; E = Edwards AFB; HW = Hawes; H = Helendale; K = Kramer; P = Palmdale; SB = San Bernardino; VV = Victorville.

(Jennings and others, 1962), the Bakersfield sheet (Smith, 1964), and the Los Angeles sheet (Jennings and Strand, 1969) of the Geologic Map of California, California Division of Mines and Geology map sheet series.

Recent work in the Antelope Valley region of the western Mojave Desert by Ponti (1985), Ponti and others (1981), and Ponti and Burke (1980) described sequences of soil development, including the Tylerhouse series of soil horizons that may date to 500,000 BP. Well-developed soil profiles on sediments within the boundaries of Edwards Air Force Base and at Boron and Kramer may be of similar age (Reynolds 1987b, 1988a).

IRVINGTONIAN LAND MAMMAL AGE FAUNAS

Irvingtonian LMA faunas (Table 1) have been recognized in the western Mojave Desert at Hesperia (Table 2)(Reynolds, 1987a, Jefferson, 1986), Cajon Summit (Reynolds, 1985), Victorville (Jefferson, 1986), Adelanto/George Air Force Base (Jefferson, 1986; Reynolds 1986), Hawes (Reynolds, 1988a), in the Harold Formation (Jefferson, 1986; Repenning, U.S. Geological Survey, Denver, personal communication to author, 1985), and at Calico (Lander and Reynolds, 1985; C.A. Repenning, op. cit., 1984). Taxa from four of these localities are temporally restricted to the Irvingtonian LMA or earlier: Prodipodomys idahoensis; Sigmodon medius; and the Irvingtonian packrats Neotoma (Teanopus) "prealbigula" (Repenning, op. cit., 1984), which is comparable to the El Casco Irvingtonian LMA Neotoma (Repenning, op. cit., 1984) and Neotoma (Teanopus) "prefucipes", comparable to the Neotoma from the Irvington Local Fauna of the San Francisco Bay Area (Repenning, op. cit, 1984).

A combined faunal list from Irvingtonian LMA sediments in the west-central Mojave Desert is given in Table 1.

DISCUSSION

Summit

The Summit Safety Rest Area (SBCM 01.103.080) is located at Cajon Summit on Interstate Highway 15. At Summit, near Crowder Canyon, Weldon (1985) identified the 700,000 BP Brunhes/Matuyama paleomagnetic reversal event within the lower portion of the Old Alluvium. The Jaramillo event, 900,000 BP, is in the upper Shoemaker Gravels at the same location (Harland and others, 1982; Weldon, 1985). None of the taxa recovered from the Summit Safety locality are exclusively restricted to the Irvingtonian LMA, but all genera are known to occur within the late Irvingtonian and Rancholabrean land mammal ages (Carroll, 1988; Kurten and Anderson, 1980).

Hesperia/Victorville

Sediments in the Hesperia/Victorville area are distal counterparts of the Victorville Fan complex. The Shoemaker Gravels are unconformably overlain by the Old Alluvium of Noble (Bowen, 1954). They are separated by an erosional surface that may correspond to the one between the Shoemaker Gravels and the coarser Old Alluvium such as is seen at Cajon Summit (Reynolds, 1985). These two units were deposited in response to uplift in the San Gabriel Mountains (Meisling and Weldon, 1989). The occurrence of Sigmodon medius at the Hesperia Road site (SBCM 01.114.038) is within the base of the coarse sediments, suggesting that they were deposited during the late Irvingtonian LMA.

Adelanto/George

In the area between Adelanto and George Air Force Base, west of the Mojave River, a series of lacustrine sediments (Power, herein; Reynolds, 1987a) are overlain by fanglomerates. East of Adelanto, near George Air Force Base, paleomagnetic samples from the lacustrine series (K. Meisling, ARCO, Dallas, personal communication to author, 1984) are normally-oriented, suggesting that the latest portion of the lacustrine sequence, the unconformity, and the earliest fanglomerates are post-Brunhes/Matuyama reversal and pre-Rancholabrean LMA. This would suggest an age of latest Irvingtonian, perhaps between 450,000 and 700,000 BP (Harland and others, 1982; Repenning, 1987). Temporal data in this region does not exclude the possibility that younger, Rancholabrean LMA localities exist in the overlying Pleistocene Old Alluvium.

TABLE 1
West-Central Mojave Desert Irvingtonian Taxa

Anodonta sp.	fresh water mussel
Succinea sp.	fresh water snail
Gopherus sp.	tortoise
Lepus sp.	jack rabbit
Sylvilagus sp.	cotton tail rabbit
Dipodomys sp.	kangaroo rat
Microtus sp. cf. M. californicus	vole
Neotoma (Teanopus) "prefucipes"	pack rat
Neotoma (Teanopus) "prealbigula"	pack rat
Peromyscus sp. cf. P. longimembris	extinct deer mouse
Peromyscus sp.	deer mouse
Prodipodomys idahoensis	extinct ancestral kangaroo rat
Thomomys sp.	pocket gopher
Antilocapridae	prong-buck antelopes
Camelidae	camels
Hemiauchenia sp.	extinct llama
Equus sp. (large)	extinct large horse
Mammut sp.	extinct mastodon
Mammuthus sp.	extinct mammoth

Hawes

The Hawes site (SBCM 01.123.002) is located south of Highway 58 and east of Helendale Road. The fossil vertebrates occur in greenish-gray silty sands attributed to deposition in ponds or lakes. These interdigitate laterally with deeply-weathered fluviatile sediments (Reynolds, 1988a). The sediments are assigned to the Irvingtonian LMA based on the presence of Prodipodomys idahoensis (Savage and Russell, 1983). The degree of soil profile development in adjacent sediments may correspond to that seen in the Tylerhorse series (Ponti, 1985).

Edwards/Kramer

Vertebrate fossil localities at the Luz SEGS sites at Kramer and west through Edwards Air Force Base occur in sediments above the elevation of Rancholabrean age Lake Thompson (elevation 2325 feet). Sediments at Kramer are deeply weathered to a depth of at least 5 feet (Reynolds, 1987b).

Within Edwards Air Force Base, fossil localities occur in fanglomeratic sands between 2325 feet and 3,000 feet on the slopes of Leuhman Ridge, Haystack Butte and Jackrabbit Hill (Reynolds, 1988a, 1988b). These dissected fanglomeratic sands also show well-developed soil profiles and caliche horizons.

Barrel Springs

The Barrel Spring locality (SBCM 09.001.001, UCR RV 7618) is within the Harold Formation in a fault sliver along the San Andreas Fault, south of the town of Palmdale. Fossils were recovered from gray-green sandstones approximately 14 feet below a caliche horizon near the top of the Harold Formation. The Neotoma in the assemblage (Appendix 1) is particularly significant because it is the same form found in the Irvington Local Fauna of the San Francisco Bay Area. This form represents the late Irvingtonian LMA, approximately 800,000 BP (Repenning, 1987 and op. cit., 1984).

Calico

The historic town of Calico was built upon terraces developed on flat-lying silts, sands, and fanglomerates. These sediments are deeply-weathered and contain kernals of caliche and pyrolusite. The Calico Ghost Town Local Fauna (SBCM 01.128.024) includes Neotoma (Teanopus) "prealbigula", which is comparable to similar Neotoma from middle Irvingtonian LMA sediments at El Casco (Repenning, 1984; Lander and Reynolds, 1985). Other taxa in the fauna are given in Appendix 1.

SUMMARY

Fossil assemblages in the western Mojave Desert near Palmdale, Edwards Air Force Base, Kramer, Calico, Victorville, and Cajon Summit are assignable to an Irvingtonian LMA of the middle late Pleistocene. Age ranges of the faunas may be from 800,000 to 450,000 BP and are consistent with paleomagnetic reversal data (Weldon, 1985; Meisling and Weldon, 1989) as well as ages assigned to well-developed soil horizons in the western Mojave Desert (Ponti, 1985).

The geographic distribution of the faunas and the lack of dissection or deformation of formations that contain the fossils suggest that the Mojave Desert west and northwest of the Mojave River has been relatively stable for the last half million years.

REFERENCES CITED

Bortugno, E.J. and T.E. Spittler, 1986. Geologic map of the San Bernardino quadrangle, scale 1:250,000. Regional Geologic Map Series, Map No. 3A, California Division of Mines and Geology.

Bowen, O.E. Jr., 1954. Geology and mineral deposits of the Barstow quadrangle, San Bernardino County, California. California Division of MInes Bulletin 165:1-85.

Carroll, R.L., 1988. Vertebrate paleontology and evolution. New York, W.H. Freeman & Co: 698 p.

Dibblee, T.W. Jr., 1958. Geologic map of the Boron quadrangle, Kern and San Bernardino counties, California. U.S. Geological Survey Mineral Inv. Field Studies Map MP-204, scale 1:62,500.

_____, 1960a. Geology of the Rogers Lake and Kramer quadrangles, California. U.S. Geological Survey Bulletin 1089-B: 139 p.

_____, 1960b. Geologic map of the Hawes quadrangle, San Bernardino County, California. U.S. Geological Survey Mineral Investigations Field Studies Map MF-226, scale 1:62,500.

_____, 1963. Geology of the Willow Springs and Rosamond quadrangles, California. U.S. Geological Survey Bulletin 1089-C.

_____, 1964. Geological map of the Rodman Mountains quadrangle, San Bernardino County, California. U.S. Geological Survey Mis. Geol. Invest. Map I-430, scale 1:62,500.

_____, 1967. Areal geology of the western Mojave Desert, California. U.S. Geological Survey Professional Paper 522.

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

Harland, W.B., A.V. Cox, P.G. Llewellyn, C.A.G. Pickton, A.G. Smith, and R. Walters, 1982. A geologic time scale. Cambridge, Cambridge University Press.

Jefferson, G.T., 1986. Fossil vertebrates from late Pleistocene sedimentary deposits in the San Bernardino and Little San Bernardino Mountains region, IN Geology around the margins of the eastern San Bernardino Mountains, M.A. Kooser and R.E. Reynolds, eds. Redlands, Inland Geological Society Publications, 1:77-80.

Jennings, C.W., J.L. Burnett, and B.W. Troxel, 1962. Geologic map of California, Trona sheet, scale 1:250,000. California Division of Mines and Geology.

Jennings, C.W. and R.G. Strand, 1969. Geologic map of California, Los Angeles sheet, scale 1:250,000. California Division of Mines and Geology.

Kurten, B. and E. Anderson, 1980. Pleistocene mammals of North America. New York, Columbia University Press: 442 p.

Lander, E.B. and R.E. Reynolds, 1985. Fossil vertebrates from the Calico Mountains area, central Mojave Desert, California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:153-156.

Meisling, K.E. and R.J. Weldon, 1989. Late Cenozoic tectonics of the northwestern San Bernardino Mountains, southern California. Geological Society of America Bulletin 101:106-128.

Noble, L.F., 1953. Geology of the Pearland quadrangle, California. U.S. Geological Survey geologic quadrangle map GP-24, scale 1:24,000.

_____, 1954. Geology of the Valyermo quadrangle and vicinity, California. U.S. Geological Survey geologic quadrangle map GQ-50, scale 1:24,000.

Ponti, D.J., 1985. The Quaternary alluvial sequence of the Antelope Valley, California, IN Soild and Quaternary geology of the southwestern United States, D.L. Weide, ed. Geological Society of America Special Paper, 203:79-96.

Ponti, D.J. and D.B. Burke, 1980. Map showing Quaternary geology of the eastern Antelope Valley and vicinity, California. U.S. Geological Survey open-file report 80-1064, scale 1:62,500.

Ponti, D.J., D.B. Burke, and C.W. Hedel, 1981. Map showing Quaternary geology of the central Antelope Valley and vicinity, California. U.S. Geological Survey open-file report 81-737, scale 1:62,500.

Repenning, C.A., 1987. Biochronology of the Microtine Rodents of the United States, IN Cenozoic mammals of North America, M.O. Woodburne, ed. Berkeley, University of California Press:236-268.

Reynolds, R.E., 1985. Paleontologic salvage, Summit Safety site, Cajon Pass, San

Bernardino County, California. Redlands, San Bernardino County Museum: 51 p.
_____, 1986. Paleontologic monitoring and salvage, Intermountain Power Project, Intermountain-Adelanto Bipole I transmission line, California section. Redlands, San Bernardino County Museum: 447 p.
_____, 1987a. Paleontologic salvage, Southern California Edison Company Victor Valley branch office, Victorville, San Bernardino County, California. Redlands, San Bernardino County Museum: 54 p.
_____, 1987b. Paleontologic mitigation, Kramer SEGS sites, San Bernardino County, California. Redlands, San Bernardino County Museum: 30 p.
_____, 1988a. Paleontologic monitoring and salvage, Federal lands along the All American and Celeron pipeline project, California section. Redlands, San Bernardino County Museum: 428 p.
_____, 1988b. Paleontologic resource overview and management plan for Edwards Air Force Base. Redlands, San Bernardino County Museum: 199 p.
Smith, A.R., 1964. Geologic map of California, Bakersfield sheet, scale 1:250,000. California Division of MInes and Geology.
Weldon, R.J., 1985. Implications of the age and distribution of the late Cenozoic stratigraphy in Cajon Pass, southern California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:59-68.
Weldon, R.J., D.S. Winston, J.L. Sirscvink, and D.W. Burbank, 1984. Magnetic stratigraphy of the Crowder Formation, Cajon Pass, southern California, IN Abstracts with Programs, 97th Annual Meeting Geological Society of America, 16:689.

APPENDIX 1

Irvingtonian Land Mammal Age Taxa from the West-Central Mojave Desert

Palmdale

Barrel Springs (Harold Formation); SBCM 9.1.1, UC RIV 7618

Microtus californicus	meadow mouse
Neotoma (Teanopus) "prefuscipes"	wood rat
Camelops sp.	large camel
Equus sp.	horse
Mammuthus sp.	mammoth
Mammut sp.	mastodon

Pearland (Harold Formation); LACM (CIT) 589

Equus sp.	horse
Mammut sp.	mastodon

Cajon Summit

Summit Safety Rest Area (Old Alluvium or Shoemaker Gravels); SBCM 1.103.80

Spermophilus sp. (sm)	ground squirrel
Eutamias sp.	chipmunk
Dipodomys cf. D. merriami	kangaroo rat
Neotoma nr. N. lepida	wood rat

Hesperia/Victorville

Hesperia Road/SCE Branch Office; SBCM 1.114.38

Sorex sp.	shrew
Lepus sp.	jack rabbit
Sylvilagus sp.	cottontail rabbit
cf. Ammospermophilus leucurus	antelope ground squirrel
Spermophilus townsendi	Townsend's ground squirrel
Perognathus sp.	pocket mouse
Dipodomys sp.	kangaroo rat
Neotoma sp.	wood rat
Sigmodon medius	cotton rat

Dean Road/Shivers Road; SBCM 1.114.32, LACM 1224

Neotoma cf. N. lepida	wood rat
Thomomys sp.	pocket gopher
Equus sp.	horse
Proboscidea	elephant

Dean Place; SBCM 1-114.31

Camelops sp.	large camel

Thorn; SBCM 10114.6, 8-24, 33

Dipodomys sp.	kangaroo rat
Hemiauchenia sp.	llama
Camelops sp.	large camel
Equus sp. (lg)	large horse
Mammuthus sp.	mammoth

Eureka Street; SBCM 1.114.7

Mammuthus sp.	mammoth

Leon; SBCM 1.114.3

Equus sp.	horse

Victorville (Shoemaker Gravels); LACM 3352-3353

Equus sp.	horse

Victorville, east (Shoemaker Gravels); LACM 3512

Equus sp. (lg)	large horse

Victorville, west (Shoemaker Gravels); LACM (CIT) 209

Equus sp. (lg)	large horse
Mammuthus sp.	mammoth

Adelanto/George

Oro Grande/George Air Force Base Bluffs; SBCM 1.114.4

Mammut sp.	mastodon
Mammuthus sp.	mammoth

El Evado Edison Road #2; SBCM 1.114.29

Gopherus sp.	tortoise
Equus sp.	horse

Turner Spring; SBCM 1.114.24-26

Anodonta sp.	fresh water mussel
Lepus sp.	jack rabbit

Village Drive #2; SBCM 1.114.28

Equus sp. (lg)	large horse
Mammuthus sp.	mammoth

George 1-5; SBCM 1.114.33b, 34-37

Coleonyx sp.	gecko
Lepus sp.	jack rabbit
Perognathus cf. P. longimembris	pocket mouse
Neotoma cf. N. albigula	wood rat

Hawes

Hawes; SBCM 1.123.2

Anodonta sp.	fresh water mussel
Succinea sp.	fresh water snail
Cyprinidae	minnow
Sylvilagus sp.	cottontail rabbit
Lepus sp.	jack rabbit
Thomomys sp.	pocket gopher
Prodipodomys sp. cf. P. idahoensis	ancestral kangaroo rat
Dipodomys sp.	kangaroo rat
Peromyscus sp.	deer mouse
Microtus sp. cf. M. californicus	meadow mouse

Edwards/Kramer

Kramer, Luz SEGS III-VII; SBCM 1.137.3-9, 1.137.16-34

Lepus sp. cf. L. californicus	jack rabbit
Spermophilus sp. cf. S. tereticaudus	round-tailed ground squirrel
Thomomys sp.	pocket gopher
Vulpes sp. cf. V. macrotis	kit fox
Cervus elephas	wapiti
Camelidae	camel
Equus sp.	horse

Edwards Air Force Base, localities above Lake Thompson (elevation 2325'); SBCM 1.155.7, 12, 28, 29, 32, 38, 166, 167, 173, 174, 176, 181, 184, 185, 187, 194, 200, 201, 205, 236, 237, 258, 259, 298, 299, 300, 307, 313, 314, 323, 327, 349, 350, 372

Gopherus sp.	tortoise
Lepus sp.	jack rabbit
Antilocapra sp.	pronghorn antelope
cf. Hemiauchenia	llama
Camelops sp.	large camel
Equus sp.	horse
Mammuthus sp.	mammoth
Mammut sp.	mastodon

Calico

Calico Ghose Town; SBCM 1.128.24

Neotoma (Teanopus) "prealbigula"	wood rat
Perognathus sp.	pocket mouse
Dipodomys sp.	kangaroo rat
Equus ?conversidens	horse

Age and significance of the Red Buttes Andesite Kramer Hills, Mojave Desert, California

R.K. Dokka, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803
A.K. Baksi, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803

A recent synthesis by Dokka (1989) proposes that the regional pattern of early Miocene low- and high-angle normal faulting and dike swarm emplacement in the western and central Mojave Desert is the result of regional extension developed within a roughly east trending zone, named the "Mojave Extensional Belt". This zone of extension, although now disrupted by late Cenozoic right-slip faulting, can be traced from the intersection of the San Andreas and Garlock faults to the eastern Mojave Desert near Bristol Lake and the Granite Mountains Fault.

Strain within the Mojave Extensional Belt is partitioned between four domains (Edwards, Waterman, Daggett, and Bullion terranes) that each consist of one or more half-grabens. Each half-graben is composed of tilted, normal fault-bounded blocks that lie above a rooted, low-angle, brittle-ductile normal sense shear zone. The tilted rocks of the Kramer Hills are part of the Edwards Terrane and constitute the upper plate of the Harper Lake detachment. Geochronologic studies of the Red Buttes Andesite in the Kramer Hills were undertaken to more tightly constrain the timing of normal faulting and tilting associated with the opening of the Mojave Extensional Belt (Dokka, 1989).

In the Kramer Hills, the Red Buttes Andesite overlies with disconformity to slight angular unconformity a sequence of moderately tilted basalt, dolomite, sandstone, and shale. The Red Buttes Andesite is conformably overlain by shales which are, in turn, unconformably overlain by a thick assemblage of lower Miocene (?) conglomerates and breccias informally referred to as the formation of Kramer Hills (Dokka, 1989). The field location of the dated sample of the Red Buttes Andesite is 34°53'54.5"N, 117°30'50"W. Two samples were dated using the K-Ar whole rock method and yielded an age of 21.2 +/-0.5 Ma (%K-1.98; $^{40}Ar^{radiogenic} \times 10^7 (cm^3 NTP/g = 16.4$; %Atmos. Ar = 71.5).

These new observations on the age and stratigraphic setting of the Red Buttes Andesite have several important implications for the tectonic evolution and stratigraphic framework of the Mojave Desert Block. First, the age of the Red Buttes Andesite is consistent with stratigraphic and paleontologic timing relations indicating deposition in the early Miocene. This date also supports the notion of a lower Miocene age for the underlying lower part of the Tropico Group. Second, the stratigraphic position of the Red Buttes Andesite suggests that it is actually part of the lower Tropico Group and not the intervening unit (20.3 +/-0.7 Ma Saddleback Basalt of the Boron district) that subdivides the entire Tropico Group as envisioned by Dibblee (1967) and Whistler (1984). Third, the time of tilting (and by inference the time of normal faulting) in the Kramer Hills and nearby areas can be constrained using these new data and existing dated cross-cutting relations. In the hills north of Boron, moderately to steeply tilted lower Tropico Group are overlain by the slightly tilted to flat-lying Saddleback Basalt. These rocks are in turn overlain by the Kramer Beds that contain fossils of early Hemingfordian age (Boron Local Fauna of Whistler [1984]). The interval of tilting is thus bracketed between 21.2 +/-0.5 Ma and 20.3 +/-0.7 Ma.

REFERENCES CITED

Dibblee, T.W., Jr., 1967. Areal geology of the western Mojave Desert, California. U.S. Geological Survey Professional Paper 522:1-153.

Dokka, R.K., 1989. The Mojave Extension Belt of southern California. Tectonics, 8, in press.

Whistler, D.P., 1984. An early Hemingfordian (early Miocene) fossil vertebrate fauna from Boron, western Mojave Desert, California. Natural History Museum of Los Angeles County, Contributions in Science, 355: 36 p.

The Waterman Hills detachment fault, central Mojave Desert, California

Allen F. Glazner, Department of Geology, University of North Carolina, Chapel Hill, North Carolina 27599-3315
John M. Bartley, Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112
J. Douglas Walker, Department of Geology, University of Kansas, Lawrence, KS 66045

INTRODUCTION

The amount of Tertiary crustal extension expressed in the central Mojave Desert is an important but poorly known quantity. The central Mojave lies well west of the inferred breakaway fault of the Whipple detachment terrane (Howard and John, 1987), and generally has not been included as part of the highly extended portion of the Basin and Range (e.g., Davis and others, 1980). Recent work in the central Mojave Desert (Dokka, 1986; Glazner, 1988) has shown that large areas have been affected by at least moderate amounts of extension, but evidence for large-scale extension of the type found in the Colorado River trough has been lacking. In this paper we present evidence that structures exposed in the Waterman Hills area, north of Barstow, California, imply large amounts of extension in the central Mojave Desert.

The Waterman Hills detachment fault (WHDF) is a newly discovered, well-exposed, low-angle normal fault which crops out a few kilometers north of Barstow (Figs. 1, 2). The fault system comprises steeply tilted to overturned volcanic and sedimentary rocks which lie in low-angle fault contact upon mylonitized granodiorite and gneiss. Upper-plate rocks are Tertiary

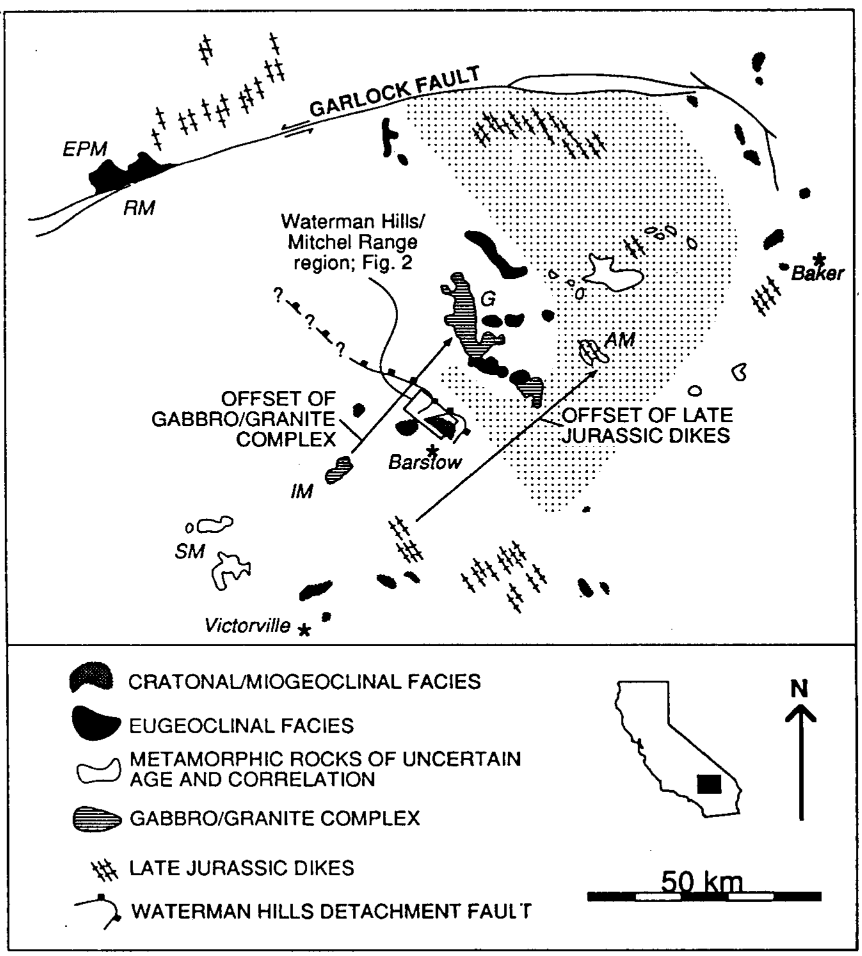


Figure 1. Paleogeographic elements of central Mojave Desert. Waterman Hills detachment fault (WHDF) may have undergone 40 km or more of low-angle displacement (arrows). Stippled area constrains location of boundary between cratonal/miogeoclinal Paleozoic rocks and eugeoclinal Paleozoic rocks; note that this contact is poorly constrained everywhere except in Waterman Hills-Goldstone area. Removing slip on WHDF places cratonal/ miogeoclinal rocks of Mitchel Range and Hinkley Hills structurally beneath eugeoclinal rocks of Goldstone area. Location of WHDF north and south of Waterman Hills is poorly constrained. AM = Alvord Mountains, EPM = El Paso Mountains, G = Goldstone-Lane Mountain area, IM = Iron Mountains, RM = Rand Mountains, SM = Shadow Mountains.

(probably early Miocene) in age. Spectacular exposures of the WHDF occur at the microwave towers at the summit of the Waterman Hills (Field Trip Stop 3); additional exposures are found in the northern Mitchel Range (immediately east of the Waterman Hills), where a series of Tertiary klippen lie in low-angle fault contact upon mylonitized gneiss.

The Waterman Hills region contains many of the features that are common to the "core-complex" detachment faults of the Colorado River trough region to the east, including (1) a well-exposed low-angle normal fault, (2) a footwall composed of pre-Tertiary igneous and metamorphic rocks, which, near the detachment, contain a mylonitic fabric that is in turn overprinted by cataclasis and intense chloritization within tens of meters of the fault, (3) a hanging wall composed of Tertiary rocks that are steeply tilted, highly attenuated, and potassium-metasomatized, and (4) a complete mismatch between upper-plate and lower-plate lithologies.

This paper summarizes our work to date in the Waterman Hills area, and is largely taken from Glazner et al. (1988), Glazner et al. (1989), and Walker et al. (submitted).

Regional Significance of the Waterman Hills Detachment Fault

The WHDF is an important structure for several reasons, including:

(1) It provides the first evidence for large-scale, "core-complex"-like crustal extension in the central Mojave Desert. Significant homoclinal tilting and extension has been documented in some of the ranges east of the Waterman Hills, such as the Newberry Mountains (Dokka, 1986) and Cady Mountains (Glazner, 1988), but structures in these areas are dominantly brittle and apparently reflect hanging-wall deformation for the most part. The WHDF represents the first evidence that rocks deformed by normal faulting in the ductile regime have been brought to the surface along a low-angle normal fault in the central Mojave Desert.

(2) It lies well west of the extended terranes of the Colorado River trough, and is separated from structures in the trough by a region where Tertiary rocks are flat-lying (Nielson and Glazner, 1986; Glazner and Bartley, 1988). Because the WHDF apparently roots to the northeast (see below), this implies that the flat-lying terrane and the younger detachment terranes to the northeast may be carried in the hanging wall of the WHDF. Any kinematic model for the early Miocene evolution of the Mojave Desert region must account for the apparent kinematic isolation of the WHDF.

(3) The possibility of large slip (tens of kilometers) on the WHDF implies that pre-Miocene structures and facies trends may be significantly disrupted. In particular, the boundary between eugeoclinal and miogeoclinal/cratonal facies in Paleozoic rocks (e.g., Burchfiel and Davis, 1981; Kiser, 1981; see below), and the western limit of the Late Jurassic Independence dike swarm (Glazner et al., 1989), are both kinked around Barstow. These kinks may be related to extension on the WHDF.

(4) Miogeoclinal/cratonal rocks are exposed in the footwall of the WHDF, whereas eugeoclinal rocks of the northern Calico Mountains are apparently carried in the hanging wall. If normal slip on the WHDF system has been about 15 km or more, then footwall miogeoclinal rocks restore to a position structurally below the eugeoclinal rocks, implying that the eugeoclinal rocks were thrust over the miogeoclinal rocks.

(5) Mylonitization in footwall rocks is demonstrably Tertiary in age, based both on field relations and on U/Pb geochronology. In some other detachment fault terranes, the age of mylonitization is equivocal.

(6) Footwall rocks exposed below the WHDF show evidence for one or more periods of pre-Tertiary deformation, so unraveling Tertiary deformation of the gneiss may allow a glimpse into the pre-Tertiary history of the region.

(7) Low-angle structures in the Waterman Hills region may correlate with seismic reflectors seen in COCORP lines run to the northwest of the area (Cheadle and others, 1986).

Previous Work

The Waterman Hills region was mapped in reconnaissance by Miller (1944), Bowen (1954), and Dibblee (1960), none of whom noted the low-angle fault contact between Tertiary volcanic rocks

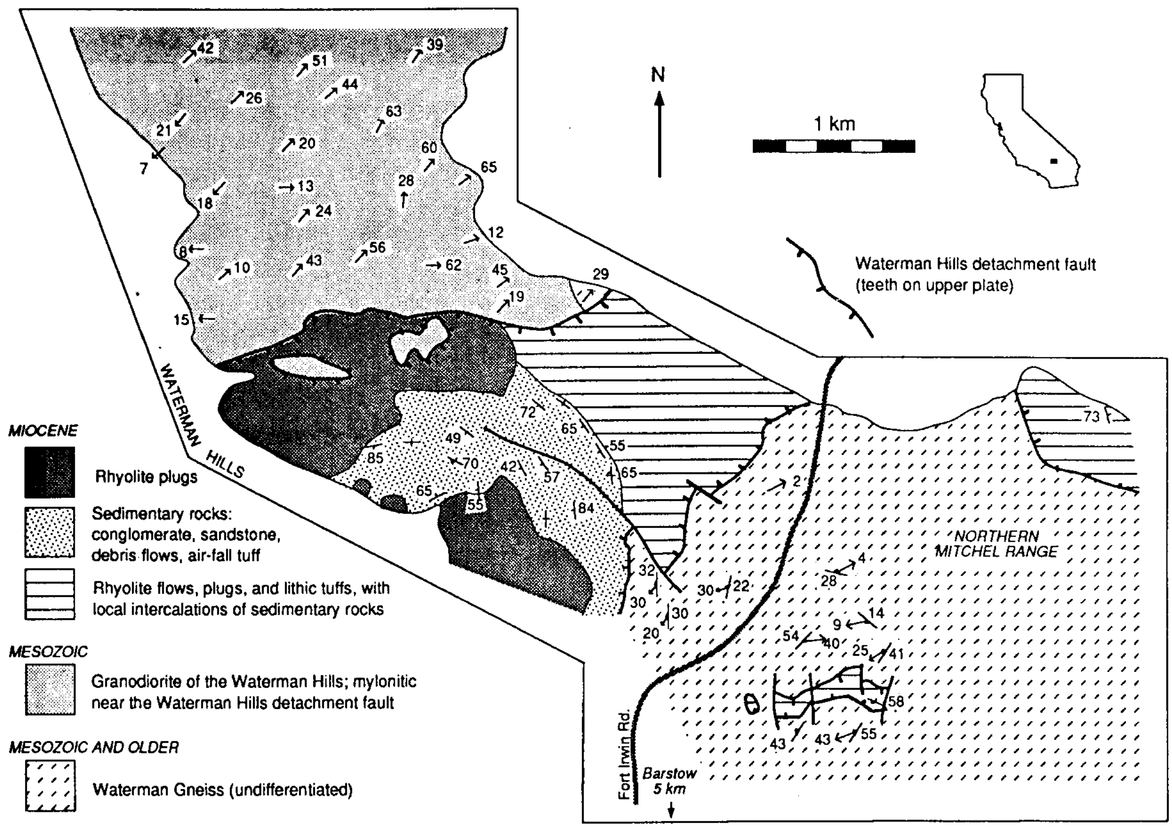


Figure 2. Preliminary geologic map of Waterman Hills and northern Mitchel Range.

and mylonite. Dibblee's map, at 1:62,500 scale, shows many of the structural features of the area, including the Tertiary syncline and northeast-trending folds in Waterman Gneiss. In the map explanation, he made the important observation that the granodiorite of the Waterman Hills "grades southeastward [toward the WHDF] into faintly gneissoid [mylonitic] quartz diorite." The area lies just south of the Opal Mountain 15' quadrangle and just west of the Daggett 15' quadrangle, both of which were mapped by Dibblee (1968, 1970).

WATERMAN HILLS DETACHMENT FAULT

Lithologies

Along the WHDF, steeply tilted to overturned Tertiary volcanic and sedimentary rocks lie in low-angle fault contact upon pre-Tertiary, mylonitized granodiorite and gneiss. Details of the stratigraphy and structure in the region are given in Glazner et al. (1988) and Walker et al. (submitted); only a brief summary is given here.

The footwall of the WHDF comprises two distinct units. The older of the two, the Waterman Gneiss, is a heterogeneous assemblage of mylonitized metasedimentary and metaigneous rocks (Bowen, 1954; Dibblee, 1967). The gneiss is intruded by a granodiorite pluton of probable Jurassic or Cretaceous age. Following correlations made in surrounding areas by Stewart and Poole (1975) and Kiser (1981), we infer that metasedimentary strata in the Waterman Gneiss correlate with miogeoclinal/cratonal strata of Late Proterozoic and early Paleozoic age in the southern Great Basin. The Waterman Gneiss shows evidence for at least two distinct metamorphic events. The first event, which predated intrusion of

Mesozoic granodiorite, reached conditions in the amphibolite facies; the second, of probable early Miocene age, is recorded by a chlorite-grade mylonitic fabric that is pervasively superimposed on the higher grade mineral assemblages.

The hanging wall of the WHDF in the Waterman Hills is composed of Tertiary rhyolite flows and lithic tuffs that pass upward into conglomerate and sandstone. These strata are intruded by rhyolite plugs, and all Tertiary units are truncated against the underlying WHDF. All hanging-wall rocks have undergone pervasive potassium metasomatism identical to that seen in other low-angle normal fault complexes (e.g., Chapin and Glazner, 1983; Brooks, 1986; Glazner, 1988; Glazner and Bartley, 1989). On the basis of lithologic similarity, we correlate these units with the nearby Pickhandle Formation, which has yielded a 19 Ma age on rhyolite (McCulloh, 1952; Dibblee, 1968; Burke et al., 1982). A minimum age for the Pickhandle Formation in the Mud Hills is given by the unconformably overlying Barstow Formation, which is approximately 18-13 Ma (Burke et al., 1982; MacFadden et al., 1988).

Structural Geology

The WHDF complex records both brittle and ductile deformation related to low-angle normal faulting. The contact between hanging-wall rhyolites and footwall granodiorite is knife-sharp where well exposed at the summit of the Waterman Hills (Field Trip Stop 3). Rocks within several metres above and below the WHDF are finely comminuted by cataclasis. For hundreds of metres both above and below the contact, the rocks are cut by myriad small faults. In the hanging wall, these faults consistently attenuate the stratigraphic section. Within several tens of metres beneath the WHDF, footwall shattering is accompanied by chloritic alteration.

The Waterman Gneiss is variably mylonitic throughout its exposure, but it is strongly mylonitic, brecciated, and chloritized within tens of metres of the WHDF. These relationships are clearly exposed at Field Trip Stop 3. The granodiorite is isotropic to faintly lineated away from the WHDF. However, it contains a diffuse mylonitic fabric about 2 km from the trace of the fault that becomes intense within tens of metres of the WHDF. On the basis of these field relations, we infer a Miocene age for formation of the mylonites. In addition, Walker et al. (submitted) report an age of 23 $\pm$0.9 Ma on a dacite intrusion in the Mitchel Range which is cut by thin mylonitic shear zones. The mylonitic fabric is distinctive because only a lineation is apparent in many samples; it is uncommon to find that lineation developed within a coeval foliation. The mean mylonitic lineation trends N40°E, and field and microscopic features of footwall mylonites consistently indicate a top-to-northeast shear sense (Glazner et al., 1988).

TECTONIC HISTORY

Timing of deformation

Movement on the WHDF occurred no longer ago than the age of hanging-wall strata, which is poorly constrained at about 19 Ma. The 23 Ma age on weakly mylonitic dacite indicates that at least some mylonitization occurred after 23 Ma. Further interpretation of this age awaits detailed mapping in progress by J. Fletcher (University of Utah). A minimum age of faulting can only be inferred indirectly. The extremely coarse nature of clastic rocks in the Pickhandle Formation indicates that they are syntectonic deposits related to displacement on the WHDF. Fine-grained fluviolacustrine strata of the Barstow Formation lie in angular unconformity upon the Pickhandle Formation in the Mud Hills (Dibblee, 1968). We interpret the 18-13 Ma Barstow Formation to record post-tectonic filling of an extensional basin formed adjacent to the Waterman Hills metamorphic core complex by displacement along the WHDF. These relationships indicate that displacement on the WHDF occurred approximately 18-23 Ma.

This is consistent with timing of extension in surrounding ranges. For example, mapping by Dibblee (1964) indicates that tilting in the Newberry Mountains is constrained to the interval between eruption of tilted basalt, dated at 23.7 $\pm$2.3 Ma (Nason et al., 1979; corrected to new decay constants of Dalrymple, 1979), and eruption of the flat-lying Peach Springs Tuff, which has been dated at 18.5 $\pm$0.0.2 Ma (Nielson et al., submitted; also see Glazner et al., 1986). In the southeastern Cady Mountains, which lie 70 km east of the Waterman Hills, tilting is bracketed between eruption of 20 Ma tilted volcanic rocks and eruption of the Peach Springs Tuff (Glazner, 1988).

Tectonic Model

Tentative correlations between the hanging wall and footwall indicate that the WHDF may have accumulated slip of 40-50 km or more. Distinctive gabbro complexes that are cut by dikes of muscovite-garnet granite crop out in the footwall in the Iron Mountains, 20 km southwest of the Waterman Hills (Bowen, 1954, and our reconnaissance) and in the hanging wall in the Lane Mountain area, 20 km northeast of the Waterman Hills (McCulloh, 1952; Miller and Sutter, 1982). Restoring slip on the WHDF so that these areas are aligned straightens a 50-km jog in the western edge of a Late Jurassic dike swarm (Fig. 1; Miller and Sutter, 1982). In addition, Stone and Stevens (1988) noted that miogeoclinal/cratonal strata near Victorville and in the San Bernardino Mountains crop out anomalously far to the west, relative to an inferred irregular Paleozoic continental margin; aligning the gabbro-granite complexes brings these western exposures much closer to the inferred continental margin.

Figure 3 is a series of schematic cross sections that illustrate our interpretation of relations between the WHDF, sedimentation, and pre-Tertiary basement terranes.

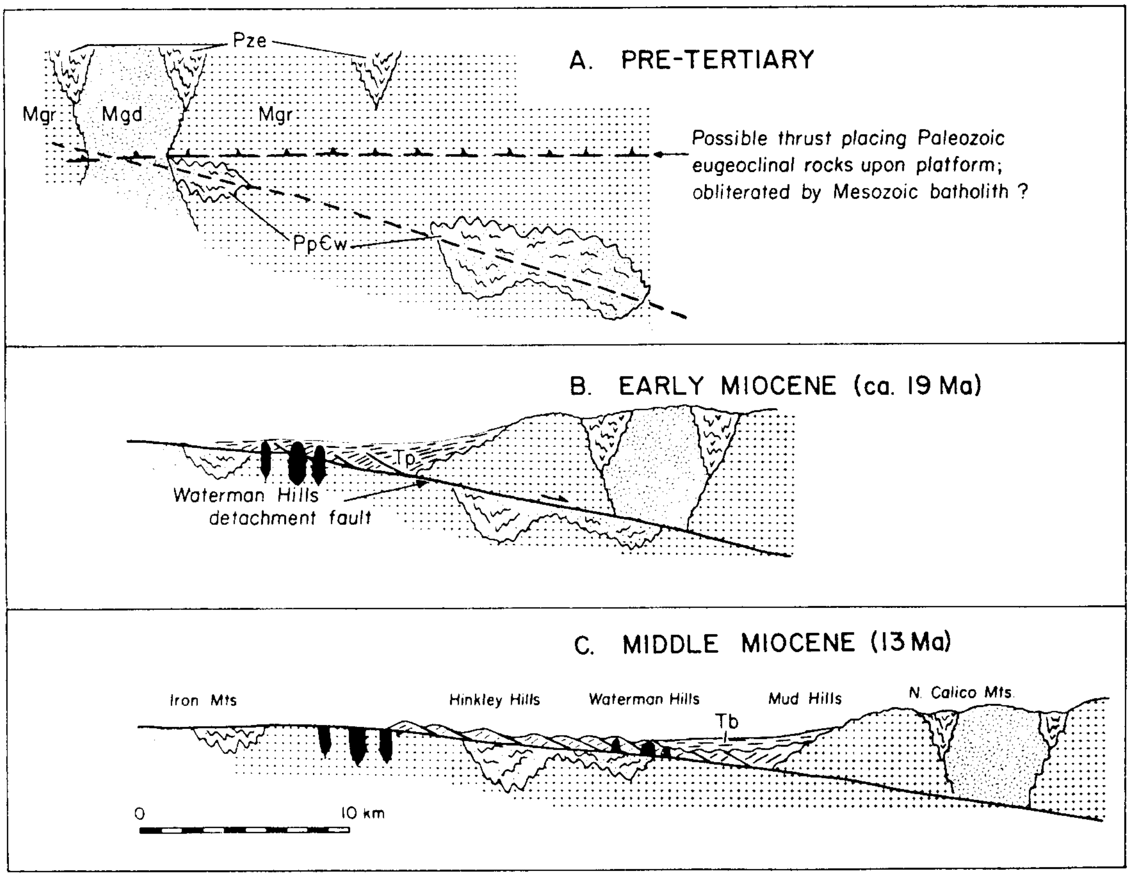


Figure 3. Conceptual model for evolution of Waterman Hills detachment fault. Neogene folding related to right-slip Calico fault (Dibblee, 1968) has been removed. A: Geometry with 40 km of displacement on WHDF restored. Eugeoclinal Paleozoic rocks (Pze) lie structurally above miogeclinal/cratonal Paleozoic strata in Waterman gneiss (PpCw). These strata are engulfed by Mesozoic batholith, including gabbro-diorite complex (Mgd) and more widespread granodioritic intrusions (Mgr). B: Geometry during displacement along WHDF. Pickhandle Formation (Tp) is deposited in extensional basin formed by displacement along WHDF, and is syntectonically intruded by rhyolite plugs (black). Continued displacement truncates plugs, upper parts of which now are exposed in Waterman Hills; roots of plugs have not been located. C: By mid-Miocene time, after movement has ceased, post-tectonic Barstow Formation (Tb) accumulates unconformably upon Pickhandle Formation in topographic depression formed by extension.

REGIONAL IMPLICATIONS

Recognition of the WHDF as a major extensional fault is important for several reasons. It provides the first unambiguous evidence for large-scale, core complex-like crustal extension in the central Mojave Desert. Although domino-style normal faulting was recognized in ranges east of the Waterman Hills (e.g., Newberry Mountains, Dokka, 1986; Cady Mountains, Glazner, 1988), structures in these areas are brittle and probably reflect hanging-wall deformation for the most part. The WHDF represents the first direct evidence that extension in the central Mojave Desert was of a large enough magnitude to bring ductilely extended rocks to the surface.

The WHDF lies well west of the extended terranes of the Colorado River trough, and is separated from that region by an area where Tertiary rocks are nearly flat lying and little extended (Nielson and Glazner, 1986; Glazner and Bartley, 1988). Field relations of the Peach Springs Tuff indicate that extension in the central Mojave Desert ended before extension in the Whipple area ended. In the central Mojave Desert the Peach Springs Tuff is generally flat lying above tilted rocks, and thus was erupted after major extension; in the Colorado River trough, significant tilting and extension occurred after eruption of the tuff (K. A. Howard, 1985, pers. commun.; Davis, 1986; Nielson and Glazner, 1986). Davis and Lister (1988) proposed that the Whipple detachment system lies in the hanging wall of a slightly older, northeast-dipping detachment system, and that mylonitic gneisses in the footwall of the Whipple detachment are exhumed mid- to lower crustal rocks related to the older system. Davis and Lister's (1988) conceptual model of imbricate major detachment systems is therefore supported by timing and kinematic relations between the central Mojave Desert and the Colorado River trough, after removal of Neogene slip on intervening right-lateral faults.

The possibility of large slip (tens of km) on the WHDF implies that pre-Miocene structures and facies trends have been significantly modified. Stratigraphic data demonstrate that the original juxtaposition of miogeoclinal/cratonal and eugeoclinal strata in the Mojave Desert was of Permian-Triassic age (Burchfiel et al., 1980; Walker et al., 1984; Walker, 1988). However, the trace of the boundary between eugeoclinal and miogeoclinal/cratonal facies of Paleozoic rocks is sharply kinked around Barstow (Fig. 1; Burchfiel and Davis, 1981; Kiser, 1981). The coincidence of this kink with the area affected by the WHDF strongly suggests that the kink is a consequence of Tertiary extension.

Miogeoclinal/cratonal Paleozoic facies are exposed in the footwall of the WHDF, whereas eugeoclinal facies in the northern Calico Mountains are carried in the hanging wall (Figs. 1 and 3). If normal slip on the WHDF system has been about 15 km or more, then footwall miogeoclinal rocks restore to a pre-Tertiary position structurally below the eugeoclinal rocks. This restoration is consistent with the low metamorphic grade of the eugeoclinal sequence, which contrasts sharply with the amphibolite-facies metamorphism that has affected the miogeoclinal/cratonal rocks. This restoration implies that, before Tertiary extension, the eugeoclinal rocks lay upon a thrust contact above the miogeoclinal rocks. Verification of this thrust geometry, the age and significance of the thrusting, and its ultimate implications for Paleozoic-Mesozoic paleogeography must await documentation of the magnitude and areal distibution of the Tertiary extensional overprint.

CONCLUSIONS

1. The Waterman Hills detachment fault is a major low-angle detachment system, and may be the master shear zone above which hanging-wall extension of ranges to the east was accommodated. Kinematic data indicate that the hanging wall moved northeast relative to the footwall. Low-angle normal faulting occurred in the Miocene, approximately 18-19 Ma, and mylonitization of footwall rocks apparently accompanied faulting.

2. The WHDF roots to the northeast, beneath extensional systems in the Colorado River trough (after restoration of Neogene right-lateral shear), and is slightly older than detachment faults in the Whipple Mountains area. This geometry is compatible with the recent model of Davis and Lister (1988).

3. The Miocene Pickhandle and Barstow Formations were deposited during and after

extension, respectively, in an extensional basin or set of basins formed by normal displacement on the Waterman Hills detachment fault.

4. Tentative correlation of gabbro-granite complexes in the hanging wall and footwall of the WHDF indicates 40 km of normal slip on the fault. Removal of this slip straightens the western boundary of a prominent Late Jurassic dike swarm.

5. Restoration of slip on the WHDF moves cratonal/miogeoclinal Paleozoic rocks in the footwall structurally beneath eugeoclinal Paleozoic rocks in the hanging wall, implying that a thrust fault juxtaposed the facies belts prior to Tertiary extension. Restoration also reduces, and perhaps even removes, a prominent bend in the facies boundary, suggesting that the bend is a Tertiary feature.

ACKNOWLEDGMENTS

Supported by National Science Foundation grants EAR-8219032 (A.F.G.) and EAR-8600518 (J.M.B.), by the University of North Carolina Research Council, and by a Shell Faculty Fellowship to J.D.W. We thank S.B. Dent, M.W. Martin, W. Ussler III, and P.G. Feiss for field assistance, S.J. Reynolds and C.F. Miller for constructive reviews, K.A. Howard for logistical and cerebral support, and T.W. Dibblee, Jr., for his pioneering work in mapping the Mojave Desert.

REFERENCES CITED

Bartley, J. M., and Glazner, A. F., 1985, Hydrothermal systems and Tertiary low-angle normal faulting in the southwestern United States: Geology, v. 13, pp. 562-564.

Bowen, O.E., Jr., 1954, Geology and mineral deposits of Barstow quadrangle, San Bernardino County, California: California Division of Mines and Geology Bulletin, v. 165, p. 185.

Brooks, W.E., 1986, Distribution of anomalously high K_2O volcanic rocks in Arizona: Metasomatism at the Picacho Peak detachment fault: Geology, v. 14, p. 339-342.

Burchfiel, B.C., and Davis, G.A., 1981, Mojave Desert and environs, *in* Ernst, W.G., ed., The geotectonic development of California: Englewood Cliffs, New Jersey, Prentice-Hall, p. 217-252.

Burchfiel, B.C., Cameron, C.S., Guth, P.L., Spencer, J.E., Carr, M.D., Miller, E.L., and McCulloh, T.H., 1980, A Triassic overlap assemblage in northern Mojave/Death Valley region, California: An interpretation: Geological Society of America Abstracts with Programs, v. 12, p. 395.

Burke, D.B., Hillhouse, J.W., McKee, E.H., Miller, S.T., and Morton, J.L., 1982, Cenozoic rocks in the Barstow Basin area of southern California--stratigraphic relations, radiometric ages, and paleomagnetism: U.S. Geological Survey Bulletin, v. 1529-E, p. 1-16.

Chapin, C.E., and Glazner, A.F., 1983, Widespread K_2O metasomatism of Cenozoic volcanic and sedimentary rocks in the southwestern United States: Geological Society of America Abstracts with Programs, v. 15, p. 282.

Cheadle, M. J., and others, 1986, The deep crustal structure of the Mojave Desert, California, from COCORP seismic reflection data: Tectonics, v. 5, pp. 293-320.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558-560.

Davis, G.A., 1986, Tectonic implications of variable southwestward tilts in Tertiary upper-plate strata of a Miocene detachment terrane, southeastern California and west-central Arizona: Geological Society of America Abstracts with Programs, v. 18, p. 98.

Davis, G.A., and Lister, G.S., 1988, Detachment faulting in continental extension; perspectives from the southwestern U.S. Cordillera, *in* Clark, S.P., Jr., Burchfiel, B.C., and Suppe, J., eds., Processes in continental lithospheric deformation: Geological Society of America Special Paper 218, p. 133-159.

Davis, G. A., Anderson, J. L., Frost, E. G., and Shackelford, T. J., 1980, Mylonitization and detachment faulting in the Whipple-Buckskin-Rawhide Mountains terrane, southeastern California and western Arizona: Geological Society of America Memoir 153, pp. 79-129.

Dibblee, T. W., Jr., 1960, Geologic map of the Barstow quadrangle, San Bernardino

County, California: United States Geological Survey Map MF-233, scale 1:62,500.

_____ 1961, Evidence of strike-slip movement on northwest-trending faults in Mojave Desert, California: United States Geological Survey Professional Paper 424-B, pp. 197-198.

_____ 1964, Geologic map of the Rodman Mountains quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-430, scale 1:62,500.

_____ 1967, Areal geology of the western Mojave Desert, California: U.S. Geological Survey Professional Paper 522, 153 p.

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

_____ 1970, Geologic map of the Daggett quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-592, scale 1:62,500.

Dokka, R.K., 1986, Patterns and modes of early Miocene crustal extension, central Mojave Desert, California, *in* Mayer, L., ed., Extensional tectonics of the southwestern United States: A perspective on processes and kinematics: Geological Society of America Special Paper 208, p. 75-95.

Glazner, A.F., 1988, Stratigraphy, structure, and potassic alteration of Miocene volcanic rocks in the Sleeping Beauty area, central Mojave Desert, California: Geological Society of America Bulletin, v. 100, p. 424-435.

Glazner, A.F., and Bartley, J.M., 1988, Early Miocene dome emplacement, diking, and faulting in the northern Marble Mountains, Mojave Desert: Geological Society of America Abstracts with Programs, v. 20, p. 163-164.

Glazner, A.F., and Bartley, J.M., 1989, Source of potassium in potassium-metasomatized, extended Tertiary rocks of the Mojave Desert: International Association of Volcanology and Chemistry of the Earth's Interior Meeting, Santa Fe, in press.

Glazner, A.F., Bartley, J.M., and Walker, J.D., 1988, Geology of the Waterman Hills detachment fault, central Mojave Desert, California, *in* Weide, D.L., and Faber, M.L., eds., This extended land, geological journeys in the southern Basin and Range (Geological Society of America Cordilleran Section field trip guidebook): Las Vegas, University of Nevada Department of Geoscience Special Publication No. 2, p. 225-237.

Glazner, A.F., Bartley, J.M., and Walker, J.D., 1989, Magnitude and significance of Miocene crustal extension in the central Mojave Desert, California: Geology, v. 17, p. 50-53.

Glazner, A.F., Nielson, J.E., Howard, K.A., and Miller, D.M., 1986, Correlation of the Peach Springs Tuff, a large-volume Miocene ignimbrite sheet in California and Arizona: Geology, v. 14, p. 840-843.

Howard, K. A., and John, B. E., 1987, Crustal extension along a rooted system of imbricate low-angle faults: Colorado River extensional corridor, California and Arizona, *in* Coward, M. P., Dewey, J. F., and Hancock, P. L., eds., Continental Extensional Tectonics, Geological Society of London Special Publication No. 28, pp. 299-311.

Kiser, N.L., 1981, Stratigraphy, structure and metamorphism in the Hinkley Hills, Barstow, California [M.S. thesis]: Palo Alto, California, Stanford University, 70 p.

MacFadden, B.J., Woodburne, M.O., and Opdyke, N.D., 1988, Paleomagnetism and negligible tectonic rotation of Miocene Hector and Barstow Formations, Mojave Desert, California: Geological Society of America Abstracts with Programs, v. 20, p. 176-177.

McCulloh, T.H., 1952, Geology of the southern half of the Lane Mountain quadrangle, California [Ph.D. thesis]: Los Angeles, University of California, 180 p.

Miller, E.L., and Sutter, J.F., 1982, Structural geology and ^{40}Ar-^{39}Ar geochronology of the Goldstone-Lane Mountain area, Mojave Desert, California: Geological Society of America Bulletin, v. 93, p. 1191-1207.

Miller, W. J., 1944, Geology of parts of the Barstow quadrangle, San Bernardino County, California: California Journal of Mines and Geology, v. 40, pp. 73-112.

Nason, G.W., Davis, T.E., and Stull, R.J., 1979, Cenozoic volcanism in the Newberry

Mountains, San Bernardino County, California, *in* Armentrout, J.M., Cole, M.R., and TerBest, H., Jr., eds., Cenozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 3, p. 89-95.

Nielson, J.E., and Glazner, A.F., 1986, Introduction and road log: Geological Society of America Cordilleran Section guidebook to Miocene stratigraphy and structure: Colorado plateau to the central Mojave Desert: Los Angeles, California State University, p. 1-6.

Nielson, J.E., Lux, D.R., Dalrymple, G.B., and Glazner, A.F., Age of the Peach Springs Tuff: submitted to Journal of Geophysical Research.

Stewart, J.H., and Poole, F.G., 1975, Extension of the Cordilleran miogeosynclinal belt to the San Andreas fault, southern California: Geological Society of America Bulletin, v. 86, p. 205-212.

Stone, P., and Stevens, C.H., 1988, Pennsylvanian and Early Permian paleogeography of east-central California: Implications for the shape of the continental margin and the timing of continental truncation: Geology, v. 16, p. 330-333.

Walker, J.D., 1988, Permian and Triassic rocks of the Mojave Desert and their implications for the timing and mechanism of continental truncation: Tectonics, v. 7, p. 685-709.

Walker, J.D., Burchfiel, B.C., and Wardlaw, B.R., 1984, Early Triassic overlap sequence in the Mojave Desert: Its implications for Permo-Triassic tectonics and paleogeography: Geological Society of America Abstracts with Programs, v. 16, p. 685.

Walker, J.D., Bartley, J.M., and Glazner, A.F., Large-magnitude Miocene extension in the central Mojave Desert: Implications for Paleozoic to Tertiary paleogeography and tectonics: submitted to Journal of Geophysical Research.

The Coon Canyon Fault Crevice Local Fauna: preliminary evidence for recency of faulting in the Mud Hills, San Bernardino County, California

Robert E. Reynolds, Division of Earth Sciences, San Bernardino County Museum, Redlands, CA 92374
Leslie P. Fay, Division of Earth Sciences, San Bernardino County Museum, Redlands, CA 92374

INTRODUCTION

The type location for the Barstovian Land Mammal Age is within the Barstow Formation in the Mud Hills, north of Barstow, California. Because of the importance of the late Miocene faunas (Wood and others, 1941) and their relationship to the stratigraphy, geologists and paleontologists have studied the structure of the Barstow Formation for more than 70 years (Merriam, 1919; Steinen, 1966; Dibblee, 1968; Lindsay, 1972; Woodburne and Tedford 1982; Woodburne and others, 1982).

The Coon Canyon Fault bounds the Barstow Formation to the southwest. A fossil assemblage deposited in fractures along the trace of the Coon Canyon Fault (SBCM 01.130.383) suggests that movement along this fault has occurred into Holocene times.

The Barstow Formation has been cut by northwest-trending faults and is folded along northwest axes into spectacular synclines and anticlines. The south flank of the Barstow Formation is exposed and the section is visible in canyons that drain south and west. Dibblee (1968) maps the Coon Canyon Fault from Coon Canyon to West Rainbow Wash at the Loop Road exit, separating the southwest margin of the Barstow Formation from Pleistocene older alluvium.

METHODS

Everett Lindsay (University of Arizona) and Robert E. Reynolds (San Bernardino County Museum, SBCM) initiated a joint project in 1988 under Bureau of Land Management permit CA-8814 and with funding from the National Science Foundation to study fossil assemblages at the Hemingfordian/Barstovian Land Mammal Age Boundary. During exploration in the Barstow Fossil Beds, Julia Sankey located post-Tertiary vertebrate fossils weathering from a ridge on the south flank of the Barstow Syncline between Coon Canyon and the Loop Road exit. Her discovery was followed with detailed excavations by the SBCM to recover representative fossils and explore their stratigraphic occurrence.

A 20 cm-wide trench was excavated across the locality perpendicular to the strike of the fossil occurrence. Samples were removed in 10 cm levels and were taken to 110 cm below the surface. A cross-section showing fossils filling fractures was exposed (Fig. 1). Six hundred pounds of fossiliferous matrix (0.24 m^3) were removed from the site, washed through 20- and 40-mesh screens, and hand-sorted at 1x to 10x magnification.

MODE OF OCCURRENCE

The fractures are near the trace of the Coon Canyon Fault as mapped by Dibblee (1968). The strike of the fractures (N50°W) is sub-parallel with that of the fault trace (N70°W). Local offset and folding of the Barstow Formation suggests complex movement of blocks of Miocene sediments within the Coon Canyon fault zone. One hundred feet south of the locality, the Barstow Formation is in contact with Pleistocene alluvium.

The fractures cut arkosic sands and silty sands of the Barstow Formation that dip shallowly to the north. Fractures do not appear to have been made by solution piping, which is common in the silty facies of the formation. Fractures are filled with small to large cobbles and a sandy loam that does not appear to have been derived from the current surface of the adjacent Barstow Formation.

Fractures remained open long enough to be filled with the remains of at least 17 taxa, including

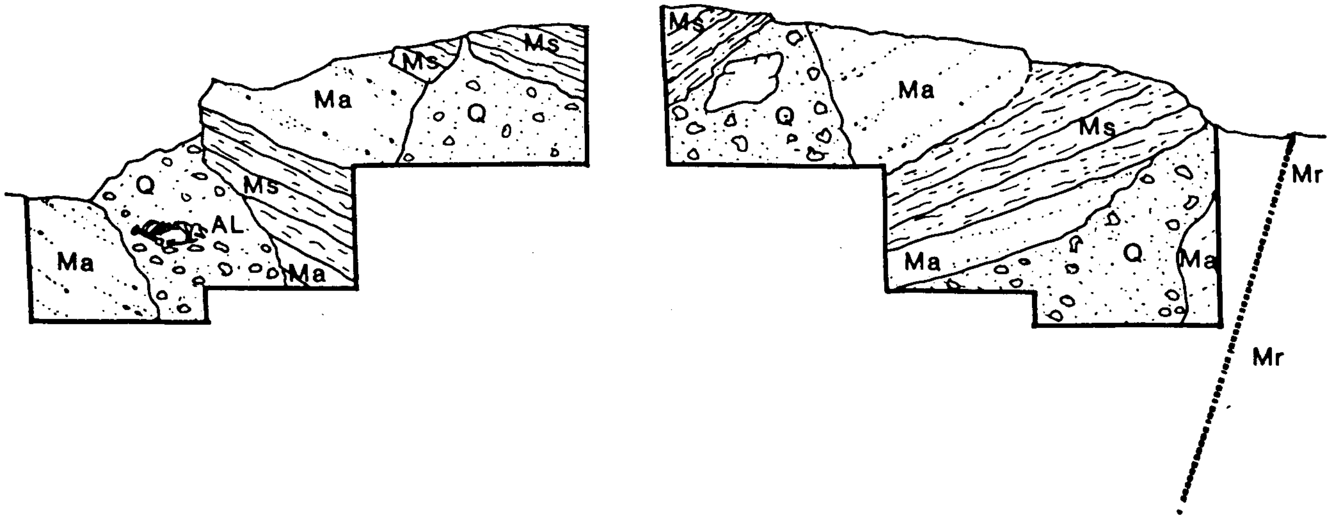


Figure 1 a,b. Cross sections, Coon Canyon Fault Crevice, SBCM 1.130.383. 1a (left): view northwest along test excavation; 1b (right): view southwest along test excavation. Q = Quaternary gravel loam containing fossils; AL = articulated lagomorph; Ma = Miocene Barstow Fm arkose; Ms = Miocene Barstow Fm siltstone; Mr = Miocene Barstow Fm red sandstone.

the articulated skeleton of a jack rabbit, Lepus cf. L. californicus. The presence of the articulated rabbit suggests that the fossils were not accumulated by raptors or carnivores. Skeletal remains of the pack rat, Neotoma lepida, are present as fossils in the fractures, as are pack rat feces; pack rats may be in part responsible for the accumulation of bones in the fractures.

Recovered specimens have a tan to brown mottled color; some appear to be etched by ground water, and many are coated by caliche.

FOSSIL ASSEMBLAGE

A minimum of two lizard, three snake, two bird, and ten mammalian taxa are present in the sample (Table 1). For this preliminary report, emphasis was placed on identification to subfamily or generic level, using tooth-bearing elements for lizards and mammals and postcranial bones for snakes and birds. Sciurids were examined in greater detail due to a degree of utility as biostratigraphic indicators in the Quaternary record of the Mojave Desert. Goodwin and Reynolds (in press) have identified now-extirpated ground squirrels in the Late Wisconsinan--early Holocene Kokoweef Cave and Newberry Cave local faunas.

The color, etching, and caliche coatings suggest the antiquity of the specimens. However, as extirpated forms could not be recognized in the present study, the Coon Canyon local fauna is tentatively assigned to a post-early Holocene time interval.

IMPLICATIONS FOR TECTONIC ACTIVITY

The Barstow area contains faults known to have been active in Late Pleistocene, Early Holocene, and recent times, including the Manix Fault (McGill and others, 1988) 30 miles east-southeast of the Mud Hills. The Calico Fault is 20 miles southeast of the Coon Canyon Fault and was active in late Pleistocene times (Reynolds and Reynolds, 1985).

Fractures that cut the bedding planes of the Barstow Formation in the Coon Canyon area may have formed in response to activity along the Coon Canyon Fault. The presence of Holocene fossils in these fractures suggests that the Coon Canyon Fault has been active at least until post-early Holocene times.

REFERENCES CITED

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

Goodwin, W.T. and Reynolds, R.E., in press. Late Pleistocene Sciuridae of the Mojave Desert.

Lindsay, E.H., 1972. Small mammal fossils from the Barstow Formation, California. Berkeley, University of California Publications in Geological Sciences, 93.

McGill, S.F., Murray, B.C., Maher, K.A., Lieske, J.H. Jr., Rowan, L.R., and Budinger, F., 1988. Quaternary history of the Manix Fault, Lake Manix Basin, Mojave Desert, California. Redlands, San Bernardino County Museum Quarterly XXXV(3,4):3-20.

Merriam, J.C., 1919. Tertiary mammalian faunas of the Mojave Desert. Berkeley, University of California Publications, Department of Geology Bulletin, 11(5):437a-437e, 438-585.

Reynolds, R.E. and Reynolds, R.L., 1985. Late Pleistocene faunas from Daggett and Yermo, San Bernardino County, California, IN Geological Investigations along Interstate 15, Cajon Pass to Manix Lake. Redlands, San Bernardino County Museum:175-191.

Steinen, R.P., 1966. Stratigraphy of the middle and upper Miocene Barstow Formation, San Bernardino County, California [Masters thesis]. Department of Geological Sciences, University of California, Riverside: 150 p.

Wood, H.E. II, Chaney, R.W., Clark, J., Colbert, E.H., Jepsen, G.L., Reeside, J.B. Jr., and Stock, C., 1941. Nomenclature and correlation of the North American continental Tertiary. Geological Society of America Bulletin, 52:1-48.

Woodburne, M.O. and R.H. Tedford, 1982. Litho- and biostratigraphy of the Barstow Formation, Mojave Desert, California. Guidebook, Late Cenozoic tectonic and magnetic evolution of the central Mojave Desert, California. Geological Society of America, Cordilleran Section:65-71.

Woodburne, M.O., Miller, S.T., and Tedford, R.H., 1982. Stratigraphy and geochronology of Miocene strata in the central Mojave Desert, California. Geological Society of America, Cordilleran Section Guidebook:47-64.

TABLE I
Coon Canyon Local Fauna

Reptilia	
Squamata	
Sauria	undetermined small saurian
Iguanidae	
Sauromalus obesus	chuckwalla
Serpentes	
Colubridae	
"colubrine"	small colubrine
"xenodontine"	small xenodontine
Viperidae	
Crotalus sp.	rattlesnake
Aves	
sp. a	undetermined small bird
sp. b	undetermined small bird
Mammalia	
Chiroptera	
?Vespertilionidae	
?*Myotis* sp.	mouse-eared bat
Lagomorpha	
Leporidae	
Lepus sp. cf. *L. californicus*	jack rabbit
?*Sylvilagus* sp.	cottontail rabbit
Rodentia	
Sciuridae	
Ammospermophilus sp.	antelope ground squirrel
Spermophilus ?*tereticaudus*	round-tailed ground squirrel
Geomyidae	
Thomomys sp.	pocket gopher
Heteromyidae	
Dipodomys sp.	kangaroo rat
Chaetodipus or *Perognathus* sp.	pocket mouse
Cricetidae	
?*Reithrodontomys* sp.	harvest mouse
Neotoma lepida	dusky-footed pack rat

Time-space patterns of late Cenozoic strike-slip faulting in the Mojave Desert, California

Roy K. Dokka, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803
Christopher J. Travis, Dept. of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803

INTRODUCTION

The broad transform boundary between the Pacific and North American plates has had a profound influence on the tectonic evolution of the western U.S. since middle Cenozoic time (Atwater, 1970). Although much of the shear has occurred on faults of the San Andreas system and subparallel faults to the west, recent studies by Dokka (1983) and Dokka and Travis (manuscript in review in Tectonics) assert that a significant portion of middle Miocene to recent transform shear has been accommodated on faults of the Mojave Desert-Death Valley region (Fig. 1). Approximately 66 km of distributed right shear is predicted to have occurred across the province (between the Helendale and Granite Mountains faults). Dokka and Travis and Brady and Dokka (1989) also reckon that this broad network of faults, along with kinematically and temporally similar strike-slip faults of the Death Valley region (Furnace Creek and Southern Death Valley fault zones), constitute a regional, throughgoing zone of right shear named the Eastern California Shear Zone (ECSZ)(Fig. 1). Because of its physical connection of the San Andreas fault system, the ECSZ has also accommodated a portion of Pacific-North American transform motion. More importantly, this previously unappreciated shear zone represents a major threat to the critical communication, power, water, transportation, and commerce infrastructure elements that support

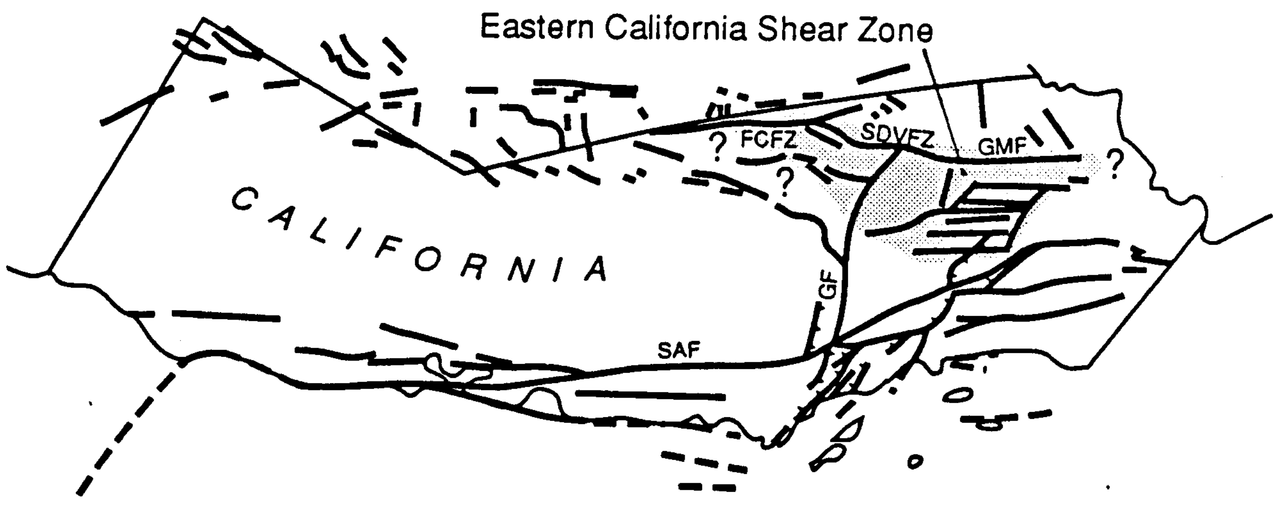
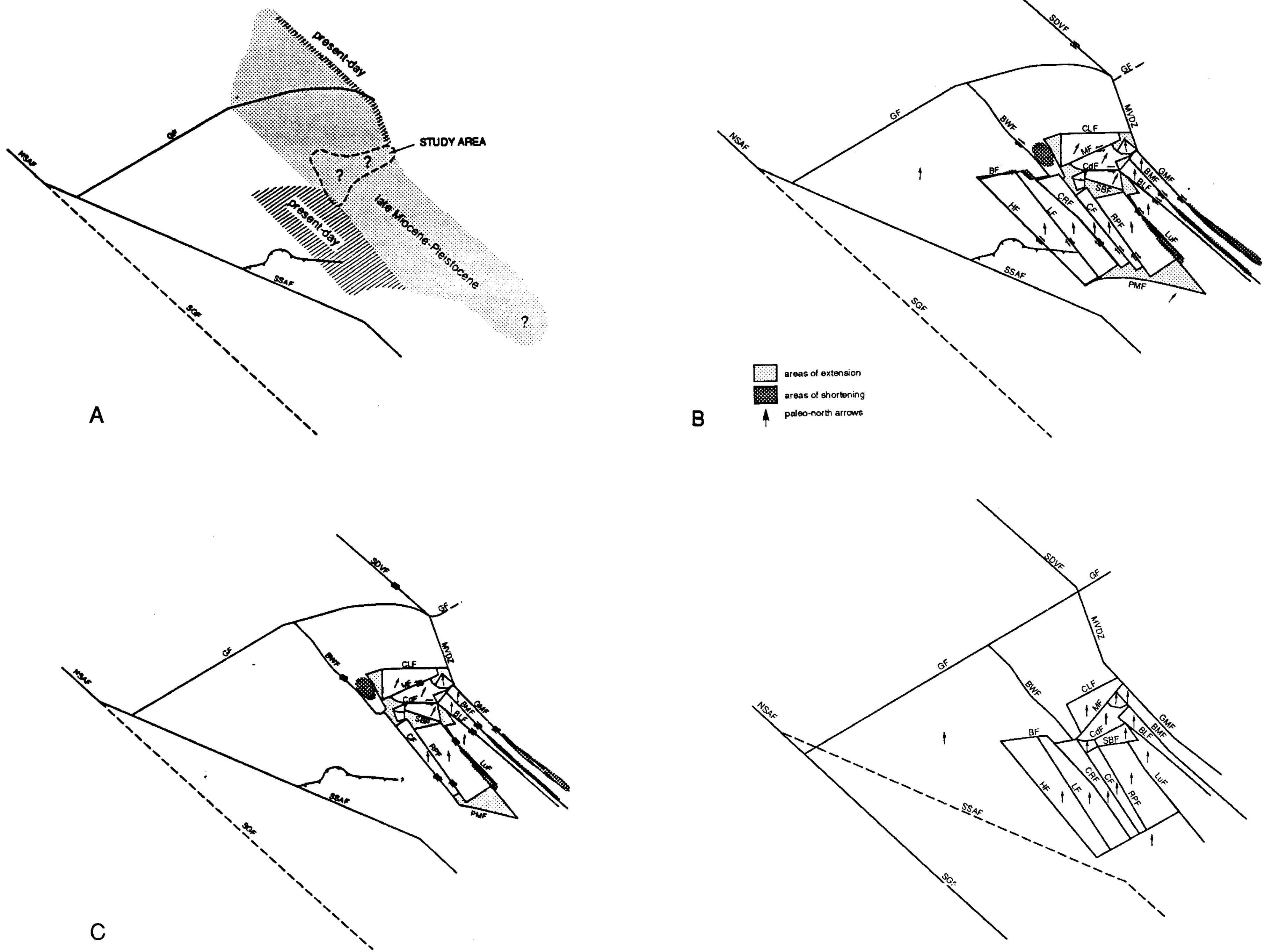


Figure 1. Index map of southern California highlighting the location of the newly recognized Eastern California shear zone (shaded) and other major faults of the Pacific-North American transform boundary. Key to abbreviations: SAF, San Andreas fault zone; SVFZ, Death Valley fault zone; FCFZ, Furnace Creek fault zone; GF, Garlock Fault; GMF, Granite Mountains Fault.



A
NSAF
GF
present-day
STUDY AREA
?
present-day
late Miocene-Pleistocene
SSAF
SGF
B
SDVF
GF
MVDZ
BWF
CLF
MF
CdF
GMF
BMF
BLF
SBF
BF
HF
LF
CRF
CF
RPF
LuF
PMF
SSAF
SGF
NSAF
areas of extension
areas of shortening
paleo-north arrows
C
SDVF
GF
MVDZ
BWF
CLF
CdF
SBF
BMF
BLF
GMF
CF
RPF
LuF
PMF
NSAF
SSAF
SGF
SDVF
GF
MVDZ
BWF
CLF
MF
GMF
BMF
BLF
CdF
SBF
BF
HF
LF
CRF
CF
RPF
LuF
NSAF
SSAF

Figure 2. (a) Time-space patterns of strike-slip faulting in the Mojave Desert. (b-d) Proposed kinematic model for the late Cenozoic evolution of the Mojave Desert (Dokka and Travis, ms in prep.). Internal structure of northeastern Mojave not shown. (b) Present-day. (c) Intermediate step (ca. 1 Ma). (d) Pre-faulting (late Miocene) restoration of structural blocks. Internal structure of northeastern Mojave not shown. Key to abbreviations: NSAF, northern San Andreas Fault; SSAF, southern San Andreas Fault; SGF, San Gabriel Fault; GF, Garlock Fault; PMF, Pinto Mountain Fault; SDVF, Southern Death Valley fault zone; HF, Helendale Fault; LF, Lenwood Fault; CRF, Camp Rock Fault; CF, Calico Fault; BWF, Blackwater Fault; BF, Barstow Fault; RPF, Rodman Pisgah Fault; SBF, Sleeping Beauty Fault; LuF, Ludlow Fault; BLF, Broadwell Lake Fault; BMF, Bristol Mountains Fault; GMF, Granite Mountains Fault; CdF, Cady Fault; MF, Manix Fault; CLF, Coyote Lake Fault; MVDZ, Mesquite Valley disturbed zone.

the metropolitan Los Angeles area as well as a potential hazard to the population of the fast-growing Barstow-Victorville region.

TIMING AND SLIP RATES

Faulting along the ECSZ most likely began between 13.4 and 6 Ma (Dokka and Travis, ms in review). By using the values of Stock and Molnar (1988) for predicted Pacific plate motion relative to North America, we calculate that 9% to 24% of the total transform slip between the two plates has been accommodated by the ECSZ. The integrated slip rate, given these constraints, ranges from 6 and 12 mm yr^{-1} and is similar to the present-day rate of approximately 7 mm yr^{-1} determined from geodetic measurements (Sauber and others, 1986). These data suggest that the regional slip rate across the Mojave Desert block has been nearly constant since inception. If, however, motion along the ECSZ started near the end of the Miocene (approximately 6 Ma) as is suggested by the work of Stewart (1983) in the Death Valley region, the integrated slip rate would be higher (approximately 12 mm yr^{-1}). This value, compared with the present-day displacement rate, would imply that the rate of shear across the region has slowed recently.

PATTERNS OF FAULTING

Long- and short-term structural and chronologic data from the ECSZ indicate that the locus of faulting and deformation in this broad, regional zone has not been static, but has instead shifted with time (Fig. 2). Much of the regional right shear in the Mojave Desert Block has been accommodated by faults of the eastern portion of the province (Granite Mountains and Bristol Mountains faults; Fig. 2)(Dokka and Travis, ms in review). This is in marked contrast with the present pattern of faulting where the distribution of earthquakes (Goter, 1988), distortion of the Mojave regional strain net (Sauber and others, 1986), and ground rupture (Morton and others, 1980) indicate that regional shear is now concentrated in the south-central Mojave Desert between the Helendale and Ludlow faults (Fig. 2b)(Dokka and Travis, ms in review). Modern strain, however, is not apparent north, west, and east of the south-central Mojave (King, 1985; Goter, 1988) nor is right shear transferred elsewhere in any obvious way to the Death Valley area. This westward shift in the locus of activity has occurred quite recently (< 1 Ma ?) judging by late Quaternary gravels that overlie faults of the eastern Mojave Desert (Davis, 1977; Brady, 1988; Ford and others, 1989).

Three testable hypotheses can explain the lack of corresponding right shear in the areas north of the current locus of activity in the south-central Mojave Desert Block. The first considers the ECSZ to be currently locked in the central and northeastern Mojave (Cady Mountains-Troy Dry Lake area). Infrequent, moderate (and larger?) earthquakes such as the 1947 Manix event (magnitude = 6.2; Richter, 1949) may be the primary strain release mechanism in these areas. According to the second hypothesis, strain is accommodated north and east of the Cady Mountains-Troy Dry Lake area by aseismic creep along unknown faults. The third hypothesis considers the Troy Dry Lake-Coyote Lake region to be the active tip of a northward propagating shear zone that includes the presently active faults of the south-central Mojave Desert.

REFERENCES CITED

Atwater, T., 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. Geological Society of America Bulletin, 81:3513-3536.

Brady, R.H. III, 1988. Southward continuation of the Southern Death Valley fault zone from the Avawatz Mountains to the Bristol Mountains, San Bernardino County, California. Geological Society of America Abstracts with Programs, 20:145.

Davis, G.A., 1977. Limitations on displacement and southeastward extent of the Death Valley fault zone, California. California Geology, 30:27-33.

Dokka, R.K., 1983. Displacements on late Cenozoic strike-slip faults of the central Mojave Desert, California. Geology, 11:305-308.

_____, 1986. Patterns and modes of early Miocene extension of the central Mojave Desert, California, IN Continental extension processes, L. Mayer, ed. Geological Society of America Special Paper, 208:75-95.

Dokka, R.K. and C.J. Travis, 1989. Geologic constraints on models of late Cenozoic strike-slip faulting in the Mojave Desert, California. in review, Tectonics.

Ford, J.P., R.E. Crippen, R.G. Blom, and R.K. Dokka, 1989. Neogene strike-slip faults revealed by enhanced Landsat TM images in the Mojave Desert, California. Geological Society of America Abstracts with Programs, 21: in press.

Goter, S., compiler, 1988. Seismicity of California, 1808-1987, scale 1:1,000,000. National Earthquake Information Center.

King, N.E., 1985. Horizontal deformation in the Mojave Desert near Barstow, California, 1979-1983. Journal of Geophysical Research, 90:4491-4494.

Morton, D.M., F.K. Miller and C.C. Smith, 1980. Photo-reconnaissance maps showing young-looking fault features in the southern Mojave Desert, California. U.S. Geological Survey Miscellaneous Field Studies Map MF-1051.

Richter, C.F., 1949. The Manix (California) earthquake of April 10, 1947. Seismol. Soc. Am. Bulletin, 37:171-179.

Sauber, J., W. Thatcher, and S. Solomon, 1986. Geodetic measurement of deformation in the central Mojave Desert, California. Journal of Geophysical Research, 91:12,683-12,694.

Stewart, J.H., 1983. Extensional tectonics in the Death Valley area, California: Transport of the Panamint Range structural block 80 km northwest. Geology, 11:153-157.

Stock, J. and P. Molnar, 1988. Uncertainties and implications of the Late Cretaceous and Tertiary position of North America relative to the Farallon, Kula, and Pacific plates. Tectonics, 7:1339-1384.

Early Miocene clockwise tectonic rotations in the central Mojave Desert, California

Timothy M. Ross, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803

Seventy-four early Miocene volcanic flows in the central Mojave Desert display stable, consistent paleomagnetic directions. The magnetic declinations carried by these flows are deflected clockwise from north, suggesting that these rocks have undergone clockwise tectonic rotations about a vertical axis. The mean rotations for 8 structurally bounded domains are: Alvord, 53° +/- 9.9°; West Cady, 124° +/-16.2°; South Cady, 57° +/-11.6°; Bristol, 30° +/-19.8°; Lava Bed, 62° +/- 13.6°; Rodman, 26° +/-13.6°; and Newberry, 73° +/-20°. The average clockwise rotation for the central Mojave Desert (excluding the anomalous West Cady Block) is 50° +/-15.6°.

An outcrop of flat-lying tuff that overlies clockwise rotated early Miocene volcanic flows in the southern Newberry Mountains has been interpreted as the 19 Ma Peach Springs Tuff (Glazner and others, 1986). The paleomagnetic direction for this tuff shows no rotation with respect to the Peach Springs Tuff on the stable Colorado Plateau (Wells and Hillhouse, 1989). These interpretations suggest that clockwise rotation in the Newberry Mountains ceased before about 19 Ma.

All of the structural domains listed above except the Alvord Mountains lie within the Daggett terrane of the Mojave Extensional Belt, a region that experienced detachment style extension (21-19 Ma)(Dokka, 1986, 1989). These observations suggest that the coherent clockwise rotation of a large area of the central Mojave Desert is spatially and temporally associated with an episode of early Miocene crustal extension (Ross and others, 1989). A recent paleomagnetic study in the northern Cady Mountains (MacFadden and others, 1989) suggests that a younger episode of clockwise rotation occurred after 16 Ma in the northern Cady Mountains and possibly in the Alvord Mountains. The timing and loeation of this rotation supports models for late Miocene clockwise rotation associated with movement of northwest-trending right-lateral faults in the Mojave Desert.

REFERENCES CITED

Dokka, R.K., 1986. Patterns and modes of early Miocene crustal extension, central Mojave Desert, California, IN Extensional tectonics of the southwestern United States--a perspective on processes and kinematics, L. Mayer, ed. Geological Society of America Special Paper, 208:75-95.

Glazner, A.F., J.E. Nielson, K.A. Howard, and D.M. Miller, 1986. Correlation of the Peach Springs Tuff, a large-volume Miocene ignimbrite sheet in California and Nevada, IN Cenozoic stratigraphy, structure, and mineralization in the Mojave Desert, J.E. Nielson and A.F. Glazner, eds. Los Angeles, California State University, Geological Society of America Cordilleran Section meeting guidebook, field trip 5:65-68.

MacFadden, B.J., M.O. Woodburne, and N.D. Opdyke, 1989. Paleomagnetism and Neogene clockwise rotation of the northern Cady Mountains, Mojave Desert of southern California. Journal of Geophysical Research, in press.

Ross, T.M., B.P. Luyendyk, and R.B. Haston, 1989. Paleomagnetic evidence for Neogene clockwise tectonic rotations in the central Mojave Desert, California. Geology, in press.

Wells, R.E. and J.W. Hillhouse, 1989. Paleomagnetism and tectonic rotation of the lower Miocene Peach Springs Tuff--Colorado Plateau, Arizona to Barstow, California. Geological Society of America Bulletin, in press.

Ostracoda of the late Pleistocene Manix Formation, central Mojave Desert, California

James J. Steinmetz, Biological Sciences Dept., California State Polytechnic University, Pomona, CA 91768

INTRODUCTION

The Ostracoda were named and placed under the Class Entomostraca by Latreille in 1802. From that time this important group of bivalve crustaceans has received much attention. Zoologists have identified and studied the ecology of numerous ostracode species which, through the process of adaptive radiation, inhabit all oxic aquatic habitats. Paleontologists also found this group of organisms interesting and useful. Their small size and simple carapace structure makes them highly resistant to destruction after burial and later sediment diagenesis. The ostracode fossil record is continuous from the Cambrian period and over 10,000 extinct species have been identified on the basis of carapace morphology.

The biogeographic distribution and ecology of North American ostracodes has been a subject of intense study in recent years by scientists and students from a broad range of disciplines. Individual ostracode species display differential sensitivity to variations in dissolved ion concentration (Forester, 1983, 1986), oxygen tension, temperature, and lake trophic state (Crisman, 1978; Delorme, 1969; Forester, 1985). These factors in conjunction with numerous biological processes including competitive exclusion, resource partitioning, and potential for emigration and immigration, regulate ostracode occurrence and abundance.

The solute composition of lakes results from a complex balance between climatic and nonclimatic processes (Garrels and MacKenzie, 1967; Eugester and Jones, 1979). Variations in regional precipitation and evapotranspiration regulate the inflow of solutes by atmospheric precipitation and local weathering. The salinity (concentration of solutes) of lakes is a function of the evaporative concentration of water which controls the precipitation of minerals by chemical and biological processes (Al-Droubi et al., 1980).

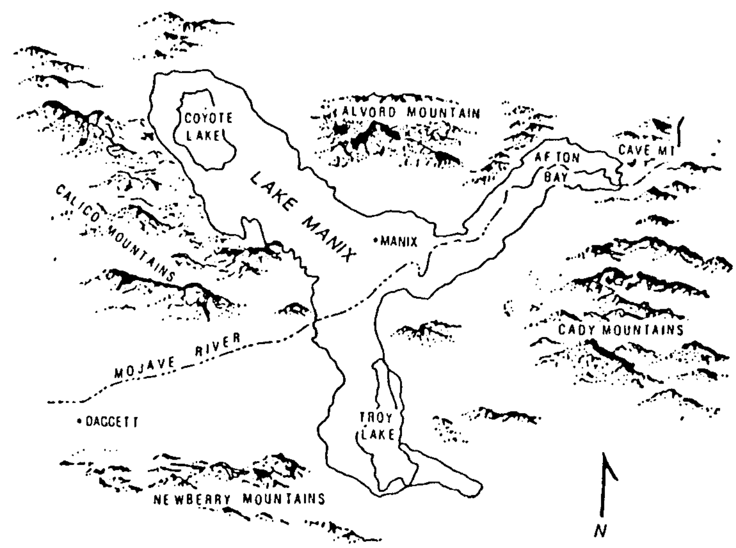


Figure 1: The Lake Manix Basin.

We can therefore use ostracode species composition and abundance to provide qualitative temperature and hydrochemical information. Many of the ostracodes found in Pleistocene sediments have extant relatives. Under the limitations of uniformitarian principles investigators can use ostracodes to confidently reconstruct paleoclimates and paleoenvironments. The Manix Formation provides an ideal location for the study of lacustrine ostracode assemblages over much of late Pleistocene time.

LAKE MANIX BASIN

Lake Manix was a relatively freshwater lake covering approximately 215 square kilometers (Meek, 1989) in the lower Mojave River Valley (Figure 1). Primary inflow was from waters originating in the San Bernardino and adjacent

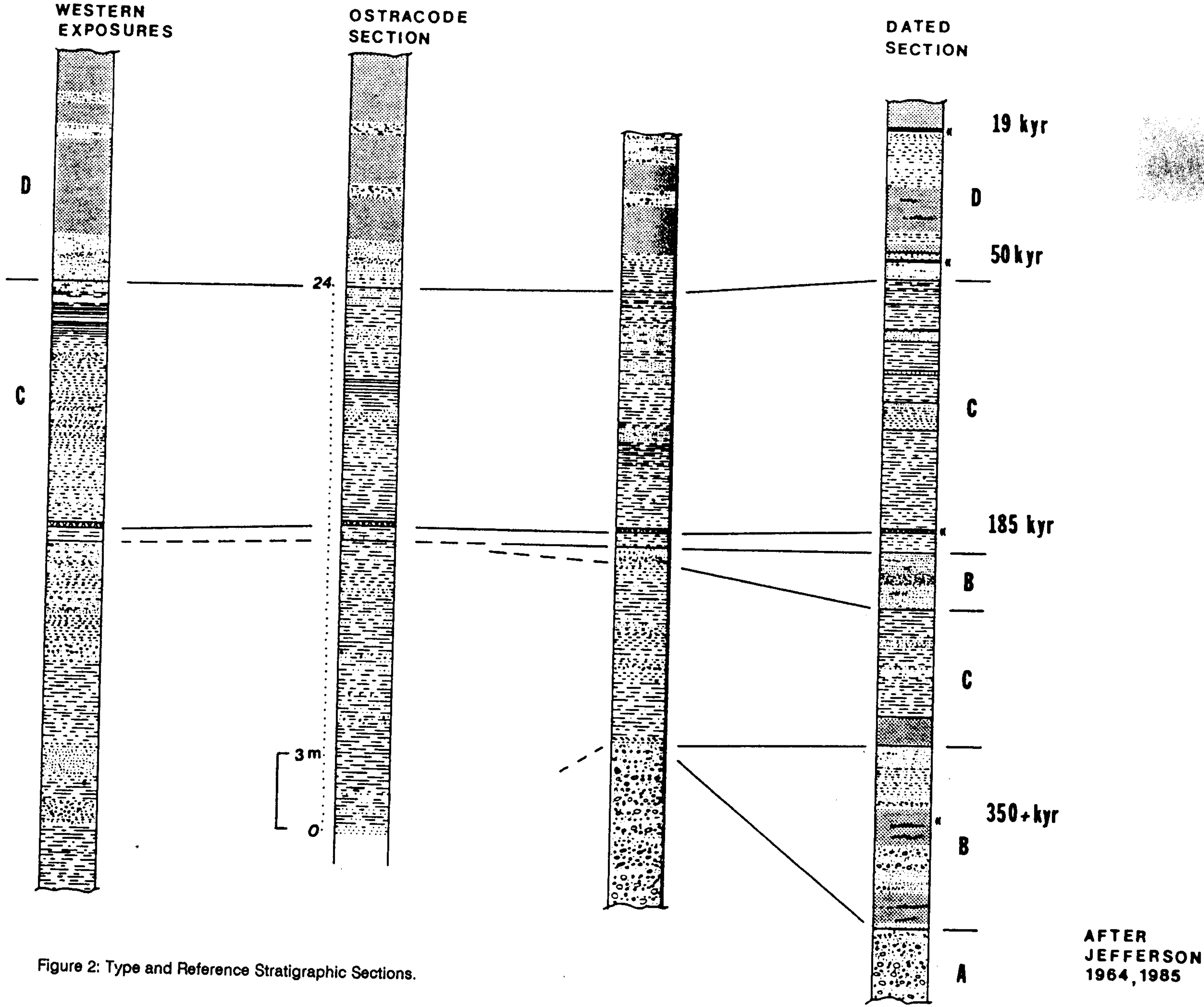


Figure 2: Type and Reference Stratigraphic Sections.

mountains and transported by the Mojave River. Lake Manix can be divided into three sub-basins, the present day Coyote and Troy playas and Afton Bay. Topographic features in the Lake Manix basin created a unique paleohydrologic setting. The lake was bound on the north and northwest by the Alvord and Calico Mountains, respectively. The Newberry Mountains to the southwest restricted the inflow of the Mojave River forcing the water into the central part of the basin. The Cady Mountains and Cave Mountain to the east formed the lock on the system with an overflow sill at Afton Canyon.

Variations in the size and shape of the lake are documented by the lateral and vertical distributions of sedimentary facies and fluctuations in the depositional system which reflect changing climatic conditions (Jefferson, 1985). Detailed stratigraphic mapping of the Manix Formation (Winters, 1954; Jefferson, 1968, 1985) has provided a generalized paleoenvironment and climatic picture. However, these interpretations have not been tested against other lines of evidence. A 39 m thick stratigraphic reference section (Jefferson, 1985) exposed along the Mojave River east of Camp Cady and south of Manix railroad siding (Figure 2) ranges in age from approximately 500,000 yr B.P. to about 20,000 yr B.P. based on C-14 analysis of bivalves (Fergusson and Libby, 1962; Hubbs et al., 1962; Bassett and Jefferson, 1971), uranium/thorium dates on mammal bone (Bischoff pers. comm., Jefferson 1985), and tephrachronologic correlation with a potassium/argon dated tuff (Sarna-Wojiciki et al., 1980). In order to more precisely define changes in the depositional system as lake level fluctuations resulting from climatic change a multidisciplinary approach is required. Changes in basin paleohydrology due to tectonics or local shifts in drainage patterns may be misinterpreted as climatic events when only analyzing the sedimentary record.

OSTRACODE BIOSTRATIGRAPHY AND PALEOECOLOGY

The presence of ostracodes in lacustrine sediments of the Manix Formation was first documented by Winters (1954). Early attempts to analyze the ostracode biostratigraphic record were conducted by Jefferson, Budinger and Kilday (personal communication, 1985). Samples for this study were recovered from eight lithologic horizons in upper member C of Jefferson (1985). Individual ostracode taxa were not identified due to their small size, < 0.8 millimeter, and the complexity of surface ornamentation. Variations in carapace size and the relative abundance of ostracodes was observed at these different horizons. Preliminary investigation warranted a more detailed biostratigraphic analysis.

A continuous 24 m stratigraphic section (Figure 2) approximately 2.2 km west of the dated reference section of the Manix Formation was sampled at 0.3 m intervals (Jefferson and Steinmetz, 1986). These samples were excavated from eroded bluffs along the Mojave River drainage and incorporate all major sediment lithologies for the central part of the Lake Manix Basin. This midbasin sequence of lacustrine clays and silts lacks lenses of coarse-grained fluvatile sediments common to the lake margins. This suggests a low energy depositional regime which may minimize mixing of near shore assemblages with the deep water forms. Faunal mixing and reworking are two important aspects which may lead to misinterpretation of data.

Four species of limnic ostracodes were isolated from these samples. The modern biogeographic distribution and ecology of these taxa is relatively well known. Cyprinotus incongruens is a smooth shelled ostracode which can tolerate a wide range of environmental conditions. This taxon is found throughout the Manix Formation but occurs predominantly in sediments which represent paralimnic environments. C. incongruens presently inhabits the quiet ponds in Afton Canyon. The other three ostracode species belong to the Family Limnocytheridae. Limnocythere platyforma dominates the basal 3 m of the sampled stratigraphic section. Limnocythere robusta (extinct) codominates these basal sediments. Limnocythere ceriotuberosa forms a more or less monospecific group in the upper 21 m of sediments.

Carapace morphology of intermediate forms between Limnocythere ceriotuberosa and L. platyforma provide evidence that these taxa are conspecific (Forester personal communication, 1987). These two ostracodes are possibly ecophenotypic variants reflecting different hydrochemical systems. L. platyforma is the freshwater form of L. ceriotuberosa. Modern populations of L. platyforma are quite rare. However, this taxon is abundant in early and middle Pleistocene lacustrine deposits. The evolutionary relationship of the L. platyforma/ceriotuberosa complex is currently under investigation (Forester pers. comm., 1988).

Sediments from the basal 0.3 m of the sampled section consist of well sorted fine sand-grained silts which are relatively devoid of ostracodes (See Figure 3-4 for biostratigraphic discussion). Water, if present, may have been restricted to a more central part of the basin. Peak abundance of ostracodes is quite high at 0.6 m above the base of the sampled section. This assemblage is dominated by Limnocythere platyforma and L. robusta. Large numbers of these taxa suggest a shallow freshwater perennial lake as a result of colder and wetter regional climatic conditions. From 1 to 1.6 m above the base the numbers of Limnocythere platyforma and L. robusta are much lower and relatively stable. Temperatures may have been higher at this time reducing lake volume.

At 2 m above the base of the sampled section the abundance of Limnocythere platyforma increases dramatically reaching a level nearly identical to the 0.6 m horizon. L. robusta is not observed in this assemblage. This suggests a return to cooler and wetter climatic conditions and higher water levels in the basin. The absence of L. robusta in this assemblage may indicate different paleohydrochemical or biological lacustrine conditions. However, this loss may also be interpreted as competitive exclusion displacing L. robusta to another part of the lake or possibly a local extinction event. Without additional biostratigraphic data this problem cannot be resolved. In the 2 to 2.6 m interval, the abundance of L. platyforma is again low and stable. Warmer and dryer climatic conditions prevailed during this time.

The 3 to 3.3 m interval of the sampled section records a major biostratigraphic event in the Manix Formation. Here, the abundance of Limnocythere platyforma rises dramatically and the sediments are codominated by Cyprinotus incongruens. The presence of C. incongruens here may indicate shallow perennial freshwater marches or paralimnic environments with a fine muddy substrate. Co-occurrence with L. platyforma suggests cold and highly fresh water. L. ceriotuberosa replaces L. platyforma at the 3.3 m level. The abundance of L. ceriotuberosa increases rapidly to 4.3 m. This suggests an increase in the trophic state of the lake and a major filling of the basin. This zone of ecological replacement has been tentatively correlated with the 7/8 marine oxygen isotope stage boundary (Jefferson, 1985; Steinmetz and Jefferson, 1988).

Modern populations of Limnocythere ceriotuberosa inhabit moderately alkaline lakes of the central Canadian prairies and south into parts of Colorado and Nevada. The temperature and salinity of these lakes varies seasonally. Sodium is usually the dominant cation in these lakes with varying amounts of bicarbonate, carbonate, sulfate and chloride anions. The Ph of these waters is normally quite high, in the 8 to 10 range (Benson and Spencer, 1983; Forester, 1986). These data suggest Lake Manix changed from a relatively cold shallow freshwater ecosystem into a moderately alkaline lake during this time interval.

The abundance of Limnocythere ceriotuberosa declines significantly from 4.6 to 5.6 m , increases rapidly at the 6 m level and again drops off from 6.3 m to a minimum at 7.3 m level. The bimodal distribution of ostracodes within this part of the sampled stratigraphic section suggests a short lake regression and subsequent transgression with only a slight change in population dynamics during the low lake stand.

Sediments in the 7 to 7.3 m sample interval consist of coarse to fine-grained sandy and silty redish brown mudstones. Low numbers of poorly preserved ostracodes, many fragmented and iron oxide stained, suggest sedimentary reworking. A major desication of Lake Manix is interpreted from these data.

Peak abundance of Limnocythere ceriotuberosa is high and variable from 7.6 to 9 m above the base of the sampled section. The condition is correlated with another cooling trend and high water levels in the basin. Low numbers of poorly preserved ostracodes occur again at 9.3 m. Here, sediments exhibit desication cracks with infillings of clays, silts, and coarse-grained sand.

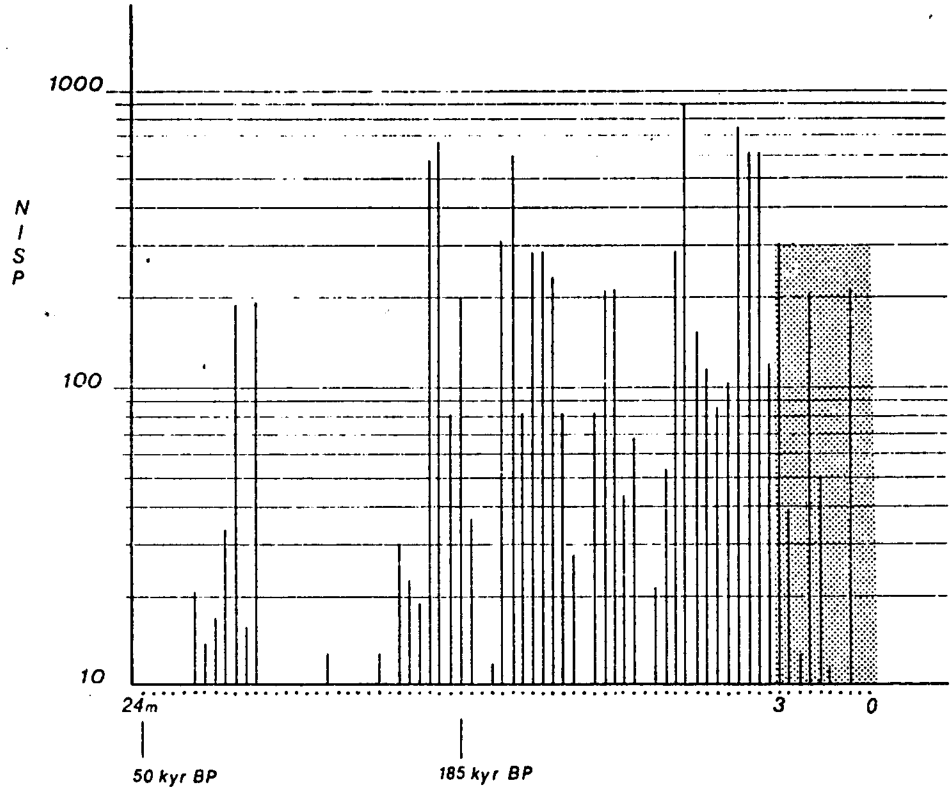


Figure 3: Number of Identified Specimens (ordinate) and Stratigraphic Distribution (abscissa) of Limnocythere platyforma (shaded) and L. ceriotuberosa.

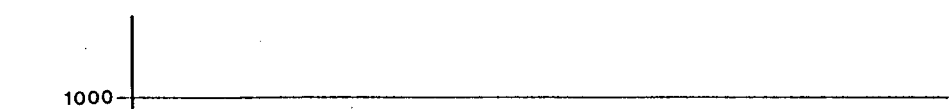


Figure 4: Number of Identified Specimens (ordinate) and Stratigraphic Distribution (abscissa) of Cyprinotus incongruens and Limnocythere robusta.

This pattern of high to low abundance is repeated 2 additional times within the 9.6 to 15.3 m interval. High lake stands, as a result of cool and equable climate, prevailed from 10 to 12 m and 13.3 to 15.3 m.

Numerous samples devoid of ostracodes occur from above 15.3 to 19.6 m . These sediments consist of dense fissile claystones and poorly sorted silty sandstones. This suggests complete desication of the lake and playa conditions prevailed at the sample locality. Very low numbers of well preserved Limnocythere ceriotuberosa occur at 16 and 17.6 m which may indicate ephemeral lake conditions. Based on direct stratigraphic correlation with the dated section of the Manix Formation the 15.3 to 19.6 m interval represents the Sangamon interglacial (Figure 2).

Large numbers of Limnocythere ceriotuberosa are recorded at 20 and 20.6 m above the base of the sampled section. These peak abundances are correlated with high lake levels at the onset of the Wisconsin glaciation.

The relative abundance of Limnocythere ceriotuberosa declines rapidly from 21 to 22 m and the stratigraphic section is devoid of ostracodes from 22 to 24 m above the base. A few badly weathered and fragmented specimens suggest that sediments at the top of the sampled stratigraphic section have been reworked.

Member D of the Manix Formation (Jefferson, 1968) overlies Member C at the sample locality. No ostracodes have been recovered from any horizons in Member D. These fluvatile sediments were deposited as a delta prograded eastward from where the Mojave River entered the basin.

SUMMARY

It is evident that species abundance and the biostratigraphic distribution of ostracodes in the Manix Formation reflect changing paleoclimatic conditions. Variations in peak abundance of Limnocythere platyforma and L. ceriotuberosa are correlated with colder and wetter regional conditions and high lake levels. Modern ostracode biogeographic and ecological data support this paleoclimatic interpretation.

Apparently there were two cold, possibly shallow freshwater stands recorded in the basal 3 m of the sampled stratigraphic section. The third event of peak abundance at 3 m above base section represents a major climatic shift which is tentatively correlated with the 7/8 marine oxygen isotope stage boundary. The ecological replacement of Limnocythere platyforma by L. ceriotuberosa at this horizon suggests that a major filling event occurred. At this time the paleohydrochemistry of the lake changed as a result of changes in temperature, source water and drainage patterns. Peak abundances of L. ceriotuberosa that follow this event indicate four additional high stands prior to the Sangamon interglacial. Manix basin may have held a dry playa during much of this period. Two ephemeral lake phases occured late in the interglacial. The Wisconsin record is not well represented at the sample locality but there appear to have been two high lake stands early in this period.

SUPPORTING EVIDENCE

Additional biostratigraphic data on ostracode assemblages from the Lake Manix basin comes from Coyote Dry Lake (R. Reynolds pers. comm. 1986). Sediment samples collected from auger borings were analyzed by R.M. Forester of the U.S. Geological Survey. Forester (pers. comm. 1986) reported the occurrence of five ostracodes, four of the taxa are the same as those described here. The fifth taxon, Limnocythere bradburyi, dominates the majority of the auger samples.

Limnocythere bradburyi presently lives in the semi-arid and sub-humid regions of southwest New Mexico into the central plateau of Mexico (Forester, 1985). Lakes that support L. bradburyi are shallow, turbid, and isothermal with ambient air. They may undergo seasonal drying. Cold temperatures are lethal to the eggs of L. bradburyi where as L. ceriotuberosa eggs require some minimum temperature prior to hatching (Forester, 1985). The co-occurrence of L. bradburyi and L. ceriotuberosa in the Coyote Dry Lake samples suggests climatic conditions intermediate between warm Mexican and cold Great Basin air masses. No stratigraphic correlation can be derived between the ostracode biochronology of Coyote Lake and the midbasin section (Steinmetz, 1986).

Auger borings from Coyote Lake were sampled at five foot intervals and undoubtedly incorporated broadly different stratigraphic horizons. The presence of L. bradburyi in Coyote Dry Lake suggests seasonality was not extreem and the sub-basin was relatively shallow. Coyote basin served as an overflow reservoir for Lake Manix during major stadials (Meek pers. comm. 1987). The diversity of the ostracode fauna in the Coyote Dry Lake samples indicates that water depth, temperature, and quality fluctuated considerably during the late Pleistocene.

CONCLUSION

These preliminary investigations provide substantial evidence that a relatively complete paleoclimatic and paleoenvironmental late Pleistocene record exists in the Lake Manix deposits. Utilizing ostracodes alone, further potential studies include biostratigraphic, paleochemical, and evolutionary investigations.

ACKNOWLEDGEMENTS

I would like to thank George Jefferson and Bob Reynolds for their support and critical evaluation of this research. Richard Forester generously provided information on the systematics and ecology of ostracodes. Additional thanks to Jennifer Reynolds and members of the San Bernardino County Museum for the use of their computer facility for the production of this manuscript.

REFERENCES CITED

Al-Droubi, A., B. Fritz, J. Gac, and Y. Tardy, 1980. Generalized residual alkalinity concept: Application to prediction of the chemical evolution of natural waters by evaporation. American Journal of Science, 280:560-572.

Bassett, A.M. and G.T. Jefferson, 1971. Radiocarbon dates of Manix Lake, central Mojave Desert, California. Geological Society of America special paper, Abstracts to Meetings 3:79.

Benson, L.V. and R.J. Spencer, 1983. A hydrochemical reconnaissance study of the Walker River Basin, California and Nevada. United States Geological Survey, open-file report 83-740.

Crisman, T.L., 1978. Reconstruction of past lacustrine environments based on the remains of aquatic invertebrates, IN Biology and Quaternary Environments, D. Walker and J.C. Guppy, eds. Canberra City, Australia Academy of Sciences:69-101.

Delorme, L.D., 1969. Ostracodes as Quaternary paleoecological indicators. Canadian Journal of Earth Sciences, 6:1471-1476.

Eugester, H.P. and B.F. Jones, 1979. Behavior of solutes during closed-basin brine evolution. American Journal of Science 279:609-631.

Fergusson, G.J. and W.F. Libby, 1962. UCLA radiocarbon dates. Radiocarbon, 4:113.

Forester, R.M., 1983. Relationship of two lacustrine ostracode species to solute composition and salinity: Implications for paleohydrochemistry. Geology, 11:435-438.

_____, 1985. Limnocythere bradburyi n. sp.: A modern ostracode from central Mexico and a possible Quaternary paleoclimatic indicator. Journal of Paleontology, 59(1):8-20.

_____, 1986. Determination of the dissolved anion composition of ancient lakes from fossil ostracodes. Geology, 14:796-798.

Garrels, R.M. and F.T. MacKenzie, 1967. Origin of the chemical composition of some springs and lakes, IN Equilibrium concepts in natural water systems. American Chemical Society Advances in Chemistry, 67:222-242.

Hubbs,C.L., G.S. Bein, and H.E. Suess, 1962. La Jolla natural radiocarbon measurements II. Radiocarbon, 4:204-238.

Jefferson, G.T., 1968. The Camp Cady local fauna from Pleistocene Lake Manix, Mojave Desert, California. Department of Geology unpublished masters thesis, University of California, Riverside: 130 p.

_____, 1985. Stratigraphy and geologic history of the late Pleistocene Manix Formation, central Mojave Desert, California, IN Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, R.E. Reynolds, ed. Redlands, San Bernardino County Museum:157-169.

Jefferson, G.T. and J.J. Steinmetz, 1986. Ostracode biostratigraphy and paleoecology of the late Pleistocene Manix Formation. Current Research in the Pleistocene, 3:55-56.

Meek, N., 1989. Geomorphic and hydrologic implications of the rapid incision of Afton Canyon, Mojave Desert, California. Geology, 17:7-10.

Sarna- Wojiciki, A.M., H.R. Bowman, C.E. Meyer, P.C. Russell, F. Asaro, H. Michael, J.J. Rowe, P.A. Baedecker, and G. McCoy, 1980. Chemical analyses, correlations, and ages of late Cenezoic tephra units of east-central and southern California. United States Geological Survey open-file report 80-231.

Steinmetz, J.J. and G.T. Jefferson, 1988. Biostratigraphy and Paleoecology of ostracodes from the Pleistocene Lake Manix, central Mojave Desert, California. Current Research in the Pleistocene, 5:61-62.

Winters, H.H., 1954. The Pleistocene fauna of the Manix Beds in the Mojave Desert, California. Department of Geology unpublished masters thesis, California Institute of Technology, Pasadena: 58 p.

Physiographic history of the Afton basin, revisited

Norman Meek, Department of Geography, University of California, Los Angeles, CA 90024

ABSTRACT

Surveying errors and interpretative differences between the first two reports (Ellsworth, 1932; Blackwelder and Ellsworth, 1936) on eastern Afton basin indicate that the physiographic history of the basin requires revision. New data indicating offset shorelines and a new interpretation of the sediment wedge adjacent to the Manix fault suggest uplift of the Cady Mountains during the middle and late Pleistocene. Moreover, deposits attributed to a lake in the dissected basin may instead be due to local ponding.

INTRODUCTION

In 1932, Elmer Ellsworth, a doctoral student at Stanford University, completed an admirable dissertation entitled "Physiographic History of the Afton Basin" (Ellsworth, 1932). Because of financial difficulties associated with the Great Depression, Ellsworth left academia to work in the oil business, and the task of further publication on the subject was left to his dissertation advisor, Professor Eliot Blackwelder. Although Blackwelder visited the basin for at least one day in 1931, and again in 1932, his responsibilities as chair of Geology at Stanford (1922-1945) and his fragile health apparently prevented him from independently investigating the basin in detail prior to writing the widely cited summary article: "Pleistocene lakes of the Afton basin" (Blackwelder and Ellsworth, 1936).

In the fifty years since its publication, the Blackwelder and Ellsworth article has remained unchallenged. Partly because Ellsworth did not review the article prior to its publication, several important differences exist between the article and his dissertation. These differences, as well as the recent discovery of important elevational errors in the original study, lead to the conclusion that several parts of Blackwelder and Ellsworth (1936) are incorrect, and must now be revised. The purposes of this paper are to discuss the errors in the original study, to note the importance of factual and interpretative differences between the two works, and to provide the results of new surveys and observations of the same features studied by Ellsworth in order to revise the physiographic history of eastern Afton basin.

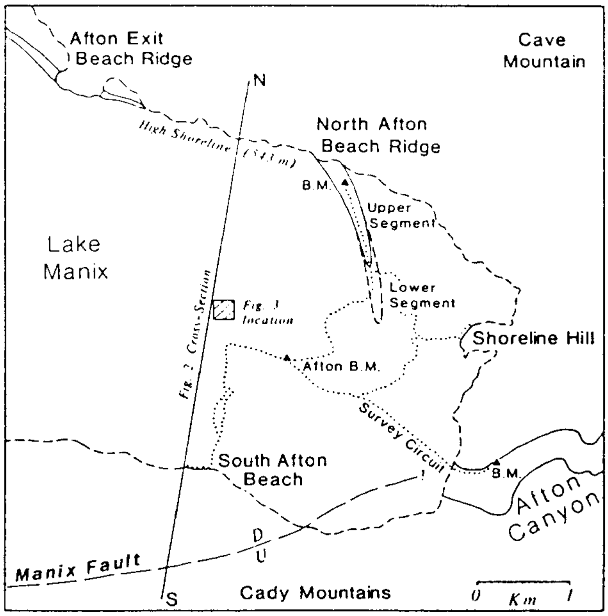


Figure 1: The Lake Manix basin

IMPORTANT DIFFERENCES BETWEEN ELLSWORTH (1932) AND BLACKWELDER AND ELLSWORTH (1936)

Three differences between the two earliest reports on eastern Afton basin involve critical aspects of basin history. First, Ellsworth (1932, p. 63) suggested that all lakes in Afton basin were probably correlative with substages of the Tioga glacial. Relying on the same evidence, Blackwelder apparently disagreed, correlating the two recognizable lacustrine periods with the Tahoe and

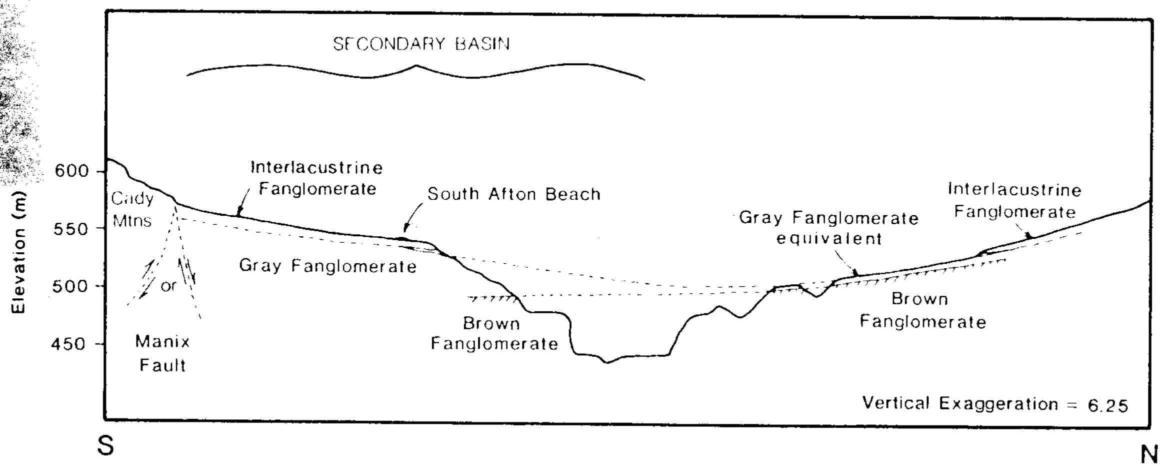


Figure 2. North-south cross-section of eastern Afton basin. The location of this diagram is shown on Fig. 1.

Tioga glaciations (Blackwelder and Ellsworth, 1936, p. 463). The correlations in each report were based on qualitative assessments, such as the fresh appearance of the beach ridges and the time believed necessary to erode the basin. The age of the first lacustrine period is still not known even though absolute-age dating techniques have been available for decades. Consequently, previous correlations of lacustrine periods in eastern Afton basin are speculative.

Secondly, Blackwelder and Ellsworth (1936, p. 459) reported the maximum stage of the first lake to be 1795' (547 m). In his dissertation, Ellsworth (1932) did not provide data to support such a statement other than a dashed line on one figure (p. 23), and in fact, never specifically discussed the maximum stage of the first lacustrine period. Indirectly, he suggested a maximum stage of the first lake by stating that the second lake crested "about 20 feet higher" (Ellsworth, 1932, p. 49). Because Ellsworth provided data indicating that the second lake peaked at 1800' (548.8 m), one can infer that the first lake peaked about 1780' (542.7 m). In any case, no evidence was provided to indicate the maximum stage of the first lake, probably because the uppermost shore facies of the first lake have been erosionally truncated in all known exposures.

Finally, Blackwelder and Ellsworth (1936) report a sheet of gravel atop the lacustrine clays "not less than 20' thick near the middle of the basin and perhaps somewhat thicker toward the margin" (p. 459). In contrast, Ellsworth's (1932) cross-sections show the same fanglomerate thinning to less than 20' at distances far removed from the basin center (p. 26).

SURVEYING ERRORS IN ELLSWORTH (1932)

Generally speaking, the descriptive data provided by Ellsworth (1932) are reliable, and serve as a simple, but adequate introduction to the stratigraphy of eastern Afton basin (Fig. 1). However, recent repetitions by the author of Ellsworth's field surveys indicate that his measurements of beach-ridge elevations are erroneous.

Ellsworth reported a maximum elevation of 1800.1' (548.8 m) for north Afton beach ridge, and 1783.2' (543.7 m) for south Afton beach ridge. He also reported closing his survey circuits with net vertical closure errors of 0.2' (0.06 m) and 1.2' (0.37 m) respectively (1932, p. 73).

Recent resurvey of these features indicates that north Afton beach ridge tops out at 542.6 m (1779.8'), and that south Afton beach ridge crests at 541.0 m (1774.5'). The survey closure errors are 0.11 m (0.36') and 0.03 m (0.10') respectively. The accuracy of the north Afton beach ridge resurvey was independently verified at the beach ridge benchmark by the Los Angeles Department of Water and Power (1779.2'; 542.4 m).

There is a possibility that the large surveying errors may not be entirely Ellsworth's fault, as he mentions using a benchmark at Afton Station reported to be at an elevation of 1425.0' (434.5 m) by the Union Pacific Railroad (Ellsworth, 1932, p. 5). The modern benchmark at Afton Station is at an elevation of 1408' (429 m; NGS/USGS datum), and my casual observations suggest that Afton siding is probably at the same elevation today as in

1931. It is therefore possible that railroad surveyors could be responsible for a major error in the datum used by Ellsworth. However, at least one of Ellsworth's circuits must have been inaccurate because the measurement errors are not constant.

Apparently failing to independently measure local shoreline features, numerous authors have reported 1800 +/- 5' (549 +/- 1.5 m) shorelines in the Manix basin. Weldon (1982, p. 80) even developed a tectonic hypothesis to explain the reported shoreline elevations. The fact that the maximum shoreline elevation is 543 m, and that the maximum stage of the first lake is unknown, indicates that Weldon's hypothesis is based on erroneous information.

The reduction in maximum stage from 549 to 543 m also has enormous implications regarding Lake Manix hydrology. For example, lake surface area decreases from about 380 km2 to about 215 km2 (a 44% reduction), lake volume decreases from about 4.55 km3 to about 3.0 km3 (a 34% reduction), and the direction of flow over interfluves reverses in some lake-history reconstructions. Clearly, the original surveying errors have compounded over the years, creating a lake history based more on legend than fact.

REVISION OF THE PHYSIOGRAPHIC HISTORY

The pre-lacustrine stratigraphic sections have not been investigated in detail, and so the physiographic history of the basin prior to the late Pleistocene lakes requires further study. However, preliminary investigations reveal that Ellsworth failed to describe several thick carbonate accumulations in the Brown Fanglomerate (Fig. 2), perhaps mistaking the indurated layers for mudflows (Ellsworth, 1932, pp 15-16). The carbonate accumulations cement the top of fanglomerate members, and suggest that much of the basin history (early and middle Pleistocene, perhaps extending back into the Pliocene) was characterized by episodic deposition with long intervals of fan-surface stability and carbonate accumulation. As Ellsworth correctly noted (1932, p. 28-29), these fanglomerate deposits provide evidence of post-depositional tectonic folding in eastern Afton basin. There is some evidence east of Afton Station that suggests syn-depositional warping.

The thickness of the uppermost carbonate accumulation in the Brown Fanglomerate marks a lengthy period of surface stability throughout the area, and serves as a crude time-stratigraphic marker. Large boulders of Cave Mountain granite are found south of the Mojave River in the Brown Fanglomerate, indicating that the former basin depocenter was farther south than during the late Pleistocene. Cady Mountains volcanics are comparatively rare in the Brown Fanglomerate southwest of Afton Station. It is therefore unlikely that the Cady Mountains had significant relief in their present position during the deposition of the Brown Fanglomerate. However, increasing quantities of volcanics in carbonate-cemented strata to the east near Afton Canyon suggests that debris was locally shed to the north from the Cady Mountains.

The Gray Fanglomerate is a thick, uncemented, volcaniclastic deposit that overlies the Brown Fanglomerate south of Afton. Notably, the Gray Fanglomerate has only a thin corresponding depositional unit north of Afton Station (Fig. 2). A likely explanation for this difference is that renewed diastrophism has formed a secondary basin between the Mojave River and main trace of the Manix Fault two km to the south. In this interpretation, the Gray Fanglomerate is sedimentary fill in a basin formed adjacent to the Manix Fault during late, and perhaps middle Pleistocene time.

This secondary basin may represent a local depression at the surface of a south-dipping thrust fault which uplifted the Cady Mountains, or alternately, it may represent a down-dropped block adjacent to a predominantly strike-slip fault. In either case, continuous deposition is indicated by the relative lack of carbonates in the Gray Fanglomerate relative to the Brown Fanglomerate, and suggests that the Cady Mountains were rapidly uplifted south of Afton during the middle and late Pleistocene.

New shoreline elevation data support this hypothesis of basin development, and suggest that tectonic deformation is continuing. Beach remnants south of Afton Station attain a maximum elevation of 541.0 m. Comparative topographic profiles and the relationship of the beach deposit crests to the edge of undisturbed fan deposits just to the south suggest that the beach deposits are not highly eroded remnants of much larger features, but rather, are locally intact and provide accurate lake elevations. The maximum shoreline elevation south of Afton Station is 1.6 m less than the maximum shoreline elevations north of Afton Station, which are all accordant. Because the south Afton beach deposits lie in the middle of the proposed secondary basin, it is likely that the area has dropped approximately 1.6 m in the past 14,000 years in much the same way as during the deposition of the Gray Fanglomerate. Tectonic instability is also suggested by a fault (described by Ellsworth, 1932) with apparent normal offset and a displacement of about 5 m that cuts lake strata in this area.

The lacustrine history of Afton basin is far more complex than Ellsworth (or I) imagined. Although several buried and/or truncated beach deposits have been discovered at various places and at many different elevations throughout Afton basin, none has yet permitted the maximum elevation of the first lake period in Manix basin to be determined. Only circumstantial evidence, and certainly not the ideal stratigraphic relations shown by Ellsworth (1932, p. 23; p. 26) and Blackwelder and Ellsworth (1936, p. 458), suggests that parts of the major beach ridges in Afton basin could be deposits from the first lacustrine period. To emplace the uniform interlacustrine fan unit on both sides of the beach ridges suggests that the ridges were probably eroded first. My observations of the cross-sectional exposures of the beach ridge north of Afton and stratigraphic sections south of Afton suggest that most of the beach deposits equivalent to the first lacustrine period were erosionally truncated during the interlacustrine interval. Consequently, no maximum elevation can be assigned to the first lake period, but it is probable that the lake attained about the same maximum stage as during the second lacustrine period.

The interlacustrine fanglomerate which overlies the green lacustrine clays in the area is enigmatic. The basic details are simple:

1) the unit is uniformly thin (< 10 m) and forms lithologically resistant terraces above the lacustrine deposits from the first lake;

2) in several places large boulders with diameters greater than 0.7 m are found in the deposit far removed from bedrock sources;

3) the deposit thins towards the basin center, and is thickest south of Afton Station in the proposed secondary basin.

4) if beach ridges formed in roughly the same positions during the first lake as during the most recent lake, then the beach ridges had to have been mostly eroded before the fanglomerate could have been uniformly deposited in many places where it is now found.

Because the fanglomerate remnants decrease in thickness towards the basin center, and are very thin at their current margins, they probably did not extend significantly farther into the basin on the north site of eastern Afton basin. South of Afton Station, the interlacustrine deposits probably extended north of their present limit, but nowhere do the exposures suggest that the basin center contained anything close to the 6.1 m (20') of coarse fill suggested by Blackwelder and Ellsworth (1936, p. 459).

The presence of large boulders in the thin fanglomerate deposit might indicate that large flash floods occurred at this time. However, the transport of such enormous boulders may have been greatly facilitated by decreased percolation into the underlying lacustrine clays.

The final lacustrine stage in Afton basin probably consisted of several different lakes. Preliminary radiocarbon dates on lacustrine materials are clustered into four late Wisconsin intervals ending about 14 ka with the breaching of the basin. It is necessary to complete additional in-progress radiocarbon dating before discussing the late Pleistocene lacustrine chronology in more detail.

It is now clear that the north Afton beach ridge is composed of several superposed beach deposits. As lake levels rose, the primary zone of beach-ridge deposition apparently moved northwards up the gradient of an alluvial fan. There is little evidence to support the belief of Blackwelder and Ellsworth (1936, p. 462) that half of the [north Afton] beach ridge has been removed through erosion. A likely alternative is that the north Afton beach ridge did not close off the eastern end of Afton basin because of rapidly increasing water depths to the south. It is possible that a distinct upper and lower segment of the north Afton beach ridge could represent deposits of two different late Wisconsin lakes.

As suggested by Ellsworth (1932) and Blackwelder and Ellsworth (1936), much of Afton Canyon was rapidly cut by the draining of Lake Manix. The timing and consequences of this event are discussed by Meek (1989). It is not clear how much of the canyon below the floor of Lake Manix was eroded in the initial canyon-cutting event. Cation-ratio dates in progress on exposed bedrock surfaces in the canyon may soon answer this question. In any case, the rapid base level drop initiated rapid downcutting of all tributary drainages upstream of the mouth of Afton Canyon, with consequent aggradation in the main channel due to the enormous sediment influx.

Ellsworth proposed a third lake in Afton basin sometime after significant dissection of the basin had occurred. Most of the evidence cited by Ellsworth for a third lake consists of isolated clay deposits in several canyons. Close inspection of the deposits reveals that:

1) most deposits are secondary clay deposits, usually colluvial in origin, and contain numerous locally derived clasts.

2) the few deposits which appear to be "primary" are thick (up to 6 m), are not fossiliferous, have horizontal bedding, are composed almost entirely of fine sediments, and occur in spatially discontinuous locations in left-bank tributary canyons of the Mojave River in eastern Afton basin.

Several hypotheses which do not require a third lake could explain these primary deposits. For example, some of the clay deposits could be due to slumping, since many sit at the base of steep hills. The absence of coarse debris within the clays in such settings argues against lengthy lacustrine sedimentation and suggests that either slumping or rapid accumulation occurred. The spatial discontinuity also suggests that some of the clays could be local lacustrine deposits within fissures in the underlying fanglomerates.

I believe that most of the clay deposits are best explained by side-canyon ponding, possibly caused by levees of coarse debris deposited by the Mojave River when it flowed at elevations higher than at present (Fig. 3). Notably, all of the primary clay deposits are found in tributary canyons. Remnants of a levee or debris apron at the mouth of one canyon may have formed in an ancient Mojave River flood. This entire primary clay deposit lies below the crest of the levee remnant. Had a Mojave River flood occurred not long after the formation of Afton Canyon, but after initial tributary cutting, instabilities in the Mojave River grade due to a rapid base level drop and abundant sediment supply could have caused ponding in tributary canyons. With an enormous supply of eroding clays from the exposed lacustrine sections in tributary drainage basins, it is not difficult to imagine rapid local redeposition of these clays in such locations.

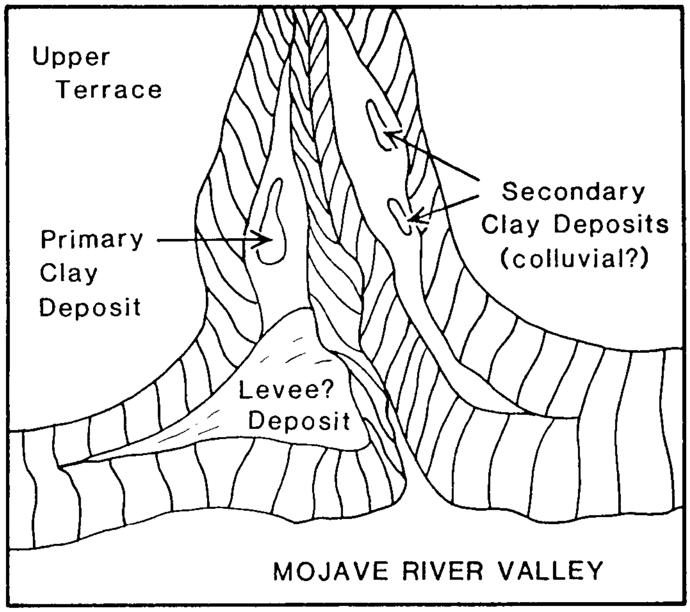


Figure 3. Typical setting of Ellsworth's Lake 3 clay deposits. Mojave River levee deposits may have caused local ponding and rapid clay deposition in the tributary canyons.

Blackwelder may also have had reservations about a third lake, because in his description of the clays he stated: "This deposit is identical in character with the green clay deposited in Lake No. 1 and may well have been derived in large part from erosion of that formation" (Blackwelder and Ellsworth, 1936, p. 460). In any case, there are several unusual post-lacustrine deposits in eastern Afton basin that defy simple explanations, perhaps resulting from combinations of rapid downcutting and slackwater conditions during floods. None of the deposits provides incontrovertible evidence for a third lacustrine period, but the existence of such a lake cannot be entirely dismissed.

CONCLUSIONS

The physiographic history of Afton basin as widely accepted for the past 50 years is incorrect because there are major measurement errors in the original study (Ellsworth, 1932) and both factual and interpretative discrepencies between the first two reports (Ellsworth, 1932, and Blackwelder and Ellsworth, 1936). Careful review of the supporting evidence and new measurements suggest that a significant portion of the previous work and interpretations must be discarded.

The basin stratigraphy indicates that eastern Afton basin was a stable sedimentary basin prior to renewed diastrophism during the middle and late Pleistocene. Active tectonic deformation continues in the vicinity of the Manix fault.

The Pleistocene lacustrine history is more complex than previously reported. No maximum stage can be assigned to the first major lacustrine period. After a period of alluvial-fan progradation, a series of late Wisconsin lakes filled Afton basin, ending about 14,000 ka when Afton Canyon was cut and the basin permanently drained.

ACKNOWLEDGMENTS

I would like to thank Ms. Lucia Barbato and Ms. Jody Musengo, my field survey assistants in eastern Afton Basin; Mr. Elmer Ellsworth for recollections and pictures of the area; and Professor Raymond V. Ingersoll and Richard L. Ford, University of California, Los Angeles, and George T. Jefferson, George C. Page Museum, for editing assistance. The National Science Foundation (SES 87-19442 to R. Berger) has provided funds for this project.

REFERENCES CITED

Blackwelder, E. and Ellsworth, E.W., 1936. Pleistocene lakes of the Afton basin, California. American Journal of Science 31:453-463.

Ellsworth, E.W., 1932. Physiographic history of the Afton basin: Ph.D. Dissertation. Palo Alto, CA, Stanford University: 99 p.

Meek, N., 1989. Geomorphic and hydrologic implications of the rapid incision of Afton Canyon, Mojave Desert, California. Geology 17:7-10.

Weldon, R.J., 1982. Pleistocene drainage and displaced shorelines around Manix Lake, IN Cooper, J.D., (comp.), Geologic excursions in the California desert. 78th annual meeting of the Cordilleran section of the Geological Society of America:77-82.