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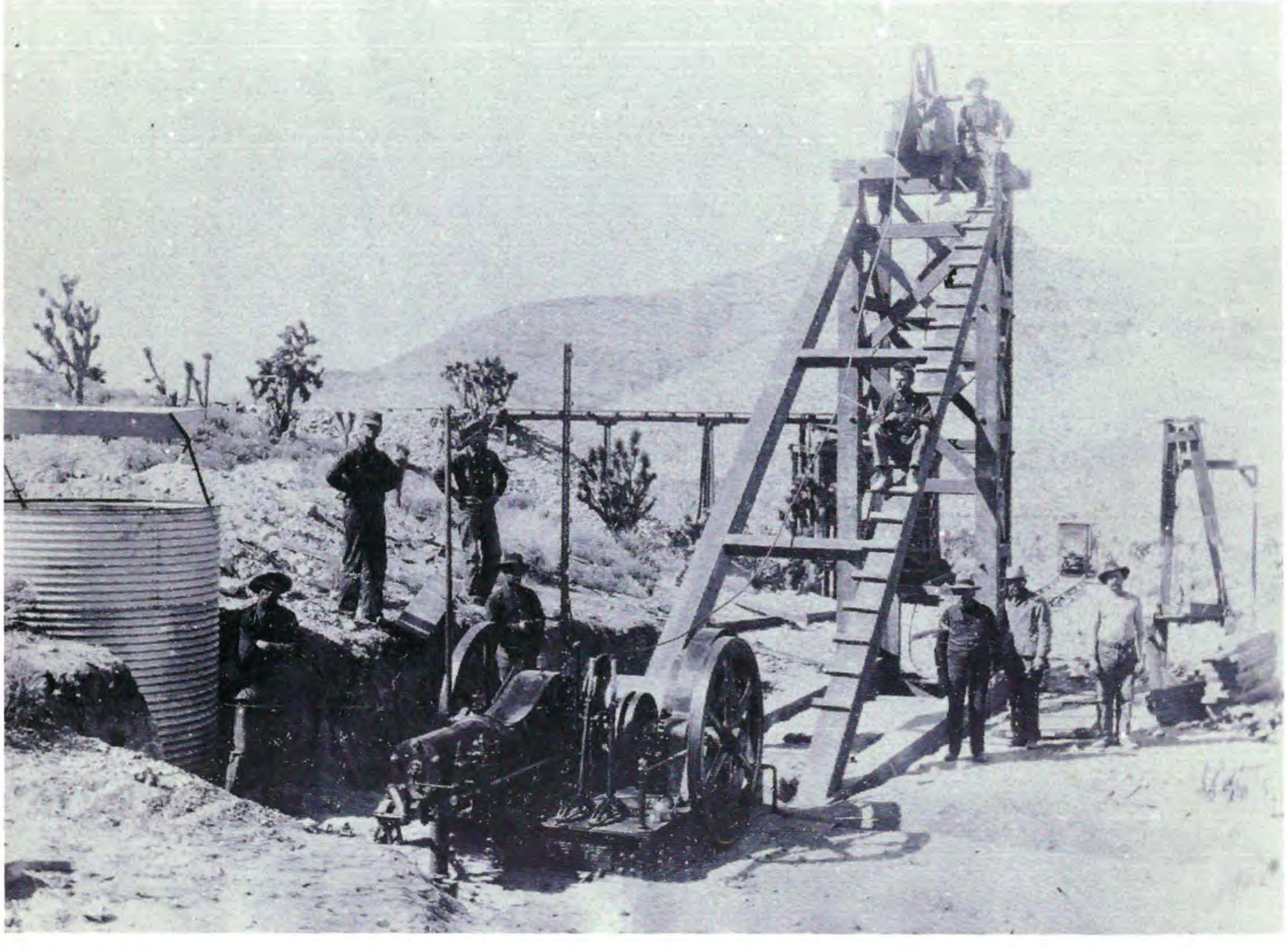
PUNCTUATED CHAOS
in the Northeastern Mojave Desert



edited by
Robert E. Reynolds
Jennifer Reynolds

Robert Wiley Adams
Dec. 4, 1919 - Aug. 15, 1995

In the summer of 1985, Bob Adams and friends organized an "Air Conditioned Arm Chair Field Trip" to share information about current work in the Mojave Desert. From this informal meeting in the recreation room of Bob's apartment grew the Mojave Desert Quaternary Research Center. The second "Arm Chair" session was held at the George C. Page Museum of Rancholabrea Discoveries in Los Angeles, followed by a series of meetings in which the Mojave Desert Quaternary Research Center was organized and an advisory board and steering committee were formed. By 1987, with the support of the San Bernardino County Museum and its Association, MDQRC became a formal organization headquartered at the Museum in Redlands. Bob was an active and involved member of both the MDQRC board and steering committee until his untimely death from cancer.

Bob earned a degree in Geology from the University of California, Los Angeles, in 1941. He worked with Richfield Oil and served in the U.S. Navy in Photo Intelligence until striking out on his own in hydraulic and electronic custom designing. He involved himself with a detailed study of Pleistocene lakes in the Mojave Desert and conducted research in plate tectonics and earthquakes (brought close to home with the Northridge quake, epicentered just one-half mile from his family home).

This volume is dedicated to the memory of Bob Adams.

Reynolds, Robert E. and Reynolds, Jennifer (editors)
Punctuated Chaos in the Northeastern Mojave Desert
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2024 Orange Tree Lane, Redlands CA 92374

Front cover: The Standard #1 mine in 1907. *J. Riley Bembry collection, San Bernardino County Museum.*

Back cover: Hauling ore from the Standard #1 mine to the Valley Wells smelter, 1907. *J. Riley Bembry collection, San Bernardino County Museum.*

Punctuated Chaos in the Northeastern Mojave Desert

Robert E. Reynolds and Jennifer Reynolds, editors

Abstracts from the 1996 Desert Research Symposium

Jennifer Reynolds, Compiler

The Tidewater and Tonopah depot at Silver Lake at the turn of the century. *Larry Vredenburgh collection.*

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Table of Contents

PUNCTUATED CHAOS:

A Field Trip in the Northeastern Mojave Desert

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En Route to Day One

Leave the parking lot of the San Bernardino County Museum in Redlands and TURN RIGHT onto Orange Tree Lane, left of California, and right onto Interstate 10 West. Follow I-10 to the interchange; go north on I-215 and continue on I-15 past Barstow to Baker. Exit in Baker and check your vehicle for gas, fluids, and tire pressure. Continue east on I-15 about 30 miles to Cima Road; exit, cross over freeway, and proceed one mile north along pavement. Turn right on dirt track to the Valley Wells copper smelter site (Rosalie), marked by a cottonwood tree and a black slag deposit.

Day One

0.0 0.0 CONVENE in open area on the north side of Cima Road at I-15. **Overview.** We will be looking at geologic relationships that suggest detachment faulting during the Late Cretaceous and Late Miocene. On Day One we will travel through the lower plate rocks of the Mesquite, Clark, Mescal, and Ivanpah core ranges. Rocks to the west of this core were an upper plate of the Late Miocene detachment fault that moved westward. The core ranges were left standing at elevations up to 7929' (Clark Mountain, Fig. 1) and host diverse flora, including fir (Jones, this volume) and fauna that are relicts from the Pleistocene (see Czaplewski, McDonald, Saysette, and Scott, all in this volume). The intrusive history of the rocks made the area subject to intense mineral prospecting over the last 150 years (see Adams, Hensher, Jessey, Ririe and Nason, and Vredenburgh, all in this volume). Return to vehicles, CROSS OVER FREEWAY, and TURN LEFT to enter eastbound Interstate 15.

0.4 0.4 Proceed east on I-15.

3.4 3.0 The canyon to the south-southeast developed along the breakaway of the Mescal allocthon (Burchfiel and Davis, 1988).

4.9 1.5 Agave roasting pits are in the wash on the right (south) side of road (Schneider and others, this volume).

8.4 3.5 The Mountain Pass rare earth mine is to the north at 9:00 - 11:00 (Hensher, this volume; Ririe and Nason , this volume). Prepare to exit on Bailey Road.

8.9 0.5 EXIT at Bailey Road.

9.2 0.3 Stop at stop sign. TURN RIGHT across cattle guard to frontage road, then TURN LEFT (east).

9.6 0.4 **STOP 1.** Overview of Molycorp's Mountain Pass mine operations. The view to the northwest of the Mountain Pass mine from west to east shows the following landmarks: 1) current overburden stockpile which is material removed from above the ore body, 2) flotation plant where ore from the mine is concentrated, 3) immediately to the north of the flotation plant is the open pit mine, 4) chemical and specialty plants where solvent extraction is used to upgrade the ore into the final products, 5) the dam for the tailings pond is on the easternmost side of the operations, 6) old Mountain Pass townsite, revegetated with native Joshua trees and yuccas, and, 7) inactive overburden stockpile that will contain re-vegetation test plots. Continuing east along the frontage road, the road cuts expose Tertiary gravels and fanglomerate that once probably covered the Mountain Pass ore body (Castor, 1991).

The Miocene gravels are important to the history of the area. From the oldest, clast content includes QTg1: Precambrian lithologies; QTg2: Cambrian Tapeats Sandstone mixed with QTg1; QTg3: Delfonte volcanic and Aztec clasts with QTg1; QTg4: Paleozoic limestone and Delfonte volcanics. According to Castor (1991), "Clast contents of certain gravels suggest that they are of Tertiary age because they do not reflect modern distribution of source material. The earliest gravels (QTg1) were deposited on an old erosional surface and were probably transported from the east. The lack of carbonate detritus in early gravels (QTg1 - QTg3) at Mountain Pass indicates that they were deposited before uplift of the Mescal Range."

Three miles north is one of the southernmost outcrops of the Cambrian Tapeats Sandstone.

9.8 0.2 Exposures of the 1.7 billion year old (Ga) regionally


Figure 1. Clark Mountain viewed from the Valley Wells copper smelter. *R.E. Reynolds photograph.*

Figure 2. Syenite knobs and dikes at Stop 2. View north-northwest toward Clark Mountain, with the Mountain Pass rare earth mine in the center distance. *R.E. Reynolds photograph.*

metamorphosed rocks comprise the majority of the Precambrian exposures in the Mountain Pass area. Exposures along this road cut include mafic gneiss, granitic pegmatite, and garnet-rich felsic gneisses. Intruded into these rocks are several small Tertiary andesite dikes. These dikes typically trend east-west and have small hydrothermal contact aureoles along their margins.

10.1 0.3 Road bears right at end of pavement.

10.5 0.4 Road bears left at corral.

10.7 0.2 PARK at outcrops.

Stop 2. Syenite outcrops (Fig. 2). Fresh exposures of syenite and syenite dikes are on the right (Morton and others, 1991). Outcrops in this area are dominated by a maroon-colored coarse-grained syenite. This syenite is typical of the syenites within the 1.4 Ga sequence of alkalic rocks that host the Mountain Pass ore body. The syenite at this location is composed of coarse potash feldspar and biotite which demonstrates the potassic nature of the alkaline complex at Mountain Pass. Shonkinite also crops out here; it is a highly unusual biotite-rich rock that barely looks igneous. Both syenite and shonkinite are about 1400 Ma and are related to the mineralized carbonatite at Mountain Pass. PROCEED along road.

11.0 0.3 We are traveling through exposures of garnet gneiss on the east side of the Kokoweef Fault.

12.0 1.0 Road crests at summit.

12.2 0.2 BEAR LEFT at road junction.

12.6 0.4 TURN LEFT toward Windy Claims.

13.3 0.7 Bear left.

13.8 0.5 Proceed straight past a left turn and go 1/10 mile to a small but steep hill. At the top of the small hill, TURN LEFT, then immediately TURN RIGHT, taking the right fork and avoiding the steep road.

14.0 0.2 If you have four-wheel drive, TURN LEFT and charge up the hill; don't stop until you get to the top.

14.1 0.1 PARK at junction. **Stop 3**. View stop. HIKE eastward on the ridge crest. Due north is Potosi Peak; to its west is Charleston Peak, to the right Devil Peak (McDonald, this volume), to the east is Ivanpah Lake, Stateline, and Roach Lakes, N45°E are the Lucy Grey and McCullough Range; Nipton and the road to Searchlight are north of due east (the red patches south of the road are the fluorite mines west of Crescent Peak; the peak is known for its turquoise); south of that are the Castle Peaks (Nielson, 1995) and Castle Butte. S45°E is the road that runs past Ivanpah and the Vanderbilt mine (Reynolds and others, 1995); east of Vanderbilt are the grey sediments of the Willow Wash paleovalley (Miller, 1995). Preliminary magnetic and gravity studies (Swanson and others, 1980) suggest that the Clark Mountain Fault to the south (Hewett, 1956), the Kokoweef Fault (Burchfiel and Davis, 1971) and associated structures were once continuous with the Slaughterhouse Fault and structures in the northern New York Mountains (Miller and Wooden, 1992).

We are standing on Proterozoic gneissic rocks. The New York Mountains are on the skyline from S45°E to due S. Also due south we can see Eagle Crags in the Mid Hills, and Fountain Peak in the Providence Mountains. S55°W we can see Kokoweef Peak (Fig. 3) (Reynolds and others, 1991a; Force, 1991; Saysette, this volume). Low on the peak above the graded road is the trace of the Kokoweef Fault which separates Paleozoic limestone from metamorphic rocks like those we stand on. To the southwest is Crystal Cave, marked by a trailer and a mine dump. The opening to Kokoweef Cave (Reynolds and others, 1991a; Force, 1991; Saysette, this volume) is above this at elevation 6000'. South of due west is a view down Piute Valley with basalt flows and cones of the Cima volcanic field in the distance. Due west in the south edge of the Mescal Range we see imbricated thrusts: from west to east, the Mescal thrust, Mesquite Pass thrust, and Keystone thrust (Burchfiel and Davis, 1971) and the Keaney/Mollusk Mine thrust (Fleck and Reynolds, this volume). These are youngest to the east and place older rocks over younger. They are the allochthonous rocks that have been pushed from the west to the east over the autochthonus rocks which include the Permian through Jurassic rocks overlain by Cretaceous Delfonte volcanics. Our next stop

Figure 3. Kokoweef Peak, the site of Kokoweef Cave, Crystal Cave, Quien Sabe Cave, and the Carbonate King Mine. *R.E. Reynolds photograph.*

will be near the base of the Aztec Sandstone. View N30°W is a thick section of Paleozoic rocks comprising Clark Mountain. The Colosseum mine is east of Clark Mountain, and the Clark Range runs to Devil Peak, where caves produce Pleistocene faunas (Karnes and Reynolds, 1995; Reynolds and others, 1991b; McDonald, this volume). Return to vehicles; PROCEED LEFT down hill, TURN RIGHT to find the road with the steep small hill, and RETRACE to the road to Kokoweef.

15.5 1.4 TURN RIGHT (north) onto graded Kokoweef Road and continue 0.5 mile to junction. There is a good view north of Mescal Range with red Aztec sandstone anticlinally overturned to the north and synclinally overturned further west.

Figure 4. Thrusts faults on the south side of the Mescal Range place older rocks over younger strata. *R.E. Reynolds photograph.*

15.9 0.4 TURN LEFT at junction. We are crossing the trace of the Kokoweef Fault and leaving metamorphic terrain. Red sand in road is from the Chinle Fm. We are going to a point where we can see the late Permian, Triassic, and early Jurassic equivalents to the Colorado Plateau section.

16.6 07 Leave graded road and TURN RIGHT (northwest)

16.7 0.1 Proceed up gravel terrace.

16.9 0.2 Pass car bodies and PARK. **Stop 4. Aztec Sandstone.** If time allows, we will WALK northwest on a dirt road between the two hills of Aztec Sandstone and see a section of Early Triassic Moenkopi, Late Triassic Chinle, Lower Jurassic Moenave/Kayenta equivalent(a brick red sandstone), and the Aztec Sandstone (alternating red and white beds) (Evans, 1971; Marzolf, 1982; Fleck and Reynolds, this volume). Clastic and volcanic rocks from this sequence are seen in the Mountain Pass gravels (Castor, 1991), in Shadow Valley basin fill (Reynolds, 1991), and in the Willow Wash paleovalley in the New York Mountains (Miller, 1991). Return to vehicles, RETRACE to graded road that goes westward towards the Iron Horse/Blue Buzzard mine.

17.1 0.2 TURN RIGHT on graded road.

17.7 0.6 TURN LEFT (south) at fork in the road.

17.9 0.2 Continue across junction at landing strip.

18.0 0.1 PROCEED RIGHT (west-southwesterly) at junction.

18.4 0.4 TURN LEFT (south) at T intersection. **STOP 5. Thrust faults.** Look north towards the Mescal Range at thrust faults (Fig. 4) which place older rocks over younger rocks. To the west, the Mescal thrust places Precambrian clastic and Cambrian clastic and carbonate rocks over the Mesquite Pass thrust, which in turn is thrust over the Keystone thrust. The most easterly and youngest thrust, the Keaney/Mollusk Mine Fault, involves the Delfonte volcanics and places a maximum age on thrusting in this belt (Burchfiel and Davis, 1971, 1988; Fleck and Reynolds, this volume).

18.7 0.3 Continue past junction on left.

19.3 0.6 Continue southwest at crossroad.

19.7 0.4 Continue through junction with oblique road to the left.

20.1 0.4 Continue left, avoiding right turn to the Striped Mountain limestone prospects on the west. Striped Mountain has relatively pure deposits of bleached limestone. The Ivanpah Mountains on our left are composed of Jurassic granitic rocks. Subsurface weathering has developed large round boulders.

20.4 0.3 Cross the divide that separates Piute Valley on the north from the drainage south toward Cima Dome. We are passing the Standard #1 mine (Fig. 5, and Vredenburgh, this volume). To the north, the Jurassic Ivanpah granitics have intruded and metamorphosed Paleozoic limestone.

Figure 5. The Standard #1 mine, viewed after a snowstorm in 1907. *Bembry collection, San Bernardino County Museum.*

Figure 6. View southeast of the New York Mountains from the gravel outcrop at Stop 4. *R.E. Reynolds photograph.*

21.1 0.7 Continue past a left turn toward the Standard #2 mine.

21.7 0.6 On our left is a grave site containing the graves of J. E. Ginn (d. 1924), Raymond Arthur Walker (1914-1987), J. Riley Bembry (1899-1984) and John T. Feery (d. 1909).

22.1 0.4 Proceed southwest, continuing past junction due south that heads toward mines.

22.3 0.2 Road to the east leads to Riley's camp. CONTINUE STRAIGHT across the road to the Evening Star mine.

22.4 0.1 Cross second road parallel to the road to Riley's Camp.

22.8 04 Proceed southwest at intersection; the easterly branch goes to the Evening Star tin mine, one of the few mines in eastern and southern California to produce cassiterite, a tin oxide. It occurs in association with scheelite, chalcopyrite, pyrite, and copper carbonate minerals (Wright and others, 1953).

23.0 0.2 Continue south past left turn to Evening Star mine.

23.6 0.6 Continue south past a turn to the Copper King mine. Workings expose garnet epidote skarn with secondary copper oxides (Wright and others, 1953).

23.8 0.2 TURN LEFT at an intersection and proceed easterly.

24.8 1.0 TURN SHARP RIGHT (south). Tin cabins to northeast.

24.9 0.1 TURN LEFT (east). We are entering an area with rounded, subsurface-weathered Ivanpah granitic rocks.

25.5 0.6 Continue due east past intersection to left.

25.6 0.1 TURN LEFT at "Y" intersection.

25.9 0.3 **STOP 6. Hike to Gravels.** (Fig. 6) Park and enjoy a view south-southeast to the New York Mountains and Table Mountain. We are surrounded by round boulders suggesting deep subsurface weathering of the Jurassic Ivanpah granite. HIKE due west to a prospect on the west side of a low hill. Well-cemented gravels exposed in the prospect contain *no* Mescal Range clasts. They were deposited when the surrounding ranges were not a significant topographic high. Clasts in this strongly cemented gravel match the rocks we drove by at the Evening Star and Copper King mines. These rocks are marbleized Permian to Cambrian carbonate rocks, Tapeats quartzite, the two intrusive phases of the Ivanpah pluton (Ivanpah Granite and Striped Mountains Granodiorite), and an unusual alteration of the Ivanpah Granite that is only present in the area east of the hills those mines are located in. This information suggests that the gravel was shed southeastward. What sort of landscape change is required for this observation is a matter of speculation, but the gravel clearly could not have been placed in this location with topography anything like today's. Return to vehicles, RETRACE route westerly.

26.9 1.0 TURN LEFT (southwest) south of cabins.

27.4 0.5 TURN RIGHT (southwest) onto sandy road.

28.1 0.7 TURN RIGHT across sand wash.

28.3 0.2 TURN LEFT (southeast) at junction at Y prior to north-south road. and proceed to conical butte.

28.5 0.2 PARK near well head. **STOP 7. Possible breakaway zone.** HIKE to prospects. North-trending fractures (Miller and others, this volume) and chlorite breccia zones may mark a Tertiary fault that acted as a possible breakaway for moderately extended Cima Dome terrain to west. Return to vehicles, RETRACE to Y junction.

28.7 0.2 TURN LEFT at Y junction and prepare to turn left almost immediately.

28.2 0.1 TURN LEFT (south) at north-south road.

29.1 0.3 We are amidst large, round boulders on an erosional surface, suggesting deep subsurface mid-Tertiary weathering (Oberlander, 1972) in the granitic rocks.

29.7 0.6 TURN LEFT(south-southeast). onto pavement at Cima Road. Watch for oncoming vehicles.

30.2 0.5 After road crosses wash, prepare to turn left across pavement onto the dirt road to Kessler Springs Ranch.

30.3 0.1 TURN LEFT

30.6 0.3 PULL OFF at slight right bend in dirt road and PARK. HIKE 200 feet northeast, looking for chlorite breccia zones. **STOP 8. Chlorite Breccia Zone.** At a distinct "S" curve in the wash, the east side of the wash has relatively unaltered Kessler Springs Adamellite with large phenocrysts. On the west side of the wash, a chlorite breccia zone gives the Kessler Spring Adamellite a greenish-gray appearance. Return to vehicles, RETRACE to pavement of Cima Road.

30.8 0.2 TURN RIGHT onto Cima Road.

31.3 0.5 Continue on pavement past north-trending dirt road.

31.7 0.4 SLOW for curves.

33.0 1.3 TURN LEFT toward Valley View Ranch.

34.6 1.6 Pass barn and BEAR SHARP LEFT (south) at 4-way intersection.

34.7 0.1 TURN 90 degrees LEFT (due east) and proceed towards gate.

34.8 0.1 Gate (last vehicle through closes it, please). Proceed east to a right turn at the fence line road toward the Teutonia mine.

35.0 0.2 TURN RIGHT.

35.4 0.4 Fence line bends right.

Figure 7. A gouge zone is exposed at the Teutonia Mine near Milepost 35.8. *R.E. Reynolds photograph.*

35.8 0.4 STAY RIGHT. The road to the left leads to the Teutonia mine. The first mine shaft exposes a very well developed gouge zone several feet thick (Fig. 7). Continue along fence line to fresh steel hiking gate.

35.9 0.1 Hiking gate. PARK, follow trail west-southwest 500 feet and start up the slope. **Stop 9. Mylonite zone.** At the first switchback examine the outcrop immediately to the south. This is a very good example of a mylonite zone. Asymmetric deformed feldspar phenocrysts within the mylonite zone indicate that the top (southwest side) moved down to the southwest with respect to the bottom. This suggests the Ivanpah Granite moved down and laterally (extensionally) during ductile faulting. This mylonite zone strikes toward the town of Cima, where it is cut by the Nipton Fault. Its offset equivalent is a similar mylonite zone in the western New York Mountains. It was active at about 69 million years ago (Miller and others, this volume). The mylonite zone here on Cima Dome is probably the same age. The view to the east is of a broad field of round granitic boulders developed subsurface during middle Tertiary time. Return to vehicles and PROCEED along south-southeast fence line road toward 3 way junction and then to Cut Springs.

37.0 1.1 Open and close gate; proceed southwest toward small knoll.

37.9 0.9 Continue past road on the left coming from Kessler Springs Ranch.

38.2 0.3 Continue through gate at corral. Cut Spring, marked by mesquite and other vegetation, is to our right.

38.3 0.1 Continue south over first hill to wash. A spring supports cottonwood, Joshua tree, and mesquite 1/10 mile west up the wash. TURN SHARP LEFT down wash.

38.6 0.3 The fault zone that controls springs is on the right (west). An extensive breccia zone is to the east. Several small faults in the Teutonia Adamellite cause the breccia and jumble the intrusive contact with the Kessler Springs Adamellite. A much larger fault near the last exposures down this wash to the southeast dips moderately to the northwest and has nearly down dip striae. This fault is overlapped by Tertiary boulder gravel (Miller and others, this volume).

39.4 0.8 Gate at White Rock Springs. Proceed through the gate (last vehicle closes it) and PARK. **Stop 10. Breccia.** WALK WEST and look at the breccia. Breccia here is much more extensive than at Cut Spring, forming a zone nearly half a mile wide. The protolith rock appears to be the Kessler Springs Adamellite. The broad breccia is unlike breccia in faults elsewhere; it could be broken rock near a low-angle fault related to Tertiary extension. Return to vehicles and CONTINUE.

41.2 1.8 Pass through gate at water tank.

41.3 0.1 TURN LEFT onto power line road. PROCEED EAST to Cima Road.

43.3 2.0 Open and close cattle guard gate.

43.6 0.3 Watch for traffic and TURN LEFT onto Cima Road.

47.4 3.8 Pass north entrance to Kessler Spring Ranch.

48.5 1.1 Veteran's Memorial is marked by a cross.

49.9 1.4 Continue past Valley View Ranch road. Good view at 1:00 of Mescal Range and imbricated thrusts. Two repeated red beds of Wood Canyon and Zabriskie Quartzite, among the oldest rocks in the Mescal Range are at the west end of the range, thrust over the gray carbonates in the center of the range. These gray carbonates are in turn thrust over the-black rhyolite complex of the Delfonte Volcanics at the east end of the range (Fleck and Reynolds, this volume).

Figure 8. Mohawk mine workings on Mohawk Ridge. At upper left, on Clark Mountain proper, is the A&M Mercury mine. *R.E. Reynolds photograph*

Figure 9. A faint, curving horizontal line delineates the Yucca Metals granitic slab. *R.E. Reynolds photograph*

50.2 0.3 Corral on right.

57.2 7.0 South side of the freeway at Cima Road.

57.4 0.2 On ramp on north side of freeway.

57.7 0.3 TURN RIGHT (east) on gas line road.

58.0 0.3 The Valley Wells lacustrine sediments contain late Pliocene through Late Pleistocene faunas (Reynolds and others, 1991c; Scott, this volume). The fossils provide a chronological framework that dates faulting from 2.4 Ma through 200 K. Initial faulting resulted in east-side-up movement along the unnamed north-striking fault, but later displacement resulted in west-side-up displacement.

59.0 1.0 Pass water tanks.

61.6 2.6 TURN LEFT on Mohawk Mine road at cleared area with a red-orange warning sign and an 8' tall wooden post with telephone signs.

61.7 0.1 PARK before you reach the yellow gas line post.

STOP 11. Mohawk Mine (Fig. 8) (Jessey, this volume; Wise, this volume). Look north to the Mohawk granite slab and east to the Yucca Metals granite slab (Fig. 9). At 11:00, left of the westerly brown dump of the Mohawk Mine, the contact between granite (below) and limestone (above) is seen as is a thin brown line that runs uphill at 15 degrees. The line continues through the three westerly Mohawk dumps almost at the ridge line. Part of the ridge line is light colored limestone. Below that is the grayish green granite slab. The contact continues above the easterly-most Mohawk dump, then curves down and where it is marked by a relatively flat line of bushes. Above the west dump to the Mohawk you can see Mercury Ridge and the A&M Mercury mine which produced cinnabar and myrickite, a cinnabar cemented with agate. CONTINUE on Mohawk mine road.

62.1 0.4 Road bends westerly. The contact of the granitic Yucca Metals granite plate with Paleozoic limestone is exposed in the prospects at 2:00.

62.2 0.1 Continue past first turnoff to eastern Mohawk workings.

62.4 0.2 At 3:00, due north, we are adjacent to the normal portion of the fault that separates the granite from the limestone on the Mohawk plate. The trace of the fault runs east and flattens in a listric scoop. View south of Teutonia Peak (Fig. 10). This coxcomb on Cima Dome is underlain by the Jurassic Ivanpah Granite. It is more resistant to erosion than adjacent Cretaceous granites, which underlie the smoothly sloping sides of the dome.

63.2 0.8 TURN LEFT on faint road at the top of Pleistocene fan towards power lines. Road to right leads to the Copper World mine (Fig. 11).

63.3 0.1 Cross power line road.

63.5 0.2 Cross historic road to Valley Wells.

64.7 1.2 The road crosses the fan surface and approaches the wash. PARK off the road before you reach the wash. **STOP 12.** Foliated Granite. Walk 200 feet east to a 6-foot deep prospect pit to examine foliated Teutonia granites with top-to-the-east foliation. The Copper Commander mine road granitic plate maps as low angle fault that is steep on the east end where it is in contact with light colored Paleozoic limestone and then shallows to the west. Structural relationships may be similar to those described for the Pachalka pluton (Walker, this volume). Return to vehicles and RETRACE to power line road.

66.1 1.4 TURN RIGHT onto power line road.

69.7 3.6 TURN RIGHT onto Cima Road. Proceed north to the intersection with the LADWP power line.

69.9 0.2 SLOW: road bears left.

70.4 0.5 Continue past right turn towards Valley Wells copper smelter.

70.8 0.4 Continue past right turn to Valley Wells cemetery. Here are buried S.E. "Boots" Yates (1876-1923) and Bessie Yates (1888-1951), Frederic W. Mitchell (1901-1967), and Joseph Riser (1887-1908) along with about 19 additional graves. Yates is a familiar name in Ivanpah Valley. One headstone with a drill hole is a felsite block that had been used as an arrastra base stone and was smoothed by a drag stone.

Figure 10. Cima Dome, view south from Interstate 15. Teutonia Peak is just right of center on skyline. *R.E. Reynolds photograph*

71.4 0.6 SLOW for bend in road to right. We are traveling through a saddle and can see late Miocene gravels and breccia sheets. The source of clasts at this (west) end and center of the ridge is primarily from the Mescal Range; however, the east end of the ridge contains shales and slates and mylonites indicating a Pachalka Springs source area.

74.4 3.0 Reflectors mark a left bend in the paved road. At this bend is the dirt road right to Pachalka Springs. See Burchfiel and Davis (1971 and 1988) for a side trip to this area.

Figure 11. Camp at the Copper World mine, 1900. *Bailey Gill photograph, Riley Bembry collection, San Bernardino County Museum.*

77.0 2.6 TURN RIGHT onto LADWP power line road.

80.2 3.2 Park. **STOP 13. Translated thrust.** The prominent gray and white carbonate hill to the north in the middle of the power line valley contains the Mesozoic Mesquite Pass thrust (Fig. 12). The thrust juxtaposes Cambrian Bonanza King and Carrara Fm. strata over light-colored Devonian (Sultan) and Mississippian (Monte Cristo) carbonates (Friedmann and others, 1994). Bedding in the lower plate units dips eastward; correlative strata in the hills north and south of the power line valley dip west. A second thrust fault, covered by alluvium on the small hill further east, separates gray Bonanza King and Carrara rocks of the carbonate hill from structurally higher reddish Eocambrian clastic units (Johnnie, Stirling, Wood Canyon) in the small hill further east. The two correlative thrust faults (Eocambrian/Cambrian/ Devonian-Mississippian) are present in the hills north and south of the power line valley, but crop out about 2.5 miles farther east of both sides of the valley. The thrust faults have been displaced westward above the Kingston Range/Halloran Hills detachment fault, a west-southwest-plunging, scoop-like corrugation with a structural relief of about 1 mile(Friedmann and others, 1994). This fault is not present in the hills bordering the power line valley. Friedmann and others (1994) interpret this corrugation as comparable to that underlying the Mescal Range allochthon. CONTINUE along road.

80.8 0.6 Cattle guard.

83.1 2.5 Continue past right turn (south) to Colosseum mine. The Colosseum Mine, located immediately adjacent to the Ivanpah silver mines on the east, was discovered in the 1870s. Many times through the years various companies attempted to develop the property, but the low grade of the gold always doomed the attempts. In 1931 the Colosseum Mines Inc. erected a mill and mined the property continuously until 1942. In 1972, Draco Mines New Colosseum acquired the property as a molybdenum target. None was found, but with Amselco Minerals Inc. as a partner, between 1982 and 1985 they developed reserves of 10.5 million tons that averaged .062 ounces of gold per ton. Exploration drilling totaled 147,000 feet and cost $2 million. Bond Gold Colosseum Inc, an Australian company, acquired the property in 1986. Construction of a 3,400 ton per day carbon in pulp mill began in January, 1987. Total construction costs were $35 million. Bond employed 115 employees, with an annual payroll of about $ 4 million. Production began in January 1988. Average annual gold production was 72,000 ounces. The final ore was produced August 1993, and by the summer of 1994 reclamation had been completed (Fig. 13). (Am. Mining Review, 1907, 1919; Mining Record 1988; Eng. and Mining Jour. 1988).

83.7 0.6 View at 2:00, southeast, to the Beatrice mine(Fig. 14). The Beatrice is the westernmost in a series of rich silver mines discovered and first worked in 1870. The mines stretch eastward to the breccia pipe exploited by the Colosseum gold mine. The McFarlane brothers, John, Tom William, and Andrew, worked this and other adjacent mines, hauling ore to primitive smelters. By early 1875 they moved a five-stamp mill from the New York Mountains to Ivanpah Spring, about six miles east of the mines and about one-half mile southeast of the town of Ivanpah. A second mill was erected about one-quarter mile to the north of the first a year later. Mining was sporadic through the 1880s and ceased by 1893. The Beatrice mine was the most productive, yielding

Figure 12. View south of Clark Mountain and Mesquite Pass. *R.E. Reynolds photograph*

about $2.5 million (Hensher, 1984).

83.9 0.2 TURN LEFT (north) from power line road onto road to Winters Pass.

86.2 2.3 TURN RIGHT onto road leading to Mesquite Valley.

86.9 0.7 CAUTION: steep rocky downhill road and sand wash ahead! Road splits and then rejoins..

87.1 0.2 A landslide breccia ridge is to the north.

87.6 0.5 PARK at wide spot along road.

STOP 14. **Basement lithologies.** HIKE southeast to the left of the easternmost brownish hill and then go south, following the prominent drainage that lies east of the hill. The drainage is generally along the contact between Precambrian basement rocks and the west-tipping Tapeats strata deposited on the basement. As you walk up canyon, notice the pre-Tertiary lithologies which comprise a distinctive suite of rocks which appears as detritus near the basin depocenter. They include a cratonal stratigraphy, most importantly the Cambrian Tapeats Sandstone and Proterozoic amphibolites, gneisses, and anorthosites. About one-half mile south along the wash, the basement/Cambrian contact is exposed (Friedmann and others, 1994). Close to the breakaway exposure (and just north of where the cars are parked) is a Tertiary felsite dike with a K-Ar age on biotite of 13.4 Ma (Fleck, unpubl. data; Friedmann and others, 1994).

Figure 13. Colosseum mine at Clark Mountain in the fall of 1988. *Larry Vredenburgh photograph.*

Figure 14. The Beatrice mine, an undated but pre- 1890s image by Wm. Vale. *Macfarlane collection, San Bernardino County Museum.*

Breakaway. A down-dip cross section of an anastamosing shear zone 10-20 m thick is a key outcrop of the Mesquite Pass breakaway. The breakaway cuts and incorporates cratonal Bright Angel Shale with minor Cambrian Tapeats Sandstone, Cambrian Bonanza King F., the 13.4 Ma felsic dike, and Miocene basin sediments. The fault zone consists of finely comminuted rock with larger particles showing cataclastic deformation, faceting and rolling. Kinematic indicators within the shear zone indicate a direction of transport ~S70°W down the trend of Mesquite Pass (Friedmann and others, 1994). The current westward dip of the breakaway zone is ~20° and the lack of rotation in neighboring footwall thrusts and strata suggests that the fault is unrotated. Along the breakaway, a second slide or lateral ramp locally cuts across hanging wall Tertiary strata, juxtaposing sheared Bright Angel peltic rocks and overlying Bonanza King(?)-derived sedimentary breccias. At least two phases of westward displacement of hanging wall units are required to explain these relationships. The detachment occurs just below or along the Mollusk Mine/Keaney Pass thrust. This is the latest and forward-most thrust of the Clark Mountain complex and separates a cratonal sedimentary succession from a transitional to miogeoclinal sedimentary succession. Although at this location the thrust may be reactivated, within a mile to the north and south the detachment cuts Mesozoic structures (Friedmann and others, 1994).

Return to vehicles and RETRACE to intersection of power line road and Cima Road.

89.3 1.7 TURN LEFT at junction.

91.6 2.3 TURN RIGHT on power line road.

97.9 6.3 TURN LEFT (south) on Cima Road toward I-15.

End of Day One

Figure 15. Kingston Peak (left), Charleston Peak (right distant), and the Blacksmith Hills (right mid-ground). *R.E. Reynolds photograph.*

DAY TWO

CONVENE at the north side of the freeway overpass at Cima Road and I-15. Today we will visit the Halloran Hills and Silurian Hills, looking at the geology of Miocene basins, the structure of the detached upper plate, and the erosional structures that form the present-day topography. Our objectives include (1) recognizing the mid-Tertiary erosional surface characterized by hematite-stained, subsurface- weathered granitic boulders overlain by the Tertiary sequence; (2) identifying basin relationships; (3) recognizing regular outcrop patterns on east tilted fault blocks; (4) look at the Late Miocene erosional surface developed by stripping, and contrast it to the mid-Tertiary surface; (5) visit small granitic domes in the Halloran Hills developed by late Miocene erosion; (6) compare avalanche breccias to large glide blocks; and (6) look at offset relationships of northeast-trending and northwest-trending strike-slip faults.

Mining history in the regional started in prehistoric times when turquoise was mined from the Halloran Hills. We will visit areas mined for silver, gold, and talc since before the turn of the century. Because we will be traveling at lower elevations than Day One (a maximum of 4880' at Squaw Mountain, the vegetation includes Joshua tree, yucca, mesquite, and desert willow mixed with creosote scrub.

On the skyline we see Kingston Peak (elevation 7323') (Fig. 15) to the north-northwest, snow-capped Charleston Peak (elevation 11,918') to the north-northeast, Clark Mountain (elevation 7,929') to the northeast, Mohawk Ridge to the east, the Mescal Range to the east-southeast, Striped Mountain and the Ivanpah Mountains to the southeast, Teutonia Peak (elevation 5,755') to the south-southeast on Cima Dome (which covers the southern horizon), the Halloran lava beds and cinder cones to the southwest, and to the west, Solomon's Knob and Squaw Mountain (elevation 4,880').

0.0	0.0	PROCEED SOUTH to onramp

0.2	0.2	ENTER FREEWAY west.

1.6	1.4	Pass rest area

2.8	1.2	Look north at 2:00 at low group of hills: the Valley Wells granitic dome on the west, and a narrow patch of Tertiary lacustrine sediments overlain by late Miocene gravels. This is an east-tilted fault block where erosion has produced the Valley Wells granitic dome which may have the least topographic exposure of any dome in the area.

5.6	2.8	At 2:00 notice a white sedimentary section similar to that at Valley Wells, the basin in which we convened. The difference in elevation suggests 60 m (180 ft) of offset between the two exposures in the last 200,000 to 300,000 years (Reynolds and others, 1991c).

7.1	1.5	EXIT at Halloran Summit Road.

7.5	0.4	TURN RIGHT at end of offramp and PARK in a clearing. **Stop 1.** Basalt flows to the north-northeast are less than 5 million years old (Turrin and others, 1985). The view north-northeast shows Potosi Mountain , Shenandoah Peak, and the Mesquite Range. Clark Mountain is northeast; Mohawk Ridge is east-northeast, and Mountain Pass and the north end of the Mescal Range are due east. The Ivanpah Range is east-southeast, and Cima Dome and Teutonia Peak are to the south. Return to vehicles, PROCEED SOUTH over freeway to the gate.

7.8	0.3	Go through the gate (last person through closes it). At this 3-way intersection, follow the wooden pole lines to the south-southwest.

8.1	0.3	Proceed on good graded road to the west, ignoring the faint turn to southwest.

9.0	0.9	TURN LEFT (south) on dirt road towards low hills.

9.6	0.6	PARK at saddle in low hills. **Stop 2.** **Pyroxene Andesite.** Here, Wilshire (1991) obtained dates of 12.8 Ma on the pyroxene andesite. We can see the pyroxene andesite sitting on the mid-Tertiary erosional surface (recognized by rounded, red-stained boulders) developed on Teutonia Quartz Monzonite. (Fig. 16). Further south-southeast along this contact silts underlie the pyroxene andesite, which dips shallowly to the east at this position south of the Halloran Fault. To

Figure 16. View south from Stop 2 toward basalts overlying granite. *R.E. Reynolds photograph.*

Figure 17. Yucca Grove granitic dome (on horizon) with pyroxene andesite in right foreground and rounded granitic boulders, left. *R.E. Reynolds photograph.*

the southeast and east is a large hill composed of Tertiary granitic gravels and boulders. To our west is the Yucca granitic dome, developed by surface pedimentation which did not later develop rounded, red-stained boulders (Fig. 17). This pattern (planed granite, mid-Tertiary erosional surface and boulders, silts and andesite, then coarse basin fill) will be encountered in several following stops. (see Fig. 19). RETURN to pole line road.

9.8 0.2 En route to pole line road, notice the east-dipping sediments of pyroxene andesite exposed in freeway cuts that run almost to the basalt knob at 1:00. We are south of the Halloran Fault (Jennings, 1961).

10.1 0.3 TURN RIGHT onto pole line road and RETRACE to freeway.

11.2 1.1 Gate: last one through closes it. Proceed over freeway to power line westward. South of the Halloran Fault we are in minimally extended terrain and east-tilted blocks have shallow dips. The Halloran Fault may run eastward toward the Mescal allochthon (Burchfiel and Davis, 1988). A stack of Paleozoic sediments moved minimally westward in this southern area of minimal extension.

11.8 0.6 TURN LEFT (west) at end of pavement onto utility access road.

12.1 0.3 We are driving through rutted gray silt.

12.5 0.4 At the base of this hill the granitic rock is similar in appearance to Rock Springs Monzodiorite.

13.5 1.0 Enter sand wash. Do not slow or stop. We are passing by a prominent basalt plug or vent, the source for 5.12 and 4.24 Ma basalt which flowed downhill to the west into Soda basin.

14.3 0.8 Avoid the huge hole that someone left after digging themselves out of the sand.

14.5 0.2 PARK. **STOP 3. Monzodiorite and Quartz Monzonite.** At this outcrop the light-colored, coarsely porphyritic quartz monzonite supports and cuts dark monzodiorite. The dark clasts are rounded, much as in a conglomerate (Fig. 18). Some of them are apparently metamorphosed and epidotized to a green color. The Telegraph mine, across the freeway to the south, is a gold mine with sporadic production. The Halloran Wash granitic dome is southwest (Dohrenwend and others, 1984). Return to vehicles and PROCEED.

14.6 0.1 We are leaving dark outcrops of monzodiorite. Exposed beneath basalt is light colored quartz monzonite.

15.6 1.0 White quartz monzonite and red quartz monzonite are exposed in the bluff with prospect pits, to the north.

15.8 0.2 West of the prospect pits is a buttress unconformity of shallowly east-dipping arkosic sediments. These sediments indicate a source from the south across the Halloran fault scarp. This buttress unconformity might be the weathered surface of a branch of the Halloran Fault viewed at nearly 90°. This fault extends east-northeast from here to Halloran Summit, and marks the boundary between the mildly extended terrain to the south and the relatively severely extended terrain to the north (Reynolds and Calzia, this volume).

16.7 0.9 Cross the north-south trace of a fault which places metamorphic rocks on the east against the upper portion of a section of

Figure 18. Conglomerate of rounded "biscuits" of dark Jurassic monzodiorite. Basalt plug or vent, in background may be the source for 5.12 and 4.24 Ma basalt which flowed downhill to the west from the Halloran Hills into Soda basin *R.E. Reynolds photograph.*

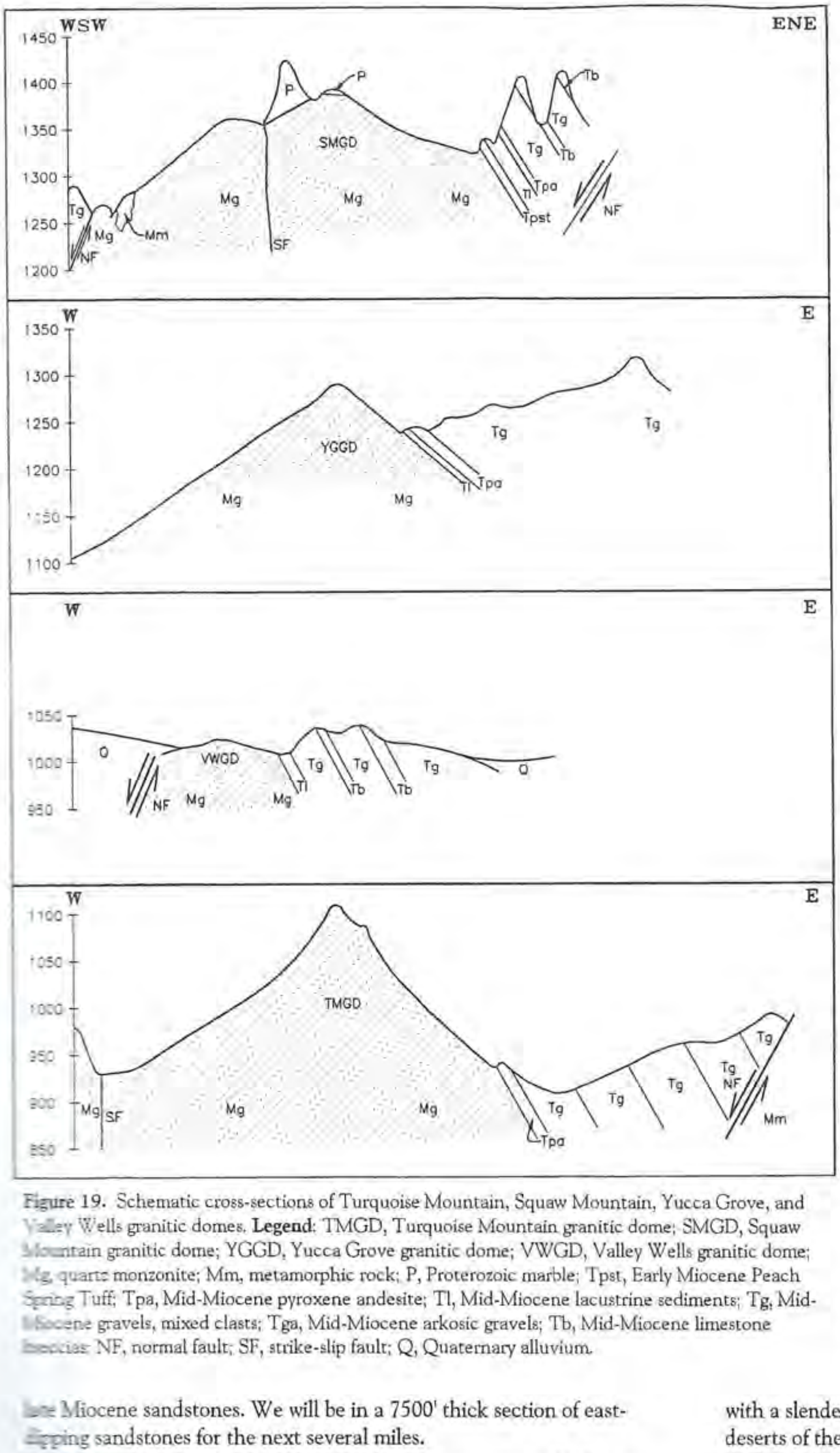

Figure 19. Schematic cross-sections of Turquoise Mountain, Squaw Mountain, Yucca Grove, and Valley Wells granitic domes. **Legend**: TMGD, Turquoise Mountain granitic dome; SMGD, Squaw Mountain granitic dome; YGGD, Yucca Grove granitic dome; VWGD, Valley Wells granitic dome; Mg, quartz monzonite; Mm, metamorphic rock; P, Proterozoic marble; Tpst, Early Miocene Peach Spring Tuff; Tpa, Mid-Miocene pyroxene andesite; Tl, Mid-Miocene lacustrine sediments; Tg, Mid-Miocene gravels, mixed clasts; Tga, Mid-Miocene arkosic gravels; Tb, Mid-Miocene limestone breccias; NF, normal fault; SF, strike-slip fault; Q, Quaternary alluvium.

late Miocene sandstones. We will be in a 7500' thick section of east-dipping sandstones for the next several miles.

17.9 1.2 PARK in graded area prior to the pavement at Halloran Springs Road. **Stop 4.** Halloran Fault. We are parked near the Halloran Springs National Forest, a prospering tamarisk tree. The hill to our northwest, grey and white zebra-stripes of early Proterozoic quartzofeldspathic gneiss (gray) and Middle Proterozoic diabase sills (green) (Friedmann and others, 1994), is a shutter ridge between branches of the Halloran Fault. There is extensive gouge developed in outcrops along the branch on the south side of the hill. This fault apparently trends westward toward Cree Camp. Early activity on the fault was post-12.8 Ma; late activity may have been as recent as 10 Ma. It separated the metamorphic hill from red arkose that we can see due west. This reworked arkose came from the red sediments on the east side of the hill to our northeast. In that hill is a gravity glide block of Rock Springs Monzodiorite (Fig. 20, 21) and reworked pyroxene andesite that was shed from the south side of the fault scarp from areas that are now 6 miles east)Stop 2). Return to vehicles and TURN RIGHT onto the pavement; PROCEED NORTH.

18.1 0.2 Pass Halloran Springs. Look north at arkosic sandstone dipping 45°E.

18.4 0.3 TURN LEFT off of pavement onto graded dirt road; proceed westerly.

18.8 0.4 Pass by an outcrop of west-striking pyroxene andesite (discussed at MP 21.9, below).

19.0 0.2 TURN SHARP LEFT at Bull Springs Was, proceed about 100 feet, and TURN RIGHT onto an ungraded dirt track. This right turn is often marked by old tires.

19.4 0.4 Pass through east-dipping arkose and approach north-striking bed of pyroxene andesite breccia. Minor east-west faults have offset this contact so that it runs north-northeast around the east side of Turquoise Mountain. The Turquoise Mountain granitic dome is to the west(Fig. 22). We see a similar outcrop pattern to that at Stop 3: from west to east, granitic dome, mid-Tertiary surface, fine-grained sediments, andesite, and coarse gravels.

19.6 0.2 TURN LEFT at Y intersection.

19.7 0.1 Proceed south down Mesquite Wash.

19.8 0.1 We can see deeply weathered and hematite stained granitic boulders to the west and a chalky surface with gray silts developed on quartz monzonite to the east, overlain by the pyroxene andesite. This exposure is roughly comparable to that we saw at Stop 2, Day 1.

20.3 0.5 Pass a mine on the right. We are driving parallel to pyroxene andesite outcrops.

20.9 0.6 Bull Spring Wash and patchy asphalt. TURN LEFT (north).

21.0 0.1 Pass east dipping arkosic sediments with reworked pyroxene andesite to the left (west) and the zebra-striped metamorphic hill on the east. A fault separates the hill from silicified arkose on its north side.

21.6 0.6 TURN RIGHT at junction with graded road. Note red sediments in the little bluff. The color may be due to reworked pyroxene andesite. There is a notable amount of mistletoe in the mesquite in this area (Fig. 23), and phainopepla are common. These glossy, black birds with a slender crest and conspicuous white wing patches winter in the deserts of the southwest and nest in the early spring; they then move to cooler and moister areas in the northern Sacramento Valley of California, southern Nevada, southern Utah, southwestern New Mexico, and west Texas to southern Mexico, and raise a second brood. Phainopepla feed on mistletoe berries, and seeds broadcast in bird droppings allow this parasitic plant to spread through mesquite and catsclaw groves (Peterson, 1961).

21.9 0.3 This pyroxene andesite outcrop strikes east-west because it is a drag fold on the left lateral Halloran Fault which separates the minorly extended terrain to the south from the severely extended terrain to the north. The first phase of left-lateral faulting started after deposition of the

12.8 Ma andesite.

22.3 0.4 TURN LEFT (north) on to paved road to the microwave facility. To the east are west-flowing basalts (5.12 and 4.24 Ma, Turrin and others, 1984) that suggest that the Soda Lake Basin had been formed by that time. These flows provide minimum constraints on the end of listric normal faulting and on the late Miocene erosional surfaces that developed. Further south, basalts dated at 7.55 Ma (Turrin and others, 1984) sit on a similar surface and further constrain the age of surface development.

23.2 0.9 Outcrops at 10:00 to the west are cemented, hematite stained arkose.

23.5 0.2 TURN RIGHT, leaving pavement for a graded dirt road in Bull Springs Wash.

25.6 2.1 TURN LEFT towards Bull Spring.

25.7 0.1 TAKE RIGHT FORK at intersection. Left forks goes to Bull Spring. We are driving north-northeast up Squaw Mountain dome.

Figure 20. East-dipping arkosic sediments at Halloran Springs, tilted 45°, were derived from across the Halloran Fault to the south. The top of the hill contains a gravity glide block. *R.E. Reynolds photograph.*

26.7 1.0 We are north of Solomon's Knob, a basalt plug. The basalt from Solomon's Knob flowed northeasterly suggesting that Shadow basin (to the east) had been formed by 4.48 Ma (Turrin and others, 1984). We are on the divide between Soda basin and Shadow basin. Below Solomon's Knob is a deposit of talc in Proterozoic rocks akin to what we see further north in southern Death Valley. To the northeast is a degraded cinder cone which produces the zeolites phillipsite and faujasite. This is the only faujasite locality in North America (Wise, 1991).

27.8 1.1 Continue past intersection.

27.9 0.1 Road parallels a north-south contact between the mid-Tertiary erosional surface and Miocene lacustrine silts, pyroxene andesite, and overlying gravels and breccia deposits.

28.1 0.2 Continue north past intersection from left that also runs diagonally and crosses to the right towards a prospect which was cut into the Peach Springs Tuff. Notice the deeply red-stained, spheriodially weathered granitic boulders to our right. We are paralleling this contact which runs north-northwest to a saddle north of Squaw Mountain and south of other Proterozoic carbonates (Fig. 24).

28.9 0.8 PARK near intersection.

Stop 5. **Mid-Tertiary Erosional Surface at Squaw Mountain.** Examine the mid-Tertiary erosional surface of round, red-stained, subsurface-weathered quartz monzonite boulders. Soils were stripped prior to 18.5 Ma and lag deposits of Wood Canyon and Zabriskie Quartzite were deflated to this surface. The Peach Springs Tuff was laid down at 18.5 Ma (Nielson and others, 1990; local date 19.05 Ma, pers. comm. C. Swisher 1987). In contrast, surficial pedimentation has developed a relatively smooth surface to the southwest on Squaw Mountain dome, below the carbonate rocks of Squaw Mountain. This pedimentation occurred after the 12.8 Ma pyroxene andesite was deposited.

The area was covered with lacustrine silts and limestones with remains of water reeds. The silts contain late Barstovian LMA rodents (Reynolds, 1991) and fish (Reynolds, this volume). High in the silt section is a pyroxene andesite that is chemically similar to the dated andesite (12.8 Ma, Wilshire, pers. comm. 1988) at Halloran Summit. This is overlain by coarse conglomerates with clasts that suggest a Mountain Pass-Mescal Range source, and avalanche debris of Paleozoic carbonate rocks (Beratan, this volume). The relatively thin sheets of dark carbonate

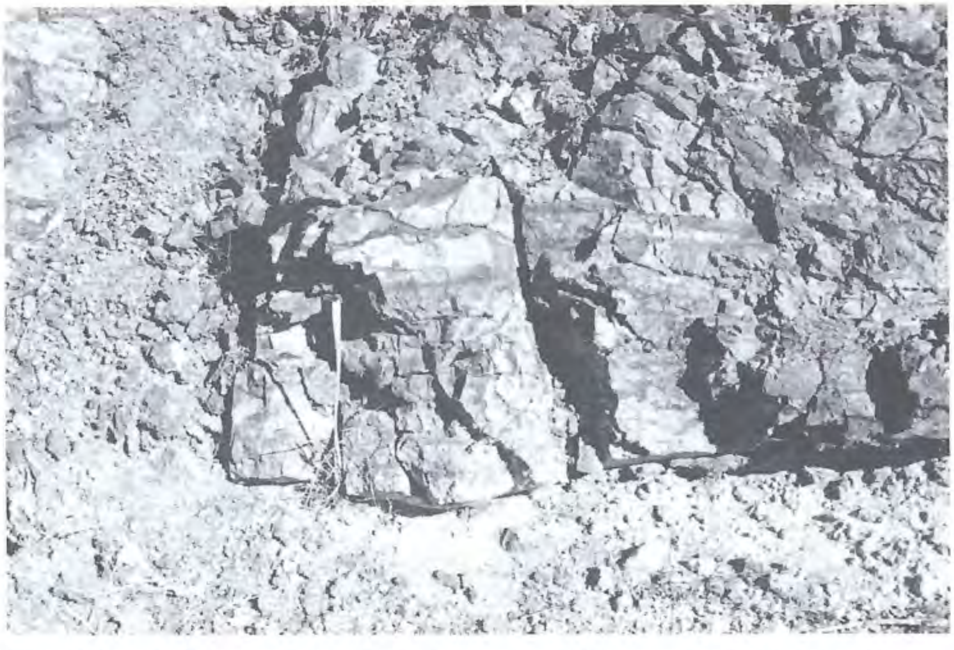

Figure 21. Smooth, flat contact of the underside of the gravity glide block near the top of the hill northeast of Halloran Springs. *R.E. Reynolds photograph.*

avalanche debris contrast with the thick brecciated block of bleached Squaw Mountain carbonate. The north-trending contact has been tilted eastward by listric normal faulting during dismemberment of the upper plate of the Halloran detachment. This north-trending structure actually runs north and bends westward near the fault scarp on the north side of Squaw Mountain. This outcrop pattern suggests post-detachment, left-lateral faulting.

The Squaw Mountain dome is a late Miocene erosional surface that formed after basin filling ended at 10.8 Ma (Friedmann and others, 1994) and after listric normal faulting tilted the granitic upper plate and sedimentary section eastward. Squaw Mountain is a slide or glide block of late Proterozoic to early Paleozoic carbonate rock that possible slid to position on top of the Squaw Mountain granitic dome. After glide block emplacement, Squaw Mountain and upper plate structures were cut by left lateral north- to northeast-striking faults. PROCEED northeasterly to Francis Tank and Francis Spring.

Figure 22. The Turquoise Mountain granitic dome curves on the horizon; pyroxene andesite boulders in foreground. *R.E. Reynolds photograph.*

29.1 0.2 Pass Francis Tank. Continue uphill through the lacustrine silts which produced fossil rodents to the pyroxene andesite.

29.2 0.1 Pyroxene andesite. From here northeast to when we exit the hills, we are in coarse gravels that are either in a white ground mass, perhaps suggesting they were from fresh rock exposures, or in a red ground mass perhaps indicating that they were from sources where the conglomerates had been sitting and weathering for quite some time.

29.8 0.6 Pass Francis Spring.

30.6 0.8 At 4:00 we can see the 4.48 Ma basalt flow (Turrin and others, 1985). It covers a Proterozoic slide block so we know that emplacement of these large blocks was completed by that time.

Figure 23. Mistletoe thrives in the catsclaw groves. *R.E. Reynolds photograph.*

31.5 0.9 We have passed the last small hill of late Miocene gravels composed primarily of Paleozoic limestones. PROCEED STRAIGHT across intersection to right. This historic road runs to corrals and then to the Valley Wells Copper Smelter. In a view to the north at 10:00 we see Kingston Peak (Fig. 25), consisting of 12 Ma (Calzia, 1990) granite. At 11:30, Shadow Mountain (Fig. 26) is a metamorphic slide block that sits on Miocene sediments. The dark stripes of the Shadow Mountains, at 9:30, are Paleozoic avalanche breccias. Charleston Peak is at 11:00; Potosi Peak is straight ahead at 12:00; the Mesquite Range and Winters Pass are at 12:30. Clark Mountain is due east at 2:00, and the Mescal Range and the Ivanpah Range are southeast at 3:00.

33.5 2.0 We are approaching the LADWP power line road. This road is sandy. Look for dust on the power line road that will indicate oncoming traffic. Our junction with power line road is an acute turn at a very sandy spot: it is best to not stop but proceed slowly through and turn to the right. We will go right (east), turn the vehicles around, and then head west.

33.9 0.4 TURN RIGHT onto power line road, TURN AROUND, and

34.0 0.1 HEAD WEST.

36.9 2.9 View north at 2:30 of beige fine-grained sediments in Shadow Valley basin. They are overlain by coarse basin fill and avalanche breccia and then by slide blocks such as Shadow Mountain.

37.7 0.8 Proceed past a road to the right that leads to the Eastern Star Mine (Fig. 27).

38.4 0.7 CAUTION; SLOW. We are in an area where the road has many sharp bends, tight curves, and poor visibility.

38.7 0.3 SLOW for sharp bend.

39.1 0.4 Around curve, pass through a saddle in Paleozoic breccia. These Paleozoic rocks sit on east-dipping Miocene sediments that have produced fossil rodents and fossil fish. Pyroxene andesite 1/4 mile up Willow Wash is located below these lacustrine sediments.

Figure 24. The Squaw Mountain granitic dome is mid-ground; Peach Springs Tuff and mid-Tertiary rounded granitic boulders in foreground. *R.E. Reynolds photograph.*

39.4 0.3 TURN LEFT (south) into Willow Wash and go 1/4 mile upstream to examine clasts of distinctive lithologies from the Mescal Range.

39.7 0.3 PARK before reaching the Kern River pipeline.

STOP 6. Clasts and Sources. Pyroxene andesite crops out to the east. The clasts we see are of Tapeats Sandstone from the north side of Clark Mountain mixed with Mescal Range clasts. Garnet gneiss and gneiss with bleached feldspar is from the east side of the Kokoweef Fault. Syenite, Delfonte Volcanics, and Aztec Sandstone come from the southeastern Mescal Range. Note that the cobbles are in a red ground mass suggesting that the debris were derived from an area where they underwent a long period of subsurface weathering (Fig. 28). Return to vehicles and PROCEED SOUTH.

40.5 0.8 PARK where a breccia ridges cross the wash. **Stop 7.** Crackle Breccia. The ridge was formed by a northeast-trending fault which postdates listric faulting of upper plate and is roughly parallel to the northeast-trending fault that cuts Squaw Mountain to the southeast (Fig. 29, 30). This is an excellent opportunity to examine the "crackle breccia" texture (Beratan, this volume) of a rock avalanche (Fig. 31), here consisting of Paleozoic carbonate rocks and overlain by Proterozoic quartzite. Return to vehicles and RETRACE along Willow Wash to the power line road.

41.7 1.2 TURN LEFT (west), watching for traffic.

42.3 0.6 Hill at 9:00 to the south is of the same lithology as Squaw Mountain, with bleached carbonate that may be the equivalent of the Riggs carbonate.

43.4 1.1 Prepare for dips.

43.6 0.2 Cross Beudantite Wash. Sediments up this wash to the south have produced fossil fish. There is a pipeline metering station on the right. Were we to go a mile north and downstream in this wash we would encounter a northern exposure of the mid-Tertiary erosional surface on granite covered by pyroxene andesite and lacustrine sediments.

43.7 0.1 PARK at turnout. **Stop 8.** North-striking contact. We are at a north-south striking contact between the mid-Tertiary erosional surface and the pyroxene andesite and lacustrine sediments. Here the mid-Tertiary erosional surface trends north and is overlain by pyroxene andesite and lacustrine sediments. From this graded area, PROCEED WESTERLY less than 1/10 mile and before we reach the next hill TURN RIGHT (north) down a wash that leads to a road that goes to Valjean Valley. If you go further than 1/10 mile you have missed the road.

Figure 25. Kingston Peak rises above Shadow Valley basin sediments. *R.E. Reynolds photograph.*

43.8 0.1 TURN RIGHT (north) down sand wash. Four wheel drive recommended.

44.1 0.3 Pass through low weathered granitic outcrops. On the right (east) we see red Tertiary gravels. On our left is a bedded limestone block that sits on the mid-Tertiary erosional surface. This road joins a larger sand wash coming from the southwest. PROCEED

Figure 26. Shadow Mountain, on the center of the horizon, is a huge gravity glide block of metamorphic rock. *R.E. Reynolds photograph.*

Figure 27. Paleozoic carbonate avalanche breccia overlying coarse fanglomerate in Eastern Star Wash. R.E. *Reynolds photograph.*

NORTH (down wash).

45.0 0.9 Pass through Proterozoic carbonates sitting on the mid-Tertiary erosional surface.

45.8 0.8 PARK. **Stop 9.** West-striking contact. Red gravels and gray limestone breccias on both sides of the wash are sitting on the mid-Tertiary erosional surface developed on quartz monzonite. WALK about 1/4 mile around the south base of the red gravel hill to the west and over a saddle. We will see the mid-Tertiary erosional surface on granitic rocks striking to the west and, of special interest, a thick swale filled with quartzite cobbles. Above it is a very thick deposit of pyroxene andesite and a minor amount of lacustrine sediments. This outcrop is the northernmost where andesite sites on quartz monzonite. The outcrop configuration strikes westward and the contact is exposed for five miles into the eastern Silurian Hills (Fig. 32), where the mid-Tertiary erosional surface is overlain by silicified lacustrine sediments and pyroxene andesite. In all the outcrops we have visited to the south, this outcrop configuration (granite, mid-Tertiary erosional surface, pyroxene andesite, and fine-grained sediments) strike to the north. The west-striking configuration here suggests that this wedge of granite was rotated counter-clockwise westerly at about the time Shadow Valley basin started filling at 13.1 Ma (Friedmann and others, in press). Notice the Pleistocene? pediment supported by pedogenic carbonates dipping shallowly north to Valjean Valley. Return to vehicles, RETRACE south.

47.2 1.4 BEAR LEFT (south) up side wash.

47.6 0.4 BEAR LEFT at the small sand wash out of the main wash and connect with road at power line. TURN RIGHT (west) on power line road.

49.9 2.3 We are on the trace of an approximately north-striking fault which separates the granitic and metamorphic rock on the east from late Miocene gravels on the west (Dewitt, 1980). Although andesite and fine-grained sediments are not visible, this is typical of east-tilted upper plate blocks.

50.9 1.0 PARK in cleared area. **STOP 10.** Pyroxene andesite. Leave vehicles and look at pyroxene andesite on mid-Tertiary erosional surface and look north-northwest where you also see rounded boulders of the same surface (Fig. 33). There is no andesite at that outcrop but there are silicified lacustrine sediments and quartzite cobbles. This surface has been folded into a broad U because of west trending faults that cut through this portion of the eastern Silurian Hills. Return to vehicles and PROCEED DUE WEST. Don't turn left on power line access road.

51.5 0.6 Caution: slow for bend south and dip. Look to the south-southeast to Turquoise Mountain. Here, turquoise has been mined for about 1300 years (Leonard and Drover, 1980; Vredenburgh, this volume). The feldspar in local quartz monzonite was probably altered by fluids to alunite or kaolinite. The phosphate radical may have been derived from basalts. Minor amounts of copper in Miocene carbonate-rich gravels would produce turquoise, $CuAl_6(PO_4)_4(OH)_8{\cdot}4H_2O$. The gemstone was distributed to Snaketown in central Arizona in 700 A.D., and worldwide by Tiffany's of New York from 1897-1903 when the Himalaya Mining Company was active.

Figure 28. Miocene gravels in red matrix overlain by Plio/Pleistocene(?) calichified sediments. *R.E. Reynolds photograph.*

Figure 29. View from Willow Wash of north-northeast striking left lateral fault cutting the northwest face of Squaw Mountain. *R.E. Reynolds photograph*

51.9 0.4 Continue past right turn into Riggs Wash.

52.7 0.8 Look right (north) at 3:00 to the Silver Lake talc mines (Wright, 1954; Vredenburgh, this volume).

53.2 0.5 TURN LEFT (south) on Cree Camp road south of power line metering station.

53.3 0.1 Sharp left bend. We are traveling southeast along the possible trace of the southeast-northwest trending Cree Fault. The ridge to our west consists of quartz monzonite and zones of migmatitic gneiss.

54.2 0.9 BEAR RIGHT at fork in the roads and continue south up the wash. Do not go left up a low terrace.

55.2 1.0 On our right we are passing the mid-Tertiary erosional surface with round boulders.

55.4 0.2 In the ridge to our right (west) is a dark andesite porphyry dated at 9.89 Ma (Calzia, writ. comm. 1987). Although this is an east-dipping surface, the age and appearance of the andesite indicate it is different than the 12.8 Ma andesite seen at Stop 3.

55.7 0.3 PARK at junction with east-west road and WALK 1/10 mile south-southwest to andesite outcrop. **Stop 11.** Cree Fault. The outcrop configuration in this area suggests a drag fold with right lateral sense of movement on the northwest-striking Cree Fault (Fig. 34). The fault cuts and is younger than the 9.89 Ma andesite (Calzia, pers. comm. 1987). It has the correct attributes to be a part of Eastern California Shear Zone activity (Richard, 1992). RETRACE to LADWP road.

Figure 30. In Willow Wash, a north-east striking fault deforms east-dipping sediments and avalanche breccias (right). *R.E. Reynolds photograph*

Figure 31. Crackle breccia, typical in avalanche deposits. Here, the breccia is Paleozoic limestone and includes large angular pieces. Lens cap for scale. *R.E. Reynolds photograph.*

58.4 2.7 TURN LEFT (west) onto LADWP power line road and proceed toward Highway 127.

60.1 1.7 Look to the northwest at 2:00. We are traveling across a Pleistocene? pediment supported by pedogenic carbonates which runs downhill into the Salt Springs area. This is similar in age and surface development to the pediment (Stop 10) that runs into Valjean Valley.

64.7 4.6 Stay on the east-west road towards the Edison tower complex; avoid roads to the left that go to the historic townsite of Silver Lake.

65.7 1.0 Stop at the pavement of Highway 126, look for traffic and TURN RIGHT (north) towards Shoshone. Silver Lake, to the southwest, was filled in the Late Pleistocene (Reynolds, Wells, and Brady, 1990). B. Troxel is working on offset relationships of the Soda-Avawatz fault in this area.

68.1 2.4 The Avawatz Mountains are to the northwest at 11:00 at the junction of the left-lateral, west-trending Garlock Fault and the right lateral Mule Canyon branch of the Southern Death Valley fault zone and the Soda-Avawatz fault zone. Because of this relationship of left lateral and right lateral faults, the Avawatz Mountains are gaining elevation. The Mesozoic and Miocene rocks in the Avawatz are overriding Pleistocene alluvium in fans at their eastern base (Brady, 1990).

72.8 4.7 Two white reflectors mark an upcoming right turn toward Riggs. If you reach the green sign to Shoshone, you have gone too far.

Figure 32. View west over the west-striking mid-Tertiary erosional surface with subaerially weathered granitic boulders, looking toward the Silurian Hills. *R.E. Reynolds photograph*

72.9 0.1 TURN RIGHT and proceed easterly towards the site of Riggs. The Dumont Dunes are visible to the north at 9:00. The Sperry Hills are at 10:00. Kingston Peak and, below it, the westernmost ridge of the Silurian Hills, are at 11:00. Kupfer (1954) mapped this area, naming these ridges and valleys, from west to east: The Islands, Railroad Valley, Riggs Ridge, Road Valley, Meeker Valley, Trough Canyon, and Citadel Ridge. He suggested that the name "Silurian Hills was probably given by a Cornish miner, after the hills of his homeland."

73.1 0.2 CAUTION watch for dip.

73.2 0.1 STAY LEFT at fork in road. Right fork goes to Silver Lake talc mines which we can see to the east-southeast below the microwave tower.

74.0 0.8 CAUTION, watch for dip.

75.9 1.9 CAUTION, watch for dip.

76.0 0.1 Continue right; do not take left turn along Tonopah and Tidewater railway, which ran through Railroad Canyon. The T&T was constructed in 1906-7 by Borax Smith from the AT&SF mail line in Ludlow to connect with the Lila C. borax mine in Death Valley. Never profitable, the railroad nonetheless was a vital link through the area, connecting widely scattered populations and providing economic shipping of ore and supplies. The line from Ludlow to Crucero ceased operations in 1933, and damage from severe floods in 1938 led to the abandonment of the entire line by 1940. Tracks were removed from Beatty south to Ludlow in 1942-43 (Myrick, 1963). Continue on right fork to the southeast. The historic debris and cement structures are all that remains of the former site of Riggs (see Duffield-Stoll, this volume). Proceed east-southeast along the south face of the Silurian Hills.

77.7 1.7 Continue easterly past left turn. The Riggs mine, to the north, may have been active as early as 1890. Between 1913 and 1920 it produced $200,000 in silver (Tucker, 1921). North of the Riggs mine are the Anderson, Annex, and Berry Hill talc mines (see Duffield-Stoll, this volume; Vredenburgh, this volume).

78.3 0.6 Pass the left turn to the cabin and head frame of the Lone Wolf mine.

78.6 0.3 Proceed slowly as road dips steeply into wash.

78.8 0.2 To our left at 9:00 (north) the foot of the Silurian Hills consists of weathered granitic rock. It appears to have concordant summits of the low hills and it might be a dissected mid-Tertiary erosional surface. Note the very tortured appearance of the Proterozoic lithologies in the Silurian Hills adjacent to us. The attitudes of the beds are at all angles.

79.6 0.8 Proceed east past right turn that goes south to Silver Lake talc mines.

80.3 0.7 Proceed into Trough Canyon. On the left (north) note the section of Tertiary gravels. Ahead at 1:00 is a low hill with a chocolate colored top. This hill has a contact toward us with granitic rock. The dark color is overlying brown-stained arkosic conglomerates. This may be a contact of arkosic sediments on the mid-Tertiary erosional surface.

80.6 0.3 BEAR LEFT (north) past the chocolate-capped hill; Citadel

Figure 33. View northwest across Riggs Wash area. Large round quartz monzonite boulders and pyroxene andesite are foreground; boulders and silicified lacustrine sediments are upper left in distance. *R.E. Reynolds photograph.*

Figure 34. The mid-Tertiary erosional surface marked by rounded granitic boulders (center) and 9.9 Ma volcanic rocks (foreground) cut by the northwest-trending Cree Fault. *R.E. Reynolds photograph.*

Ridge and Silurian Peak are on our right Pass the chocolate-capped hill. The road proceeds north into the canyon. The white streaks on the hill ahead to the northeast are the Blue White, Ceramic, and Patricia talc mines (Wright and others, 1953).

80.8 0.2 Road forks. STAY LEFT and avoid road to talc mine. View east of the white talc and dark diabase characteristic of the talc deposits of the Pahrump group from the Halloran Hills to southern Death Valley.

80.9 0.1 Note north-dipping Miocene sediments.

81.1 0.2 The wash to our right exposes Miocene thin-bedded sandstones and silty sandstones that dip shallowly to the south or are flat-lying.

81.2 0.1 PARK in wide bulldozed area. **STOP 12. Citadel Canyon Sediments.** At this point the valley opens to the north and the washes branch to northwest and northeast. The road bends northeasterly towards the Silver Hills mine (malachite, cuprite, barite, and quartz). HIKE northwesterly to see 3 outcrops. The first is a purplish volcanic porphyry in a stratigraphic position which indicates it may have a similar age to volcanic rocks dated between 13.2 (J. Calzia, pers. comm. 1987) and 12.8 Ma (Wilshire, 1991) that we have seen at previous stops on Day 2 of this trip. We then hike northerly to a drainage that exposes thin-bedded, north-dipping Miocene sandstone with flamingo tracks. Hike another 1/4 mile easterly to a gully where these Miocene sediments have been bulldozed by overlying Proterozoic rocks of the Pahrump Group (Fig. 35). At this stop we do not see the mid-Tertiary erosional surface on granite, we do see volcanic porphyries and fine-grained lacustrine sediments. Hike back to vehicles and RETRACE.

Summary

Our trip over the last two days has shown us Jurassic and mid-Cretaceous thrust faults and late Cretaceous detachment faults.

A mid-Tertiary erosional surface was developed on all the pre-Tertiary structures. The large, hematite-stained granitic boulders suggest that thick soils covered the area, and that the boulders weathered chemically under the surface of the soil.

Crustal extension caused Miocene detachment faulting that began at approximately 13 Ma and continued until 10.8 Ma. Shadow Valley basin filled with coarse debris from distinct sources in the core ranges. The granitic upper plate and basin fill above the Kingston Range/Halloran Hills detachment fault were tilted eastward by listric normal faults. The scarps exposing quartz monzonite eroded to form granitic domes. Large blocks of Proterozoic rocks moved onto the upper plate. A sequence of northeast through northwest trending, strike-slip faults cut the area between 10 and 7.8 Ma. Dated basalts between 7.6 and 4.5 Ma provide temporal constraints on all previous tectonic activity.

Miocene detachment faulting and chaotic basin fill developed the terrain and habitat we see today. The Halloran Hills are dominated by creosote scrub brush, yucca, willow, catsclaw and mesquite. Clark Mountain and the Mescal Range are covered with pinyon and juniper, and Clark Mountain supports a grove of fir. These higher ranges are well watered and support bighorn sheep and deer.

Mineralization in this portion of the eastern Mojave Desert has supported 1300 years of mining, from Native American turquoise mining to the exploitation of copper, silver, and gold from the 1860s to today.

85.3 4.2 Complex intersection at Riggs. BEAR LEFT (southwesterly) and head towards Highway 127. Remember there are deep dips in the road ahead.

88.3 3.0 Highway 127. TURN LEFT (south) towards Baker.

95.6 7.3 Cross under LADWP power line.

96.8 1.2 Salt Cedar trees and melting adobe marks the site of the

Figure 35. Miocene sediments in Citadel Canyon (Stop 12) show "bulldozed" debris from glide blocks of Proterozoic carbonate rocks. *R.E. Reynolds photograph.*

second townsite of Silver Lake (Fig. 36). The first townsite on the lake bed was moved following the flood of 1916 which inundated 7 miles of Tonopah and Tidewater tracks. The tracks were moved to the eastern shore of the lake, and following the collapse of the depot and warehouse, the small town was reestablished alongside the new rail line (Myrick, 1963).

104.7 7.9 Baker.

End of Trip

Figure 36. Silver Lake in the early 1900s. *Larry Vredenburgh collection.*

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The Geology of Southeastern California, Viewed with Detachment

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Structural Setting

The field trip will visit the Halloran Hills and Shadow Valley, a part of the major Cordilleran extensional belt largely of Cenozoic age (from 65 to about 5 million years ago: Ma), which is part of the southern Basin and Range physiographic province (figure 1). A parallel extensional belt, the Rio Grande Rift, lies farther east (figure 1). Both extensional belts also expose older rocks and complex geological relations that formed over thousands of millions of years, and record folding, thrust-faulting, plutonism, and at least one earlier episode of extensional faulting in late Cretaceous time (Miller and others, this volume). From southern Canada the Cordilleran extensional belt traverses the northern Cordillera, Idaho batholith, Snake River Plain, and trends generally southward across the northern and southern Basin and Range provinces of the western United States (figure 1). South of Las Vegas, NV, the belt crosses the Mojave desert and trends generally southeast across southeastern California and southern Arizona to its southern terminus in Sonora, Mexico (Coney, 1980).

Tertiary Detachment Faults and Core Complexes

During tectonic extension, the earth's crust was literally ripped apart on normal faults, called "detachment faults," of regional scale (some detachment fault systems are more than 100 km^2 in extent) and have generally low, unidirectional dips, although the surfaces commonly undulate. Detachment faults are exposed locally at the surface in "core complexes" (Coney, 1980), which comprise a central dome of deep-seated rock (lower plate), flanked by one or more detachment faults; variably-tilted upper crustal rocks (upper plate) overlie the detachment faults. Lower plates contain rocks with chlorite alteration that resided in the lower or middle crust prior to extension, which commonly are capped by mylonitic zones. The lower plates of earliest-studied core complexes contain high-grade metamorphic rocks and thus originally were called "metamorphic core complexes." The upper plates comprise rocks that contain hematitic alteration minerals, indicative of residence in upper crustal levels prior to extension. Upper plate rock types can include Mesozoic or older crystalline rocks, overlain nonconformably by syntextentional rocks of Tertiary age (Carr, 1991).

Episodes of Tertiary detachment faulting fragmented the upper plates into blocks bounded by high-angle normal faults. Adjacent sets of upper plate blocks generally have unidirectional tilts, but the degree of tilting produced by a single extensional episode may vary significantly across an extensional belt (from more than 60° to essentially zero: c.f. Nielson and Beratan, 1995). Tilting of upper-plate blocks created gaps that formed depositional basins, which accumulated as much as 4 km of syntextensional sedimentary and volcanic deposits. The basins and their fillings evolved as detachment fault movements continued (Nielson and Beratan, 1995; Beratan and Nielson, 1996).

Detachment Terranes of of Southeastern California

Examples of Miocene core complexes in southeastern California include the central Mojave desert (for example, Dokka and others, 1991; Fletcher and others, 1995) and the lower Colorado River south of Needles, California (Colorado River extensional corridor, CRec, of Howard and John (1987). A more recently extended area includes Las Vegas and Death Valley; the Death Valley area may still be extending. The central Mojave and CRec core complexes were produced by an episode of rapid detachment faulting in highly strained crust (Nielson and Beratan, 1995) followed by uplift of the lower plate. The lower plate cores in these terranes locally display a zone of mylonite beneath

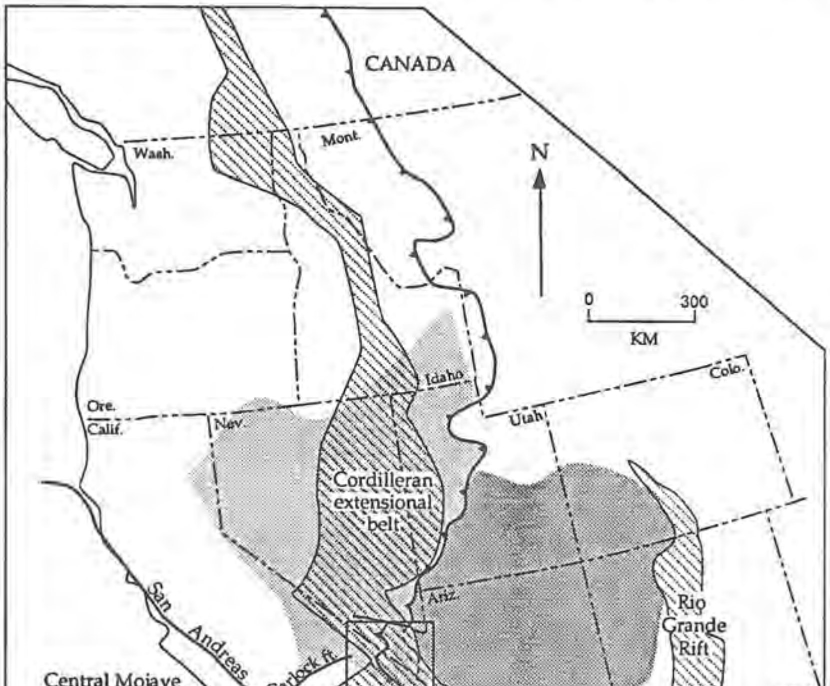

Figure 1. Map showing North American extensional belts related to other continental-scale Cenozoic and Mesozoic structures. Box includes area of field trip. Sources: Coney (1980); Armstrong and Ward (1991).

the detachment fault but in neither area are the cores composed of high-grade metamorphic rocks (for example, Davis and others, 1980; Howard and John, 1987; Dokka and others, 1991; Fletcher and others, 1995). We therefore follow Nielson and Beratan (1995) and Beratan and Nielson (1996) in abandoning the term "metamorphic" core complex.

The extensional terranes of the Mojave desert and CRec underwent detachment faulting in early Miocene time. The detachment faults dip generally to the east (Davis and others, 1980; Spences, 1985; Howard and John, 1987; Cox and others, 1987), and upper-plate faul blocks were tilted generally toward the west on steep, northeast-dipping normal faults. In contrast, middle Miocene and younger extension to the north in the Las Vegas and Death Valley areas is related to a system of west-dipping detachment faults (Wernicke, 1985; Weber and Smith, 1987; Wernicke and others, 1988; summarized in Duebendorfer and others, 1993). Upper plate normal faults that tilted upper-plate strata to the east are also west-dipping (figure 2). The direction of upper-plate transport is to the east or northeast in both the Las Vegas-Death Valley area and the terranes to the south. The Black Mountains accommodation zone (figure 2) lies between these two major systems of detachment faults (Faulds and others, 1990; Faults, 1993).

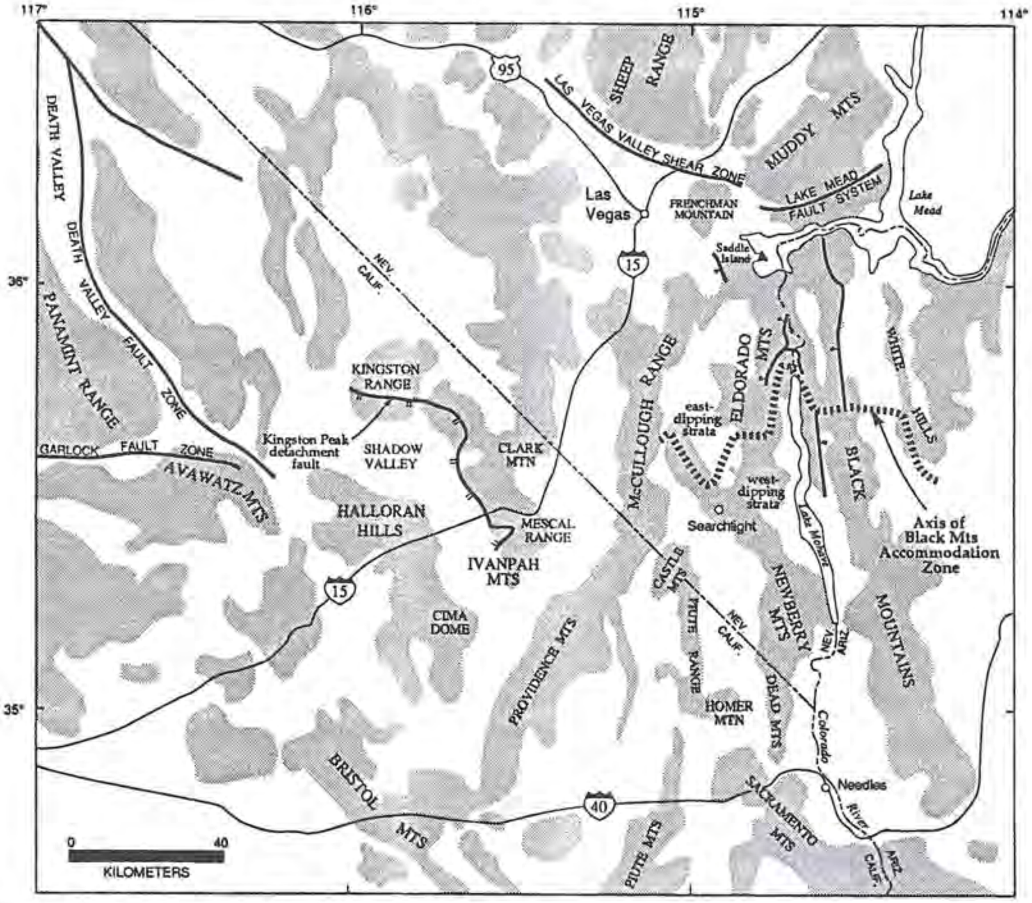

Figure 2. Map showing the field trip area and relation to some structures of the Black Mountains accommodation zone. Sources: Duebendorfer and others (1993); Faulds (1993).

Black Mountains Accommodation Zone

The 40-km-long, east-striking Black Mountains accommodation zone separates a northern set of east-tilted fault blocks in the Las Vegas-Death Valley area from a southern set of dominantly west-tilted blocks (Faulds and others, 1990; Faulds, 1993), which include the central Mojave area and CRec. The 10-km-wide accomodation zone exposes upper plate blocks and a complex of normal faults. There is no evidence for strike-slip displacement of upper-plate blocks within or between the east-tilted and west-tilted domains (Faulds, 1993). In areas close to the accommodation zone, tilting in both domains occurred primarily between about 16 and 11 Ma (Faulds and others, 1995).

East-dipping Domain

Colorado River extensional corridor (CRec)

Core complexes of the southern detachment fault system are best exposed in the Chemehuevi Mountains of California near Needles, California, and in the Buckskin and Rawhide Mountains near Parker, Arizona (Carr and others, 1980; Davis and others, 1980; Spencer, 1985; John, 1987; Carr, 1991). Basin formation in the southern part of the CRec began before 26 million years ago (Lucchitta and Suneson, 1993) but major regional detachment faulting occurred between about 21 and 20 Ma, ending at about 8 Ma (Lucchitta and Suneson, 1993; Nielson and Beratan, 1995). Other detachment faults of the southern system crop out in California north of the CRec, in the Dead and Sacramento Mountains (McClelland, 1982; Fedo, 1993) and at Homer Mountain (Spencer, 1985). Earliest extension on those faults is less well-defined, but may be coeval with the Whipple-Chemehuevi faults. Detachment faulting in this area appears to have ended at about 14.6 Ma (Spencer, 1985).

Central Mojave Desert

In the central Mojave Desert, areally-restricted exposures of detachment faults and underlying lower plate rocks crop out in a narrow belt that trends northwest from Barstow, California (Fletcher and others, 1995). Miocene upper plate rocks in the area are moderately-tilted. Dokka and others (1991) suggested that extension in the Cady and Newberry Mountains (Daggett terrane) occurred about 24 Ma, substantially earlier than extension at about 18 Ma in areas related to exposures of lower-plate cores in the Waterman Hills, Kramer Hills and Mitchell Range areas close to Barstow (Waterman terrane). An age of 23 Ma produced from a lower plate dike in the Waterman terrane (Walker and others, 1990) may correspond to the time of ductile deformation in the lower plate, a suggestion that major extension occurred bewteen 23 and 20 Ma all across the central Mojave Desert area. The Daggett terrane contains both southwest- and northwest-dipping strata in upper-plate blocks that comprise the Newberry and Rodman Mountains (southwest-dipping; Cox and others, 1987), and Cady Mountains (northwest-dipping;Dibblee and Bassett, 1966).

West-dipping Detachment Fault System (Las Vegas-Death Valley area)

The northern, west-dipping detachment fault system may comprise several low-angle normal faults that slipped at different times (Duebendorfer and others, 1993). Associated core complexes are not as well defined for this fault system as in the CRec but detachment-fault segments are exposed in the South Virgin Mountains (Wernicke and Axen, 1988; Fryxell and others, 1992), at Saddle Island in the western part of Lake Mead (Smith, 1982; Choukroune and Smith, 1985; Duebendorfer and others, 1990), and in the area of Death Valley (Burchfiel and others, 1987; Wernicke and others, 1988). The time of detachment faulting is loosely constrained for this system: between about 16 and 9 Ma in the area of Lake Mead, and after late Miocene time in the Death Valley area (Duebendorfer and others, 1993). Strike-slip faulting between 17 and 10 Ma in the Lake Mead and Death Valley regions appears to be coupled to the west-dipping detachment system (for example, Wernicke and others, 1984; Burchfiel and others, 1987; Weber and Smith, 1987; Duebendorfer and Wallin, 1991).

Rocks of the Detachment Terrane

Near the latitude of the Black Mountains accommodation zone, Miocene sedimentary and volcanic rocks were deposited during detachment faulting onto a basement of older (Mesozoic and Proterozoic), mostly metamorphic and igneous upper plate rocks (Wooden and Miller, 1990).

Tertiary Deposits

Detachment-related Tertiary volcanic rocks erupted widely across the extensional terranes of southeastern California, both at localized volcanic edifices and in basinal settings. Isolated basins that ranged in size from tens to thousands of km2 accumulated thick sequences of sedimentary and volcanic rocks. Individual basins differ in the sequence of rock units, time of deposition, and deformational history, but significant similarities include (1) presence of a basal conglomerate or arkosic sandstone; (2) coarse sedimentary (landslide?) breccia deposits, and (3) pronounced variations in rock facies along strike and (or) abrupt changes in stratigraphic thickness, especially near faults.

Lower and middle Miocene volcanic rocks related to the detachment terranes of southeastern California are generally calc-alkalic or alkali-calcic, with basaltic andesite, andesite, and dacite compositions predominating. Basalt and rhyolite units were erupted locally before and during extension (for example, the Peach Springs Tuff of Young and Brennan, 1974; Buesch, 1993), but voluminous basalt erupted after the main period of extension (post-9 Ma), along with subordinate amounts of rhyolite. This pattern of extension-related intermediate volcanism followed by postextension basaltic volcanism is recognized throughout the Basin and Range province (Anderson, 1973; Glazner, 1990; Armstrong and Ward, 1991).

Plutonic Rocks

Early to middle Miocene diorite to quartz monzonite plutons, which are in part cogenetic with the volcanic rocks, are well exposed in the northern Colorado River trough. Many of these plutons are tilted as much as 90° (Hopson and others, 1994; Faulds and others, 1995). Tilted upper-plate plutons include Spirit Mountain (Hopson and others, 1994), Nelson (Anderson and others, 1972), Mount Perkins (Faulds and others, 1990, 1995), Searchlight (P.E. Proctor, unpublished mapping, 1950 to present), Boulder City (Anderson, 1969), and Wilson Ridge (Anderson and others, 1972; Larsen and Smith, 1990; Smith and others, 1990).

Detachment-Fault Basins of the Halloran Hills and Shadow Valley area

Basins that collected substantial amounts of sedimentary strata crop out throughout the extensional belts. The Shadow Valley basin preserves a remarkably complete section of fine-grained clastic sedimentary rocks, interbedded with volcanic units (Reynolds, this volume; Friedmann, this volume). The Peach Springs Tuff, dated at 18.5 Ma (Nielson and others, 1990) is preserved locally in the lowest units of the Miocene basinal sequence. The upper part of the basinal sequence is middle Miocene in age, as indicated by conventional K/Ar dates on steeply dipping lava flows that produced ages of 13.3 (biotite: J.P. Calzia, written commun., 1987), 12.8 Ma (Wilshire, 1991), and 12.1 (whole rock:Wilshire, 1992) and uppermost units are as young as 11 Ma (Reynolds, 1993, this volume; Friedmann and others, in press). Internal unconformities indicate that basin-forming processes and infilling were contemporaneous, as inferred by Nielson and Beratan (1990, 1995) and Duebendorfer and Wallin (1991) for Miocene basins of both the west- and east-dipping detachment fault domains.

Tilted basin-fill strata range from freshwater limestone and fine-grained clastic rocks to extremely coarse fanglomerate and avalanche deposits. The coarse sediments were derived from older rocks like those now exposed east of the basinal deposits, but also include clasts from more distant sources. For example, deposits of Miocene gravel may contain clasts of Paleozoic limestone, Triassic and Jurassic sedimentary rocks, Cretaceous volcanic rocks, and Proterozic syenite. These clasts appear to come from sources in and near the southern Clark Mountains and Mescal Range, about 30 km to the east (Reynolds and Nance, 1988). Interspersed landslide breccia units are composed of Proterozoic, Paleozoic, and Mesozoic rocks derived from locations east of the Halloran Hills (Reynolds and Nance, 1988; Wilshire, 1991; Reynolds, 1992).

Alkali basalt flows, locally bearing mangle and crustal xenoliths, overlie the tilted and beveled basin deposits on an angular unconformity. The alkaline basalt volcanism began at about 7.5 Ma (Turrin and others, 1985). The stratigraphically lowest upper Miocene basalt flows are partly buried by flows and cinder cones dated at 5.1 - 3.7 Ma (Turrin and others, 1985).

The 12 Ma Kingston Peak pluton (Calzia, 1990, 1991) intrudes both lower and upper plate rocks, and indicates the time of the last faulting events on the Kingston Peak detachment fault (Davis and others, 1993).

Sketch of Tectonic History

The accumulation of Tertiary sedimentary and volcanic rocks record local subsidence and the formation of basins at the onset of regional extensional tectonism. Basinal strata of lower Miocene age in the CRec and Eldorado-Black Mountains are very highly tilted, and the tilts of middle Miocene sedimentary and volcanic sequences change from steep to shallow upsection, indicating deposition in basins as they subside along steep upper-plate normal faults (Lucchitta and Suneson, 1993b). The time-stratigraphic evidence in the CRec shows two major episodes of extension between about 20 and 18 Ma, whereas in the McCullough Range and Eldorado and Black Mountains, the main extension occurred between 16 and 14 Ma (Faulds and others, 1995). Upper Miocene rocks generally are much less deformed than the older basin deposits, apparently reflecting the waning stages of detachment faulting and documenting a marked decrease of extension after middle Miocene time in areas to the south of Death Valley.

The coarse-grained character of middle and upper Miocene basin fill deposits in the Halloran Hills , and the presence of landslide megabreccia, indicate the presence of steep slopes and active tectonism at the basin margins during extension and tilting of the strata. Dates on tilted and untilted volcanic rocks in the Halloran Hills sequence suggest that the major episode to detachment faulting in this area occurred at about 13.2 Ma (J.P. Calzia, written commun., 1987), but may have been younger (10.8 Ma) in the Shadow Valley area (Friedmann and others, in press) after emplacement of the Kingston Peak pluton at about 12 Ma. Exposure of the Kingston Peak pluton at 9 Ma (Topping, 1993) indicates continued uplift and denudation in the area. Widespread erosion and beveling of tilted granitic basement and Miocene sedimentary rocks was followed by upper Miocene volcanic activity at 7.5 Ma.

A pattern of late, possibly diachronous, onset of extension in less-extended areas that flank a more highly-extended zone of core complexes has been documented in upper plate rocks of the CRec (Nielson and Beratan, 1995). There, early Miocene basin formation was followed shortly by episodic movement on the Whipple Mountain and correlative detachment faults, which caused extreme tilting of upper-plate fault blocks (Howard and John, 1987; Lucchitta and Suneson, 1993a). Consequent uprise of the lower plate culminated in surface exposure of the detachment faults 4 to 6 million years later (Nielson and Beratan, 1995).

The Miocene basin deposits of the Halloran Hills and Shadow Valley may record a similar sequence of events: early Miocene extension and basin formation, middle Miocene episodes of detachment faulting and localized tilting of upper plate fault blocks, followed by slower uplift of lower plate that culminated in surface exposure of the Kingston Peak pluton and adjacent lower plate. Alternatively, the ages may document a northward younging of late Miocene detachment faulting events toward Death Valley, which is still undergoing extension.

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Roasting Pits and Agave in the Mojave Desert: Archaeological, Ethnobotanical, and Ethnographic Data

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Circular or ring-shaped elevated surface features composed of rock and soil accumulations are commonly found in the Mojave Desert. These features often are generically called "roasting pits," although there is only minimal information about their actual functions. In this paper, we review what is known about these features from archaeological, ethnobotanical, and ethnographic viewpoints.

Description of the Features

The term *ring middens* has been used to describe these features (see Kroesen and Schneider 1991) because this term is descriptive of the morphology of the features and does not imply function. In general, ring middens are composed of elevated rings of stone and soil, between five and twenty meters in diameter, surrounding a ground-level central area. The rings of rock rubble may be either slightly elevated (a few centimeters) or more elevated (up to a meter or more) above the ground surface and, in the Mojave Desert, are usually composed of limestone fragments, dark ashy soil, and sometimes charcoal fragments. They usually appear at higher elevations, on surfaces with minimal slope near limestone outcrops. Although they are common features in the Eastern Mojave Desert of California and southern Nevada, identical or similar features appear in Arizona, New Mexico, southern Utah, southern Colorado, western Texas, and northern Mexico (Castetter et al. 1938:37, Fig. 4; Greer 1965:45, Fig. 5).

Ring midden features have sometimes been called roasting pits. While some may extend below the surface, central depressions having been excavated into soil, others appear to be purely surface phenomena, with the "pit" a depression within the accumulated mound of rock and soil. Most investigators agree that cooking of food resources occurred within enclosed areas in the features (similar to an oven) whether or not the "pit" was above the ground surface or below it (Kroesen and Schneider 1991:45-46).

Ring middens have often been associated with the preparation of mescal (*Agave* spp.) and sotol (*Dasylirion* spp.) both because of their geographical proximity to stands of mescal and sotol and through archaeological remains recovered within the features. Some investigators suggest that they are used as more generalized camp cooking activities (e.g., Mera 1938; Blair 1986). Archaeological data have associated the ring middens with mescal and sotol by the finding of quids (chewed fiber remains) of the plants and other plant parts in rockshelters near pits, and occasionally the discovery of plant remains within the ring midden features themselves (Pearce 1933; Word 1971). Most often, the association of the features is geographical only; the ring middens are found at elevations similar to the elevations at which mescal and sotol grow and often are nearby (e.g., Katz 1978).

Very little direct archaeological evidence of the use of ring midden features for cooking mescal and sotol (i.e., the recovery of plant parts in the features) is available from the Mojave Desert, although a number of investigations have taken place. One study found a single Lower Colorado Buffware ceramic sherd, a burned *Olivella* sp. shell bead, and no plant remains (Venner and Benton 1980). "Paiute" and "Anasazi" ceramics, but no plant remains, were recovered in another study (Ellis et al. 1982). More recent work in the Clark Mountains identified animal remains (desert tortoise, artiodactyl, leporid, and other small mammals) as well as Virgin Anasazi ceramic sherds and *Olivella dama* beads in one of the features (Rafferty and Blair 1988). In her study of roasting pits in the California Wash region of southern Nevada, Blair (1986) noted that isolated features at higher elevations were probably specific to a single task while those at lower-elevation habitation sites apparently were associated with a wider range of activities.

An Archaeological Study of Ring-midden Features in the Clark Mountain Range

Kroesen studied 11 sites that included 18 intact and 7 partially eroded ring middens in portions of the Clark Mountains, Mescal Range, and Mesquite Mountains, and excavated two ring-midden features, one at each of two sites (Kroesen and Schneider 1991). Limestone and dolomite geological formations are prominent in these mountain ranges (Jennings 1961). Fifty-five percent of the sites studied had more than one ring-midden feature. Most sites were located in the Blackbush Scrub plant community (Prigge 1975) and all were between 975 and 1,600 m (3,200 and 5,200 ft) elevation, coinciding almost exactly with the elevational range of *agave utahensis* (pigmy agave), indigenous to the Eastern Mojave (Munz 1974:864; Prigge 1975:85). Another species indigenous to the Eastern Mojave, *Agave deserti* (desert agave), although having a wider distribution and a similar elevational range, does not grow in the Clark Mountains. All but two of the sites that Kroesen studied were located within 100 m of hillsides where there was abundant pigmy agave currently growing; at the two other sites, pigmy agave was growing within 200 m. Ethnographic reports from the area state that the most intensively exploited resource associated with pit roasting was agave (Bell and Castetter 1941:18-22; Bean and Saubel 1972:150-153). All sites were located on flat areas within a few meters of ephemeral drainage channels.

Artifact associations were very scanty; no artifacts were found at the majority of the sites, while a single Cottonwood Triangular projectile point, few lithic debitage flakes, ceramic sherds, and a metate fragment were found at one or the other of four sites. The paucity of remains suggests transient use of the ring-midden features. All but one of the 26 ring middens were composed of limestone rocks.

Excavation of two ring-midden features (Kroesen and Schneider 1991:52-61) consisted of longitudinal trenches sectioning the features; one excavation (at CA-SBR-798) was more extensive than the other (CA-SBR-806). The excavation at CA-SBR-798 exposed a large central hearth surrounded by mixed debris of rock, soil, and charred plant remains; at CA-SBR-806, no central hearth could be discerned. Numerous fragments of plant remains were recovered within the features: large pieces of charcoal (probably pinyon or juniper used for fuel) and small clumps of thin plant fibers (similar to what would be expected from leaves of agave or yucca). At one site, a few faunal remains included desert tortoise carapace fragments and one artiodactyl bone, all unburned. Artifacts recovered included three crude brownware ceramic sherds (often associated with Paiute groups), a small, bifacially flaked tool, two flakes, and many fragments of historic bottle glass, indicating that the feature may have been used as late as the historic period. At the other site, fewer cultural remains were located: a chalcedony Cottonwood Triangular projectile point, a single quartzite flake, and twelve brownware sherds.

Three charcoal samples submitted for radiocarbon determination (see Kroesen and Schneider 1991:61 for further information about the interpretation of these radiocarbon dates) yielded dates of 220±70 (UCR-1309), 460±70 (UCR-1310) from the ring-midden feature at CA-SBR-798 and a date of 624±100 (UCR-1311) from the feature at CA-SBR-806 (all expressed in radiocarbon years B.P.).

From the data acquired from excavation, evidence of intense heat, charcoal, plant fibers, Kroesen and Schneider (1991:61-63) concluded that the ring-midden feature at CA-SBR-798 was used repeatedly for cooking and that the hearth was within a matrix of culturally derived rock and soil refuse originating in previous use of the feature. Moreover, it is likely that pigmy agave (*Agave utahensis*) was cooked in the feature; this did not rule out the possibility that other foods, such as desert tortoise and large and small mammals, and other plants, were also cooked in this feature and others.

Ring-midden features often have voluminous amounts of stone and debris. Southwestern ethnographers suggest that "roasting" features were used on an annual basis and over a long period of time (Curtis 1907:17; Saunders 1926:135; Goddard 1927:150; Castetter et al. 1938:45). The increasing size of the features has been attributed to the need to add fresh limestone rocks at each event (Blair 1986) and the necessity to clean out the used, fire-affected rocks from the center of the feature. Over time and with reuse, the characteristic ring form developed and enlarged the feature.

Ethnographic Sources on Agave, Its Use and Preparation

Information regarding Native American use of the two agave species present in the Mojave Desert has been gathered from unpublished field notes, manuscripts, and published ethnographic works of early observers of native plant use (Harrington 1981; Kelly 1964; Laird 1976; Bean and Saubel 1972; Lawlor 1995; Dozier 1996). In addition, today's Native American people with ties to the Mojave Desert, continue to retain knowledge and maintain traditions regarding the use of many plants by their ancestors. Some information here is from direct observation of plant gathering and preparation practice; some has been passed on through oral tradition in families and tribal groups. Although there are variations in the details of some of the information, there are many commonalities. These serve to enrich our understanding of how the ring-midden features that we see on the landscape today were used and what their meaning was to the aboriginal peoples of the Mojave.

In ethnohistoric times (1776 - 1940), dialects of ten languages were spoken in the Mojave Desert region. We will discuss groups that spoke Southern Paiute, Chemehuevi, Walapai, and Cahuilla. The two species of agave (*Agave deserti, Agave utahensis*) may not have been distinguished linguistically by the Chemehuevi (Lawlor 1995:493-497). We can probably determine which species were used by specific groups by what we know about the distribution of the two species and what we know about the hunting-gathering region of different groups. For example, it is likely that the Chemehuevis used both species, but the mescal used by the Nevada and Arizona Southern Paiute and the Walapai could only have been *A. utahensis* because of its distribution (Lawlor 1995:493).

Chemehuevi Practices (from Lawlor 1995)

From Chemehuevi documentary sources (Van Valkenburgh 1976:16, 24; Van Valkenburgh notes in Harrington 1981:Rl. 147, Fr. 493, 495), it is known that mescal was an important food in the "old days" and that there were at least two ways of preparation. Sometimes the outer fiber portions were stripped off the stalk, dried, and chewed raw; it was reported to taste like "just like burned sugar." The other method of preparation was cooking the whole plant in a pit. From April through the summer, as the mescal reached the proper stage of ripeness, a pit was dug large enough to accommodate the number of plants to be cooked. Among the Chemehuevi and other Southern Paiute groups, a specialist (either male or female, depending on area) supervised both the harvesting and the roasting of agave, sometimes lighting the fire and saying "special prayers for the success of the roast" (Fowler 1995:106). A fire was built on a rock platform within the pit; the fire was heated until coals remained. The mescal was placed on top of the coals and covered with a layer of grass, and then topped by mixed dirt and rocks. Cooking lasted about 12 hours.

> sharp points were cut off, and the remainder of the plant was roasted. Then the leaves were pulled off one by one, and it was eaten like a giant artichoke, the tough and stringy parts being discarded. The heart . . . was either eaten at once or pounded out with a pestle to form a cake several feet in circumference. When dried, it is flexible but very tough [Laird 1976:108, 121]

One way to consume the preserved heart was to pound it, soak it in water, and drink the nonfermented liquid.

Kaibab Southern Paiute Practices (from Kelly 1964 [Sapir MS])

The Kaibab gathered mescal mostly in the winter and spring, when the food supply was sparse, but sometimes in the fall when the pinyon harvest was inadequate. The year-round availability of mescal made it a particularly valuable resource. The women prepared the mescal. The plant was cut off at the base with a stone tool; about half of each leaf was cut away, leaving the head (a preparation similar to the way many people prepare an artichoke today). The prepared heads were carried to camp in a basket, a very heavy and cumbersome load and an extreme physical challenge. They were roasted in a pit oven. Sapir, reporting his own observations or information provided by informants, described the cooking process: women dug a hole three feet deep and about eight to ten feet in diameter. Although the mescal was gathered by individuals, the cooking pit was used communally. Stones were placed in the pit, a large fire kindled, and the resulting ashes spread evenly throughout the pit. The mescal heads were placed in the pit at night, covered with hot rocks, grass or juniper bark, and dirt. The cooking pit now resembled a low mound (see archaeological description above). Roasting lasted two nights and one day; at intervals the mescal was tested for doneness. The partial leaves were pulled from the head and the heart was pounded flat and dried. The leaves were also dried, pounded, and ground into meal (flour) and saved for winter food supplies. Mescal stalks were also eaten; they were gathered and roasted in the spring when they were full of juice.

Moapa Southern Paiute Practices (from Stuart 1945; Kelly 1964)

Moapa gathering and use of mescal were described by Stuart (1945). Again, the year-round availability of mescal was noted, but springtime, "when the bud was just about ready to open" was a favored time. When the men reported that the mescal was ready to harvest, men, women, and children would gather it. Roasting was a community event, and a holiday atmosphere prevailed. Families first gathered firewood and then the mescal itself. They cut it off horizontally and then chopped the leaves off the head). The heads were heavy and difficult to handle. A pit was dug, lined with rocks, and a large fire built. The space in the pit was allocated to family units. When the coals were ready, the mescal was placed at designated locations within the pit and covered with rocks and dirt. A fire was built on top and burned throughout the night and the next day. The night was spent in "gambling, dancing, and tending the fire." When the fire died, the mescal was taken out and eaten. Portions were prepared for storage; the roasted hearts were pounded thin and mixed with mesquite flour.

Cahuilla Practices (from Bean and Saubel 1972:31-34)

Agave (mescal) was so thorny that it was prepared where it grew: on rocky, western-facing slopes along drainages. It was used throughout the year: young stalks and flowers in spring and summer; leaves, year-round. The availability of the plant as food in winter and its storability when properly prepared made it extremely important to desert groups. Stalks, the favorite parts, were gathered after reaching a height of four to five feet but before flowering, and were harvested in limited quantities "so that more would be available later in the season" Large quantities were collected (i.e., hundreds of pounds in a single day), but it was very hard work. The stalks were detached from the base of the plant with a sharply pointed pole of oak or ironwood. Like the Chemehuevi, the Cahuilla also ate the cooked mescal immediately or prepared it for storage by pounding and drying.

The roasting pit for leaves and stalks would be about three feet deep and five feet long.

> A large rock was placed in the center and smaller rocks were place around it. Logs were next placed in the pit and permitted to burn into a bed of long-lasting coals. The coals were covered with a layer of rocks, and agave stalks and leaves were laid across these rocks. The pit was then covered with grass and leaves to facilitate steaming and enhance the flavor of the roasted stalks. Several bushels of stalks and leaves could be roasted in one pit. The cooking process lasted three nights, each night having a special name [Bean and Saubel 1972].

Cahuilla Practices (from Dozier 1996)

More detailed information on agave harvesting, roasting, and use (sometimes slightly different from previously published ethnographic information) is based on 1992 through 1996 conversations with Cahuilla and other Indian elder friends who were willing to share their knowledge of traditional plant gathering and preparation.

Agave Harvesting

Even in paleolithic times men must have known they would more than likely get a painful poke or two while harvesting agave, but the rich rewards must have made the risk seem reasonable. Agave was so intractable that it was prepared where it grew, on rocky, western-facing drainages and slopes. It was here that the roasting pits were constructed. So perilous was the harvesting, that a Western Apache headman cautioned his people:

> If you get a mescal head ready to cut off, don't stand on the lower side of it; always work on the upper side. If you stand below it while you cut, it will roll on you and its sharp points will stick into you. If you cut it off and are about to chop away the leaves from the head, don't open your eyes wide. Close them halfway so the juice won't get in them and blind you [Goodwin 1942:166]

The return from the agave roasting pits was the finale of a long chain of events which had begun months earlier. Before the plants were harvested in April, when the leaves and stalks were full of sap, lineage members scouted their traditional, family agave stands noting the vigor of individual stands of plants, the presence of disease or parasites, and any changes in the population since the last year's roasting. After the spring harvest of flowers, stalks, and leaves, the plants were watched to see which stands prospered and offered hope of a good late-fall harvest. Because the areas harvested varied from year to year, pits were sometimes not used for generations, only to be returned to when the agave was again ready at that location.

The men sometimes stored the long hardwood, fire-hardened poles and other tools used to harvest the agave in caves near the roasting pits. Agave is a treacherous plant with sharp, hard thorns at each leaf tip and in saw-toothed ridges on each leaf margin (see quote above). The poles were protection against the painful sting of the agave, as they allowed the harvester to remain well out of range of the thorns. The "business end" of the pole was sharpened to a point, slightly oval in cross-section. The pole was made from a sapling and ideally, the point was made from the root or bole end. The point sometimes was fire-hardened for added strength. A slightly bent pole made a better tool, because the "elbow" could act as a fulcrum. The hardwood poles were heavy; they needed to be very strong since their job was actually to sever the agave stalk and lever the heavy heart out of the plant.

The sharpened, blade end of the pole was forced deep between the leaves and into the succulent flesh at the hidden base of the agave stalk above the place where the plant stem meets the root. The harvester worked around the base of the stem, severing any tenacious fibers, until the mass of heart and leaves could be levered out and separated for further preparation. It was hard, sweaty work; the toughness of the job was matched by the toughness of the agave. In some places, a short stake was driven into the hard-hearted agave with a rock hammer. Once the underside of the plant was exposed, the leaves could be removed, beginning at the base, by separating them from the hearts with a hardwood, shovel-shaped, fire-hardened hand tool. The creamy, satiny stalks, some the size of a woman's thigh, were left exposed after removal of the leaves and were ready for roasting.

Agave Roasting

The men dug three-foot deep, parabolic pits in sandy, out-of-the-way locations. Some of the pits were as long as twenty feet. A largish hearth stone was set in the bottom center of the hole and the sloping sides were lined with smaller stones. A fire of logs was built and maintained until the hearth glowed red and a thick bed of hardwood coals had been banked. The coals were covered with a layer of rock, then a layer of succulent agave leaves was added. The clean, trimmed agave stems sometimes called hearts, were added to the pit and covered over with flavorful, herbaceous greens, and more agave leaves covered the whole. Finally, the pit was sealed with sand. The contents steamed and baked in this oven for three nights and two days. The entire process varied slightly from group to group, some elders do not recall herbs being added in their favorite family recipe; others do.

Although they are known elsewhere, the presence of roasting ovens corresponds roughly to the geographic limitations of agave growth, extending from southern Mexico northward nearly to the Four Corners area and southwestward to the Pacific coast. In other places pit roasting ovens were known and used for other purposes. Even in agave country, such a pit is dug and used to roast packets of steer every year at the annual fiesta at the Malki Museum on the Morongo Indian Reservation, held the Sunday of Memorial Day Weekend.

In the old times, when the air grew warmer, the shadows became shorter, and the sun lingered longer in the sky, the children knew it would soon be time to eat the sweet, meaty agave hearts, which to us might favorably compare with baked yams. In southern California and Baja, most roasting began in April and continued for four or five months. Further south, roasting began in December, January or February, depending on the latitude and elevation. Agaves at the lowest elevations and latitudes would generally ripen earlier than those farther north or growing higher up the mountainsides. Thus, people could following the agave as it ripening agave.

The ripening of the agave meant the end of the hungry months of winter. The acorn, mesquite, annual seeds, and piñon had ripened and been harvested before the rains began in the fall and, in most years, the supply and variety had dwindled by the end of winter. Now the children, eager with anticipation, would run to the edges of the villages as their elders left to harvest and roast agave, traveling many miles from home. The littlest boys remained at home with the women and girls, but many of the older boys went with a few of their older male relatives to work the pits and proudly transport the harvest back to the village. The men and older boys lived in camp near the roasting pit for a week or two performing the many chores necessary for the roasting: cleaning out the pit; removing broken stones and ash; gathering fresh stones to replaced those which had cracked during the previous firing; gathering the wood for firing the oven; gathering and preparing agave parts; and gathering other plants for the oven.

The Cahuilla had special songs that were sung at camp on each of the consecutive nights of the three-night agave roast; each night had a special name. Among the Digueño if one man saw the smoke from another's roasting operation, the one who's smoke was seen would have bitter agave and would never know why. The observer of the operation must remain forever mute on the subject, however, lest his braggadocio ruin his own agave.

Agave stands were frequently five miles, and sometimes more than ten miles, from a village. The roasting "tamed" the agave so that it could be taken home, soft and relenting, calorically concentrated, wrapped in leaves and packed in agave nets, the thorny tips, excess water-weight, unusable fiber, and bitter leaves left behind to recycle themselves. The first known use of pack horses by the Cahuilla was to transport agave hearts home from the roasting pits (Katherine Saubel, personal communication).

Agave as a Year-round Food Resource

Agave played a role as a major source of fresh food for four or five months in the spring and summer. The remaining months of the year, dried agave products were rehydrated for use. Men were judged by the quality and quantity of agave they provided for their families. Boys were trained, from an early age, in agave harvesting and preparation. A good provider brought home enough to fill the bellies of his family, and enough to put away dried for the hungry months of winter before the hearts, flower stalks, and blossoms were again ready for harvest. Before the flowers opened, the buds would emerge on long candle-like peduncles rising from two to forty feet above the leaves, depending on the variety of a gave. The stalks, like the hearts, were harvested and roasted when they were three or four feet tall and looked like gigantic asparagus stalks. Some stalks were spared so that the flowers they would produce later could be eaten. Similarly, some blossoms were spared so the sweet, seed pods could be harvested in high summer. Many pounds of flowers were picked by the women each spring. Like the roasted hearts and stalks, some of the flowers were eaten fresh, but most were dried and stored for future use.

Other Uses of the Agave Plant

Agave has long been used for many purposes. In Mexico, the plants frequently serve as fences. The roots of some species of agave are grated and used as soap. In 1981, an old central-Mexican Indian man showed how to peel off the impermeable exoderm of a five-foot long agave leaf in thin transparent sheets. He said the Aztecs used similar sheets as paper. Although no documentation of Aztec paper made in this manner has been found, it is possible that the thin layer was laminated onto a substrate to create a smooth, matte writing surface (Dozier field notes).

In 1992, Donna Largo, a Cahuilla basket maker, demonstrated a technique for extracting a needle and thread from a Yucca leaf. The same technique was demonstrated using agave, three-thousand miles south in central Mexico in 1981 (Dozier field notes). The thorn at the leaf tip is left attached to the fibers which run the length of the leaf. After the flesh has been scraped away and the fibers have been freed, a needle and thread appear.

Agave fibers have been mined from the leaves for thousands of years and fashioned into nets, sandals, baskets, bags, bowstrings, cordage, skirts, and mats. By the 1890s there was a thriving business in agave saddle blankets among the Cupeño at Warner's Hot Springs. The two most efficient ways to separate the fibers from the flesh were *scraping* and *retting*. Fresh or dried leaves were laid on a flat, firm surface for scraping. If dried leaves were used they were soaked until soft and pliable. A dull blade was chosen for the scraping as a sharp one might cut the fibers. The stroke direction was parallel to the fibers, and in a few firm, even strokes the fibers began to separate. Sometimes the blade was held still and the agave was pulled between the blade and the firm surface. Depending on the genus of the agave, the fibers could be left connected to each other to form 1/4" wide ribbons or separated into fine threads as thin as human hair (Donna Largo, personal communication; information stated to be from Papago basket makers).

Retting freed fibers through bacterial action. Agave leaves were soaked in stagnant water for prolonged periods, until the soft tissue became putrid and rotted away, leaving fibrous strands. These strands were washed and dried for later use. Sometimes the leaves themselves were dried and saved for future use. Leaves stored for their fiber content had to be specially treated. If white fibers were desired instead of brown or green ones, only the young leaves, never exposed to sunlight, were used. Each leaf had to be split at least once before being dried in the deep shade. If leaves were unsplit, chlorophyll developed as they dried, eventually turning them black and making them unusable. Once properly dried for storage, the fibers can remain in stasis for many, many years.

Agave and Cultivation

Although no evidence of agave cultivation has been found in the Mojave Desert, in some areas, agave was included in the complex social behavior of managing indigenous plant resources. Evidence of agave cultivation exists in central and southern Baja California and the coastal and inland valley regions of Southern California, particularly among the Kumeyaay.

Early Historic Reports of Agave

In 1596 Sebastián Vizcaíno recorded meeting people from southern Baja saying they brought various foods to him, including agave, which he described (Mathes 1992:137) "...and some thick white roots as large as an arm and very reasonable in flavor, which is the ordinary bread from which they sustain themselves." By 1602 Vizcaíno had learned much and agave had become more for him than large white roots (Mathes 1992:157), "Their ordinary meal is mescal root because there is much Maguey."

Modern Uses of Agave

Modern Indians still eat traditional foods, agave among them. They still gather agave leaves for fibers. They make sure their children learn how to prepare the plants, by demonstrating preparation and encouraging the children's participation. There is always a great deal of laughter. There are some modern differences in agave harvests and roasts: now, men, women, and children of all ages gather agave on family outings; travel to and from gathering sites, originally on foot and later by horse-drawn carts, now is by car or truck. No one stores the roasted stalks in the traditional pulverized, dried-cake form. Pit roasting is now reserved for special occasions and to teach the younger generation about the old ways. Modern appliances are preferred for routine cooking. A renewed tradition of agave collecting and roasting continue today in the Mojave (Malki Matters 1996:12).

Final Remarks

While there is a lack of direct archaeological evidence that could be used to identify the specific groups that used the roasting pits we see on the landscape, the information that our Native American people have provided has added color, dimension, and meaning to the archaeological features. The ring-middens or roasting pits are more than piles of rock, charcoal, and dirt. They represent an important food resource, hard work, community effort and tradition, problem-solving ingenuity, and good times. The variety in the ring-midden features, across their distributional range, gives us a better understanding of the varied relationships between people, their neighbors, and their environments. If your mind is clear and you listen carefully, you can almost hear the men singing before the mescal-roasting fire, anticipating that their children and grandchildren will continue to enjoy the mescal harvest and feast.

Acknowledgements

Kendall W. Kroesen gathered much of the archaeological information about the ring midden features and scientifically excavated two of the features (Kroesen and Schneider 1991). We thank Katherine Saubel, Alvino Siva, Dee Alvarez, Anthony Andreas, Jo May Modesto, Donna Largo, and Lowell Bean for sharing their knowledge with Deborah Dozier. Daniel McCarthy reviewed the manuscript and offered constructive criticism.

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Deborah Dozier's Recipes for Agave and Yucca

Agave Flowers

Try to gather the blossoms when they are just barely opened; older flowers that have developed a yellow stamen are bitter and the stamen must be removed. The blossoms hang like bells with up to a hundred groups on a single flower stalk. Their beauty, combined with the heady fragrance and the human scale of the inflorescence make gathering the flowers a totally satisfactory experience, especially when the flowers are gathered under a full moon.

The blossoms must be leached to release any remaining bitterness. Wash the blossoms, put them in a kettle and add enough cold water to cover. Bring the pot to a boil and as soon as it boils, strain off the boiling water and again cover the blossoms with cold, fresh, water. Bring the kettle to a boil again and as soon as the water boils, as before, rapidly drain and cool. Repeat this until all trace of bitterness is gone from the translucent, cream-colored flowers. Two leachings should be sufficient for young blossoms, unless there was little rain the year before. They are delicious, slightly sweet and mild in flavor. Serve them (to rave reviews) steamed with garden peas and fresh thyme. Jar them; they are beautiful and exotic on the pantry shelf with other canned goods.

Recipe with the advice of Jo May Modesto

Yucca Stalks

Modern-day Cahuilla cook Yucca stalks in a crock pot. The crock pot is probably the equivalent of a pit oven, the steam created by radiant heat. Clean the stalks and cut them to fit in the pot. Fill the pot no more than 2/3 full. Add two tablespoons of liquid. Add herbs for flavor. Seal the top of the pot very well with aluminum foil, shiny side inside. Put the lid on. Cook on high for 8 - 12 hours. The stalks can also be sealed tightly in foil and baked in a 325 ° oven until soft. They are delicious in soups and stews, or marinated and served in salads.

Recipe with the advice of Cahuilla friends

Overview of the Mountain Pass Mine, California

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Geoff Nason, *Environmental Engineer, Molycorp Inc., P.O. Box 124, Mountain Pass, CA. 92366*

Introduction

Molycorp purchased the claims in the Mountain Pass area in 1950 and initiated mining in 1951 which has continued to the present. Conventional open pit mining methods are being used to extract lanthanide-bearing carbonatite at the Mountain Pass mine. During a typical workday 2000 tons of ore are mined with an average grade of 9% bastnasite ($(Ce,La)(CO_3)F$). Although the primary lanthanides in bastnasite are cerium and lanthanum, bastnasite at Mountain Pass contains 15 different lanthanide elements. The distribution of the commercially useable elements in Mountain Pass ore are: cerium (49%), lanthanum (33%), neodymium (13%), praseodymium (4%), samarium (.5%), europium (.1%), gadolinium (.2%), and yttrium/terbium (.2%). The Mountain Pass ore body is the only deposit mined solely for lanthanides and is the largest deposit of these elements in the Western World, containing more than 30 million tons of bastnasite ore. At current mining rates the reserves at Mountain Pass are sufficient for another 50 to 60 years of production.

Mountain Pass Ore Body

The Mountain Pass mine is within a window of Proterozoic rocks that have been regionally metamorphosed to the amphibolite facies. Common rock types in the Mountain Pass area are gneisses containing an assemblage of potassium feldspar, plagioclase, garnet, quartz, and biotite (Fig. 2). Using the garnet-biotite geothermometer of Ferry and Spear (1978) we have determined that the temperature of peak metamorphism was approximately 700° Celsius. These rocks are believed to be 1.7 Ma; the carbonatite has been dated at 1.4 Ma (DeWitt et al., 1987). The Mountain Pass area is within the Clark Mountain thrust complex where several of the intrusive rocks previously assigned a Proterozoic age have been recently dated as Late Jurassic (Walker, Burchfiel, and Davis, 1995.) As defined by Walker and others (1995) the Clark Mountain thrust complex consists of: 1) an eastern autochthon of Precambrian basement rocks and a cratonal sedimentary sequence ranging in age from Cambrian (Tapeats Sandstone) to Cretaceous (volcanic and sedimentary rocks), and 2) allochthons of Precambrian basement rocks, Precambrian to Cretaceous sedimentary and volcanic rocks, and Mesozoic plutonic rocks.

The alkalic rocks that are spatially and genetically associated with the carbonatite at Mountain Pass include shonkinite (augite-altered olivine-biotite-potash feldspar), syenite (potash feldspar-albite-biotite), and granite (potash feldspar-quartz-biotite) which differ from most alkalic suites associated with carbonatites. These differences include: 1) strong light rare-earth element enrichment, 2) high potassic rather than sodic content, and 3) oversaturated rather than undersaturated with respect to silica (Crow, 1984).

The carbonatite at Mountain Pass contains a wide diversity of minerals, but is mainly composed of calcite, dolomite, barite, and bastnasite with minor amounts monazite, iron oxides, strontianite, and talc (Olson et al., 1954). The carbonatite at Mountain Pass is interpreted as an igneous intrusive rock that probably rose rapidly from great depths in a continental rift setting.

The other major commercial deposit of lanthanide elements is at Bayan Obo in Inner Mongolia, China. However, the deposit at Bayan Obo has many differences with respect to Mountain Pass including the presence of abundant iron and niobium-bearing minerals, and the geologic setting. Unlike Mountain Pass, the origin of the carbonatite ore body at Bayan Obo is controversial, with many interpreting Bayan Obo to be a hydrothermal replacement of Middle Proterozoic dolomitic rocks (Drew, et al., 1990).

The carbonatite ore body at Mountain Pass dips approximately 45° to the west and ranges in thickness from 200 to 300 feet. The mined ore is hauled out of the open pit in 85 ton trucks to a crushing plant for mechanical size reduction. Bastnasite is separated from the crushed ore by a special froth flotation technique developed by Molycorp. The flotation process yields bastnasite concentrate in which all the

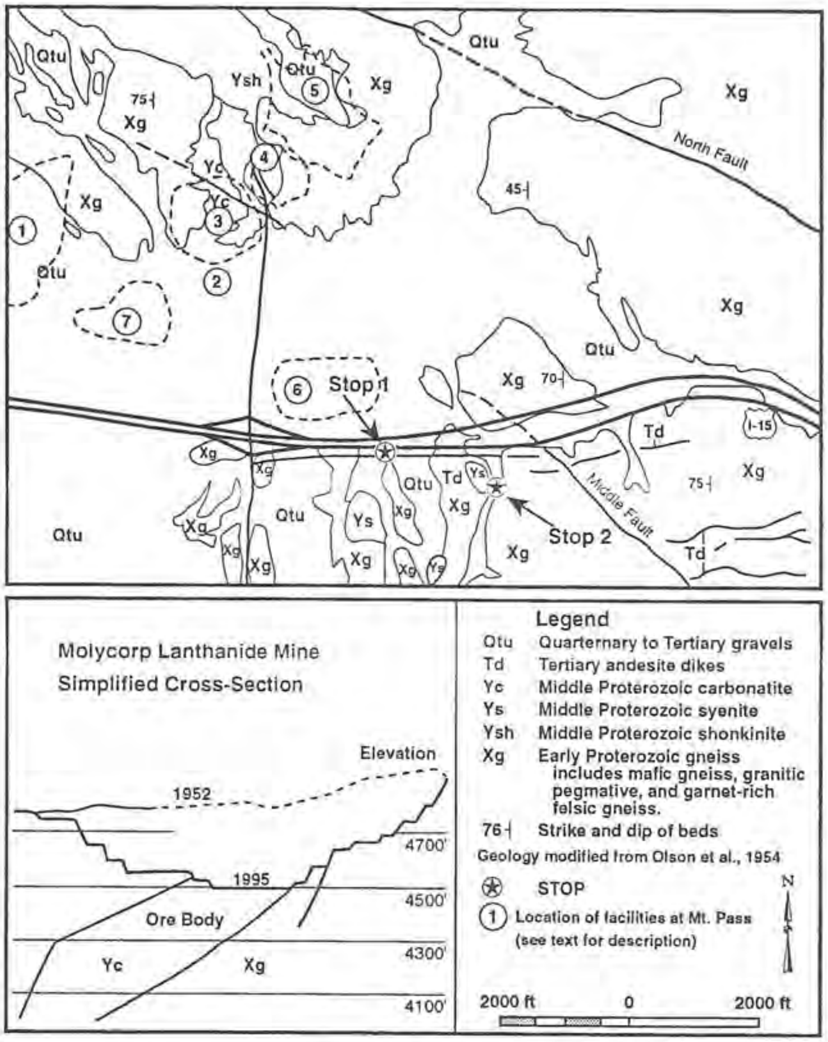

Figure 1. General geology of the Molycorp Mountain Pass mine area, showing pit location and other areas of interest.

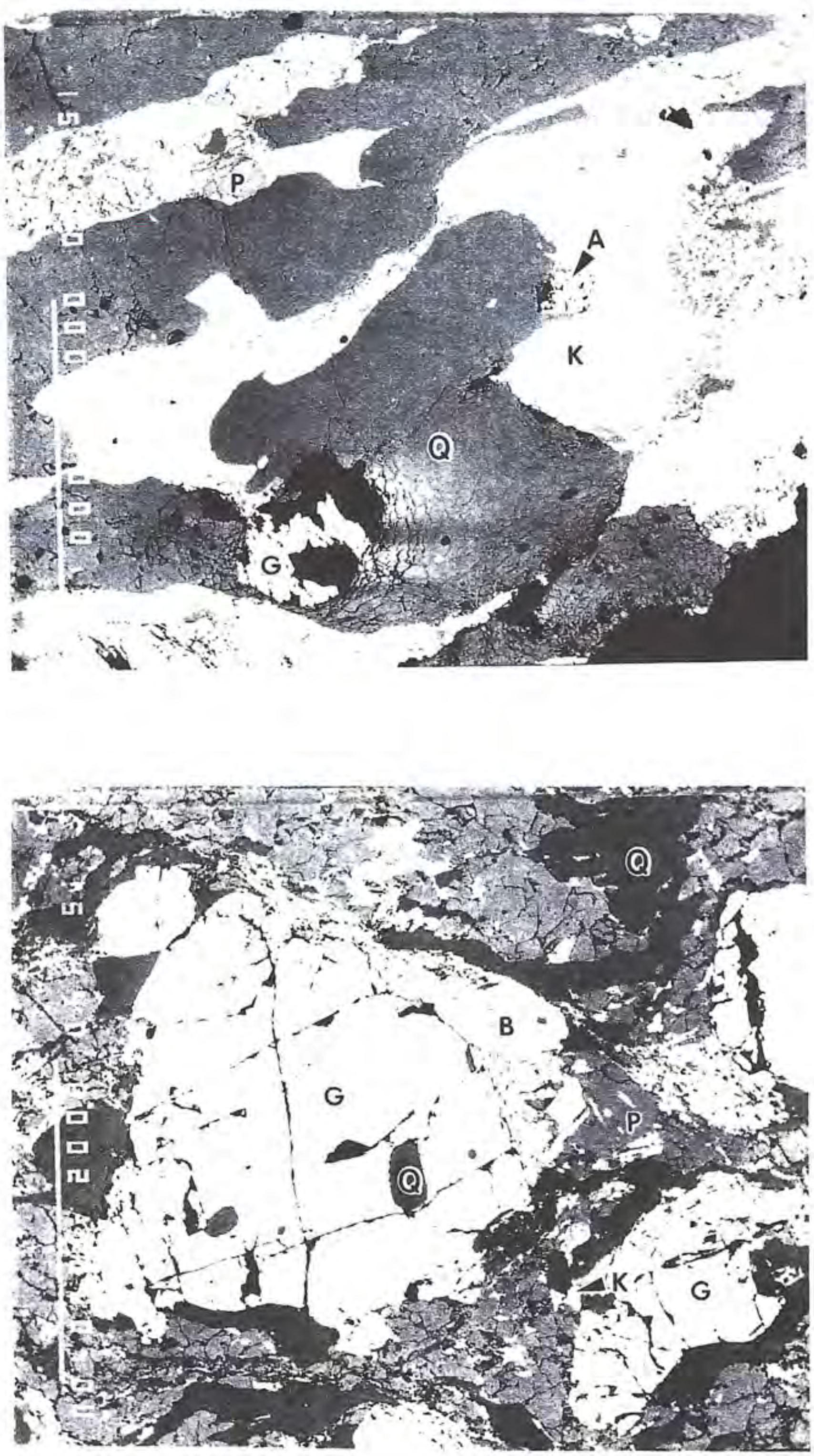

Figure 2. Scanning electron microscopy images of garnet-bearing gneisses from the Mountain Pass area. Garnet grains range in size from less than 500 microns (A) to slightly greater than 1000 microns (B). Upper image: relatively small (<500 microns) garnet grains (G) in quartz (Q), K-feldspar (K), Plagioclase (P) gneiss in sample CGN-1. Accessory apatite (A) is also present in these high-grade metamorphic rocks. Lower image: highly fractured garnets commonly are rimmed by biotite (B) and contain quartz (Q) inclusions. These large garnet porphroblasts in sample MGN-1 formed during peak metamorphic conditions at temperatures of approximately 700°C (based on garnet-biotite geothermometry).

lanthanide elements co-exist in a natural mixture. While the mined ore is approximately 9% bastnasite the concentrate is 60% bastnasite. Some of this concentrate is kiln dried, packaged and sold directly to customers. The largest percentage of the concentrate, however, moves on to nearby chemical and specialty plants. Most of the high-purity lanthanide separation takes place in the specialty plant where solvent extraction is used to produce the individual lanthanides. When the desired level of concentration is achieved the lanthanide components are precipitated out of the solutions. The end products of the chemical plant and solvent extraction processes are concentrates and compounds of various lanthanide elements. The products are produced with purities as high as 99.999%.

Reclamation Efforts at Mountain Pass

Molycorp is committed to minimizing the environmental impacts associated with the mining operation at Mountain Pass and returning the site to as natural a condition as possible when mining ceases. For example, the old Mountain Pass town site (area 6 on Fig. 1) has been revegetated with almost 300 native Joshua trees and yucca plants that have established the area to a natural setting. For this effort Molycorp received the California Mining Association's Excellence in Reclamation award in 1991. Reclamation efforts continue at Mountain Pass (see area 7 on Figure 1) where a portion of an inactive overburden dump is currently undergoing reclamation. The south facing slope will have a variety of re-vegetation test plots to determine the optimum planting techniques and vegetation for this harsh desert environment.

Commercial Applications

There are many uses for the lanthanide products of Mountain Pass. Some of the principle ones are:

- **Europium and Yttrium:** red phosphor used in color televisions and fluorescent lighting.
- **Cerium:** decolorizer in glass containers and tableware, polishing compounds for optical glass, camera lenses and TV face plates, ceramic components in catalytic converters, and improves ductility of cast iron.
- **Praseodymium:** bright yellow glaze on ceramic tile and sanitary ware, high strength magnets.
- **Neodymium:** high strength magnets, used to maintain stable electrical properties over a wide temperature range in ceramic capacitors, enhances picture brightness and contrast in color televisions.
- **Lanthanum:** used in petroleum refining to increase yield of gasoline, in high quality glass camera lenses and optical fibers to transmit more light with less distortion, in X-Ray intensification screens to reduce required exposure time.

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Mountain Pass: A Modern Ghost Town

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The Clark Mining District, the scene of the first major mineral discoveries in the Mojave Desert, at Ivanpah, also became the site of the last important strikes.

First, a promising deposit of gold ore — the Sulphide Queen — was found at Mountain Pass, 35 miles east of Baker, during the late 1920s. The property lay just north of newly built U.S. 91 (the present route of Interstate 15), where a small mill was built. A post office operated at Mountain Pass from June, 1929, to March, 1932. About 40 people were living there by 1941. They were served by a bus station, a branch of Nipton post office, and many tourist cabins occupied by highway workers and miners.

Then came the bombings of Hiroshima and Nagasaki. The demand for uranium took off. A talk in early 1949 on searching for uranium led Herbert Woodward, an assayer and chemist, on a series of prospecting trips. Woodward, who was soon joined by prospector Clarence Watkins, found intense radioactivity in a vein near the Sulphide Queen. They named the deposit the Birthday claim. Tests revealed the presence of bastnasite, a rare-earth-bearing mineral. Rare-earth elements were used in a wide variety of products, from cigarette lighters to mantles in gasoline lanterns.

The site was promising. Lying at 4,700 feet, Mountain Pass escapes the brunt of the summer heat. In the dead of winter, snow sometimes falls among the Joshua trees and yucca. Then, the air is still, and lights from the mill shine in the frosty air.

The discovery attracted a rush of Geiger-counter-toting prospectors, federal geologists, and mining companies. The Molybdenum Corporation of America, often known as Molycorp, bought the Birthday and Sulphide Queen properties in 1950 and 1951. Bringing in a steam shovel, Molycorp re-equipped the Sulphide Queen's mill and started it up in February, 1952.

Mountain Pass developed rapidly. The work force rose from 30 or 40 to 70 by late 1954, when a modern cafe and store were built. Since 50 of the men had families, who were living in trailers, the Cima School District closed its school at Nipton and put up a spacious building near the mine. Within a year, the output at the mill rose from 80 to 160 tones a day.

Mountain Pass began to boom only when the demand for improved color television sets developed. It turned out that one rare element — europium — would help provide brighter colors, especially red, on TV screens. Molycorp commissioned the construction of a second, highly advanced mill. It started up in July, 1965. The production of europium oxide soared, from 1.1 million pounds in 1972 to an estimated 12 million pounds by 1966.

As Molycorp enlarged its crew — to 75 during early 1965 — Mountain Pass again boomed. By now, 70 children were enrolled in the school. A post office was re-established in January, 1966. Molycorp put in streets, mobile-home pads, a swimming pool, a trout pond, a tennis court, a playground, and a community center. A four-land bowling alley was added in 1975. The company furnished rent-free spaces and free electricity, water, natural gas, and cable television. By 1981, the camp contained the school, the post office, the bowling alley, a small grocery store, a bar, a service station, and 200 residents.

Although many workers commuted from Las Vegas because of its abundance of services, the residents of Mountain Pass felt a sense of community. "It's kind of boring up here sometimes," Jennie Mathes, 19, newly arrived from Las Vegas, told the San Bernardino SUN. "It"s a lot cooler than living in Las Vegas. We get the utilities free. Free swimming pool. Things like that . . . . it's not bad."

Others were not as enthusiastic. Some people disliked the lack of major services, the lack of privacy, even the presence of some crime. The grocer had to install bars on the windows and doors of his store after it had been burglarized. "You have burglaries. You have dope dealers," explained John Walters, a resident California Highway Patrol officer. "You have the same [crime] here as you have anywhere else. It's just on a smaller scale."

But is was costing Molycorp a small bonanza — $600,000 a year — to maintain the camp. First, Molycorp began charging rent for the trailer spaces — $30 a month — and began trimming the work force, from 200 to 160. Finally, in early 1986, the company announced plans to remove the settlement, although it would still keep the mine and mill in operation.

Young and old alike were shocked. "I'd planned on staying here until we retired. We've raised children here for 21 years. Suddenly, someone says you have to leave. It's rotten," Wanda Sandoz told the SUN. "I went to elementary school here, we graduated from high school together [in Baker]. I married here and I'm settled here," lamented Bridget Frizzell, 21. "Now they say, 'Leave." It's like getting kicked in the stomach."

Most residents, however, had already resigned themselves to leaving. A spray-painted message on a wall proclaimed: "Here's to Mountain Past." By early June, 1986, about a third of the town had already been removed, most recently the sign at the Mobil station. "Little by little you see it happening," Mrs. Sandoz said. "People quit watering their plants. They quit worrying about what their place looks like. Then, one day, they're gone . . ."

White Fir-Pinyon Woodlands of the Eastern Mojave Desert: A Synopsis of Current Knowledge and Geomorphological Controls Affecting Their Distribution

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Introduction

Relict, Rocky Mountain white fir (*Abies concolor* (Gord. and Glend.) var. *concolor*) populations reach their western limit in the Mojave Desert of southeastern California (Griffin and Critchfield 1976, 49, map 3). The species remains as the last component of an interior montane coniferous forest association (Vasek and Thorne 1977, 823).

White fir associates with pinyon pine (*Pinus monophylla* Torr. & Frem.) and an understory of predominantly Rocky Mountain and Great Basin plant species in a white fir-pinyon woodland community (Thorne, et al. 1981). White fir-pinyon woodlands occupy physically protected sites in the Clark, Kingston and New York Mountain Ranges (Fig. 1).

This paper summarizes prior research and the current state of knowledge on the distribution of the white fir-pinyon woodlands. Distribution patterns include location, fir population, community areal cover and lower elevation limits. Access to the woodlands is then addressed. Finally, this paper reviews white fir-pinyon woodland geomorphology. Geomorphological controls affect the community's distribution.

Material for this paper has been extracted from a portion of my M.A. thesis project on the phytogeography of the lower white fir-pinyon to pinyon-juniper woodland transition in the Clark, Kingston, New York and Spring-Potosi Mountain ranges.

Previous Work

The eastern Mojave white fir-pinyon woodlands have been known since the 1930s. Initial research involved the compilation of plant and animal species lists (Miller 1940; Johnson, et al. 1948; Wolf 1938). Published descriptions were both cursory and confined to Clark Mountain (Miller 1940; Jaeger 1954, 14; Mehringer and Fergusen 1969; Prigge 1975, 10). More extensive characterizations were published in the middle 1970s and early 1980s (Henrickson and Prigge 1975; Vasek and Thorne 1977, 822-3; Thorne, et al. 1981, 85; Thorne 1982, 223).

Besides Clark Mountain, the Kingston Peak distribution was known from botanical collections, such as those by J.C. Roos and R. Weatherby (herbarium tag dated 1949, Rancho Santa Ana Botanic Garden). Castagnoli, et al. (1983) included Kingston VABM in their Kingston Range flora. Henrickson and Prigge (1975) published the first description of the New York Mountain white fir grove, while Miller (1945, 130) first described the white fir distribution on Potosi Mountain.

Current Knowledge

Locations

In southeastern California, four separate peaks on the three highest ranges support white fir-pinyon woodlands - Clark Mountain Peak (2,417 m), New York Mountain Peak (2,274 m), Kingston Peak (2,232 m) and Kingston VABM (2,175 m). New York Mountain Peak is about 25 km to the southeast of Clark Mountain Peak, while Kingston Peak is approximately 25 km to the northwest of Clark Mountain Peak. Kingston VABM lies about 3.7 km north-northwest of Kingston Peak. The next nearest relict population occurs on Potosi Mountain, 48 km north of Clark Mountain, in southwestern Nevada.

On Clark Mountain, white fir occurs in four separate canyons. Two canyons (Fir and Curtis) trend north and are adjacent. Two canyons (Westphal and Pachalka) trend east and west, respectively, and are opposite (Prigge 1975, 18; Henrickson and Prigge 1975, 165). Two of these canyons are represented here in photographs. The first photograph shows Fir Canyon (Figure 2) from above the main crest, while the second photograph shows Westphal Canyon (Figure 3) from Green's Well Road.

On New York Mountain, the main white fir grove inhabits a single ravine below the main north-facing crest (Henrickson and Prigge, 1975, 165). The next photograph, taken from about 100 m below and 300 m north, shows this enclave (Figure 4). White fir is also present to the east, and may exist to the west, of this ravine.

In the Kingston Range, white fir occurs on the two highest peaks in

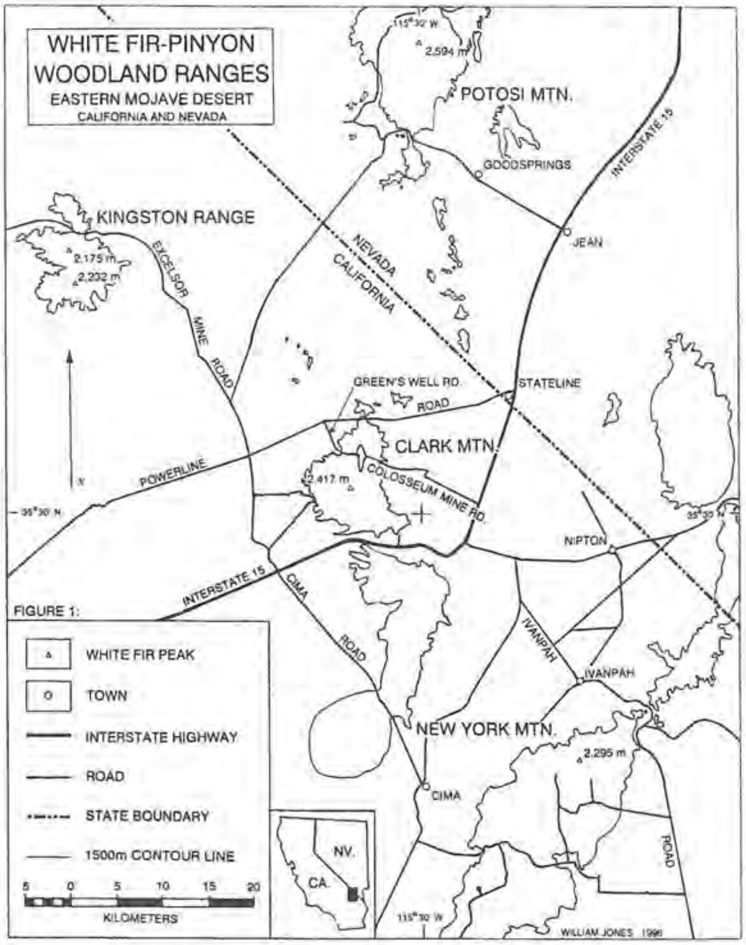

Figure 1. Map of a portion of the eastern Mojave Desert area, showing the distribution of white fir-resident peaks, relief above 1,500 m in elevation, and several access roads.

Table I. White Fir-Pinyon Woodland Statistics, Eastern Mojave Desert of California

Mountain Range	White Fir Pop.	Areal Cover (ha)	Lower Elevation Limits (m)	Ref.
Clark Mountain	1,000	65	1,890 to 1,905	2,4
New York Mountain	33	0.8	2,130	2,3
Kingston Range**	380**	61**	1,830 to 1,950**	1,2,3**
Kingston Peak*	150*	12*	1,950*	2*
Kingston VABM*	230*	49*	1,830*	1,3*
Total	1,413	126.8	1,830 to 2,130	

**= Kingston Range total includes totals from both peaks(*)

References: 1. Castagnoli, et al. (1983) 2. Henrickson & Prigge (1975) 3. Jones (1994) 4. Prigge (1975)

five north-facing canyons (Henrickson and Prigge 1975, 164; Stone and Sumida, 1983, 293). The last photograph shows the woodland community in an unnamed canyon draining north from Kingston VABM (Figure 5). White fir occurs across the north-face of Potosi Mountain, along benches and at the base of cliffs (Wells 1983, 371).

Population and Areal Cover

Table I summarizes white fir-pinyon woodland statistics, including population, areal cover and lower elevation limits for each range. The summary is based upon research by Henrickson and Prigge (1975), Castagnoli, et al. (1983) and Jones (1994).

Clark Mountain supports about 70% of the total Mojave white fir population, which is thirty times greater than that found on New York Mountain and about two-and-one-half times greater than that found on the Kingston Range (Jones 1994, 218). The Kingston VABM fir population exceeds the Kingston Peak fir population by about fifty percent. The total eastern Mojave fir population exceeds 1,400 trees in California (Jones 1994, 218).

Based upon the prior estimate by Henrickson and Prigge (1975), and assuming little or no change in areal habitat, the white fir-pinyon woodland community covers nearly 127 ha in California (Jones 1994, 302). The estimated areal cover for the white fir-pinyon woodlands on Clark Mountain is slightly higher than estimated for the Kingston Range. On Clark Mountain, the white fir-inhabited area may be underestimated.

Based upon Miller (1945), the Potosi Mountain white fir population is about two thousand individuals. On Potosi Mountain's north-facing slope, the white fir-inhabited area has been calculated to be about 74 ha, above the 2,150 m level (Jones, 1994 302). White fir descends to about the 2,130 m level on Potosi Mountain (Wells 1983, 371; Miller 1945, 130).

Lower Elevation Limits

Henrickson and Prigge (1975, 165) reported the white fir-pinyon woodland's lower elevation limit for Clark Mountain (1,905 m), New York Mountain (2,073 m) and Kingston Peak (1,950 m). Prigge (1975, 18) noted a lower white fir limit (1,890 m) on Clark Mountain.

Castagnoli, et al. (1983, 64) reported a lower elevation limit (1,830 m) for Kingston VABM, a peak not included in Henrickson and Prigge's 1975 survey. On New York Mountain Peak, the lower (2,130 m) and upper (2,220 m) fir elevation limits are higher than provided by Henrickson and Prigge (Jones 1994, 335). The lower white fir-pinyon woodland limit has been mapped for all four ranges (Jones 1994, figs. 4 to 6).

Access

A network of unpaved roads facilitates access into the Clark, Kingston, New York Mountain Ranges; no road directly penetrates the white fir-pinyon woodland community. However, the woodlands can be seen at a distance with a good pair of binoculars from vantage points along several roads.

On Clark Mountain's north side, Fir Canyon (the largest white fir resident canyon) is immediately visible from the unpaved, Green's Well Road. Green's Well Road branches southeast from Powerline Road, 9.6 km northeast from Excelsor Mine Road. Fir Canyon's white fir-pinyon woodlands, at least the lower portion, can be reached by hiking southward from the end of two jeep roads that radiate southward from Green's Well Road. Driving further east and southward, about 7.1 km from Powerline Road, the Curtis Canyon and Westphal Canyon, white fir distributions are apparent to the south and southeast. Beyond the Colosseum Mine, and prior to descending into Colosseum Gorge,

Figure 2. White fir-pinyon woodland on Clark Mountain, looking north from the crest and down into the Fir Canyon amphitheater. Mesquite Dry Lake and Green's Well Road are visible in the distance.

Green's Well Road becomes Colosseum Mine Road.

From Clark Mountain's west side, the firs are tucked into a small amphitheater high up in the north-facing reaches of Palchalka Canyon. In order to reach the firs, one must hike eastward, up along the canyon, from Palchalka Spring.

The New York Mountain grove can be seen by looking almost directly south from the town of Ivanpah. From Ivanpah Road, at the intersection with the railroad tracks, sight 2.5 degrees west of south from the prominent saddle. The small amphitheater is framed by a high ridge to the south and west and large dike outcrop to the east, which confines the grove. The firs are located 400 m to the west of this saddle, just below the main crest and between two protruding knobs. Precipitous and rugged Prospect Canyon restricts access from the south. However, the woodlands can be physically reached from the east or north, via either Keystone or Caruthers Canyons.

The Kingston Peak population is not visible from any road. The population can be reached by hiking east from the mouth of Porcupine Canyon, then south up along either of two steep, narrow ravines below the Peak. The total (one way) distance is about 10 km. Another route, shorter, yet more strenuous, requires scrambling up and over a (2,000 m) high ridge that trends south of and parallel to Excelsor Mine Road. On Kingston VABM, two of three white fir-resident canyons (an unnamed canyon trending north from the peak and another adjacent canyon south of Beck Spring) are visible from Excelsor Mine Road, 1.6 km, up to 2.2 km, northwest of the road summit. The population can be viewed by looking south from Beck Spring, west to east along the main ridge.

Figure 3. White fir-pinyon woodland along the base of cliffs on Clark Mountain, looking south from Green's Well Road and up into Westphal Canyon.

On Potosi Mountain, the north-facing slope can be seen from an unpaved road around Potosi Pass. The road branches southwest from Nevada State Route 162.

Geomorphology and Geology

White fir-pinyon woodlands share common geomorphic features among all ranges. Landforms specific to the white fir-pinyon woodland community on the Clark, Kingston, New York and Spring-Potosi Mountain Ranges are described below.

At the lower white fir-pinyon woodland limit, firs were observed in steep sided ravines (which drain perpendicularly away from the crests). Otherwise firs were found at the base of, or a short distance from, cliffs or outcrops. At the upper limit, firs occurred on exposed talus slopes or on cliff benches below the crests (Jones 1994, 332). White fir-pinyon woodlands occur on both limestone (Clark Mountain and Potosi Mountain) and granitic (New York Mountain and the Kingston Range) substrates (Henrickson and Prigge 1975, 165). On each substrate, certain aspects of the geology help to characterize and define the white fir-pinyon woodland environment.

Clark Mountain shares analogous stratigraphic and structural features with Potosi Mountain (Hewett 1956, 8). Folding and faulting of limestone and shale beds define the white fir-pinyon woodland habitat on both ranges. Clark Mountain's geology and geomorphology is described in Dobbs (1961) and Clary (1967) and Burchfiel and Davis (1971). Although not directly discussed, Potosi Mountain's geology can be extracted from Hewett (1931 and 1956) and Longwell, et al. (1965).

The New York Mountains share comparable features with the Kingston Range. Both ranges have similar quartz monzonite facies and common structural features, such as block faulting, jointing, large boulders and prominent dike outcrops (Hewett 1956, 67). These features also serve to define and physically protect the white fir-pinyon woodlands. Kingston Range geology and geomorphology are examined by various authors (Hewett 1956; Stone and Sumida 1983; Reneau 1983; Calzia, et al. 1987; Calzia 1991). New York Mountain geology is discussed by Haskell (1959).

Geomorphological Controls

Several integrated geologic and geomorphic factors assist the growth and survival of white fir in the eastern Mojave Desert. Such factors include elevation, steep north-facing slopes, high ridges or cliffs, amphitheaters, opposite ridges, dike outcrops, jointing and talus slopes that provide shade, shelter and thermal and moisture stress relief. Geomorphic controls and the survival of relict-plant distributions have been considered by Wells (1983, 377), Shreve (1915, 97), Axelrod (1976, 21), Clements (1934, 50-1) and Castagnoli, et al. (1983, 95).

Elevation

High elevation moderates air and soil temperatures and reduces evapotranspiration in the white fir-resident ranges (Axelrod 1976, 21). For example, in the Kingston Range, both white fir resident peaks are located in the high elevation interior of the mountain mass. These upland areas may provide a source of cooler air to moderate summer temperatures in the white fir-pinyon woodland community (Jones 1994, 350).

The lower white fir-pinyon woodland elevation limit coincides with certain geomorphic features common to limestone and/or granitic

Figure 4. Main white fir enclave on New York Mountain Peak, looking south and up into a small amphitheater. A high ridge to both the south and west and a large dike outcrop to the east frame the amphitheater. Jointed rock and large boulders are prevalent.

ranges. These features interact with other edaphic and phytosocial controls to provide suitable habitat. The lower white fir limit was approximately at the same level in both the Kingston Range and Clark Mountain, and much lower than on New York Mountain.

At limestone range sites, the lower white fir limit begins just upslope from denser rock layers, such as shale or dolomite, which form a sharp break in slope. The strata help to confine and retain subsurface moisture (Hewett 1956, 10-11). Denser rock layers are likely to impede and retain subsurface moisture for longer periods than more porous layers. At the granitic range sites, jointed quartz monzonite provides avenues of moisture storage (Haskell 1959, 91) and large boulders serve as traps for deep soil accumulation and as barriers for subsurface water movement. Large boulders or dike outcrops act as catchments for the firs. Boulders also provide condensing surfaces that draw deeper-lying moisture into the root zone (Wilde, 122-3). In addition, towering outcrops with steep sidewalls form small amphitheaters or cliffs, capture moisture, provide shade, and protect firs from intense summer insolation.

Moreover, shallower gradients, deep narrow canyons, and high vegetation cover also enhance the soil moisture regime at the lower elevation limit (Jones 1994, 366).

Steep, North-Facing Slopes

Steep north-facing slopes at the base of steep cliff walls protect relict stands against direct insolation and suppress moisture losses. Steep slopes imply a lower solar incidence angle and less terrestrial heating of soils in the white fir-pinyon woodlands. At the lower limit, slopes were steepest on granitic ranges and more gentle on limestone ranges (Jones 1994, 363).

High Cliffs and Ridges

Firs are afforded maximum protection in upper white fir-resident canyons against high north-facing cliffs. High cliffs and ridges provide shade, improve the local moisture regime, and provide shelter to the enclaves. Cliffs also control the period of insolation (Miller, 1940, 160) and aid precipitation capture (Lull and Ellison 1950, 481; Potter 1957, 131; Danin 1972, 437). High ridges also control shading and insolation on the white fir-pinyon woodlands (Miller, 161; Castagnoli, et al. 1983, 64). Gaines and Logan (1956, 61) offer a fine discussion on the influence of cliffs on insolation, shading patterns, and diurnal temperature variation in the eastern Mojave Desert ranges.

Shade is an essential attenuation of limiting conditions of heat and drought. White fir's ability to grow and reproduce under shade has been discussed (Sudworth 1967, 120; Fowells 1965, 47; Gordon 1970, 31). White fir probably would perish in the Mojave without shade protection.

High north-facing cliffs enhance precipitation capture in the New York Mountains (Trombulak and Cody 1980, 67). In an area of minimal moisture availability, without a high north-facing cliff, white fir may not be supportable.

Amphitheaters

Amphitheaters are common among all white fir-resident canyons. These canyons have steep sidewalls formed by high ridges, cliffs or outcrops, which rise high to the south, east, and west above the firs. Mehringer and Ferguson (1969, 289) and Prigge (1975, 10), commented upon the shielding cliff environment of Clark Mountain's amphitheaters.

Clark Mountain is comprised of a series of major east-west and minor north-south trending anticlinal folds (Burchfiel and Davis 1971, 20-1). Two massive anticlines comprise the eastern and western limbs of Fir Canyon, the largest amphitheater. The eastern limb, an overturned anticline, serves as the watershed divide with Curtis (Forsellsia) Canyon. Another, smaller amphitheater (Palchalka Canyon) is formed by folded anticlines and a syncline that plunges southwest from the main ridge, west of Clark Mountain Peak (7, fig. 2).

On New York Mountain, the small white fir habitat is physically protected by a small amphitheater of jointed dike outcrops which form high cliffs near the crest. Elsewhere, these dike outcrops appear along most of the north face, but are too far below the crest to offer shade protection or enhanced precipitation capture. Moisture enhancements on outcrops and cliff faces have not been adequately studied.

No fir habitat occurred below a peak or ridge that crested below an elevation of 2,150 m (Jones 1994, 335). Based upon the crest elevation of the highest ridge immediately south from each amphitheater, all fir locations except Clark Mountain are shaded in winter. In summer, high enclosures reduce the period of insolation, and steep, north-facing slopes limit the amount of absorbed radiation.

Opposite Ridges

Each amphitheater is physically protected by a high ridge or relief, always directly north and opposite from the white fir-pinyon woodland enclaves. Since desiccating air masses push vegetation zones upward (Bradley 1964, 46), high opposite ridges restrain the air masses from invading the amphitheaters, enclose pockets of cooler air and thus

Figure 5. White fir-pinyon woodland on Kingston VABM, looking directly south from an opposite ridge and toward the peak's steep north-face.

shield the firs from direct desert influences.

Outcrops and Jointing

Rocky outcrops and talus slopes increase soil moisture and nutrient storage capacity and enable accumulation of fine soil and organic material in crevices and fissures (Danin 1972, 437; Mason 1946, 219-220; Wilde 1958, 122-3). In the granitic ranges, outcrops and rock joints control the local white fir-pinyon woodland soil moisture regime.

Talus Slopes

Common on all three ranges, talus slopes improve soil moisture, increase nutrient storage capacity, and allow deep root penetration (Wilde 1958, 122-3). Miller (1940, 161) noted the relative abundance of subsurface soil moisture collected and stored within talus slopes in the upper drainage basins of Clark Mountain. Snowmelt water, seeping down into the deep soil at base of cliffs, serves as an important water supply. Henrickson (Interview, 5/8/90) commented that Mojave fir growth is helped by this moisture.

Conclusion

White fir-pinyon woodlands is limited to favorable sites with minimum conditions necessary for the growth of white fir. Limited soil moisture and intense insolation must be offset by various external means or controls, landforms being among them.

Steep, north-facing slopes protect relict stands against direct insolation and suppress moisture losses. High elevation moderates air and soil temperatures, reducing evapotranspiration. Amphitheaters, framed by ridges, outcrops, dikes or anticlines, enclose and protect the firs from direct sunshine in summer and enhance moisture capture, while opposite ridges block invasions of desiccating air masses. Outcrops or rock joints, as well as talus slopes at the base of cliffs, improve soil and subsurface moisture collection and storage. At the lower elevation limit, boulders or denser rock layers compensate for drier conditions by retaining subsurface soil moisture.

In the Clark, Kingston and New York Mountain Ranges, the white fir population totals over 1,400 trees and the white fir-pinyon woodland community covers an area of about 127 ha.

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Abiotic and Biotic Inflorescence Damage and Reproductive Strategy for *Yucca whipplei*

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Introduction

Variation in reproductive strategies exist within the genus *Yucca* in North America, with some species being semelparous while others are iteroparous (Schaffer and Schaffer, 1979; Udovic, 1981; Aker, 1982). Semelparity is the life history phenomenon in which a single episode of reproduction is followed by rapid degeneration and death of the reproductive individual (Schaffer and Schaffer, 1977), while iteroparous individuals produce offspring over several reproductive events and spend energy on post-flowering survival (Schaffer, 1974a). Semelparous reproduction in yuccas and agaves is characterized by the post-flowering half life (the length of time after flowering for half of the population to senesce, usually around 3 months for yuccas and agaves) and measurements of reproductive expenditure and efficiency (Schaffer and Schaffer, 1977 and 1979). Semelparous reproduction does not follow specific phylogenetic patterns within yuccas and agaves (i.e. it has apparently evolved independently in the two taxonomic groups), nor does this type of reproduction follow the phylogeny of the yucca and agave pollinators (Schaffer and Schaffer 1977). The conditions which give rise to semelparous reproduction are critical to the understanding of life history theory, as semelparity is taxonomically and ecologically wide spread (Young, 1990).

Optimal Reproductive Strategies

Different selective pressures apparently exist which may have produced the semelparous reproductive strategy including biotic interactions with predators and pollinators (Schaffer and Schaffer, 1977), and destructive abiotic disturbances interacting with flowering cycles (Young and Augspurger, 1991). The theory of optimal reproductive strategies predicts that there is a trade off between: 1. energy placed into current fecundity 2. energy available for post-flowering adult survival and 3. subsequent fecundity (Williams, 1966; Schaffer, 1974a). Reproductive value is the output of seeds by an individual (at a particular age a) relative to a newly established individual (Schaffer 1974b; Ricklefs, 1990). When post-flowering survival is low or uncertain (because of abiotic or biotic pressures), and current reproductive value is higher than subsequent reproductive value (at ages $a+1$, $a+2$, $a+3....a+n$), current fecundity is high. This can lead to selection favoring semelparous reproduction (Schaffer and Schaffer, 1977). If the relationship between initial reproductive value and post-flowering reproductive value increases, selection may favor an iteroparous reproductive strategy.

The theory of optimal reproductive strategies predicts three situations in which the selection for a larger seed crop in a single reproductive event (semelparity) is favored (Schaffer and Schaffer, 1977; 1979; Rathcke and Lacey, 1985). In the first situation, small inflorescences with small seed crops are heavily preyed upon while larger inflorescences produce sufficient numbers of seeds to overwhelm seed predators (Rathcke and Lacey, 1985). In the second situation, pollinators would forage primarily on the largest inflorescences because they would have a large number of flowers, and therefore, greater rewards than small inflorescences (Schaffer and Schaffer, 1977; Udovic, 1981). In the third situation, when there is a positive correlation between reproductive effort and reproductive success per unit reproductive effort, semelparity will be favored, but when this relationship is absent or negative, iteroparity will be favored (Schaffer and Gadgil, 1975; Young and Augspurger, 1991). This third situation is predicted to occur under resource-limited conditions (Schaffer and Schaffer, 1977).

If large inflorescences lead to an increase in seed production under conditions of heavy seed predation, the semelparous strategy would be favored over an iteroparous reproductive strategy (Schaffer and Schaffer, 1977). This requires the assumptions that inflorescence size determines the number of seeds produced, and that as more seeds are produced there is an increased chance of seedling establishment. Reaction to heavy seed predation pressure can shape individual and population reproductive behavior as in the case of mass synchronized flowering by bamboos (Janzen, 1976), and masting for the southwest riparian walnut, *Juglans major* (Stromberg and Patten, 1990). It is unknown if seed predation plays a role in the reproductive habit of the genera *Yucca* and *Agave*, which both have semelparous species.

In addition to seed crop damage by seed predators, abiotic plant damage can act as a selective pressure in promoting the semelparous reproductive habit (Young, 1981). Differences in disturbance rates in populations can affect the production of seed crops and limit the reproductive success of individuals. This could occur by non-specific plant herbivory, or other modes of disturbance which reduce reproductive success. The interaction of both a seed predator and an abiotic disturbance is not unlikely. Herbivory has been shown to make a plant more susceptible to the influence of abiotic damage from sources such as fire (Paige, 1992), seed predation and fire could interact in a similar manner.

Yucca whipplei (Liliaceae) Torr. is a monocarpic perennial that is distributed throughout southern California, from the Pacific coast on the Baja Peninsula north as far north as Monterey County and east into the margins of the Mojave Desert as far east as Barstow (Haines, 1941; Aker, 1982b). Schaffer and Schaffer (1977) have classified this species of yucca as semelparous due to the extremely low post-flowering half-life exhibited by several populations. This is the only yucca species which is considered semelparous, even though several varieties in this species have conspicuously iteroparous life history strategies. There is considerable variation in growth form for *Y. whipplei*, with up to five subspecies or varieties being recognized depending on taxonomic reference (Wimber, 1958; Hickman, 1993). Two of the subspecies are truly monocarpic (semelparous), whereas three are polycarpic (iteroparous; Haines, 1941; Wimber, 1958). Within the San Bernardino basin, two varieties, *Yucca whipplei* var. *whipplei* and *Yucca whipplei* var. *caespitosa*, overlap in distribution (Haines, 1941).

Yucca whipplei produces a large floral display after a vegetative phase lasting several years (Haines, 1941). The inflorescence varies in height from two to over four meters (max. 4.5 m) tall depending on the variety (Haines, 1941). The single panicle contains between one hundred and several thousand hermaphroditic flowers, which progressively open from the bottom to the top of the inflorescence (Aker, 1982a). The inflorescence is primarily pollinated by the moth, *Tegeticula maculata* (Wilder, 1964; Udovic, 1981). A significant difference exists between the number of flowers pollinated and the number of fruit which are maintained by the inflorescence, and variation in the ratio of matured fruit to the number of flowers appears to be correlated with

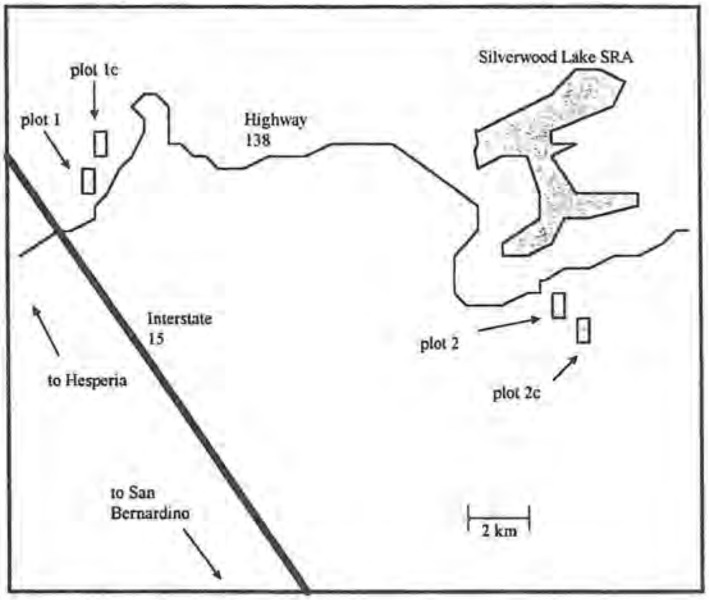

Figure 1 - Map of the study sites.

inflorescence size (Udovic, 1981). Germination can take place within fruit while on the inflorescence during the following season, which suggests that the structural integrity of the inflorescence may be important for providing an appropriate microclimate for within-fruit seed germination (Huxman and Loik, 1996).

The yucca weevil (*Scyphophorus yuccae*) is a seed predator of *Yucca whipplei* and may significantly influence reproductive success (Vaurie, 1971; Huxman, 1995). The adult usually occupies a low position on the plant, feeding and reproducing on the inflorescence (Coquillett, 1892) and larvae can be found in the non-flowering stems between October and June (Anderson, 1948). The female weevil is attracted to the plant when the yucca develops its inflorescence in the spring, and deposits eggs that develop over the next year. During the summer and fall, *S. yuccae* is in a larval stage and lives bored into the caudex and inflorescence of the yucca (Blaisdell, 1892). Larvae bore up the inflorescence producing a network of tunnels and finally reach a high position on the stalk; they then pupate and exit the plant (Huxman and Loik, 1995). The damage produced by the tunneling is hypothesized to affect the structural integrity of the smaller inflorescences.

This study reports data that demonstrates an interaction between an abiotic (fire) and a biotic (the yucca weevil) selective pressure that may act together to reduce seed set for *Yucca whipplei*. We describe the interaction between yucca weevil infestation and fire for two long-term sampling locations that burned during the summer of 1995. Prior to the burns, measurements of yucca weevil infestation on inflorescences and floral characteristics of the yucca had been made for marked individuals of *Yucca whipplei* at a number of sites. If fire and weevils have interacted to overwhelm or destroy small seed crops, then according to the predictions of the theory of optimal reproductive strategies, selection or maintenance of a semelparous reproductive strategy may occur for *Yucca whipplei*.

Materials and Methods

Study Sites

Two study sites were established in the spring of 1994: plot 1 was located about 1 km north of Crowder Canyon in the Cajon Pass (San Bernardino County, CA, elev. 1001 m; Figure 1), a control site (plot 1c) was established adjacent to this site in June, 1995. A second plot (plot 2) was located 1 km south of Silverwood Lake State Recreation Area (San Bernardino County, CA, elev. 1086 m; figure 1), at the headwaters of the Mojave River, with a control site established within 500 m (plot 2c). Both sites consisted of *Adenostoma fasciculatum*, *Arctostaphylos pringlei*, *Eriogonum fasciculatum*, *Marrubium vulgare*, and *Quercus* sp. There were 30 and 45 flowering individuals of *Yucca whipplei* var. *caespitosa* on plots 1 and 2 respectively. Plot 2 burned on June 27, 1995 for a period of 14 hours, consuming a total of 5807 ha. Plot 1 burned on July 16, 1995 and a total of 1.8 ha acres were consumed.

Experimental Design

Plots 1 and 2 were sampled in June of 1995, prior to the burn events. Randomly selected individuals of *Yucca whipplei* var. *caespitosa* were measured for a number of floral characteristics. Inflorescence height, the total number of mature fruit per inflorescence, and the number of weevil scars on each inflorescence were recorded for 20 individuals at each site. All of the sampled plants had finished flowering and no open flowers were present on any stalks. Inflorescence height was measured from the top of the youngest leaf in the rosette to the top of the peduncle. The total number of mature fruit was counted while fruit were on the inflorescence. In addition, fruit which had matured (but fallen) were determined by the small stems that were left behind on the bracts of the inflorescence once the fruit had fallen.

Weevil scars are an indicator of the damage caused to the inflorescence by the yucca weevil. Scars are easily counted on the surface of the inflorescence, low on the inflorescence, near the base of the rosette. Regressions of the number of weevil scars to the number of tunnels bored by the weevils were used as a non-destructive tool to measure such damage (Huxman and Loik, 1995). The plants were marked for future identification and maps were made to assist locating stalks in the future.

After the

Table 1 - Floral characteristics and weevil infestation for four populations of *Yucca whipplei*. Inflorescence height is in meter ± one standard error. Small inflorescence weevil infestation rates are represented as the mean number of scars per stalk. Abreviations in the text are as follows: (infl.) refers to inflorescence, (infes.) refers to infestation, and (nr) refers to data not recorded for the particular time period.

PLOT NUMBER	BEFORE BURN	AFTER BURN
plot 1		
# small infl.	11	3
# large infl.	9	9
Mean infl. height	2.93±0.18	3.04±0.11*
Sm. weevil infes.	5.0±1.18	1.6±1.6
plot 1c		
# small infl.	nr	9
# large infl.	nr	11
Mean infl. height	nr	2.94±0.16
Sm. weevil infes.	nr	5.1±1.0
plot 2		
# small infl.	9	2
# large infl.	11	10
Mean infl. height	2.87±0.28	3.11±0.07*
Sm. weevil infes.	4.9±0.78	1.4±0.84
plot 2c		
# small infl.	nr	10
# large infl.	nr	10
Mean infl. height	nr	2.80±0.28
Sm. weevil infes.	nr	5.2±1.0

* p<0.05

USFS had performed a controlled burn (plot 2; June 27, 1995) and a construction company had accidentally set a fire (plot 1; July 16, 1995), the sites were re-visited during the first week of August, 1995. Inflorescence height, the total number of fruit, and the total number of weevil scars were counted for each inflorescence on marked individuals. All of the plants had fire scars that destroyed the majority of the vegetative rosette. Burned or fallen inflorescences were not included in this sampling period as they were either incinerated or contained no fruit with seed. In addition, the plots were well within both burns, and there was no evidence that disturbance or damage to the inflorescences had occured due to firecrews working to extinguish the fires.

Plots 1c and 2c were established within 500 m of the burn plots (Figure 1), and 20 yuccas were randomly chosen at each site to serve as adjacent controls. Plants were sampled for inflorescence height, the total number of flowers, the total number of fruit, and the number of weevil scars on the inflorescence for each plant. We attempted to repeat as closely as possible the angles and aspects of the original plots when choosing our control plot location. Both long term study plots were on east facing slopes of 30° inclination from horizontal. The control plots were considered to investigate the normal production of fruit and seeds for individuals that had not been influenced by fire.

Statistical Analyses

Comparisons between experimental and control plots were made by paired t-tests to compare mean inflorescence height, the number of fruit, and the number of weevil scars. We also compared burned plots before and after the fire, investigating differences in mean inflorescence size and fruit produced by a non-parametric Kruskal-Wallis test. The stalks were separated into two categories for each location, small (< mean height) and large (> mean height) inflorescences. This separation allowed us to investigate the effects of weevil damage and fire on different size classes of inflorescences. Data are expressed as mean ± 1 SE throughout the results.

Results

Mean inflorescence height for plot 1 and plot 2 before each burn was 2.93 ± 0.18 m and 2.87 ± 0.28 m respectively (Table 1); there was no significant difference in mean inflorescence height between these populations (t-test, df=38, $p>0.05$). Plots 1c and 2c had mean inflorescence heights of 2.94 ± 0.16 m and 2.80 ± 0.28 m respectively, with no significant differences between their means or the means of the experimental plots (for all cases, paired t-tests, df=38, $p>0.05$; Table 1). Mean inflorescence height after the burn was 3.04 ± 0.11 m and 3.10 ± 0.07 m for plots 1 and 2 respectively with significant differences between plots before the burn and both control sites (Kruskal-Wallis, df=65, $p<0.05$; Table 1). The increase in mean inflorescence height for sites after the fire is a result of the smaller stalks being removed from the plots by either burning or falling to the ground. Small inflorescences (< mean inflorescence size) that had been previously marked were removed from experimental plots by the fire, while large stalks (> mean inflorescence size) remained. On plots 1 and 2, eight and seven small inflorescences were burned during the fire, respectively (Table 1). For all sites, only one large inflorescence burned (plot 2; Table 1).

Small stalks had significantly lower numbers of fruit than large stalks within the same population (Kruskal-Wallis test, df=78, $p<0.05$). On each plot, the small stalks contained half the amount of mature fruit than large stalks. Fewer numbers of fruit on the stalk leads to fewer total seeds as there were 5,500 ± 123 total seeds for small inflorescences versus 12,300 ± 220 total seeds for large inflorescences (mean of all popuations). The greater number of seeds produced by large stalks is an advantage because of the increased probability for seedling establishment under favorable conditions. Fire had removed 72% of the seed crop produced by small stalks in plot 1 and 77% from plot 2. Zero and 9% of the seed crop was disturbed by fire for large inflorescences in plots 1 and 2 respectively. A crude estimate of fitness can be represented by the relationship [number of individuals which survive a disturbance X number of individuals flowering X number of seeds per fruit X number of fruit] for members of disturbed and undisturbed populations (Paige, 1992). Using this estimate, the number of marked individuals which survived the fire can be compared to control plots to assess the reduction in fitness due to fire. For plot 1, the small stalk population had a reduction in fitness of 2/3: 16500 total seeds compared to plot 1c which had a fitness value of 49500. A similar relationship existed for plots 2 and 2c, with fitness values of 11000 and 55000, respectively. For all parameters, total number of individuals, total number of seeds, or fitness value, smaller stalks were affected by fire.

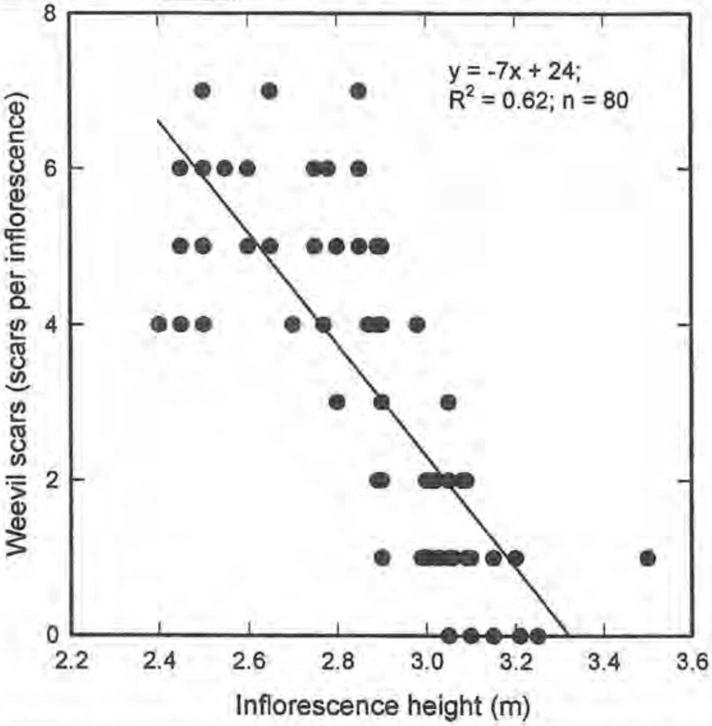

Figure 2 - Inflorescence height in meters as a function of the number of weevil scars present on the inflorescence for all four plots of *Yucca whipplei*. Weevil scars are an indicator of the amount of internal inflorescence damage.

There was a difference in the number of weevil scars on the surface of small stalks compared to large stalks. The weevils infested small stalks at twice the rate they infested large stalks and weevil scars were correlated with inflorescence size ($y= -7x + 24$; $R^2=0.62$; n=80; $p<0.05$; Figure 2). There was a noticeable difference in the number of scars on small stalks before and after the fire on plots 1 and 2 (Table 1). This is because the small stalks that survived the fire had less mean infestation rates than the mean for the population prior to the fire event (for plot 1, mean weevil scars= 1.3±0.5 for stalks that survived versus 5.0 ± 1.8 for all small stalks before the fire; Table 1). The relationship between the number of inflorescences that survived the fire and weevil invasion rates suggests that the damage caused by weevils reduces the structural integrity of small stalks, increasing susceptibility to fire.

Discussion

Small stalks, with heavier infestation from yucca weevils, were more likely to burn than large stalks resulting in decreased seed crops. This disproportionate survival of inflorescences (with larger numbers of seeds), even in a relatively rare event, could lead to the enhanced fitness of plants which utilize small versus large reproductive efforts (i.e. inflorescence size and seed numbers; Schaffer and Schaffer, 1977; Rathcke and Lacey, 1985). Disturbances that select for quantitative traits in a system can influence long term community structure (Tilman, 1988).

Yucca whipplei may improve the chances for seedling establishment if the inflorescences remain standing over a long portion of the year, allowing for within-fruit germination of the seeds in the rains of the following winter (Huxman and Loik, 1996). The interaction of fire and weevils that causes the stalk to prematurely fall to the ground eliminates this germination potential, and increases seed consumption by local herbivores (T.E. Huxman, personal observation). In addition, fire could differentially damage smaller inflorescences due to anatomical or morphological differences compared to large inflorescences, as fire can influence the differential resprouting in genets acording to size within the genera *Quercus* and *Phillyrea* (Lopez-Soria and Castell, 1992).

Fire influences community structure in terms of the density of dominant vegetation types, but the selection for a particular type of qualitative plant trait by fire may be a new role not previously considered. Lopez-Soria and Castell (1992) found only weak evidence for fire as a factor in the evolution of resprouting by monocarpic plants, with herbivory and frost damage being more important. Here we report what may be a significant relationship between fire and the life history strategy of semelparity. This probably occurs because the fire does not eliminate all of the larger inflorescences in the population. The time interval between disturbance and reproductive episodes was critical in establishing the conditions that select for semelparity in *Lobelia telekii* (Young, 1990).

The interaction between weevils and fire disturbance could be more accurately measured by developing an experimental design that would remove weevils from some stalks in the field, allow weevils to infest a portion of the other stalks in the field, artifically imitate damage (similar to the weevil) to a portion of the stalks in the field, and then monitor inflorescence survival along with size through a fire event. This would illustrate the relationship between weevil tunneling damage and the destruction of stalks by fire. However, this would be an extremely difficult task to undertake, and may require a controlled burn with inherent differences in fire quality due to community fuel load.

The ability to predict fire intervals would be helpful for determining the role of fire on yucca population structure, as it would provide a measure of the probability of an individual burning over a period of time. It is possible that a yucca has a greater chance of burning after a long period of vegetative growth diminishing post-flowering survival chances, thereby favoring an earlier use of energy on a large reproductive event. Anthropogenic changes in fire control have changed fire frequency in many areas (Minnich and others, 1995). "Original" fire cycles may have been a greater pressure on yucca floral display than current fire cycles. Fire cycles have increased in length and intensity, suggesting that stands of vegetation are allowed to grow for longer periods of time and burn more intensely (Minnich and others, 1995). A more frequent fire cycle in a particular location could represent a significant selection pressure if small stalks with few seeds were consistently removed from the population. Predictions for increased fire frequency and intensity due to anthropogenic changes in biospheric and atmospheric carbon relations may change the survival of *Yucca whipplei* with implications for community composition.

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Mesozoic Stratigraphic Units of the Eastern Mescal Range, Southeastern California

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Introduction

The Mescal Range of southeastern California (Fig. 1) represents one of the few locations in California where a complete cratonal section of Triassic to Jurassic sedimentary rocks can be seen. Capped by a sequence of Cretaceous volcanic rocks, these older Mesozoic strata are similar to those of southern Nevada and northwestern Arizona (Hewett, 1931, 1956). They include marine clastic and carbonate rocks of the Moenkopi Formation, estuarine and fluvial clastic rocks of the Chinle Formation and at least partially non-marine sandstones equivalent to the Moenave-Kayenta Formation and the Aztec Sandstone (Evans, 1971; Marzolf, 1982; Marzolf and Dunne, 1983; Wilson and Stewart, 1967).

In the eastern Mescal Range a sequence of basaltic to rhyolitic lava flows and ash-flow tuffs, the Delfonte volcanic rocks, (Figs. 2a, 2b, and 3), rest disconformably on the Aztec Sandstone. The Delfonte rocks represent the youngest stratigraphic units deformed by the late Mesozoic (Sevier) fold-and-thrust belt in this area (Burchfiel and Davis, 1971; Fleck and others, 1994). The volcanic rocks are overridden by and place a maximum age on the most easterly and probably youngest thrust fault of the fold-and-thrust belt in this area, the Keaney/Mollusk Mine thrust fault. This fault places Cambrian through late Paleozoic miogeoclinal carbonate strata over a cratonal sequence of Paleozoic and Mesozoic rocks (Fig. 5). First described by Hewett (1956), the volcanic sequence was informally called both the Delfonte volcanics and the Delfonte volcanic rocks by Burchfiel and Davis (1971), but Evans (1971) proposed the name Mountain Pass Rhyolite for these same rocks. Fleck and others (1994) retained the Delfonte volcanic rocks usage as it has been used most widely in recent literature and better accommodates the compositional variations of the unit.

Stratigraphy

Triassic and Jurassic Rocks

Lower Triassic carbonate rocks of the Moenkopi Formation rest on Permian units of the Kaibab Formation, but depositional relationships are restricted to a tight synform in the southwest part of the area studied (Fig. 2a). Moving up-section from the Moenkopi, the late Triassic red-brown sandstone of the Chinle Formation, the brick-red sandstone equivalent to the early Jurassic Moenave-Kayenta Formation, and the primarily white, Jurassic Aztec Sandstone make up the remainder of the pre-Cretaceous units (Wilson and Stewart, 1967; Evans, 1971; Marzolf, 1982; Marzolf and Dunne, 1983).

The Aztec Sandstone has been correlated with the Navajo Sandstone (Peterson and Pipiringos, 1979; Marzolf, 1982; Marzolf and Dunne, 1983), although Jurassic dune fields are probably time-transgressive. The Moenave and Kayenta formations in northwestern Arizona are Sinemurian to Pliensbachian in age (~202 - 195 Ma) and the Navajo Sandstone is Pliensbachian through Toarcian (~195 - 180 Ma) (Peterson and Pipiringos, 1979; Gradstein and others, 1995). The abbreviated sedimentary section and differing facies in the Mescal Range indicate that the Aztec Sandstone was deposited under

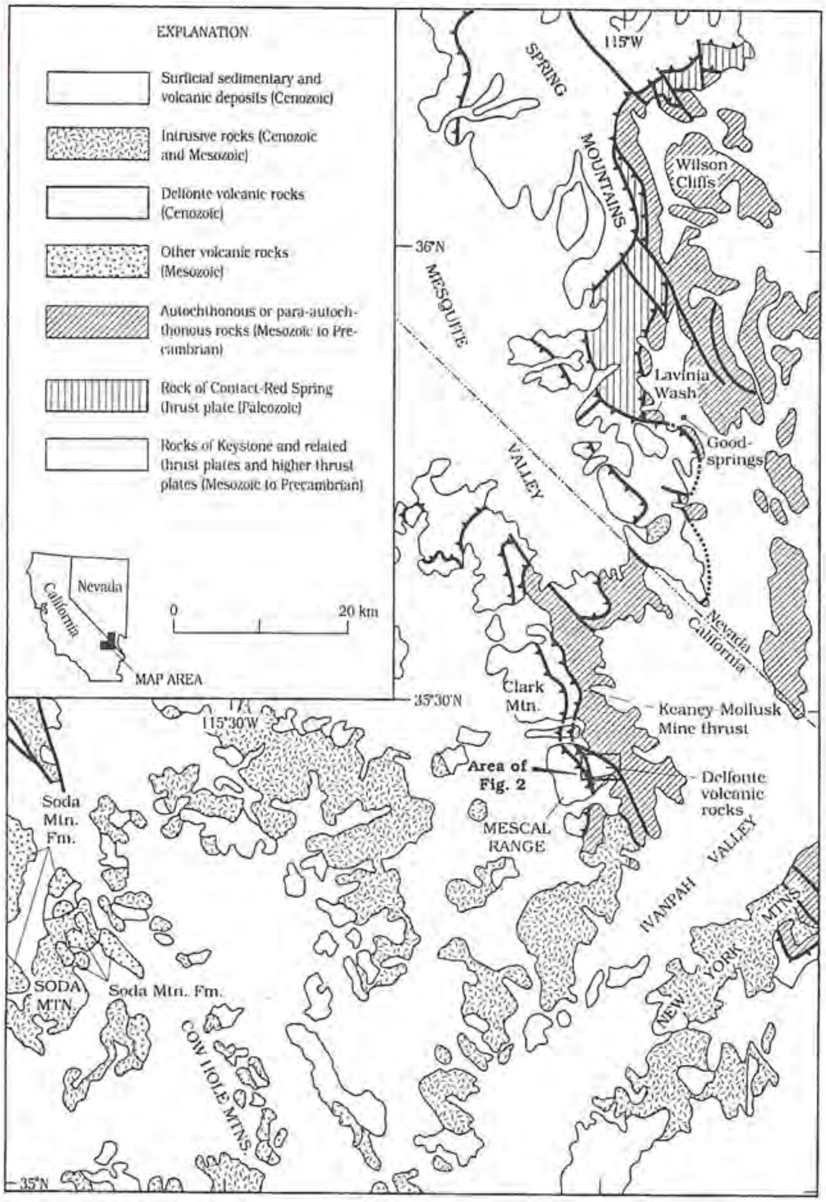


Figure 1. Generalized map of parts of southern Nevada and southeastern California, showing principal elements of the Mesozoic foreland thrust belt and distribution of Mesozoic volcanic rocks. The Keaney/Mollusk Mine thrust fault is the easternmost thrust of the foreland fold and thrust belt in the area of study, overriding autochthonous cratonal sedimentary strata and underlying Proterozoic crystalline basement rocks. Note that plutonic rocks are nearly absent north of the Mescal Range area, but abundant to the south and west. From Fleck and others (1994).

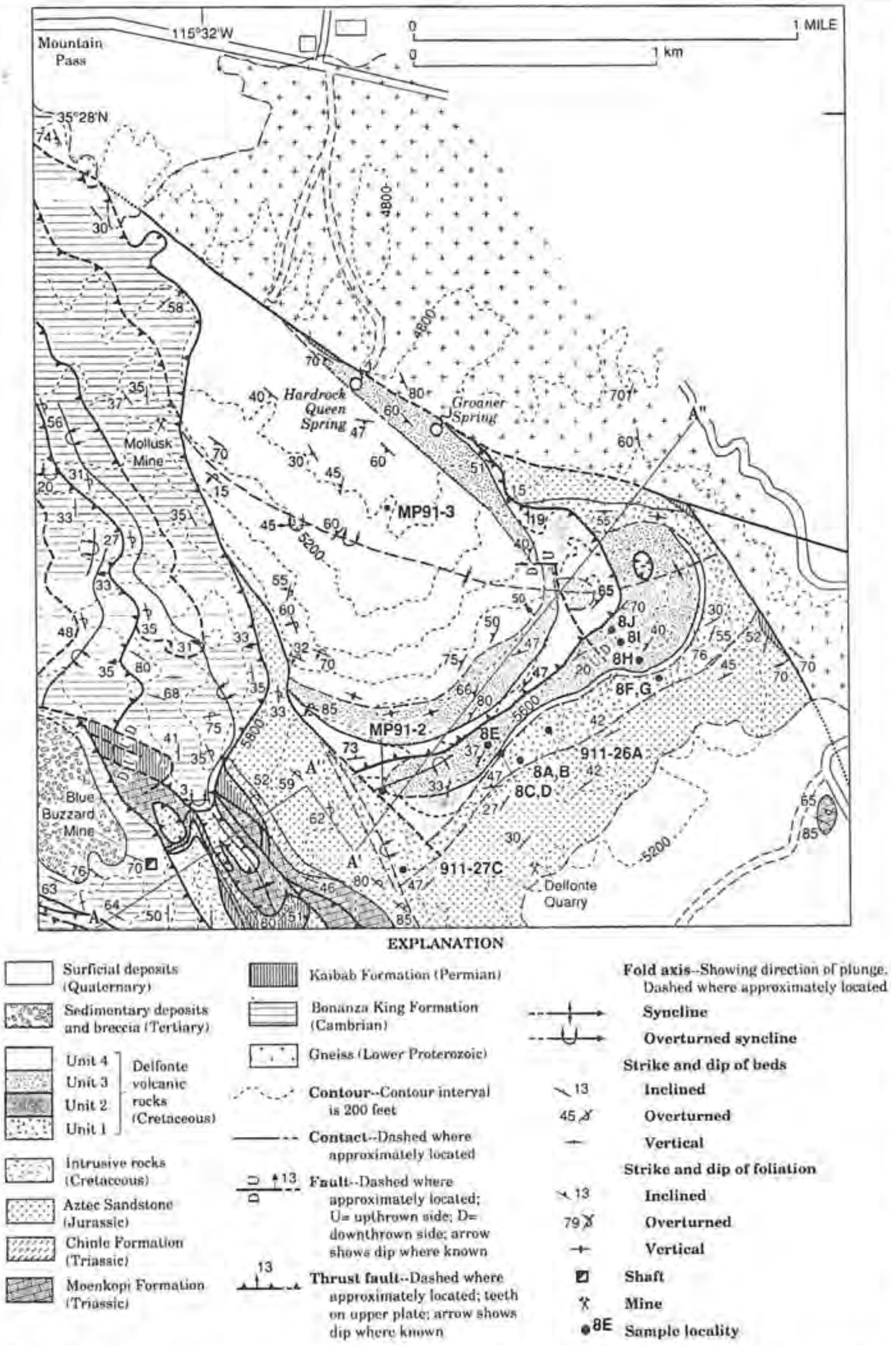


Figure 2. Generalized geologic map of the eastern Mescal Range. Mapping by B.C. Burchfiel and G.A. Davis. See figure 1 for location. Figure and sample locations are from Fleck and others (1994).

conditions somewhat different from those of the Aztec in southern Nevada (Marzolf, 1982; Marzolf and Dunne, 1983; Reynolds, 1989).

The Aztec Sandstone is the only formation in California that contains tracks of bipedal dinosaurs. These tracks provide environmental data such as surface topography and moisture as well as offering information about animal behavior (Reynolds, 1989). Although no tracks are known from the Moenave/Kayenta equivalent in California, two ichnogenera (*Anchisauripus* and *Grallator*) from the Aztec Sandstone of the Mescal Range are also found in the Moenave Formation of northeastern Arizona (Irby, 1993). A third, unnamed ichnogenus is the most common in the Mescal Range. Tracks of similar morphology but twice the size are reported from the Jurassic rocks of the Yunan Province, China (Zhen and others, 1986) and from the lower Cretaceous of South Dakota (Anderson, 1939). If the unnamed tracks in the Mescal Range have affinities to the Chinese and Dakota tracks, further study of the Aztec Sandstone in this region might determine if it differs in age from the Moenave, Kayenta, and Navajo formations in Arizona.

Delfonte Volcanic Rocks

Burchfiel and Davis (1971) considered the Delfonte volcanic rocks to rest disconformably on the Aztec Sandstone. Marzolf (1988) correlated this disconformity with the regionally recognized Jurassic J-1 and J-2 unconformities (Pipiringos and O'Sullivan, 1979) and noted that the Aztec Sandstone is relatively thin in the Mescal Range in comparison with the Wilson Cliffs area of the Spring Mountains (Fig. 1). A significant thickness of Aztec Sandstone probably was removed by erosion prior to the extrusion of the Delfonte volcanic rocks (Marzolf, 1988). Although substantial, this reduction in thickness is significantly less dramatic than at Goodsprings, Nevada, where the Late Cretaceous Lavinia Wash sequence rests unconformably on Triassic strata (Carr, 1980; Fleck and Carr, 1990). As discussed by Fleck and Carr (1990) and Fleck and others (1994), the Lavinia Wash sequence contains boulders of volcanic rocks that yield ages similar to those of the Delfonte volcanic rocks.

Fleck and others (1994) subdivided the Delfonte volcanic rocks in the eastern Mescal Range into four lithostratigraphic units, following the usage of Burchfiel and Davis (1971). A detailed description of the units by Fleck and others (1994) is presented here as Figure 3. The basal contact of the Delfonte volcanic rocks with the underlying Aztec Sandstone is exposed discontinuously, but appears to have been irregular with measurable relief. The basal unit of the Delfonte volcanic rocks is observed in gullies immediately north of the Delfonte sandstone quarry along the southeast flank of the ridge extending east to northeast from sec. 25, T. 15 N., R. 13 E., into sec. 30, T. 15 N., R. 14 E. This unit includes basalt, andesite, mudstone, and quartzite, but individual flows of the volcanic rocks have limited lateral extents. The thickness of the basal unit is quite variable, although colluvial cover may account for some of the difficulty in tracing specific horizons. Unit 2 (strongly welded, gray-green rhyolitic ash-flow tuff and tuff breccia) and unit 3 (pale red to deep red-purple, dacitic to rhyolitic ash-flow tuff and breccia) may represent a continuous sequence of pyroclastic rocks whose color may not be stratigraphic significant. These silicic volcanic rocks, which represent the bulk of exposures in the cliff face above the Delfonte quarry, exhibit gradational changes in color both laterally and vertically that may be diagenetically produced subsequent to eruption. The upper unit of the Delfonte volcanic rocks is described from exposures on the crest and along the northwest flank of the same ridge. Volcanic rocks of this unit range from andesite to dacite, dominated by brown to reddish-purple, plagioclase crystal-rich ash flows and lavas. Because any overlying units

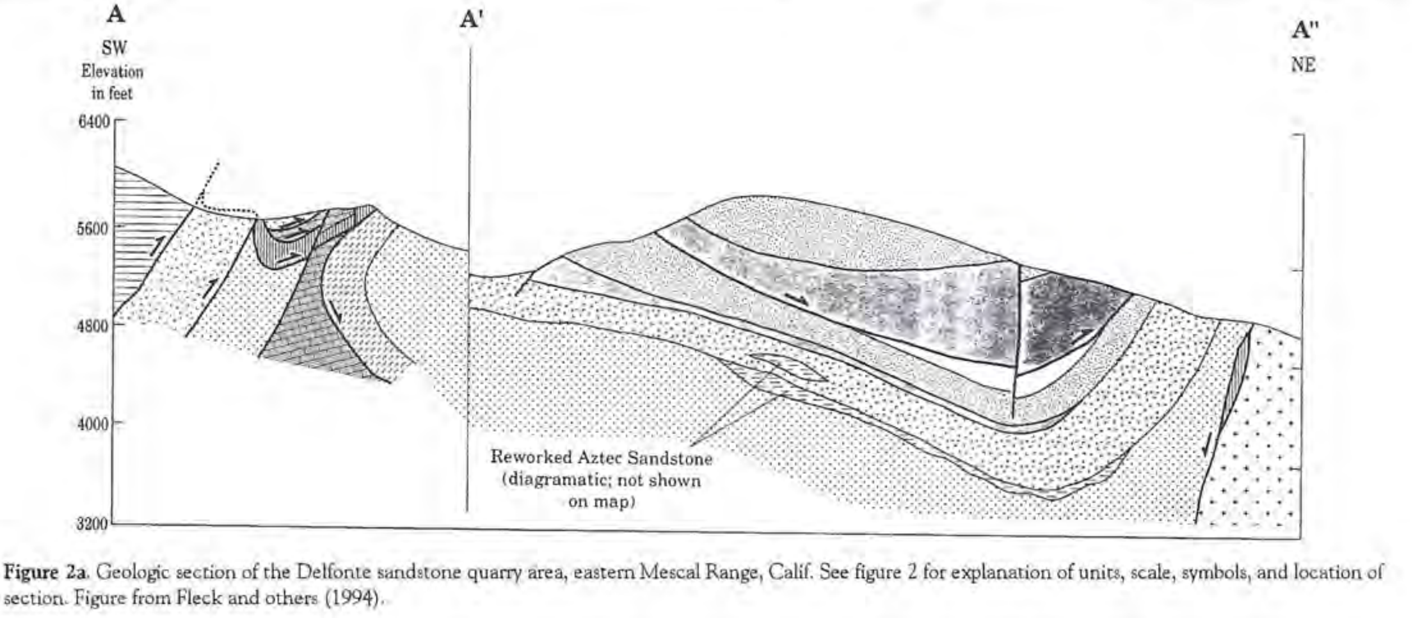


Figure 2a. Geologic section of the Delfonte sandstone quarry area, eastern Mescal Range, Calif. See figure 2 for explanation of units, scale, symbols, and location of section. Figure from Fleck and others (1994).

have been removed either by erosion or by offset on the overriding Keaney/Mollusk Mine thrust fault, the top of this unit and the original upward extent of the volcanic sequence are undefined.

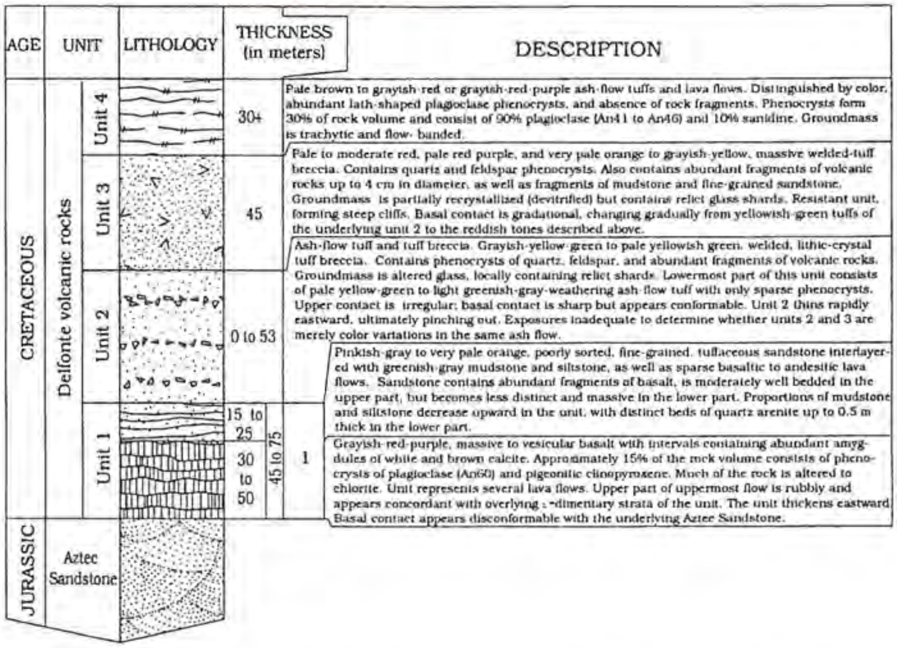
Structure

The structural setting of the Delfonte volcanic rocks, as shown by Burchfiel and Davis (1971) and Fleck and others (1994) is diagrammed in Figures 2a and 2b. Delfonte volcanic rocks cap a sedimentary succession of Paleozoic and Mesozoic cratonic platform rocks in an autochthonous or parautochthonous terrane of the Sevier foreland fold-and-thrust belt (Fig. 1; Burchfiel and Davis, 1971). The volcanic rocks occur in a northward-vergent, west- to northwest-trending, overturned syncline in the eastern Mescal Range. The volcanic sequence is repeated by a thrust fault whose dip is steeper than that of strata in the overridden limb of the syncline. The apparent displacement of this thrust fault is about one mile, carrying the upper three units of the Delfonte volcanic rocks over the Aztec Sandstone and the lower units of the volcanic sequence. This juxtaposition of both older stratigraphic units over younger and younger over older occurred following an earlier phase of deformation that folded the strata into an east-west-trending synform that was truncated subsequently by the thrust fault.

The South fault/Kokoweef fault system, a regionally important, high-angle fault system, truncates the Delfonte volcanic rocks on the north and east. The Delfonte volcanic rocks and the Paleozoic and Mesozoic cratonal section southwest of the fault are dropped down against Early Proterozoic crystalline rocks of the footwall. The cratonal rocks are entirely stripped from the upthrown Early Proterozoic basement northeast of the fault. The units in the southwest block of the South fault/Kokoweef fault system are in turn overridden by the Keaney/Mollusk Mine thrust fault. In addition to overriding cratonal strata, the Keaney/Mollusk Mine thrust fault carries continental-shelf carbonate and subordinate clastic rocks as old as Middle Cambrian eastward across the trace of the South fault/Kokoweef fault system and over the terrane of Early Proterozoic rocks at Mountain Pass (Burchfiel and Davis, 1971; Fleck and others, 1994). The Keaney/Mollusk Mine fault is the easternmost thrust fault of the foreland fold-and-thrust belt, similar to the Keystone thrust fault farther north (Fig. 1). Burchfiel and Davis (1988; unpublished mapping), however, demonstrated that the Keaney/Mollusk Mine fault lies structurally above the Keystone thrust fault in the southern Spring Mountains, where it is correlated with the Mesquite thrust fault (Fleck and others, 1994).

Age and Isotopic Studies of the Delfonte Volcanic Rocks

Fleck and others (1994) reported combined U-Pb zircon, Rb-Sr, $^{40}Ar/^{39}Ar$ laser-fusion, and conventional K-Ar geochronology indicating a late Early Cretaceous age for the Delfonte volcanic rocks. The results



Pale brown to grayish-red or grayish-red-purple ash-flow tuffs and lava flows. Distinguished by color, abundant lath-shaped plagioclase phenocrysts, and absence of rock fragments. Phenocrysts form 30% of rock volume and consist of 90% plagioclase (An41 to An46) and 10% sanidine. Groundmass is trachytic and flow-banded.

Pale to moderate red, pale red purple, and very pale orange to grayish-yellow, massive welded-tuff breccia. Contains quartz and feldspar phenocrysts. Also contains abundant fragments of volcanic rocks up to 4 cm in diameter, as well as fragments of mudstone and fine-grained sandstone. Groundmass is partially recrystallized (devitrified) but contains relict glass shards. Resistant unit, forming steep cliffs. Basal contact is gradational, changing gradually from yellowish-green tuffs of the underlying unit 2 to the reddish tones described above.

Ash-flow tuff and tuff breccia. Grayish-yellow-green to pale yellowish green, welded, lithic-crystal tuff breccia. Contains phenocrysts of quartz, feldspar, and abundant fragments of volcanic rocks. Groundmass is altered glass, locally containing relict shards. Lowermost part of this unit consists of pale yellow-green to light greenish-gray-weathering ash-flow tuff with only sparse phenocrysts. Upper contact is irregular; basal contact is sharp but appears conformable. Unit 2 thins rapidly eastward, ultimately pinching out. Exposures inadequate to determine whether units 2 and 3 are merely color variations in the same ash flow.

Pinkish-gray to very pale orange, poorly sorted, fine-grained, tuffaceous sandstone interlayered with greenish-gray mudstone and siltstone, as well as sparse basaltic to andesitic lava flows. Sandstone contains abundant fragments of basalt, is moderately well bedded in the upper part, but becomes less distinct and massive in the lower part. Proportions of mudstone and siltstone decrease upward in the unit, with distinct beds of quartz arenite up to 0.5 m thick in the lower part.

Grayish-red-purple, massive to vesicular basalt with intervals containing abundant amygdules of white and brown calcite. Approximately 15% of the rock volume consists of phenocrysts of plagioclase (An60) and pigeonitic clinopyroxene. Much of the rock is altered to chlorite. Unit represents several lava flows. Upper part of uppermost flow is rubbly and appears concordant with overlying sedimentary strata of the unit. The unit thickens eastward. Basal contact appears disconformable with the underlying Aztec Sandstone.

Figure 3. Columnar section of the Delfonte volcanic rocks in the eastern Mescal Range. Figure from Fleck and others (1994).

of that study are summarized here. U-Pb zircon analyses on a sample from unit 2 define a lower intercept age of 100.5±2 Ma that is interpreted as the crystallization age of that part of the Delfonte sequence (Fleck and others, 1994). U-Pb systematics (Figure 4) demonstrate significant amounts of Proterozoic zircon in the ash flows, but the apparent absence of post-crystallization Pb loss permits a reasonably unambiguous interpretation of the 100.5±2 Ma age as the time of final closure of U-Pb systems in the zircon. Fleck and others (1994) noted that volcanic rocks of mid-Cretaceous age occur more commonly in eastern California and western Nevada than generally recognized. For example, mid-Cretaceous volcanic rocks are reported in the Dana sequence in eastern Yosemite National Park (Kistler and Swanson, 1981), in the Excelsior Mountains south of Hawthorne, Nevada, (Speed and Kistler, 1980), and in the Kings Canyon and Lake Isabella areas of the Sierra Nevada (Saleeby and others, 1990; Busby-Spera and Saleeby, 1990), as well as at Lavinia Wash (Fleck and Carr, 1990) and the North Muddy Mountains (Fleck, 1970) in southern Nevada.

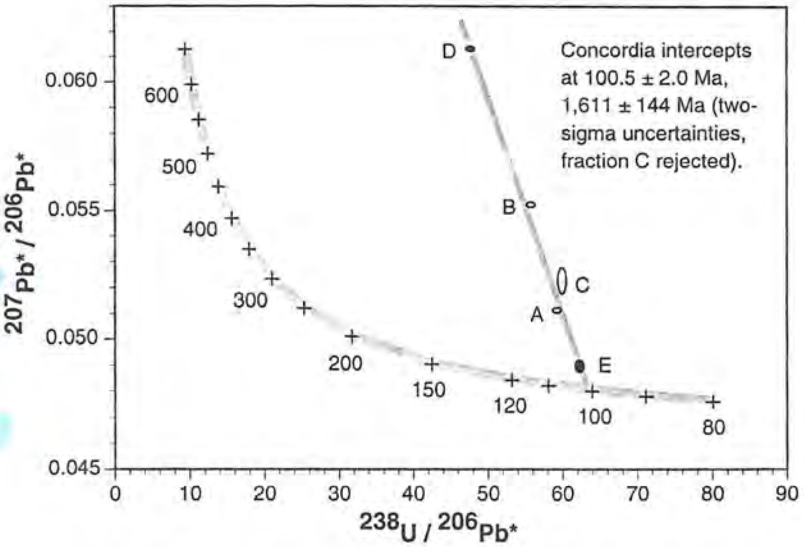


Figure 4. Tera-Wasserburg diagram, showing distribution of U-Pb zircon data and the regression line to the lower intercept with concordia. Open ellipses for sample MP91-2; solid ellipses for sample MP91-3. Figure from Fleck and others (1994).

K-Ar, ^{40}Ar/^{39}Ar, and Rb-Sr results document a complex geochronologic problem, involving xenocrystic contamination, post-emplacement disturbance of isotopic systems, and inheritance of radiogenic isotopes, that may be more common in volcanic sequences erupted through and on to ancient cratons than previously recognized. Conventional whole-rock K-Ar analyses of Delfonte unit 1 define an average age of 92.1±1.4 Ma and document thermal disturbance of the volcanic sequence after deposition. ^{40}Ar/^{39}Ar laser-fusion ages of plagioclase from ash-flow tuffs of unit 3 show a range from 103 to 448 Ma, documenting xenocrystic contamination of those units by significantly older feldspar during eruption and emplacement. Rb-Sr studies and details of the Ar results are described by Fleck and others (1994) and will not be expanded here. They demonstrate varying amounts of Proterozoic crustal contamination consistent with the U-Pb results.

The Source of Lavinia Wash Boulders

Rb-Sr analyses of two volcanic boulders from the Lavinia Wash sequence near Goodsprings, Nevada (Fig. 1) provide strong support for correlation with unit 3 of the Delfonte volcanic rocks (Carr, 1980; Fleck and Carr, 1990). A large, rhyolitic boulder in a conglomeratic phase of the sequence yielded a total-gas ^{40}Ar/^{39}Ar age of 98.0 Ma for sanidine (Fleck and Carr, 1990). Rb-Sr results from a sample of this same boulder, 911-27A, fall on the main ash-flow Rb-Sr reference isochron. A second sample, 911-27B from a smaller boulder nearby, also falls near this regression. The petrographic similarity of the boulders to the Delfonte volcanic rocks, together with similar ages and Rb-Sr chemical and isotopic compositions, is convincing evidence for identifying the boulders with a Delfonte source. If this correlation is assumed and the Lavinia Wash and Delfonte ash-flow data are regressed in two groups, ages of 101.6 Ma and 101.9 Ma are obtained from the higher- (two-point) and lower-Sr_i regressions. Both the Rb-Sr and ^{40}Ar/^{39}Ar ages (101.9 and 98 Ma, respectively) are statistically consistent with the zircon U-Pb age of 100.5±2 Ma. Because of poor constraints on the original distribution of the volcanic strata, no conclusions may be drawn about the process responsible for bringing the large boulders to their present site far north of present outcrops of Delfonte volcanic rocks.

Figure 5. The Keaney Pass/Mollusk Mine thrust over Aztec Sandstone (right). Paleozoic rocks in recumbent fold in center. *R.E. Reynolds photograph.*

Stratigraphic and Tectonic Summary

Fleck and others (1994) summarized the structural and stratigraphic implications of isotopic studies in the eastern Mescal range. We reproduce part of that summary here.

> Results of U-Pb zircon, K-Ar, ^{40}Ar/^{39}Ar laser-fusion, and Rb-Sr studies provide an internally consistent reconstruction of tectonic and magmatic events in the southern Nevada-eastern California region during the mid-Cretaceous. The Delfonte volcanic rocks were erupted at 100.5±2 Ma during late Early Cretaceous time through an Early to Middle Proterozoic basement and overlying cratonal sequence of Phanerozoic strata. The volcanic rocks were deposited on rocks of the Aztec Sandstone in the area of the present Mescal Range, but ash flows probably traveled across a surface with Proterozoic detritus. The location of the volcanic vent or source is not known. Sedimentary rocks intercalated with the mafic lavas of unit 1 are typical of a terrain of low relief with probable fluvial deposition of mudstone and very fine grained sandstone, along with eolian or fluvially reworked Aztec sands. Deposition of the volcanic sequence, including eruption of rhyolitic ash-flow tuffs, probably occurred over a geologically brief period, but the age of the basaltic to andesitic lower unit is only constrained by the underlying Aztec Sandstone and the 92.1±1.4-Ma minimum age. On the basis of the 99.0±0.4-Ma age of the synorogenic Lavinia Wash sequence (Carr, 1980; Fleck and Carr, 1990), erosion, transport, and deposition of boulders of Delfonte volcanic rocks in the coarse conglomerates closely followed eruption. Deposition of 1 to 2m boulders in the coarse conglomerate indicates clearly that the local relief between the source area and Lavinia Wash must have been significantly greater than during deposition of the green mudstones of Delfonte unit 1 near Delfonte quarry. The brief time between ash-flow tuff deposition in the Mescal Range on thick Aztec Sandstone and deposition of the eroded ash-flow tuff boulders at Lavinia Wash directly on Triassic units (Carr, 1980; Fleck and Carr, 1990) increases interest in the paleogeographic reconstruction of the region.

Marzolf (1988) recognized the abbreviated Aztec section in the Mescal Range. A much more significant non-depositional and erosional hiatus prior to about 100 Ma was required to strip several thousand feet of Aztec Sandstone from the Lavinia Wash area than is recognized in the Mescal Range. The Aztec-like sandstones and low-energy deposits such as mudstone of unit 1 of the Delfonte volcanic rocks are somewhat consistent with the character of Aztec Sandstone deposition in the Mescal Range, but contrast markedly with the high-energy environment of Lavinia Wash conglomerates. The possibility of a substantial hiatus between Delfonte units 1 and 2 needs further evaluation by determining the age of unit 1 directly.

Volcanic rocks with ages of 100±2 Ma are now recognized in the North Muddy Mountains (Fleck, 1970), at Lavinia Wash in the Spring Mountains (Fleck and Carr, 1990), and in the Mescal Range (Fleck and others, 1994). These results place a 100-Ma maximum age on movement on the Summit and Muddy Mountains thrust faults, on the Keystone thrust fault, and on the Keaney/Mollusk Mine thrust fault, respectively. These faults, representing the Sevier fold and thrust belt's youngest and easternmost foreland thrust faults, confirm that deformation continued into the Late Cretaceous. As suggested earlier by Burchfiel and Davis (1971; 1988) and documented by Walker and others (1995), Late Jurassic thrust faulting occurred in the western part of the belt. This early phase of deformation is not distinguished, however, in exposures of the Aztec Sandstone in the eastern Mescal Range, where the unit is deformed beneath the Keaney/Mollusk Mine thrust fault. Based on ages reported for the Teutonia batholith (e.g., Beckerman and others, 1982), Fleck and others (1994) and Walker and others (1995) conclude that deformation in the foreland fold and thrust belt ended between about 93 and 83 Ma.

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Preliminary Report of Molar and Alveolus Measurements as Predictive Indicators of Body Mass in Late Pleistocene Marmots

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Introduction

Late Pleistocene *Marmota flaviventris* (yellow-bellied marmot) has been identified from Kokoweef Cave in the Ivanpah Mountains in southeastern California. The modern range of the species extends into the southern Sierra Nevada, but not into the Mojave Desert where the site is located. Bell Cave, in south central Wyoming, is the site of another population contemporaneous in age with the late Pleistocene California specimens. Marmots occur in the mountains of Wyoming today, never having been extirpated at the end of the last glaciation.

Kokoweef Cave is a large, steeply dipping solution chamber, with the natural opening of the cave lying at an elevation of 5806 feet. The faunal assemblage is diverse, and is represented by 41 families and 87 species (Reynolds and others, 1991). A single radiocarbon date on charcoal found at approximately mid-level of the excavation was returned at 9830 ± 150. This date, as well as the presence of extralimital and extinct species suggest a late Pleistocene to early Holocene faunal assemblage. *M. flaviventris* is present both above and below the 9830 B.P. date, indicating a long period of time during which the environment was favorable for this species.

Bell Cave is located in the Wall Rock Canyon in the Laramie Mountains, approximately 18 miles from Laramie, Wyoming (Ziemens and Walker, 1974). The cave formed in the Casper Limestone, and rests at an elevation of 7800 feet. Archaeological excavations yielded both Holocene and late Pleistocene deposits. The fauna is diverse, containing 44 mammalian and 13 avian species, some of which are either extinct or extirpated from the area. A single radiocarbon date on bone from the Pleistocene levels was returned at 12,249 ± 330 B.P. Remains of *M. flaviventris* are common throughout all of the deposits (Ziemens and Walker, 1974).

The presence of *Marmota flaviventris* at the southern California site is interesting in that it has paleoenvironmental implications. Marmots cannot survive in a xeric environment due to dietary requirements. Yellow-bellied marmots are dependent upon grasses and forbs, legumes, and occasionally insects (Nowak, 1991). Their current range extends throughout the mountainous west, north into British Columbia, east into the Great Basin and Rockies, west into the Sierra Nevada and into northern New Mexico (Frase and Hoffmann, 1980). The animals frequent talus slopes and other rocky environments, are generally absent from valleys, and may be found up to 12,000 feet in elevation (Frase and Hoffmann, 1980). They spend most of their life in burrows, and may hibernate up to 9 months of the year (Nowak, 1991).

Pleistocene yellow-bellied marmot has been reported from San Josecito Cave in Mexico, and is probably indicative of either cooler conditions or a rainfall pattern different from that of the modern (Jakway, 1958; Harris, 1970). The southwestern United States and Mexico currently experience winter rainfall which causes a seasonal difference in the availability of forage. Resource seasonality may be a partial explanation for the modern absence of marmots from the Mojave Desert, given the uncertain climatic regime of the area today (Harris, 1970; Lindstedt and Boyce, 1985).

Body Mass

Body mass and body size are often used interchangeable in the literature. The difference is minor, with mass referring to the weight of the animal, and size referring to the physical dimensions. Weight (mass) and size correlate well, and the distinction between the two is, in most instances, insignificant. The determination of body mass of extinct mammals is of interest due to the amount of information that may be obtained from this one critical variable. Considerable research has been done on body mass over the last few years, and methods for obtaining estimates of mass have improved enough to allow more sophisticated analyses (Martin, 1984; Janis, 1990; Ruff, 1990).

Body mass is correlated to a number of physiological and metabolic variables affecting a species, and the resultant behavioral, morphological and ecological adaptations (Damuth and MacFadden, 1990). Of particular interest to paleontologists are studies exploring functional morphology and metabolic applications of body mass to environment (Wunder, 1992; Weishampel, 1995). Studies involving functional morphology can tell us how an animal may have adapted physically to the environment. For example, radiographic studies determining the cross-sectional geometric properties of long bone diaphyses have given paleontologists another tool by which body mass may be more accurately reconstructed (Runestad and others, 1993; Ruff and others, 1993).

The relationship of body mass to climate was first noted in 1847 by Bergmann, who stated that warm-blooded animals living in cold climates are larger than their relatives in warm climates (Schmidt-Nielsen, 1984). Stated in a more general way, there seems to be a relationship between increasing latitude or elevation and the mass of warm-blooded animals. Thought to be related to a decreased surface-to-volume ratio as a means of heat conservation in large animals, this relationship has generated much controversy over the years. There are many other explanations for Bergmann's Rule, including prey size (McNab, 1971), interspecific competition (Brown and Yeager, 1945), and resource seasonality (Lindstedt and Boyce, 1985). Additionally a similar response has been found in poililotherms, which also show a latitudinal and temperature related increase in weight (Lindsey, 1966). Controversial though it may be, the Bergmann response is applicable to many species, and cannot be ignored in studies of body mass.

Scaling has been defined as the "structural and functional consequences of changes in size or scale among otherwise similar organisms" (Schmidt-Nielsen, 1984:7). The concept that animals increase geometrically not only in size, but in physical and metabolic attributes as well, has profoundly affected the focus of physiologic research in biology. It has been recognized that both body size and metabolic properties of animals increase in a regular fashion that is best expressed as an allometric equation ($y = ab^x$), where y is the variable of interest.

This relationship is more commonly known as the "mouse to elephant" or Kleiber Curve. In 1932, physiologist Max Kleiber developed a graph of metabolic rates based upon data collected on a variety of placental mammals from the size of mice to steers. He found that when metabolic rates were transformed into logarithmic coordinates on a graph, the resultant best-fit regression line had a slope of 0.74 (Schmidt-Nielson, 1984). Also known as the 3/4 Mass Exponent Rule, this relationship applies to most situations concerning placental mammals. Unfortunately for vertebrate paleontologists, this rule apparently does not apply to teeth, and effectively eliminates a simple method of estimation of body mass.

Teeth and Body Mass

Teeth appear to be affected by a series of variables, including diet composition, length of time chewing food, gut size and type, and rate of passage (Gould, 1975; Demment and Van Soest, 1985; Damuth, 1990; Fortelius, 1990; Janis, 1990; Van Valkenburgh, 1990). Some initial research has been done in determining biomechanical properties of carnivore jaws, but this deals with forces needed for obtaining and processing prey, and is not related to body mass (Biknevicus, 1992). Given this limitation, traditional measurements of length, width, and occlusal surface area remain the most reliable source of information about extinct animals.

Some generalizations may be made about groups of animals that have similar eating habits. Herbivores, for example, eat food that tends to be nutritionally poor when compared to that eaten by carnivores. This problem is solved by eating large volumes and retaining the material in the gut for a prolonged period of time, with digestion being aided by the presence of fermenting bacteria (Demment and Van Soest, 1985). Tooth morphology in this group tends towards a widened toothrow to accommodate large volumes of food (Lucas and others, 1986).

These generalizations also apply to small herbivores, such as voles, that process large volumes of food in proportion to their mass. Additionally, the surface area of the tooth in microtines is increased by modifying the shape into a series of successive triangles (Gould, 1975). This is comparable to a widened toothrow in large herbivores, and accomplishes the same purpose, the processing of large volumes of food. The teeth of marmots are different from cricetine rodents, but also reflect an herbivorous lifestyle. Their teeth are relatively wide and brachydont, with the upper molars tending towards an increased surface area due to lophodonty.

In small herbivores, while the food quality foraged may be superior to that consumed by large herbivores, they face the additional problem of increased metabolic demand due to small body size (Wunder, 1992). Small herbivores in temperate climates, such as marmots, must additionally face the challenges of either hibernation or winter time foraging, as well as the energetic demands placed on them by the cold (Wunder, 1992).

Attempts at correlating traditional tooth measurements to body mass have had limited success (Gould, 1975). Van Valkenburgh (1990) looked at the length of M_1 in carnivores, and found that the highly derived carnassial was the poorest predictor of body mass. There are, however, some exceptions that provide information about body mass in particular groups of animals. Martin (1984) found a very high correlation (r-0.98) of body mass to the length of M_1 in the cricetine rodent, *Sigmodon*. From those data, he was able to estimate body mass of the genus from the late Pliocene to Recent, and detect a trend towards increased body size over time. Ungulates are another group in which the length of M_1 seems to be a good predictor of body mass. A comprehensive study by Christine Janis (1990) looked at craniodental measurements of a variety of large ungulates, and found that the length of M_1, M_2, and M^2 all showed a high correlation to body mass ($R^2 = 0.933$-0.944).

From the data in the literature thus far, it seems that an herbivorous state lends itself to a high correlation of body mass with the length of M_1, perhaps having something to do with the rather complex processing of plant material.

Materials and Methods

Mandibles from both Kokoweef Cave and Bell Cave were obtained for the study from the San Bernardino County Museum and the University of Wyoming, respectively. Many of the mandibles from both locations were edentulous, and much of the material was fragmentary. The sample consisted of 32 mandibles from Kokoweef Cave, and 43 mandibles from Bell Cave. Lefts and rights were treated the same. Mandibles that had booth teeth and exposed alveoli were used twice: once for analysis of the teeth and once for analysis of the alveolus. No juveniles were included, and mandibles with obvious anomalies or excessive alveolar resorption were eliminated. Sexual dimorphism is pronounced in these marmots, with adult males frequently being heavier and longer than adult females (Armitage and others, 1976)l No adjustments were made for sexual dimorphism, the assumption being made that each sample represents a normal distribution.

A third sample of modern *Marmota flaviventris* with known body weights (n=8) was obtained from the Provincial Museum of Alberta. The same measurements were taken on the modern specimens. This sample was used to estimate body mass of the fossil specimens using a Least Squares Regression equation. A reasonable correlation was found between the area of M_1 and body mass ($p = 0.073$), and that character was used to predict the weights of the fossil specimens. Later calculations with the fossil material found the length of M_1 to be a better indicator of body mass. The difference may be due to the small sample size of the moderns, consisting of only 8 specimens. Traditional museum curation has been biased towards skulls and skins, making access to both weight and the post-cranial skeleton impossible. Additional specimens will be added to the modern sample as they are located, with predicted fossil body masses recalculated at that time. No juveniles were included, and the 8 specimens are considered to be a random sample.

Up to 12 measurements were taken on each specimen: occlusal length and width of M_1, M_2, and M_3, and alveolar length and width of M_1, M_2, and M_3. Surface area of the occlusal area of the tooth or the surface area at the alveolus was included by simply multiplying the length times the width. Teeth and alveoli were modeled on rectangles, and no attempt was made to account for irregularities in shape. Measurements were done using Mitutoyo digital calipers.

Characters were tested statistically for correlation with the known or predicted body masses and also against each other to account for interaction among characters. Statistics used were Pearson's Correlation Coefficient, Anova, Student's T Test and Least Squares Regression.

Results and Discussion

Dental Variables

Within the fossil marmots, length of M_1 was found to have the highest correlation to body mass ($p = .001$; $R^2 = 0.957$). This is interesting in that this agrees with the results of both Janis (1990) for large herbivores, and with Martin (1984) for *Sigmodon*. The fact that tooth length is the best indicator of body mass among dental variables is confirmed by other studies of ungulates (Damuth, 1990; Fortelius, 1990). The area of M_1 also correlates well with body mass, but not to as high a degree as does the length.

The alveoli show a tendency to be different than teeth in predictive value for mass, but the difference is not very significant ($p = 0.989$). Run separately, the length of the M_1 alveolus was found to have almost as good a predictive power for body mass as the occlusal surface of the tooth ($p = 0.52$; $R^2 = 0.984$). This suggests that it may be possible to use alveolar measurements to estimate body mass in herbivores. This correlation would be most useful, given the proportion of edentulous mandibles found at paleontological sites. More work needs to be done to confirm this result, preferable with a larger sample size of modern marmots.

Body Mass

The actual mean weights of the two samples showed a slight difference of 204 grams (2082 gms vs. 1878 gms.) with the Bell Cave sample being the larger of the two. Statistical analysis of the fossil mandibles, however, showed that this difference in body mass was not very significant ($p = 0.09$). Bergmann's rule states that with increasing latitude or elevation, there is a subsequent increase in body mass. It has been reported that specimens of *Marmota flaviventris* from the central, arid portion of their modern range are smaller than those found in more mesic, montane habitats (Frase and Hoffman, 1980). Due to the latitudinal differences between Kokoweef Cave and Bell Cave, a slightly larger body mass would be predicted for the Wyoming specimens, if indeed this species exhibits a Bergmann's response.

Another possibility for the difference in body mass may be accounted for in the form of a sampling error, as there were more specimens analyzed from Wyoming than from California. A larger sample from both locations would be helpful in addressing this apparent difference in mass.

Summary and Conclusions

Body masses of late Pleistocene *Marmota flaviventris* from Kokoweef Cave and Bell Cave were found to be essentially the same. Although the actual mean weights were somewhat different, statistical analyses suggest that those differences are not terribly significant.

The length of M$_1$ seems to be the best predictor of body mass in *M. flaviventris*, as well as in cricetine rodents and ungulates. The commonality appears to lie in the condition of herbivory. As previously mentioned, a widened toothrow is necessary in order to adequately process plant material. Plant material is difficult to digest, and requires the means to break down plant cell walls as well as the presence of cellulose digesting bacteria. Furthermore, the literature suggests that body size in each species of herbivore is a complex combination of tooth morphology, rate of chewing, particle size, time of retention, gut size, and gut morphology (Bell, 1971; Demment, 1982; Demment and Van Soest, 1985; Fortelius, 1985; Owen-Smith, 1988; Wunder, 1992).

While most of the alveolar measurements do not show the predictive value of teeth, the length of the M$_1$ alveolus correlates will with body mass of marmots, and may have potential for the future. Alveolar measurements need to be refined and then tested against larger samples of specimens.

It is beyond the scope of this paper to deal with all of these complex variables in regards to marmots. The results from this brief study suggest that it would be worthwhile to pursue body mass estimates in other species of herbivores using both dental and alveolar measurements. Furthermore, reasonable prediction of body mass using only the length of M$_1$ or the M$_1$ alveolus in fossil herbivores with extant relatives may be an achievable goal.

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The Fossil Record of Bats from the Mojave Desert and Surrounding Region

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Introduction

Bats (Order Chiroptera) have one of the poorest fossil records of any group of mammals, especially considering the fact that, among modern mammal groups, their number of species earns them second place. About 900 living species of bats (of 4400 species of mammals) exist around the world; their numbers are exceeded only by the rodents, which have about 1700 living species. The paucity of bat fossils is emphasized by a comparison between the fossil records of these same two groups. Rodents first appeared in the Paleocene, bats a few million years later, in the Eocene. Yet rodents are known by thousands of extinct species worldwide; bats perhaps by a hundred globally. The difference, of course, is largely due to habitat preferences and to small size and fragile bones of the bats (all the Tertiary bat fossils mentioned in this report would not fill a thimble). Rodents and many other kinds of mammals live in or on the ground surface almost everywhere, so their bones are highly susceptible to burial and preservation. Bats rarely roost in such situations, instead preferring trees or rock crevices (where burial and preservation of their bones are unlikely), or caves. Although caves do occur that contain deposits with bat fossils in them, these sites are highly localized and usually date to the late Quaternary. Thus, they do not often preserve fossils of extinct species that might teach us more about the evolutionary history and turnover of this fascinating group.

Tertiary Records

In the Mojave Desert area, no bats of early Tertiary age are known. However, a few specimens from the late Tertiary have been published from sites in California and one site in Nevada. Lindsay (1972) identified nine isolated teeth, originating from several localities in the Barstow Formation (Miocene; Barstovian land mammal age [LMA]), as those of Chiroptera. Unfortunately, isolated teeth of bats are often difficult to identify, and it was not possible to identify them more precisely. Czaplewski (1993) identified teeth of the still-extant pallid bat, *Antrozous pallidus*, and a small fragment of humerus of an unidentifiable, small species of *Myotis* from a site in the Horse Spring Fm. in Clark County, Nevada. These specimens are of Miocene-Pliocene age (probably Blancan or late Hemphillian LMA). Czaplewski (1993) also reported a lower premolar of *Eptesicus* cf. *E. fuscus* that was found southeast of Lucerne Valley in the Old Woman Sandstone, along the northern range front of the San Bernardino Mts. Its age is Pliocene (Blancan LMA).

Although they are somewhat outside the Mojave Desert area, a few other Miocene specimens have been reported from southwest of Bakersfield and northeast of Santa Barbara, California. James (1963) reported a single fragment of a premolar of the Clarendonian LMA from the Caliente Formation in Ventura County. The specimen was identified as "Phyllostomatidae?". Hutchison and Lindsay (1974) reported a tooth and a toothless jawbone fragment, also identified as "?Phyllostomatidae *incertae sedis*", from the "?Branch Canyon Formation" in Santa Barbara County. The specimens are of the Hemingfordian LMA.

Quaternary Records

The only bat from the Mojave Desert and surrounding region known by more than isolated fragments is *Anzanycteris anzensis*. This extinct species was named by John White (1969) and is known only from (you guessed it!) Anza-Borrego Desert State Park, San Diego County, California. The specimens consist of two partial skulls and some broken jaw bones with teeth. This animal apparently is related to *Antrozous*; its bones were interred in the Palm Spring Fm. as part of the Arroyo Seco Fauna of early Pleistocene age (late Blancan LMA).

The remaining Quaternary specimens are from the late Pleistocene and early Holocene, and all pertain to extant species. Jefferson (1982) reported material of *Myotis* sp., *Eptesicus fuscus*, *Corynorhinus townsendii* (re-elevation of *Corynorhinus* to generic rank follows Frost and Timm, 1992; Tumlison and Douglas, 1992; and Bogdanowicz and Owen, in press) , and *Antrozous pallidus* from a cave in the Mormon Mts. in Lincoln County, Nevada. Reynolds et al. (1991) listed *Myotis ciliolabrum*, *M. thysanodes*, *Corynorhinus* cf. *C. townsendii*, and *Antrozous pallidus* from Kokoweef Cave and Antelope Cave in the Ivanpah Mts. in San Bernardino County, California; these sites have radiometric dates of 10,080 ± 160 and 9,850 ± 160 ybp, respectively, and both include extinct megafauna (camel and horse; Jefferson 1991). Whistler (1990) reported *Pipistrellus hesperus* as a fossil in the late Pleistocene (Rancholabrean LMA) Dove Spring Lignites local fauna in the northwestern Mojave Desert north of Mojave, California. One radiocarbon date on conifer charcoal from the lignite at this locality was 10,730 ± 110 ybp. *Antrozous pallidus* occurred as a fossil also in the Quaternary deposits at the Cool Water Coal Gassification Site at Daggett, San Bernardino County. A radiometric date of 12,210 ± 430 ybp is available for this locality. The only bats so far reported in the thousands of animal remains from the tar seeps at Rancho La Brea are *Lasiurus cinereus* (Akersten et al. 1979) and *Antrozous pallidus* (Jefferson 1991).

Thus, only one extinct bat is known in the area. All other identified fossils not only are of extant species, but the species still live in the same area today (i.e., their geographic ranges there have not changed since late Pleistocene). Two of these (*Antrozous pallidus* and possibly *Eptesicus fuscus*) have done so for perhaps as much as 5 million years.

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Biogeography and Paleoecology of Ground Sloths in California, Arizona and Nevada

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Abstract

Three species of ground sloth, *Paramylodon harlani*, *Megalonyx jeffersonii* and *Nothrotheriops shastensis* are found in California, Nevada and Arizona. Despite the overlap in distribution, the three species are not commonly found together in a fauna. This lack of association is a reflection of the different ecological requirements of the three species.

Introduction

Although originating in South America, ground sloths comprise a conspicuous portion of the Rancholabrean (late Pleistocene) megafauna of North America. Four genera, each represented by a single species in North America, are found across the continent and represent four separate dispersal events from South to North America. Two of these species, *Megalonyx jeffersonii* and *Paramylodon harlani*, were widely distributed across the North American continent during the Rancholabrean while the others, *Nothrotheriops shastensis* (Akersten and McDonald, 1991) and *Eremotherium laurillardi* (Cartelle and De Iuliis, 1995), had more restricted distributions. The distribution of *Paramylodon*, *Megalonyx* and *Nothrotheriops* in western North America broadly overlapped during the Rancholabrean, but this does not necessarily reflect similarities in ecological requirements. Each taxon represents a distinct evolutionary lineage adapted differently to its role as a megaherbivore. This distinction in habitat preference is especially important given the mosaic habitats present in the western United States. Considering these points, the questions then become whether habitat sharing existed between these species, and if so, to what degree. Preliminary to these questions, the distribution and association where examined for *Megalonyx jeffersonii*, *Paramylodon harlani* and *Nothrotheriops shastensis* found in California, Arizona and Nevada, an area where these three species are commonly found.

Paleoecology

Interpretation of the feeding habits of the three species are based on skull morphology, dentition and skeletal anatomy. *Paramylodon harlani* was a grazer while *Megalonyx jeffersonii* and *Nothrotheriops shastensis* were browsers (Stock, 1925). Direct knowledge of diet is available only for *Nothrotheriops* due to the preservation of dung in dry caves throughout the Southwest. At least 9 sites that preserve dung are known and numerous analyses (Laudermilk and Munz 1934, 1938; Martin *et al.* 1961; Hansen 1978; Thompson *et al.* 1980) have produced the degree of dietary knowledge of *Nothrotheriops* rivaled by few other Pleistocene taxa.

Although there is no direct evidence for the diet of either *Megalonyx jeffersonii* or *Paramylodon harlani*, some indirect evidence exists to support the interpretation that the latter species was a grazer. Dung is preserved for a closely related late Pleistocene South American species, *Mylodon darwinii*. This dung was analyzed by Moore (1978) and indicates that *Mylodon darwinii* fed entirely on members of the Cyperaceae, Gramineae and other species associated with cool, wet sedge-grasslands. Although morphological differences of the skull readily distinguish *Mylodon darwinii* and *Paramylodon harlani*, there are sufficient similarities in the dentition, skull morphology and skeleton of these species to infer that *Paramylodon harlani* (like its South American relative) was a grazer. The only other information regarding the diet of *Paramylodon* is based on carbon 13 analysis of bone collagen on specimens from Rancho La Brea by De Niro and Epstein (1978). The analysis produced values of -23.0 and -24.2 which indicate a C3 plant consumer. If *Paramylodon* was a grazer it was consuming C3 grasses - at least in the Los Angeles Basin.

There is no independent corroborating evidence (such as dung) to support the interpretation based on cranial, dental and skeletal evidence, that *Megalonyx jeffersonii* was a browser. However, as a browser, *Megalonyx* would be expected to utilize habitat similar to *Nothrotheriops*, even though the two species do not commonly appear together in faunas. It is most likely that *Megalonyx jeffersonii* utilized different browse than *Nothrotheriops shastensis* through habitat partitioning and did not directly compete with *Nothrotheriops* in those habitats they did share.

Distribution

Distribution of the three species is shown in Figure 1. Data for each species has been compiled from a variety of sources, both from the literature and examination of unpublished specimens in collections. Primary sources for *Paramylodon harlani* include Jefferson (1991) and McDonald (1993), for *Nothrotheriops shastensis*, McDonald (1985) and Akersten and McDonald (1991); and for *Megalonyx jeffersonii*, McDonald (1977). References to literature describing each site are provided within each of these primary sources. Each locality plotted in Figure 1 is listed in Table 1.

The general pattern of distribution for the three sloth taxa immediately indicates a usual lack of overlap by all three species throughout the region examined. Based on the 115 known localities recorded, all three taxa are found together in only three: Rancho La Brea, Manix Lake and Hawver Cave. Most obvious is the virtually complete mutual exclusion in the distribution of *Paramylodon* and *Nothrotheriops*. As noted by McDonald (1993), *Paramylodon* in California was limited to coastal and lowland areas and tended to be absent at higher elevations and inland arid areas. In marked contrast, *Nothrotheriops* inhabited more arid areas, especially those with some topographic relief, possibly to maintain thermal stability (Akersten and McDonald, 1991). The larger body size of *Paramylodon* may have provided sufficient thermal inertia that it did not use altitudinal gradients to maintain body temperature. Given what is known of their ecology, lack of overlap in these species may be explained by the preference of *Nothrotheriops shastensis* for desert vegetation (Hansen, 1978 and other papers cited) while *Paramylodon harlani* might have been limited to areas with extensive grass cover. The lack of association of the two taxa reflects that habitat preference of each species was dependent on temperature ranges and preferred forage among other factors. Distribution of each species was probably not continuous and dependent on suitable habitat availability.

Localities recording each of the three sloth taxa are not as numerous in Nevada and Arizona as they are in California. Even so, these records follow the same pattern seen in California and support the interpretation that these species utilized different habitats. In Nevada there is no close association of *Paramylodon* and *Nothrotheriops*, with the former confined to a single northern locality (Carson City) near the foothills of the Sierra Nevada Mountains while *Nothrotheriops* is restricted to the southern portion of the state. Likewise in Arizona, the known localities of the two species are not in close proximity; each is found in distinctly different portions of the state.

As mentioned above, *Megalonyx* and *Nothrotheriops* are interpreted as browsers, but both species do not always occur together in a fauna. This lack of association was noted by McDonald (1995) at the rich Leisey 1A locality from the Irvingtonian of Florida. This site included the earlier species *Nothrotheriops texanus* and *Paramylodon harlani* but lacked *Megalonyx*, a common species in other Florida Irvingtonian localities. This general lack of association seems also to have existed in the Rancholabrean, although *Megalonyx* and *Nothrotheriops* are found together in a greater number of faunas than either is found in association with *Paramylodon harlani* (see Table 1 and discussion below). One possible explanation is that *Megalonyx* was primarily an inhabitant of more heavily forested regions, particularly gallery forest associated with river systems (McDonald and Anderson 1983). If this interpretation is correct, any extension of the range of *Megalonyx* into a desert habitat preferred by *Nothrotheriops* would have been limited to areas with permanent water and associated riparian vegetation. At least this may explain the presence of *Megalonyx* in more arid inland areas such as Tule Springs and Manix Lake.

Since the three taxa occur together in only three Rancholabrean localities, these sites probably represent the exception to the normal ecological separation of the species. These sites may represent an ecotone that permitted the closer-than-normal association of *Paramylodon*, *Megalonyx* and *Nothrotheriops*. Alternatively each of these sites may represent an area consisting of a mosaic of habitats suitable for each species. This then resulted in their preservation as part of a community that otherwise did not exist throughout the major portion of each species range. For instance, the presence of all three taxa as part of the well-known Rancho La Brea fauna may have been an exception to the rule. Besides the three sites where *Paramylodon* occurs with both *Megalonyx* and *Nothrotheriops*, it is associated only with *Megalonyx* at two other sites within the area of the present study. Outside the range of *Nothrotheriops*, *Paramylodon* and *Megalonyx* occur together in a number of faunas in North America. The three localities from which all three sloth taxa have been recovered are widely separated within the area of this study and represent three distinct regions in California: coastal lowland, inland desert and inland with moderate elevation - further suggesting that these three localities represent ecotonal areas of contact between the preferred habitats of the three taxa.

The Manix Lake fauna has been dated at about 200,000 years BP (Jefferson, 1987) and is not contemporaneous with the two later Pleistocene faunas of Rancho La Brea and Hawver Cave. Manix Lake formed during a time of greater precipitation that permitted the expansion of habitat suitable for *Paramylodon* and *Megalonyx* into an area that may have otherwise been inhabited only by *Nothrotheriops*.

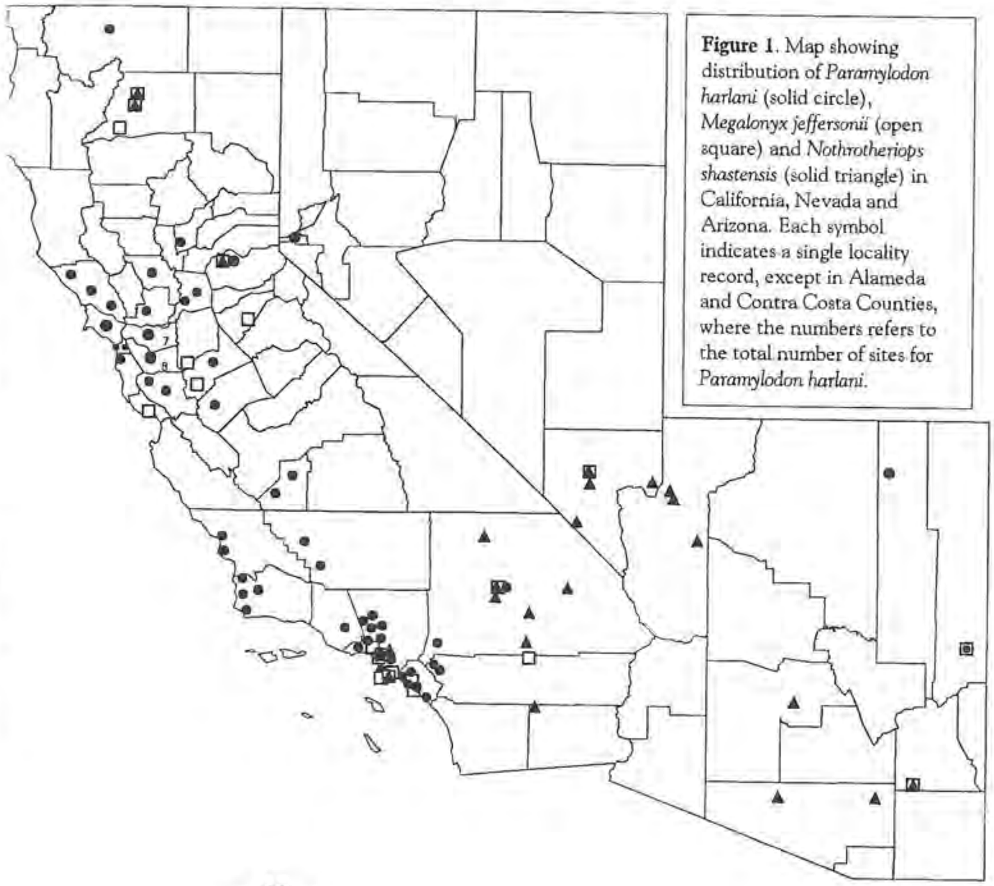

Figure 1. Map showing distribution of *Paramylodon harlani* (solid circle), *Megalonyx jeffersonii* (open square) and *Nothrotheriops shastensis* (solid triangle) in California, Nevada and Arizona. Each symbol indicates a single locality record, except in Alameda and Contra Costa Counties, where the numbers refers to the total number of sites for *Paramylodon harlani*.

Unfortunately, the samples available for each taxa at two of the sites, Manix Lake and Hawver Cave, are small and provide only enough information to establish each species presence. Rancho La Brea, however, is a site with large enough samples to provide meaningful comparisons in a quantitative sense. Sloths from Rancho La Brea were not equally abundant: based upon the census by Marcus (1960), *Paramylodon harlani* dominated (76 individuals), followed by a smaller number of *Nothrotheriops shastensis* (22 individuals) while *Megalonyx jeffersonii* is represented by only 2 or 3 individuals (C.A. Shaw pers. comm.). Likewise at the Costeau Pit, Miller (1971) recorded nine individuals of *Paramylodon harlani* but no remains of either *Megalonyx* or *Nothrotheriops* were recovered.

As noted by Shaw and Quinn (1986), the changing flood plain microenvironment documented in the sedimentary deposits at Rancho La Brea indicates that the composition and distribution of the late Pleistocene flora varied through time. Four main communities are identified as having existed in the region: coastal sage scrub, chaparral, deep canyon and riparian associations. *Paramylodon* may have utilized the coastal sage scrub habitat with *Nothrotheriops* preferring the chaparral growing on the slopes of the Santa Monica Mountains, while *Megalonyx* frequented the riparian habitat. Given the dynamic nature of changing vegetational associations and long period of time (ca. 30,000 years) over which animal remains accumulated at Rancho La Brea, each of the species of ground sloth could have lived in the area at a different time when suitable vegetation was available and may not have inhabited the vicinity of Rancho La Brea contemporaneously. Marcus (1960) observed that the relative proportion of large herbivores, including *Paramylodon harlani*, recovered from the seven major pits did not differ statistically suggesting that the abundance and entrapment of these species did not vary during the times of activity of the different pits. He noted that the number of individuals of *Nothrotheriops* did vary from pit to pit and that the presence or absence of *Nothrotheriops* is probably significant in itself. It is likely that the presence of

Table 1. Rancholabrean localities in California, Nevada and Arizona where *Paramylodon harlani, Megalonyx jeffersonii,* and *Nothrotheriops shastensis* have been found.

	Paramylodon harlani	*Megalonyx jeffersonii*	*Norhrotheriops shastensis*
CALIFORNIA			
Alameda Co.			
Alameda Canal	●		
Alameda Tube Excavation	●		
Delta Mendota	●		
Doolan Canyon	●		
Oakland Coliseum	●		
Rodeo Station #1	●		
Rodeo Station #2	●		
Shattuck Ave. #1			
Alameda Co. (?)	●		●
type of *Morotherium gigas* Marsh (1874) included remains of *P. harlani and* N. shastense			
Calaveras Co.			
Mercer Cave		●	
Contrao Costa Co.			
Alamo Creek #2	●		
Antioch Creek #2-3	●		
Bulls Head	●		
Cameo Acres	●		
Highway 40 #1	●		
Hipparion Point #2	●		
Lone Tree Point		●	
Martinez	●		
Pleasant Hill		●	
El Dorado Co.			
Hawver Cave	●	●	●
Imperial Co.			
Salton Sea			●
Kern Co.			
Maricopa	●	?	
McKittrick	●	●	
Kings Co.			
Dudley Ridge	●		
Tulare Lake	●		
Los Angeles Co.			
Beacon and 2nd St.		●	
Centinella Park		●	
Century Blvd/Van Ness	●		
Chandler Sand Pit		●	
Harbor Fwy & 112-113th	●		
La Brea and San Vincente	●		
La Mirada, Coyote Creek		●	
Los Angeles Brick Yard	●		
L.A. Harbor Berth 128	●		
Naval Housing Unit	●		
Palos Verdes Hills	●		
Rancho La Brea	●	●	●
San Fernando Dam	●		
San Pedro Hill 48/Lumber Yard		●	●
Woodland Hills	●		
Marin Co.			
Hamlet Station	●		
Merced Co.			
Merced River #1	●		
Orange Co.			
Bolsa Chica State Park	●		
Costeau Pit	●		
Emery Borrow Pit		●	
Imperial Hwy La Habra	●		
Newport Bay Mesa		●	●
Salt Creek Laguna Niguel	●		
San Clemente	●		
Riverside Co.			
Carbon Canyon Wastewater	●		
Domenigoni Valley	●	●	
Pauba Mesa	●		
Sacramento Co.			
Sacramento Sports Stadium	●		
Teichert Gravel Pit	●		
San Bernardino Co.			
Campbill Hill & 29 Palms Gravel Pit		●	●
Fort Irwin			●
Manix Lake	●	●	●
Mitchell Cavern			●
Newberry Cave			●
San Francisco Co.			
Twin Peaks Tunnel	●		
Pacific Street, S. Fran.	●		
San Joaquin Co.			
Tracy Gravel Pit		●	
San Luis Obispo Co.			
Diablo Canyon	●		
Pecho Creek	●		
San Mateo Co.			
Mussel Rock #2	●		
Santa Barbara Co.			
Lompoc-Vandenberg	●		
Los Alamos	●		
Point Concepcion	●		
Point Sal	●		
Santa Clara Co.			
Mountain View Dump	●		
Vet Hosp. Matadero Cr.	●		
Shasta Co.			
Potter Creek Cave		●	●
Samwell Cave		●	●
Siskiyou Co.			
Yreka	●		
Solano Co.			
Suisun Slough	●		

Table 1 (cont.)	*Paramylodon harlani*	*Megalonyx jeffersonii*	*Norhrotheriops shastensis*
Sonoma Co.			
McGrew's Ranch	●		
Crandall	●		
Petaluma	●		
Stanislaus Co.			
Brant Ranch	●		
Garber Farm		●	
Trinity Co.			
Douglas City		●	
Ventura Co.			
Brea Canyon, Simi	●		
Yolo Co.			
Stevenson Ridge	●		
Yuba Co.			
Marysville	●		
NEVADA			
Clark Co.			
Devil's Peak			●
Gypsum Cave			●
Las Vegas Wash			●
Tule Springs		●	●
(NV) Carson City Co.			
Nevada State Prison	●		
ARIZONA			
Apache Co.			
Springerville	●	●	
Cochise Co.			
Pyeatt Cave			●
Coconino Co.			
Coconino Cavern			●
Maricopa Co.			
Nichols Site			●
Mohave Co.			
Muav Caves			●
Rampart Cave			●
Navajo Co.			
Shonto	●		
Pima Co.			
Deadman Cave			●
Ventana Cave			●

Nothrotheriops and *Megalonyx* at Rancho La Brea reflects those times when suitable habitat existed in the vicinity of the pits. Given the preponderance of *Paramylodon harlani* remains it would seem that Rancho La Brea, situated at low elevation near the coast, may have provided the type of habitat preferred by *Paramylodon*. Habitat for the other two taxa was either marginal or restricted in distribution either geographically or chronologically, resulting in smaller populations and less chance of entrapment and preservation.

The traditional interpretation that *Paramylodon* is considered to be a grazer is seemingly contradicted by the apparent lack of evidence at Rancho La Brea for the local presence of monocots, either as pollen or seeds. The percentage of grass compared to nongrass tissue lodged in the fossettes of teeth of other presumed grazers such as camel (10.5%), bison (13.4%) and horse (44.4%) is lower than expected, based on our knowledge of the dietary habits of their living relatives (Akersten *et al.* 1988). This may indicate that *Paramylodon* was not restricted to grazing grasses exclusively and may have supplemented its diet with other local vegetation as did these other species of presumed grazers. Naples (1989) suggested that the diet of *Paramylodon* may have consisted of plants of high fiber and low nutrient content and that it should be interpreted more as a browser-grazer rather than a "pure" grazing form.

Table 2. Calculation of degree of association of *Paramylodon harlani*, *Megalonyx jeffersonii* and *Nothrotheriops shastense*. Index of Association is calculated by 100C/N1 + N2 -C. N1 (total number of sites for species 1), N2 (total number of sites for species 2), C (number of sites in which both species occur).

Paramylodon harlani (N1) 67	*Megalonyx jeffersonii* (N2) 24	Common (C) 6
Paramylodon harlani (N1) 67	*Nothrotheriops shastensis* (N2) 24	Common (C) 4
Megalonyx jeffersonii (N2) 24	*Nothrotheriops shastensis* (N2) 24	Common (C) 10
P. harlani / *M. jeffersonii* Association	7.1%	
P. harlani / *N. shastense* Association	4.7%	
M. jeffersonii / *N. shastense* Association	26.3%	

It is apparent that, while general patterns can be seen in the distribution of each sloth species, the specific factors limiting their distribution, whether food requirements, temperature or other factors, still need to be determined.

The degree of association that existed between the three species of sloths may be surmised using the coefficient of similarity developed by Simpson (1947) to calculate the degree of similarity between two faunas. This formula 100C/N1 + N2 - C has been adapted to the following species pairs: *Paramylodon harlani/Megalonyx jeffersonii; Paramylodon harlani/Nothrotheriops shastensis;* and *Megalonyx jeffersonii/Nothrotheriops shastensis* (Table 2). Table 2 indicates that the number of localities within the area of this study for *Paramylodon* is about three times greater than those with either *Megalonyx* or *Nothrotheriops*, yet the association of *Paramylodon* (the grazer) is low with *Megalonyx* (7.1%) and *Nothrotheriops* (3.5%) (both interpreted as browsers). Although neither *Megalonyx* nor *Nothrotheriops* is as common as *Paramylodon* they are known from a similar number of localities, 24, and yet are found together at 10 localities (26% of the time) despite the fewer known sites. This is probably best explained as reflecting ecological requirements as browsers, resulting in a greater potential utilization of habitat that provides browse. Despite the greater degree of overlap in habitat utilization by *Megalonyx* and *Nothrotheriops*, it was not a strong association and probably reflects use of habitat that was secondary, rather than primary, preference for one or the other species. Phillips (1984) concluded that *Nothrotheriops* selectively browsed desert vegetation and ingested woodland plants only accidently or incidently, so its association with

Megalonyx probably only occurred in ecotonal situations such as the extension of gallery forests along permanent river courses into otherwise arid regions.

In most cases each species is represented by a small amount of skeletal remains, but in those situations where the two species co-occur and large samples are available, there is a disproportionate representation of one species over the other. Rancho La Brea is one example; this disproportionate ratio is also present at San Josecito Cave in Mexico, which produced a single individual of *Megalonyx jeffersonii* but at least 19 individuals of *Nothrotheriops shastensis* and no *Paramylodon*.

Conclusions

Preservation and relative abundance of a species in the fossil record is affected by numerous factors, biotic and abiotic. Population density, social organization, size of the home range and body size determine the number of individuals in any given area. If size was a primary controlling factor, then the largest species (*Paramylodon harlani*) might be expected to be rarer than the smallest (*Nothrotheriops shastensis*); the intermediate-sized sloth (*Megalonyx jeffersonii*) would also be intermediate in the number of individuals. This is not reflected in the fossil record. The largest sloth is the most common, possibly reflecting the greater robustness of its skeleton and improved chances for preservation. Perhaps *Paramylodon* was a more social animal and formed small herds, while *Nothrotheriops* lived in smaller family groups. Perhaps *Megalonyx* was solitary in habit? While this scenario may account for the relative abundance of each species and may explain why one species is more often preserved than another, it does not explain the pattern of low degree of association between the three species. While these factors may have contributed in some part to the relative abundance seen in Table 2, it is apparent that, based on our current state of knowledge, differences in the ecological requirements of *Paramylodon harlani*, *Megalonyx jeffersonii* and *Nothrotheriops shastensis* determined their distribution. The absence of a close association among these species resulted from utilization of distinct habitats.

When two or more of these species are found as faunal associates, the sample either reflects a mosaic of different plant associations in close proximity or that the fauna (such as Rancho La Brea) is a time-averaged sample. This kind of sample will include representatives from plant communities and their associated fauna that existed at different times. Some of the species preserved together did not necessarily share a common habitat. Specific details regarding habitat requirements of those species will require additional work with larger samples.

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Early Mines of Southern Clark Mountain, the Northern Mescal Range and the Ivanpah Mountains

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Introduction

The first recorded mineral discovery in Clark Mountain, the Mescal Range and the Ivanpah Mountains was in 1868 at the Copper World mine on the southwest slope of Clark Mountain. Earlier mining occurred in 1863 at Rock Spring in the Providence Mountains, about 10 miles due south of the southern end of Ivanpah Mountains, and it has been presumed that soldiers stationed at Marl Springs, between 1867 and 1868, first worked the small gold deposits there. Although the Copper World mine was the first to be discovered, two mines discovered in 1879, the Mescal and Bullion mines, were worked in the 1880s. The Mescal mine camp, though no more than a handfull of buildings; briefly boasted mail service. The Copper World mine languished until 1898 when it became one of the most significant copper producers in the county. With a large payroll, this camp, known as Rosalie, was also served by the U.S. Mails.

Copper World Mine

Johnny Moss is credited with discovery of the Copper World mine on the southwest slope of Clark Mountain. Moss, born in Utica, Iowa in 1839, came to California in 1857, was a Pony Express rider, and in 1861 headed to the new gold discoveries in El Dorado Canyon, due east of Searchlight, Nevada. In 1863, he discovered the fabulously rich Moss gold mine in Mohave County, Arizona. The next year he took the Mojave Chief Irataba to Washington, D. C. to see the white chief, president Abraham Lincoln. During this time of Indian unrest on the Mojave, he signed a treaty with the Piute Indians which permitted him unrestricted travel and use of their territory.

In 1868 a Piute chief brought Moss a piece of metallic copper, and after some searching, Moss found the source. He then headed to San Francisco with samples to interest potential investors. On the strength of his report, the Piute Company was organized April 13, 1869 in San Francisco. Without delay a company sponsored party set out from Visalia to explore the area. Accompanied by mining expert, James H. Crossman, a Massachusetts-born "forty-niner," the party discovered silver in addition to the copper, and staked some 130 claims in the Clark and nearby Yellow Pine District.

Another member of the party was William H. Clarke, a Visalia businessman and saloonkeeper. The mining district and mountain took their name from Clarke, in time loosing the "e." These locations included additional Copper World claims staked on September 24, 1869, around the original Moss discovery of the year before. Later that year a few tons of very high grade ore were extracted from the Copper World and shipped to San Francisco.

After it lay idle for about 10 years, James H. Boyd investigated opening the mine. In April 1878 he erected a experimental smelter in San Bernardino (in back of Van Dorin and Lehman's wagon shop on Third Street) with the intention of moving it to the mine if it proved to be successful. The absence of any positive news leads to the conclusion that it was a failure. Boyd, also owner of the Bullion mine, continued to hold the Copper World for nearly twenty years, without any apparent

Figure 1. Copper World smelter crew, 1900-1901. *Bembry collection, San Bernardino County Museum.*

Figure 2. Copper World superintendent U.C. Reche and his wife. *Bembry collection, San Bernardino County Museum.*

effort toward further development. In 1884 a correspondent from Ivanpah wrote regarding the mine, "...south of Ivanpah, and in Clark's district, are some large copper mines, among which are the Copper World, Nos. 1 and 2. This group of mines would furnish a large amount of freight."

But no one took up the challenge this large copper deposit represented until late in the 1890s. The Mining and Scientific Press reported in January 1897 that eastern capitalists were negotiating for purchase of the mine. At about this time the mine was little more than a prospect, with two 50-foot deep shafts and two adits 15 and 75 feet long. According to one doubtful story, it was owned by a Mr. Lawrence, who after drilling a hole for a blast, found red copper oxide, but refrained to shoot the round, fearing a blast would destroy the evidence of mineralization. Little was he to know at that time the riches this mine would produce.

September 1898 he sold the mine to the Ivanpah Smelting Company of Los Angeles for $1,100. The company, incorporated with an original stock issue of $250,000, immediately began blocking sufficient ore to justify construction of a smelter.

Certain of enough ore to supply a smelter for five years, a crew of 85 (Fig. 1)under the superintendency of V. C. Reche (Fig. 2) sank two wells five miles west of the mine, and in December, 1898, began constructing a fifty-ton smelter capable of smelting 50 tons of ore per day. The smelter began operations March 10, 1899, and produced six to seven tons of ninety-five percent pure copper daily. (Fig. 3)

The camp at the wells was known as Valley Wells or Rosalie Wells (or simply Rosalie) (Fig. 4). The post office moved from Ivanpah to Rosalie on April 24, 1899. In November W.F. Blake visited the mine and pronounced, "The Copper World..is proving to be a veritable bonanza, and a camp is growing there that will eventually be as large as the famous Jerome copper camp." In spite of this, there are virtually no contemporary accounts of the camp, although photographs show numerous buildings at the mine. (Fig. 5)

The miners were producing one ton of ore per day, per man, but were limited by the 50-ton per day capacity of the smelter. Twenty-mule teams hauled 35 tons of ore from the mine to the smelter (Fig. 6). Altogether there were some 140 mules

Figure 3. TheCopper World copper smelter; Clark Mountain at left. *Larry Vredenburgh collection.*

utilized in the operation. After reduction at the smelter, the nearly pure copper was teamed to the California Eastern Railroad at Manvel, 30 miles southeast. Supplies and coal from New Mexico for the smelter came with the return trip. Three or four times a month a 20-ton carload of copper was shipped to New York for final smelting. Each rail-car of copper was worth $7,000. By late 1899 the Copper World was said to be one of the four largest copper mines in the United States. Up to June 1900 it was reported that 11,000 tons of 13.5% ore had been produced.

As early as July 1899 legal troubles began to surface. At that time W.E. Robinson, formerly vice president and general manager, filed suit against J.D. Hanbury, president of the Ivanpah Smelting, to recover payment for services rendered for the period July 18, 1898 to May 2, 1899. One of the issues of the lawsuit involved the company's agreement to pay him a salary of $6,000, yet he had received just $400. This litigation seriously affected subsequent production. In May 1900 the mine closed. In early June it was again operating, but with ore sufficient to last only six weeks. Work again stopped in July - the men were paid and discharged, and on July 31, the post office closed. Just one month later work briefly resumed. Factors cited for cessation of operations at the time were the high loss of copper in the slag and high cost of smelting.

Transportation to Manvel was very expensive. To cut costs the Ivanpah Smelting Company persuaded the California Eastern Railroad management to extend the line down the steep canyon from Manvel. The Santa Fe Railroad subsidized construction for this extension which began April 1901, and in January 1902, the final spike was driven for the ten mile extension to the present location of Ivanpah siding on the Union Pacific. On April 5, 1902, the Los Angeles Mining Review reported,

> A new contractor is building a three-mile extension to the to the California Eastern, beyond the extension built last year by Bright and Crandall. The latest piece of track being laid across a sandy wash to a point where teams freighting to the Copper World and other camps can load without having to pull through a stretch of sand.

But no copper was being produced from the Copper World. The California Eastern was purchased by Santa Fe on July 1, 1902.

The end of the extended rail line was 15 miles from the Copper World. A settlement named Ivanpah (the second place with that name) sprang up at the end of the line. This new Ivanpah consisted of about 20 to 30 people.

In January 1902, after the railroad reached the Ivanpah Valley, the mine and smelter resumed operations for at least two months. A new hoist was installed and the smelter was producing 10 tons of copper a week. In spite of plans to erect a larger smelter and construct a traction road to Ivanpah, the mine operated only briefly. In November 1902, the

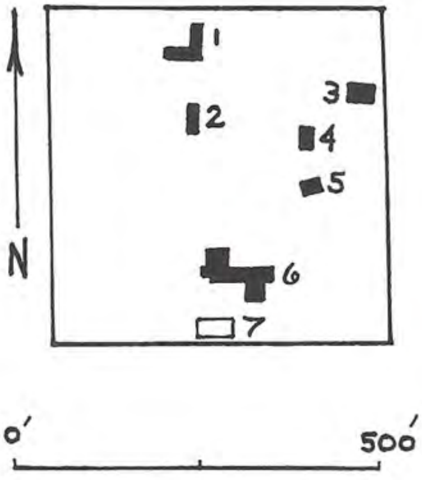

Figure 4. The Rosalie Millsite in 1918, from U.S. Mineral Survey 5372, surveyed for the Cocopah Copper Company by U.S. Mineral Surveyor Horace N. Taylor. 1: Bunk house; 2: mess house; 3: office; 4: garage; 5: assay house; 6: smelter; 7: reservoir.

Figure 5. The Copper World mine; note team on left near mine dump. *Undated photograph, Riley Bembry collection, San Bernardino County Museum.*

Figure 6. Hauling ore from the Copper World mine to the smelter at Valley Wells. *J. Riley Bembry collection, San Bernardino County Museum.*

company, now headed by George H. Sission, was in debt to a Los Angeles bank. Although some copper "bullion" was at hand - it wasn't enough. A sheriff's sale was set for December 15. During 1903 the Ivanpah Smelting Company found itself in new legal entanglements. Former superintendent Reche had apparently filed new mining claims when the Ivanpah Smelting Company let the original ones lapse.

Dr. L. D. Godshall acquired the title to the property in 1906, organized the Cocopah Mining Company, and operated the mine from August, 1906 until 1908. Over the intervening years between 1902 and 1906 the smelter had disintegrated, forcing the new owners to haul unprocessed ore rather than copper metal to the railhead at Ivanpah, and there to the Needles Smelter, another enterprise of Godshall's. To help keep costs at a minimum the new owners offered freighters a handsome bonus for hauling ore to the railroad ahead of a set schedule. Although they had plans to erect a new smelter two miles from the mine, it was not constructed.

At Ivanpah, the Santa Fe station, which had been deserted "for some time" burned April, 1908, supposedly by tramps. Four or five adjoining buildings - the entire "town" - also burned. A train ran from Manvel until 1913, and the rails were torn up in 1921.

With the high price of copper during World War I, mining resumed. The Cocopah Mining Company, reorganized under the name Ivanpah Mining Company, began operations May 1916, and continued steadily until late 1918. In November, 1917, a 100 ton capacity blast furnace for making copper matte opened at Valley Wells. About 100 tons of ore a day were hauled to the smelter by tractor. 13,000 tons of slag from earlier operations were re-smelted. This slag averaged from 2 to 10 percent copper.

The copper matte was hauled 25 miles to the Salt Lake Route at Cima and shipped to the smelter at Garfield, Utah. Sulphur for the smelter charge, in the form of iron pyrite , was obtained from Jerome, Arizona, and from the Francis copper mine (another enterprise of Dr. Godshall), located on the southwest slope of the Providence Mountains. In 1918 60 men were employed. Operations were suspended in 1918 due to the low price of copper. The average value of the ore for these operations was 4 percent copper, 3 to 5 ounces of silver and .04 to .1 ounces of gold per ton. In 1944, 3,743 tons of old tailings were treated, and in 1949 copper furnace matte was shipped in a cleanup operation.

In 1977 Philip Rivera acquired a long-term lease from the Dan Murphy Foundation, the owners of the Copper World. In June 1977, he commenced mining for "Royal Gem Azurite" a combination of malachite, azurite, and tenorite. Work continued until at least 1981.

Mescal Mine

The 1869 silver discoveries by the Piute Mining Company on the northeast slope of Clark Mountain and the subsequent discovery by the McFarlane brothers in the spring of 1870 resulted in the formation of the small but lively town of Ivanpah. The mines and mills here thrived, albeit somewhat fitfully, until 1881, when output declined even faster than the price of silver.

There was never sufficient water at Ivanpah for the mules which packed silver ore from the McFarlane brothers' mines six miles east to the mills at Ivanpah, so Mescal Spring, about eight miles to the south, was utilized to water the mules. One evening late in 1879 Mr. Orr, laying in his bunk in a rock cabin at Mescal Spring, recognized mineralization in one of the rocks with which the cabin was constructed. Then he headed up the draw with Morgan and discovered the Mescal Mine. In March 1880 it was reported that the mine was "turning out all that could be desired".

In 1882 the mine, which was interchangeably referred to as the Mescal or Cambria, was sold to William A. McFarlane and Simes A. Barrett. Little is heard about it until April 1885 when McFarlane stopped at Calico on his way to San Bernardino long enough to inform the editor of the Calico Print he intended to return to the mine with a small mill. He also reported that they had 100 tons of $100 rock on the dump, and the former operator had milled 100 tons of ore. At this time a modest crew of men had driven a 80 foot long drift.

In May 1885, a number of miners and wood choppers arrived from Providence as activity began to pick up. A month later, the Calico Print announced, "Mescal mining camp has commenced to boom. About 20 pack animals of John Domingo are making daily trips from the Cambria

Figure 7. The Mescal mill, from a contemporary publication. *Larry Vredenburgh collection.*

mines to the mill at Ivanpah." In spite of these pronouncements only seven or eight men were employed at the mine.

On Wednesday, June 17, 1885, the long idle Ivanpah mill began processing ore from the Cambria mine. By the middle of July, the first two bars of silver bullion worth $2,720 were shipped by Well, Fargo and Co.

The mine's most productive period began in January 1886 when McFarlane leased, and then sold, the Cambria Mine to a company of Los Angeles businessmen. Under the supervision of McFarlane and Barrett, the company's 20 men drove a second tunnel, 125 feet below the first, installed a 350-yard tramway, and graded a site for a five-stamp mill near Mescal Spring. The mill started up in early December, turning out four bars of bullion weighing 5,000 ounces (Fig. 7).

Mescal was a compact, well-run camp. A correspondent of the Print considered the mill "a

thoroughly substantial one in all its parts. They have a fine assay office, overseen by the painstaking assayer, Mr. L. A. Blackburn. The office is comfortable, and the boarding-house, lodging house, etc., show that they look to the comfort of their men.." A handful of men, several with families, were living in well-built adobes covered with good shingle roofs. "Good" miners were receiving $3.50 a day; "excellent" board cost $8 a week. Mescal was, a visitor was later told, a camp where wages were good, work was steady and "everybody was happy."

Three adobe structures at the camp were built here by Adolph Nevaras: an assay office, a boarding house, and the superintendent's house. Nevaras also built the assay office for Bidwell at Ivanpah and the Alf's home in Daggett.

Many changes occurred early in 1887. An additional 5-stamp battery was added to the mill in April, 1887. The 10-stamp mill ran day and night. The Cambria Mill and Mining company also purchased the mines and mill of the Ivanpah Mill and Mining Company. Mail service to the camp began in March. The post office was known as Nantan. A weekly stage meanwhile ran from Fenner station on the Santa Fe line, and a store was in business. Mescal was at its peak. But the price of silver was on a decline from an already-low 97 cents an ounce to 94 cents in 1889. The grade of the ore was also declining, to $20 a ton. One 1890 report stated "a ten-stamp mill is kept running," yet only twelve people lived in the area; and the post office closed that December. Reportedly the Cambria Mine by then had produced $250,000 in gold and silver.

Just after the turn of the century, local cattleman Sidney Yates used the boarding house in association with cattle operations. A heavy snow collapsed the roof, and the shakes were replaced with sheet iron in 1911. The mill was scrapped in 1914. A short lived revival in 1915 yielded 2,000 ounces of silver and minor gold. The assay office remained in fair condition until a story in a treasure magazine reported that gold coins had been hidden in the adobe walls. Treasure hunters soon demolished the building.

Mescal Mine Footnote

The effect of falling silver prices produced the situation where in early 1893 a silver dollar contained only 40 cents worth of the metal. It would be more profitable to counterfeit silver dollars from pure newly mined silver than to sell the silver.

In an 1895 Los Angeles Times article (Bennett, 1895), which seems to have sprung from the writer's imagination, told of two Denver business men, known only as Spencer and Davis, who sought to recoup the fortunes they had lost in the depression by counterfeiting silver coins. According to the story, Spencer and Davis bought the Mescal property and built a smelter, brought in a carefully selected crew, and installed counterfeiting machinery at the bottom of a deep shaft. Spencer and Davis soon began taking out each day 20 tons of ore containing a total of 800 ounces of silver, enough to coin one thousand bogus dollars. Tightly packed into hollow bars of silver, the coins were shipped out to cities and fenced.

The silver dollars were excellent imitations. But their accidental discovery in a hollow silver bar led John E. Bennett, a Secret Service agent, on a painstaking hunt for clues. Finally Bennett found his prey in the summer of 1893 and enlisted the aid of a detachment of soldiers. After leaving the railroad, Bennett and a guide finally "turned around a small cone-like hill and there before us, close upon us, was the Mescal camp. It lay on a ridge which made out from the mountain into the valley... Above on the bold side of the high roaring mountain was the mine, its grey dump marking with a light splotch the dark slope..." Buckets suspended on an aerial tramway carried ore from the mine to the smelter. Running down a steep slope, a pipe from the mine fed a pool of delicious water. Visitors were unwelcome, but Bennett contrived to have himself stranded in the camp.

One morning in August, Bennett identified himself as a secret Service agent and ordered Spencer and his crew to surrender. Spencer merely sneered "Pooh, you talk like a fool. I'll have you know, sir, that it will take a better man than you to arrest a whole camp and shut down a mine on such a fool charge at that..."

Spencer had prepared for such an emergency. Just as Bennett's men were about to charge over the hill, Spencer blew a whistle. The mountain inside began to rumble. An explosion blew Bennett and several others off their feet; boulders went flying. One man was fatally injured. Under the rubble, too deep to dig out, were the dies, roller, and counterfeiting press. Taken to Los Angeles for trial, Spencer, Davis, and their smelterman were acquitted for lack of evidence. But they never returned to their old ways.

Bullion Mine

The history of Bullion mine, namesake of the Bullion Mining District, has been a puzzle to researchers. In reference to this mine in their compendium of San Bernardino County mines, Wright and others, state, "Shipped high grade silver-lead carbonate ore to Wales in 1860's and 1870's via Colorado River." Paul Patchick in his Masters thesis, and a *Desert* magazine article cite the same source: the 1888 report by California Mining Bureau geologist William Ireland. However, Ireland makes no mention of shipments to Swansea; he reports in part: "Bullion. This mine is situated eight miles south of Seedlow Station on the Atlantic and Pacific Railroad. The vein on the surface showed gray copper, with 62 percent copper, a little silver, and traces of gold..." It is evident that Seedlow is a typographical error for Ludlow - and today the mine located eight miles south of Ludlow is the Bagdad Chase. On the northeast flank of the Bullion Mountains, the Bagdad Chase is the largest source of copper in the county, but is also a significant gold producer. The Bullion mine, south of Mountain Pass, while containing copper, was primarily known as a silver mine in the 1870s. It was not until 1953 that the Bullion mine in the Mescal Range is mentioned to have been worked in the 1860s.

As Paul Harvey would say, "Now for the rest of the story..." The Bullion mine is insignificant, but it does seem to have been the first mine worked in the district. It is located less than one-half mile east of the New Trail Mine on the east side of the Ivanpah Mountains. In March, 1879, James H. Boyd, owner of the mine, located a ledge here that, when assayed at Bidwell's mill at Ivanpah, ran $350 per ton in silver. Also in March 1879, Boyd, in an open letter to William Griffin, esq., president of the Workingmen's Club in San Bernardino, advertised for a boy between 15 and 18 years old to work at the Bullion Mine, driving a burro or jackass and packing water for his mine camp. He offered to pay $30 per month and board, and explained that he now employs an Indian at 75 cents per day.

The hyperbole regarding this mine is remarkable. On May 10, 1879 the San Bernardino *Weekly Times* offered: "The Bullion mine, the Bonanza of the camp, is one of the most promising mines in Southern California. At a depth of 85 feet, two feet of splendid grade milling ore, going up in the hundreds per ton, has been struck. Jesse Taylor's team makes a trip every three days hauling five tons per load." And on October 18, 1879, "Our sister district, Copoweep, where the Bullion mine is located, is an undeveloped district with the exception of the famous Bullion mine, which is one of the foremost mines in the southern country. It is down several hundred feet, with very high grade ore."

In contrast, James Crossman, who accompanied the Piute Company to Ivanpah in 1869, stated in 1890, "Bullion District. Lies seven miles southeast of Nantan. It contains a number of promising veins carrying ores of both silver and gold. But little work has as yet been done here."

About 1905 Jim Connolle and a Salt Lake City company mined several carloads of ore. Afterit lay idle for 4 years, George Bergman, an Eldorado Canyon mine owner, leased the mine in May 1909 and posted a $50,000 bond. At that time the mine was owned by Jim and Pat Monaghan of Victorville and Heber Robinson. At the mine were "fair mine buildings and a whim." It was developed by a half dozen shafts, the deepest being 250 feet with levels every 50 feet that were driven 100 feet through the rock. The Monaghans continued their interest at least until 1913. There were about 250 tons of lead- copper-silver ore produced from the mine in 1916-1917 but it apparently has not produced any since.

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Later Mining History in the Mescal Range, Ivanpah Mountains and South Clark Mountain

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ABSTRACT

Except for the Mescal and Bullion mines, discussed in a separate paper in this volume, there was no other recorded mining in the Mescal Range and Ivanpah Mountain until the mid-1890s. A new era of opportunity was ushered in with the January, 1905 completion of the San Pedro, Los Angeles and Salt Lake Railroad, (now the Union Pacific). The completion of the railroad, which runs just south of the Ivanpah Mountains, and establishment of Cima as a station, provided cheaper supplies and transportation of ores. Completion of the railroad coincided with a surge of mining interest throughout the desert. In addition, the copper mines of the district probably benefited from a spill-over effect from the 1906 Greenwater frenzy. Numerous base metal deposits were mined during the World Wars. The Morning Star mine, active between 1927 and 1942, was a significant gold producer between 1988 and 1993.

Kokoweef Caves

Paul Patchick in 1961 summed up the history of the Kokoweef Caves. His description is reproduced here:

> In the 1920s a miner named E. P. Dorr explored a cave high-up the side of Kokoweef Peak. Later, in a sworn affidavit, Dorr reported an amazing discovery - and a lost mine legend was born. Deep under Kokoweef Peak, he said he found a swiftly flowing subterranean river; lining its banks were sands rich in gold. The legend grew. "Facts" became scarce. The cave entrance was dynamited shut...there were stories of Dorr going insane, of murdered men, of men buried alive, of rich assay sheets. Some sources say the main cave chamber has several entrances on the flanks of the peak. In his book, *Adventure is Underground*, William R. Halliday reports that the Crystal Cave Mining Corporation now owns the property. Would-be lost mine hunters are not welcome. Besides, the danger to all but the best trained and equipped cave-explorer is extreme. Two persons lost their lives here in 1959.

In 1988 Bob Ausmus wrote a less cynical, updated history which appeared in The Friends of the Mojave Road, *Guide to the East Mojave Heritage Trail, Ivanpah to Rocky Ridge*. Although the Kokoweef Caves have not yielded the much advertized river of gold, a paleontological treasure has been uncovered. Bob Reynolds of the San Bernardino County Museum during the 1970s excavated remains of Pleistocene age animals including brush ox, dire wolf, large and small camels, horses, marmots, bats, shrews and birds.

Standard Camp

In 1896 the California Mining Bureau reported that the Ivanpah Mountains were the scene of active prospecting for gold-copper ore. During this revival, the Excelsior Mine was located by Joseph Nelson and Gus Moore of Manvel, and eventually a 124-foot deep incline shaft was sunk. A mine camp known as Copper Camp was established here.

Nine years later in the summer of 1905 the mine was leased from Nelson by the Standard Mines Company of Los Angeles for a 10-year period. The mine from then on was known as the Standard Number 1, or the Standard. Work soon started there and on the nearby Standard Number 2.

The company spent $25,000 sinking a two-compartment shaft and constructing a camp consisting of a bunk house and boarding house sufficient to house 100. The camp had a store and even telephone service. Wagons pulled by 16-horse teams hauled ore ten miles to the railroad at Cima, where the Salt Lake Railroad shipped it to smelters at

Figure 1. The Standard #1 camp. *J. Riley Bembry photograph, San Bernardino County Museum.*

Figure 2. The Cima 1, or Little Johnnie mine, near the Sextette Camp in 1906. *J. Riley Bembry collection, San Bernardino County Museum.*

Salt Lake City. The mine was productive for 18 months, yielding 60 railroad car loads of ore that averaged 9.2 percent copper and about $4 in gold and silver, worth a total of $68,000. By December 1906, the mine was tied up in litigation. The August 1907 American Mining Review reported, "The mine has been stripped of practically all ore that was developed, and is now closed down owing to exceptionally bad management."

Despite this bleak assessment, in September 1907 two shifts were again working the mine which continued to produce sporadically until 1919 when it was abandoned.

Evening Star Mine

The Evening Star Mine, located 1 1/2 miles south of the Standard No. 1, began life in 1935 as a copper prospect by J. Riley Bembry. Within a year he sold the property to Trigg L. Button and Clarence Hammett of Santa Ana who began sinking the No. 1 shaft. In 1940 Vaughn Maynard of Santa Ana purchased the claims, and in 1941 the Tin Corporation of America leased the property. This company continued sinking the shaft, and shipped 25 tons in June 1942 to the Tin Processing Corporation in Texas City, Texas. In 1943 the mine was leased by Carl F. Wendrick, Jr., owner of the Steel Sales and Service Company of Chicago, Illinois. Wendrick secured a government loan, employed eight men, built a larger headframe, and constructed a mill at Valley Wells. Over 400 tons of ore were processed. Several tons of tin concentrates which contained 35.96 percent tin were sold to the government stockpile in Jean, Nevada.

The claims just west of the Evening Star Mine were leased from 1939 to 1940 to W. W. Hartman of Los Angeles. Hartman shipped about 1,000 tons of tungsten ore to the mill at Valley View gold mine at Hart.

Sextette Mine Camp

The Sextette mine, also known as the Standard Number 2, consisted of eight claims. The mine, situated north of the Copper King, shared similar geology and was developed for copper. The claims were located by Richard Bayley Gill and W. M. Fee. They bonded the mine to the Johnnie Consolidated Gold Mining Company of Nevada. By January 1906 the Johnnie Company had sunk a 256 food deep shaft, as well as other shafts and tunnels, and installed a new hoist. They shipped a total of four rail car loads of high-grade (22%) copper ore in 1906; each 40-ton car load returned $1,105. But apparently the mine did not pay, for in August 1907 Gill and Fee bonded the mine to a new concern.

Toegel City

Like the nearby Standard Mine, the Teutonia Mine (situated on Teutonia Peak two miles northwest of Kessler Springs) was first worked in 1896. One 50 foot deep shaft was sunk but was shortly abandoned due to lack of transportation. On May 14, 1906, Charles Toegel discovered the old mine, interested some investors, and formed the King Thebaw Mining and Development Company. The company set to work building roads and erecting a small camp known as Toegel City. The camp consisted of residences, a general store and blacksmith shop. From the fall of 1907 until at least 1909, about 100 tons of ore running up to 150 ounces per ton silver were shipped from the mine. By the 1920s the shaft had caved in and filled with water.

Kewanee and Sunnyside Camps

During the summer of 1907, the east side of the Ivanpah Mountains was alive with mining activity. Perhaps a dozen mines were being

Figure 3. Sunnyside Camp, Palm Hills Mining Company, after a snowstorm in 1907 or 1908. *J. Riley Bembry collection, San Bernardino County Museum.*

worked, and two small camps sprang up. At the Casa Grande Mine, a place called Meadsville was established after the discoverers Dr. J.S. Mead and his son. Then, Robert Williams discovered gold-silver-lead ore north and slightly west of the Casa Grande mine, and about one-half mile west of the Morning Star (at that time known as the Clansman). William's named his discovery the Sunnyside mine, and Sunnyside Camp was soon established. A correspondent for the newly established Barstow Printer reported the comings and goings of the families.

By the summer of 1908, the Meads' discovery had been renamed the Kewanee Mine, and the camp, Kewanee Camp. Between 1907 and 1911, Dr. Mead and the Kewanee Gold Mining Company ambitiously developed the property, hiring 50 miners, and installing a mill. The small quartz veins were richly mineralized with gold. An unsuccessful attempt was made in 1952 to reopen the mine.

The Sunnyside Mine was intermittently active until 1912 when the Los Angeles based Palm Hill Mining Company sank a shaft, installed a hoist, and constructed new buildings. In 1913 a mill was planned but apparently never constructed.

Morning Star Mine

The Morning Star mine, on the east slope of the Ivanpah Mountains north of Kewanee Camp, was first active in 1907, at which time it appears to have been known as the Clansman mine. Between 1927 and 1933 the deposit was extensively explored. In 1931 two men were employed at the mine. Between 1937 and 1938 Richard W. Malik of Los Angeles optioned the property from the claim owners, J. B. Mighton and H. T. Brown. During Malik's operations 17,000 feet of crosscut drifts were driven and winzes were sunk on the tunnel level. In April, 1939, E. P. Halliburton, owner of the Halliburton oil service company, began operations. Halliburton employed ten men until the property was shut down in 1942 by War Production Board's Order L-208, closing gold mines.

The Vanderbilt Gold Corporation acquired the property in 1964, drilling and sampling the property. In late 1979 they had raised sufficient capital to begin development. In the early 1980s the Morning Star was reactivated as an underground mine using trackless mining equipment. Ore was processed at Vanderbilt's mill at the site of the 1890s townsite of Vanderbilt, seventeen miles away. The ore was processed by flotation and concentrates were shipped for smelting. With the drop in the price of gold, mining ceased in 1982, but exploration by underground long-hole drilling continued. In 1983 the mill circuit was converted to cyanide carbon-in-leach. This allowed for bullion to be produced at the mill, eliminating the expense of having concentrates smelted. Drilling during this period established an 8 million ton ore reserve averaging .062 ounces of gold. In the fall of 1984 one million tons of overburden were moved and a $500,000 heap leach facility was constructed. Full-scale leaching began October 1987, and by year end 10,000 ounces of gold and 15,000 ounces of silver had been recovered. Production of ore was 75,000 tons per month. The operation

Figure 4. Morning Star leach pad., showing the buffer of sterile rock to guard against slumping or slipping of the crushed ore laden with cyanide solution. *Photograph courtesy Bureau of Land Management.*

was initially plagued by inadequate water supply, and lower than expected recoveries. The dilemma was solved by abandoning the spray leaching to drip - this doubled the amount of solution leaching through the heap, and used less water. Two heaps were ultimately constructed. The operation suffered from environmental violations including bird and animal deaths in the cyanide ponds, and cyanide solution leaking from the heaps into the adjacent drainage. Mining ceased by 1993. The company has submitted a new Plan of Operation to the U. S. Park Service which is currently under review.

Mohawk Mine

The Mohawk Mine, owned by the Ivanpah Smelting Company, was probably first worked in conjunction with the Copper World Mine. In 1900 the mine was surveyed for patent, at which time there were several hundred feet of underground workings. L. D. Godshall and the Cocopah Mining Company owned the mine by 1908. The company operated it during World War I until at least 1921. In 1918 the claims were resurveyed and patented, as was the Rosalie millsite at Valley Wells. During this period 2,893 tons of lead- copper-silver-zinc ore were produced with a value of $70,000. The ore was hauled to the railroad at Cima. Only ore which ran over 16 percent lead was shipped. The mine remained idle until 1942 when the property was leased from Godshall by Emerson Ray and S.D. Greenwood. The mine produced continuously between 1944 and 1952.

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Late Cretaceous Extensional Fault System across the Northeastern Mojave Desert

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Abstract

Rapid Late Cretaceous uplift and attendant cooling of mid-crustal Mesozoic metamorphic and igneous complexes in the eastern Mojave Desert and adjacent parts of the Great Basin have been ascribed to large-magnitude subhorizontal extension, but only a few extensional structures have been identified. We describe several shallow-level faults that may connect the previously isolated examples to form a larger fault system. This composite fault system, here termed the East Mojave fault, would extend from the southern Providence Mountains to the area of Shadow Valley, crossing the New York Mountains and Cima Dome. The East Mojave fault is segmented by Miocene and younger faults, but each segment consists of a down-to-the-west fault with kilometers of throw. The fault cuts plutons of the 92- to 97-Ma Teutonia batholith and ~78-Ma dikes intruding the batholith, and is overlapped by early Miocene tuffs. Minerals within a mylonitic part of the East Mojave fault yield K-Ar ages of ~70 Ma, which we interpret as recording the age of unroofing.

We suggest that during the latest Cretaceous, approximately 70 Ma, the East Mojave fault system in the shallow crust connected areas of deep-seated extension in the Old Woman Mountains area and the Death Valley region. This postulated 250-km long normal fault system, if confirmed, indicates that synchronous Late Cretaceous extensional events affected long segments of the Cordilleran interior, rather than a few localized areas, and strengthens previous suggestions that Late Cretaceous extension took place widely in the North American Cordillera.

Introduction

Evidence for rapid unroofing and cooling of mid-crustal rocks in the U.S. Cordilleran interior during the Late Cretaceous is well documented in a few localities and may have occurred regionally, although requisite detailed studies are lacking (*e.g.*, Wells *et al.*, 1990; Hodges and Walker, 1992). The possibility of widespread Late Cretaceous extension led Hodges and Walker (1992) to postulate a regional event driven by gravitational collapse of overthickened crust. Although regionwide cooling during the latest Cretaceous is well documented (*e.g.*, Foster *et al.*, 1990; Miller *et al.*, 1992), in many areas extension is neither confirmed nor well dated, in part because many areas also underwent profound mid-Cenozoic extension. The lack of evidence for north-south continuity of latest Cretaceous extensional structures makes regional models uncertain, and allows alternate mechanisms for regionwide cooling of the crust, such as "refrigeration" above the shallowly subducted Laramide slab (Dumitru *et al.*, 1991).

Two areas of the northeastern Mojave Desert and adjacent Great Basin underwent profound latest Cretaceous extension. Metamorphic and plutonic rocks in the Old Woman Mountains area (Fig. 1) underwent rapid cooling between 73 and 65 Ma, almost certainly requiring tectonic denudation (Howard *et al.*, 1987; Carl *et al.*, 1991; Foster *et al.*, 1992). Structural unroofing of metamorphic rocks in the Funeral Mountains of the Death Valley region (Fig. 1) was ongoing at 72 Ma (Applegate *et al.*, 1991; Hodges and Walker, 1992; Hoisch and Simpson, 1993; Applegate and Hodges, 1995). In both regions, extension was accommodated by normal-sense movement along west-dipping shear zones.

The area between Death Valley and the Old Woman Mountains (Fig. 1) is underlain by widespread granitoid plutons separating smaller tracts of Paleozoic and older rocks (Hewett, 1956). Overlying volcanic and sedimentary strata are Miocene and younger in age. The granitoids are principally mid-Jurassic and Late Cretaceous in age (see summaries by Miller *et al.*, 1991; U.S. Geological Survey, 1991). The largest group of related plutons is the ~95-Ma (DeWitt *et al.*, 1984; Miller *et al.*, 1991) Teutonia batholith of Beckerman *et al.* (1982), which covers half of the expanse from Death Valley to the Old Woman Mountains (Fig. 1). Most of the regional faults mapped and inferred by Hewett cut Cenozoic deposits. Known Mesozoic faults include the northwest-striking Kokoweef and Slaughterhouse faults (Burchfiel and Davis, 1977), which probably had substantial strike-slip separation and are characterized by Paleozoic strata preserved on their southwest sides. Present geochronology and mapping indicate that these faults were active before the Teutonia batholith was emplaced (Miller and Wooden, 1993) and they are therefore older than faults discussed in this paper.

New geologic mapping between Death Valley and the Old Woman Mountains has revealed regional faults with large-magnitude down-to-the-west separation and that cut the Teutonia batholith. New and

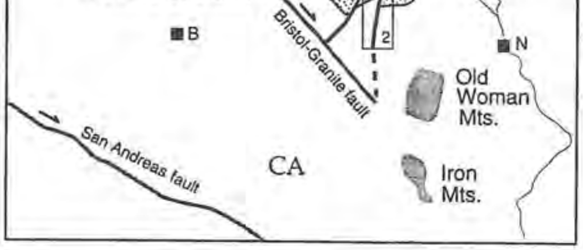

Figure 1. *Location map showing structures and areas described in this paper. Proposed Mesozoic extensional faults are in heavy black and Neogene faults in gray. Areas previously related to latest Cretaceous mid-crustal extension are in gray. B, Barstow; N, Needles; LV, Las Vegas. Boxes indicate locations of Figures 2, 3, and 5.*

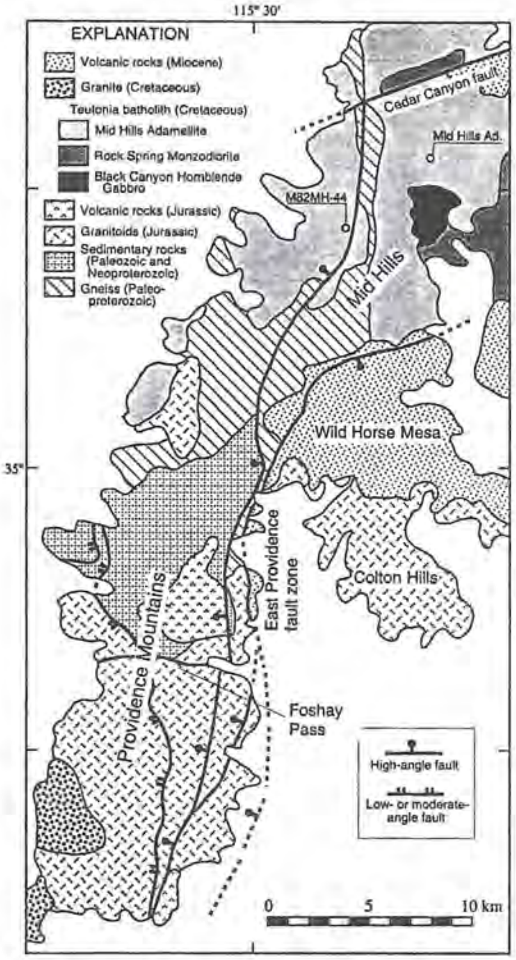

Figure 2. *Geologic map of the East Providence fault zone. Units in Teutonia batholith from Beckerman et. al. (1982). Locations of dated rocks indicated by circle.*

existing isotopic dates strongly support a latest Cretaceous timing for this fault system, raising the possibility that it was part of an integrated extensional system from Death Valley to the Old Woman Mountains.

Description of Faults

East Providence fault zone

The East Providence fault zone was mapped by Hazzard (1954) along the east side of the northern Providence Mountains (Fig. 2), where it displaces the entire Paleozoic and Neoproterozoic stratigraphic section down to the west against Paleoproterozoic basement rocks, requiring offset of more than 2.3 km. Hazzard noted that the fault zone dips 65° to 80° east and therefore is reverse. The fault zone consists of a 20- to 40-m-wide breccia and gouge zone that in places contains lenses of intact rock between discrete fault planes. Striae are nearly down-dip; at the Bonanza King mine they plunge 66° to 082°.

The East Providence fault zone was extended southward the length of the Providence Mountains (as the Bighorn fault zone) by Miller *et al.* (1985); in its southern part it consists of one to three discrete faults that cut Jurassic plutonic rocks across an area 2 to 3 km wide. The faults dip both east and west and generally dip at least 75°, and each fault typically forms a ~10 m-wide breccia zone. Exact connections with Hazzard's East Providence fault zone are obscured by Quaternary cover and complicated by an east-striking fault in Foshay Pass. However, the similar strikes of faults north and south of Foshay Pass and their general continuity strongly suggest that all belong to a single fault zone.

Northward from the Providence Mountains, Goldfarb *et al.* (1988) and Miller (1995a) traced the East Providence fault zone about 15 km into the Cretaceous Teutonia Batholith, to its truncation by the Cedar Canyon fault (Fig. 2). This northern segment of the East Providence fault zone cuts granite and gneiss and consists of breccia in places as wide as 500 m, but generally about 10 m. At one exposure a primary fault plane dips 81° east. The fault zone cuts Paleoproterozoic rocks of the gently southwest-dipping roof of the Teutonia batholith and displaces them down to the west, creating an apparent 1.5 km dextral offset in the map pattern of the roof (Fig. 2).

Overall, the East Providence fault zone is 42 km long; it strikes about 010° and dips between 65 degrees east and 75 degrees west. In the southern Providence Mountains, Jurassic volcanic and hypabyssal rocks lie within the zone of faults, perhaps as a result of downthrow along a primary eastern fault that is largely covered by alluvium directly east of the range. Many faults lie near the East Providence fault zone. West of the East Providence fault are numerous high-angle faults (Hazzard, 1954) that predate Middle Jurassic plutons (Goldfarb *et al.*, 1988; Miller *et al.*, 1994); these old faults are not shown on Figure 2. Gently west-dipping younger faults (double hachures on Fig. 2) displace Paleozoic strata down to the west by 1.5 to 1.6 km and, farther south, offset Jurassic granitoids by more than 450 m (Hidden Hill fault of Miller *et al.*, 1985). These younger faults dip 30 to 50° west, and contain striae that are down-dip. They are post-Middle Jurassic but otherwise undated. If they belong with the East Providence fault zone, total down-to-the-west throw on the composite zone exceeds 3.9 km. Interestingly, Paleozoic rocks immediately west of the East Providence fault zone form a north-trending syncline along much of the length of the fault (Hazzard, 1954). If the syncline is unfolded the East Providence fault zone rotates to parallel to the gently-dipping faults. However, little information is available on timing for the folding and the geometry of the fold is more easily reconciled with drag due to down-to-the-west separation on the East Providence fault zone. West of the Colton Hills and Wild Horse Mesa, faults lying parallel to and east of the East Providence fault cut the ~18 Ma Wild Horse Mesa Tuff, displacing it down to the east. These faults must have Miocene or younger movement and their sense of vertical separation is opposite that of the East Providence fault (McCurry *et al.*, 1995), but they could have a Mesozoic heritage.

Pinto shear zone

A mylonite zone first identified by Beckerman *et al.* (1982) crops out along the north side of Pinto Valley and continues northwest into the New York Mountains (Fig. 3); it is here named the Pinto shear zone. The shear zone is about 11 km long and its overall strike is about 330°, although the trace has an overall Z-shape. The southeast end appears to undergo several jogs to produce an apparent bend, but the shear zone and fabric within it remain parallel to those to the northwest, showing no bending. The jogs may reflect primary lateral ramps; no faults appear to extend to the northeast in the footwall. The shear widens from a 20-m-wide brittle breccia zone near Ivanpah Valley southeastward to a 1-km wide mylonite zone in Pinto Valley and then narrows to a 40-m wide ductile/brittle zone near its truncation by the Cedar Canyon fault. Plastic strain in the mylonitic part of the zone increases upward (to the west) to ultramylonite near an abrupt contact with overlying undeformed granite and, locally, marble. Lineation in the mylonite is nearly down-dip (Figs. 3, 4).

Asymmetric feldspar porphyroblasts and S-C fabrics in the mylonitic rocks consistently indicate down-to-the-southwest shear. A normal

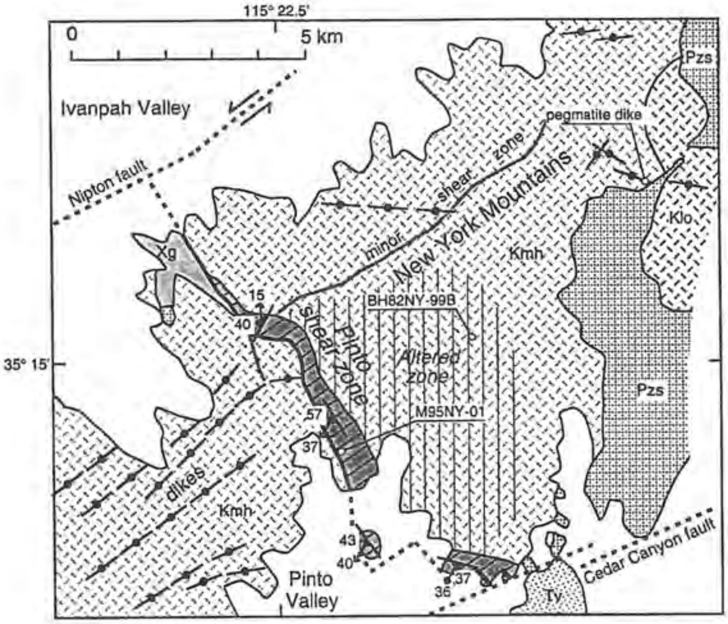

Figure 3. *Map of the Pinto shear zone, southwestern New York Mountains. Protoliths for rocks of the shear zone are the Mid Hills Adamellite (dark gray with ruled pattern). Mylonitic foliation and lineation shown by standard symbols. Sample locations for dated rocks are shown by open circles. Map units as in Figure 2: Tv, Miocene volcanic rocks; Klo, Live Oak Canyon Granodiorite; Kmh, Mid Hills Adamellite; Pzs, Paleozoic sedimentary rocks; Xg, Paleoproterozoic gneiss.*

sense of shear is also supported by the several exposures of roof rocks of the batholith on the southwestern side of the fault. Furthermore, granite in the hanging wall is pervasively diked by aplite, pegmatite, granodiorite, and monzogranite, whereas granite in the footwall contains few dikes; dikes elsewhere in the batholith are abundant near roof and wall zones. Mylonitic fabric is mainly parallel to the walls of the zone, but near the northwestern end of the exposures the mylonitic foliation shows multiple generations that are complexly overprinted by brittle shearing and the primary (youngest) plastic fabric lies nearly orthogonal to the margins of the shear zone. The overprinted fabrics apparently represent a complex evolution of the zone, perhaps caused by rocks being exhumed past a bend in the fault.

Microstructures in the mylonitic rock indicate plastic strain at moderate temperatures. Biotite and muscovite grains were reduced in size but they recrystallized during strain. In the southern part of the shear zone, quartz forms ribbon aggregates that internally exhibit polygonal mosaics of recrystallized grains with common 120° triple junctions. Relict quartz in strain shadows around feldspar porphyroclasts exhibit core and mantle structure, suggesting that the greater degree of strain recovery exhibited by the polygonal mosaics probably resulted from subgrain rotation recrystallization. Farther northwest, near where the zone is overprinted by brittle shearing, quartz displays undulatory extinction and subgrain development with recrystallization of the borders of grains to aggregates of tiny crystals. Feldspar grains in this transitional part of the zone behaved brittlely; microfracturing and granulation are common features. Southeastward, potassium feldspars exhibit incipient plastic deformation and strain-induced myrmekite along their margins, suggesting uppermost greenschist to lower amphibolite facies conditions. These several features indicate ductile deformation at temperatures between about 350 and 450 °C (Simpson and De Paor, 1991).

A broad hydrothermally altered zone along the northeast side of the Pinto shear zone structurally underlies the mylonitic rocks of the shear zone (Fig. 3). Sericitization and quartz veins, many with muscovite selvages, are typical features of the alteration. Fluids and elevated temperatures caused by the alteration may have contributed to development of ductile features in the shear zone.

Cima fault zone

The Cima fault zone was mapped by Evans (1971) near Teutonia Peak on Cima Dome (Fig. 5), a broad geomorphic dome that is underlain by several plutons (Beckerman *et al.*, 1982). Evans (1971) mapped the fault partly by aligning gouge zones within the Teutonia Mine and nearby prospects. We agree with his placement of part of the fault but think that the gouge zones in the mines belong to a different, vertical, fault. The exposed Cima fault zone as we define it is about 5 km long and separates the Jurassic Ivanpah Granite and the Cretaceous Teutonia Adamellite on the southwest from the Cretaceous(?) Kessler Springs Adamellite. Near Teutonia Peak, the fault is expressed as a poorly exposed breccia zone generally about 10 m wide on the northeast and by structurally higher mylonitic gneiss on the southwest. Mylonite in the fault zone is developed in the Ivanpah Granite; it forms a zone about 10 m thick that strikes 320 to 330° and dips ~65° southwest; lineation trends about 255°. S-C fabric and porphyroblast asymmetry indicate down-to-the-southwest (normal) sense of shear in the mylonitic rocks. Although the primary lithologic contrast lies at the base (northeast side) of the mylonite zone, in places the mylonite fabric increases in development upward to an abrupt contact with overlying undeformed Ivanpah Granite. No kinematic indicators were found in the rare outcrops of breccia.

The Cima fault zone does not crop out to the southeast and

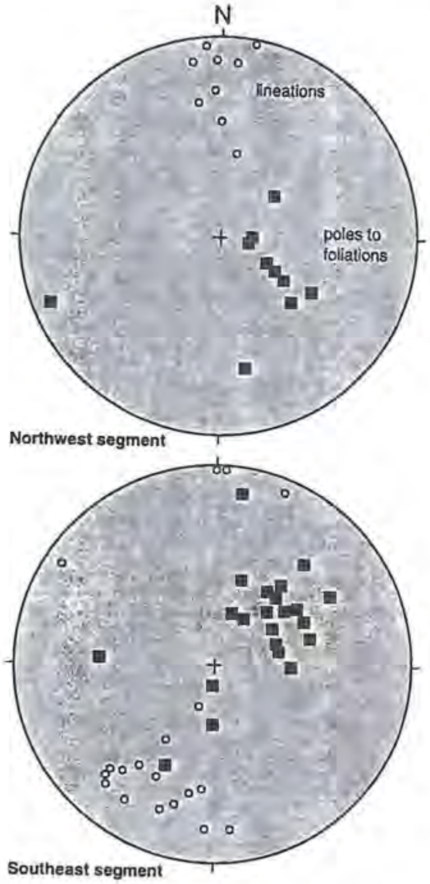

Figure 4. *Equal-area stereonet plots of foliations and lineations in the Pinto shear zone. Data for northwest segment taken north of 35° 15' (Fig. 3).*

northwest of Cima Dome, but its location can be inferred from some exposed features. Southeastward of the mapped Cima fault zone a wide breccia zone within the Kessler Springs Adamellite (Fig. 5) contains fractures that dip moderately northwest and have striae plunging to 320°. In some parts, fractures within the breccia are parallel to the Cima fault zone. No ductile strain is present in the zone of breccia, and the breccia is overlain by boulder gravel. We consider the wide breccia zone to be different from the Cima fault zone due to its lack of plastic strain and different orientation. The Cima fault zone must lie under Cenozoic alluvium northeast of the wide breccia. Northwest of Teutonia Peak the Cima fault zone is buried by Cenozoic alluvium and little is known about its location.

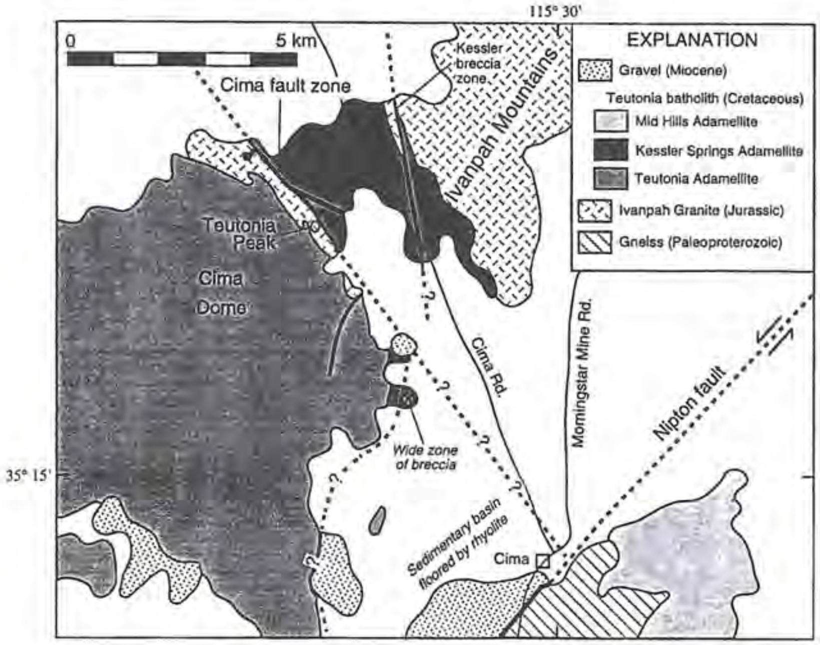

Figure 5. *Geologic map of the Cima fault. Faults bounding Miocene gravel deposits are mostly inferred. Units in Teutonia batholith from Beckerman et. al. (1982).*

Composite fault system–East Mojave fault

The primary reason to correlate the East Providence, Pinto, and Cima fault zones is that they each represent major down-to-the-southwest faults in the region that cuts the Late Cretaceous Teutonia batholith and its dikes. In addition, each predates Miocene faults and eruption of early Miocene volcanic rocks. However, the East Providence fault differs from the other two in that it strikes nearly north and mainly dips east, and has no associated mylonite. Arguments for vertical- and horizontal-axis rotations since faulting to account for the different orientation of the East Providence fault are difficult to constrain with available information. A possibility that satisfies current data on the East Providence fault zone is that it is a composite of the Kokoweef-Slaughterhouse faults and a Pinto shear zone type of fault; that is, it was formed during the mid-Cretaceous as a strike-slip fault and reactivated in latest Cretaceous time as a down-to-the-west fault.

If the three faults represent a single fault system, the East Mojave fault, it was dismembered by younger faults; two such faults are known. One, the Cedar Canyon fault, was considered to be largely younger than early Miocene volcanic rocks and to have a few hundred meters of down-to-the south separation (Miller, 1995a), although its slip is not well characterized otherwise. Our recent work has shown that most separation took place before the early Miocene Wildhorse Mesa Tuff (McCurry *et al.*, 1995) was emplaced. Conformable deposits on the ~18.0 Ma Wildhorse Mesa Tuff adjacent to the Cedar Canyon fault contain clasts derived from adjacent rocks across the fault, indicating that most or all strike-slip separation had taken place shortly after the tuff was deposited. If the correlation of the East Providence and Pinto fault zones is correct, about 12 km of right slip took place on the early Miocene(?) Cedar Canyon fault. The second, the Nipton fault, is younger than about 13 Ma (Miller, 1995b) and has about 15 km of left slip (Swanson *et al.*, 1980; Miller and Wooden, 1993), an amount compatible with offset of the extrapolated traces of the Pinto and Cima faults.

The East Mojave fault is 70 km long and is presumed to extend under Quaternary alluvium to the south and north for unknown distances. The proposed fault system strikes 010° in its southern half and 330° in the northern half. Other Mesozoic faults, such as the Kokoweef and Slaughterhouse faults (Burchfiel and Davis, 1977) do not show similar bends, so the bend in the composite fault system is probably primary. Down-to-the-west separation is greater than 2.3 km, perhaps greater than 3.9 km, along part of the system.

Timing

Establishing equivalent timing for the three segments of the East Mojave fault is crucial for demonstrating that the fault segments correlate as proposed and for establishing its role in a regional tectonic framework. Crosscutting relations require a Late Cretaceous to early Cenozoic age for all three fault segments. Each fault segment cuts early Late Cretaceous plutons of the Teutonia batholith, and each is cut by Miocene or older faults. The East Providence and Pinto segments are cut by the Cedar Canyon fault. In addition, the down-to-the-west East Providence fault zone only has the Wildhorse Mesa Tuff on its east side, so the fault zone is early Miocene at youngest. The Cima fault is cut by the ~13 Ma Nipton fault and also projects under a Miocene basin inferred by Sharp (1957) to be floored by rhyolite on the basis of geophysical and well studies. That rhyolite is probably the 18.5 Ma Peach Springs Tuff, which crops out along the southern part of the

Table 1. New K-Ar dates for rocks in the Mid Hills and New York Mountains.

Sample #	Latitude N deg min sec	Longitude W deg min sec	Material Dated	Ave.K_2O %	$^{40}Ar^{*}/Tot^{40}Ar$ %	$^{40}Ar^{*}$ moles/gm	Age	Error
M82MH-44	35 05 25	115 27 10	hornblende	0.859	68	9.66 E-11	76.5	2.0
			hornblende	0.859	75	1.02 E-10	80.3	2.0
BH82NY-99B	35 15 32	115 19 33	biotite	9.58	77	9.69 E-10	69.0	1.7

Samples analyzed at U.S. Geological Survey laboratories, Menlo Park, CA. Locations shown on Figs. 2 and 3. M82MH-44, granodiorite dike intruding Mid Hills Adamellite; BH82NY-99B, altered foliated granite (Mid Hills Adamellite).

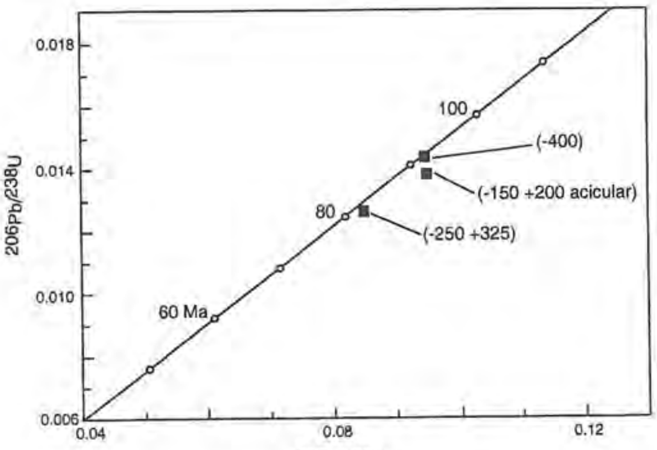

Figure 6. *U-Pb data for zircon from the Mid Hills Adamellite. Sampled at Round Valley (Fig. 2).*

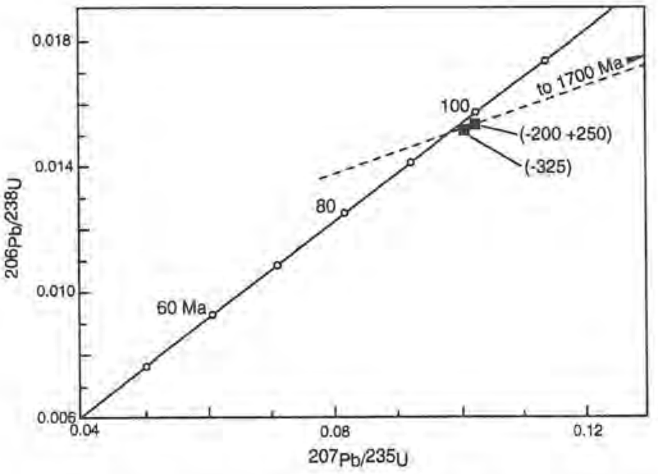

Figure 7. *U-Pb data for zircon from the Rock Spring Monzodiorite. Sampled at Rock Spring in the Mid Hills.*

basin (Miller, 1995a). We have dated several plutons, dikes, and deformed and mineralized rocks to further define the age of faulting.

Plutons within the Teutonia batholith were dated by Beckerman *et al.* (1982) using K-Ar methods; the ages were not systematic but generally clustered at 80 to 100 Ma. DeWitt *et al.* (1984) dated the Teutonia Adamellite northwest of Cima Dome at 97 Ma by U-Pb on zircon. We have dated zircon from the Mid Hills Adamellite and Rock Spring Monzodiorite by the U-Pb method. The Mid Hills Adamellite is a composite pluton made up of several lobes with differing texture and mineralogy (Beckerman *et al.*, 1982). A sample in Round Valley (Fig. 2) yielded an age of ~92 Ma (Fig. 6). The finest grained fraction of the dated sample is concordant at 92 Ma but coarser fractions are moderately discordant; the discordance we interpret as due to variable inheritance and lead loss. We take the concordant fraction as the age of the Round Valley lobe of the composite pluton. The part of the Mid Hills composite pluton that is cut by the Pinto shear zone is not dated directly but is intruded by the Rock Spring Monzodiorite, which appears to be among the oldest of plutons in the batholith (Fig. 7). Nearly concordant fractions of the Rock Spring sample have ages of 97 to 98 Ma. Passing a regression line to a presumed upper intercept of 1700 Ma modifies this result only slightly, yielding an age of 96 ± 1 Ma. We consider the age to be 97 ± 1 Ma.

The dikes that are so abundant in the Teutonia batholith near its walls and roofs may span a wide range of time, but the dates on dikes thus far point to an age of 76 to 80 Ma for all. Burchfiel and Davis (1977) dated a feldspar and quartz mixture from a pegmatite in the southeastern New York Mountains by K-Ar at 71.7 ± 0.8 Ma; our U-Pb zircon analyses for a pegmatite in the same area of the New York Mountains yielded data that can be interpreted as an age between 76 and 77 Ma (Fig. 8). If all fractions are included in a regression, the age is 75.9 ± 7 Ma. If only the most concordant fraction is considered, the age is about 76 to 77 Ma, the age we interpret to most closely reflect the crystallization age. K-Ar dates on hornblende from a granodiorite dike in the Mid Hills that is cut by the East Providence fault zone average 78.4 ± 1.9 Ma (M85MH-44; Table 1). Dikes therefore appear to be 76 to 80 Ma.

Mineral ages provide direct evidence for timing of mylonite development in the Pinto shear zone. Beckerman *et al.* (1982) reported a 73.4 ± 4.4 Ma K-Ar date on biotite plus chlorite from the shear zone. Our $^{40}Ar/^{39}Ar$ analysis of a deformed muscovite selvage associated with a mylonitic quartz vein yielded a 69.53 ± 0.12 Ma weighted mean age for "plateau" increments and 69.74 ± 0.16 Ma for total gas (Fig. 9). The microstructures within the mylonite indicate deformation temperatures close to or above the Ar closure temperature for muscovite, so this $^{40}Ar/^{39}Ar$ age records cooling following or during normal-sense shearing in the Pinto shear zone. Additionally, the absence of an apparent Ar-loss pattern in the low-temperature part of the release spectra suggests that there was not significant mylonitic shearing after Ar closure. The Ar and K-Ar ages point to mylonitization at approximately 70 Ma.

Hydrothermal alteration in the New York Mountains is spatially associated with development of mylonitic rocks (Fig. 3) and gneissic fabric is developed sporadically within the altered rocks. The age of alteration is given by a K-Ar (biotite) date of 69.0 ± 1.7 Ma on sericitized, foliated Mid Hills Adamellite (BH82NY-99b; Table 1).

All chronologic data presented above are consistent with about a 70-Ma age for the Pinto shear zone, and other data point to faulting in the composite fault system bracketed between ~80 Ma and 20 Ma. Geologic relations for all of these faults are consistent with faulting at about 70 Ma.

Regional Relations

If the correlation between segments of down-to-the-west shear zones and faults described above is correct, the picture that unfolds is that of a continuous north- to north-northwest - striking fault zone that accommodated latest Cretaceous extension. The position of the East Mojave fault provides a link between areas of well documented Cretaceous extension to the south and north. To the south in the Old Woman Mountains, intrusion of the 73 Ma Old Woman-Piute batholith was followed by rapid cooling until 70 Ma and moderately rapid cooling (10 - 30 °C/Ma) until 65 Ma (Howard *et al.*, 1987; Foster *et al.*, 1992). Four to 8 km of denudation was associated with cooling, and denudation is thought to have been accommodated along the top-to-southwest western Old Woman Mountains shear zone (Carl *et al.*, 1991). In the Iron Mountains, southwest of the Old Woman Mountains, the roof of the 70- to 73-Ma Cadiz Valley batholith (Howard *et al.*, 1987) exhibits a structural thickness of mylonitic gneiss >1.3 km (Miller *et al.*, 1981; Howard *et al.*, 1982; Miller and Howard, 1985). Miller *et al.* (1981) suggested that the package of mylonitic gneiss in the Iron Mountains formed as a result of the dynamics of batholith emplacement. Our later analysis of these mylonites suggests that noncoaxial top-to-east-northeast simple shear, during decreasing temperature conditions, operated during their formation. Reported Late

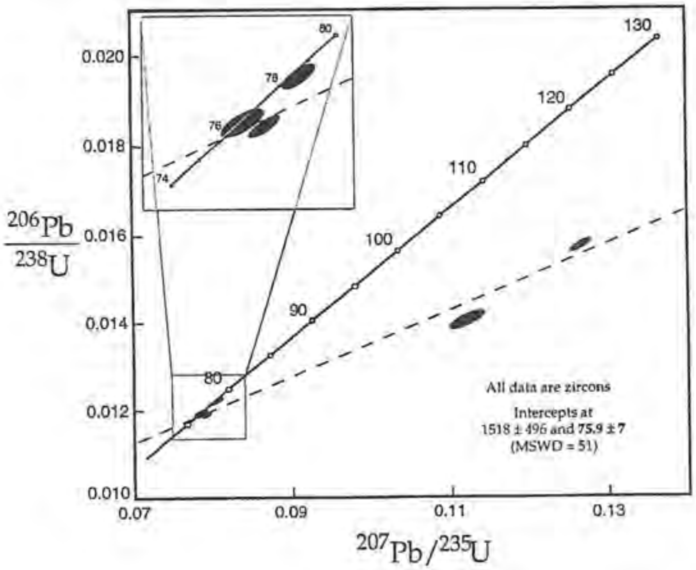

Figure 8. *U-Pb age plot for five zircon fractions, pegmatite dike in New York Mountains. Sample location shown in Fig. 3.*

Cretaceous K-Ar dates on micas that postdate deformation (Miller and Howard, 1985), indicate that the mylonites recorded Late Cretaceous extension between 73 and 61 Ma.

North of the East Mojave fault in the Panamint Range, the Harrisburg Fault is the oldest in a series of down-to-the-northwest normal faults. Its timing is bracketed as younger than the Skidoo Pluton (101 Ma, Rb/Sr; Hodges *et al.*, 1990) and older than 11 Ma strata. The Harrisburg fault has been speculated to be of Late Cretaceous age (Hodges and Walker, 1992; Applegate and Hodges, 1995). In the Funeral Mountains, the combined Monarch Canyon and Chloride Cliffs shear zones may have accommodated Late Cretaceous extension following crustal thickening. Structural unroofing was underway at 72 Ma (Applegate *et al.*, 1991; Hodges and Walker, 1992; Hoisch and Simpson, 1993; Applegate and Hodges, 1995).

Other latest Cretaceous faults may exist between the Death Valley and Old Woman Mountains areas. Some gently-dipping normal faults in the Providence Mountains, described above, could be Cretaceous in age. Late Jurassic plutonic rocks in the Granite Mountains, 10 km west of the southern Providence Mountains, were intruded at depths corresponding to 6 to 7.5 kb of pressure and must have undergone subsequent uplift (Young and Wooden, 1988). If the uplift and denudation were tectonic in origin, the only location for appropriate structures is along the west and north sides of the mountain range, where the structures may be buried or were removed by Cenozoic faults. The southeastern New York Mountains contain some low-angle faults that place less metamorphosed rock on highly metamorphosed rock, presumably in the late Mesozoic (Burchfiel and Davis, 1977).

Northeast of the Cima fault 2 km, the Kessler breccia zone (Fig. 5) extends north from the Kessler Ranch. The breccia zone strikes 350° and cuts the Ivanpah Granite and Kessler Spring Adamellite. It consists of extensively chloritized breccia in a zone 15 to 20 m wide; the primary fabric dips 65 to 80° west. Some rocks in the zone appear to be the Ivanpah Granite (Fig. 5), which indicates normal separation of approximately 0.5 km. The breccia zone could be Cretaceous or Tertiary. It is in a position to represent a smaller-separation southern extension of the Miocene detachment faults of the Shadow Valley area, but it could be older.

The mid-crustal Cretaceous extension in the Death Valley and Old Woman areas coincide spatially with preceding Mesozoic crustal thickening; the unstable thickened crust is presumed to report (Burchfiel and Davis, 1981; Howard *et al.*, 1987). A continuous belt of Mesozoic crustal thickening therefore probably existed across the region, and it probably led to subsequent extensional deformation. Following the gravitational collapse of the region at the end of the Cretaceous little tectonic activity is recorded until mid-Miocene faulting disrupted the extensively developed erosional pediments.

The shear zones in Cima Dome, the New York Mountains, and the Old Woman Mountains all exhibit down-to-the-southwest normal-sense shear, implying tensile stress oriented at ~225° for the region at ~70 Ma. This stress orientation contrasts with that recorded by ~78 Ma dikes of the Teutonia batholith that are cut by the East Providence fault; the dikes mainly strike 045° and indicate least compressive stress at about 325°. The change from crustal thickening to extension may be recorded by this stress change between ~78 and 70 Ma.

It has been suggested that addition of heat derived from cooling plutons may trigger crustal extension. In addition to thermally weakening the crust, adding plutons to the crust may result in an increase in crustal volume and/or buoyancy, which also promotes the transition from contraction to extension. The Old Woman and Funeral Mountains are two areas where a temporal correlation between magmatic intrusion and extension is established. The latest Cretaceous dikes in the Teutonia batholith may have a similar relation to the slightly younger Pinto shear zone.

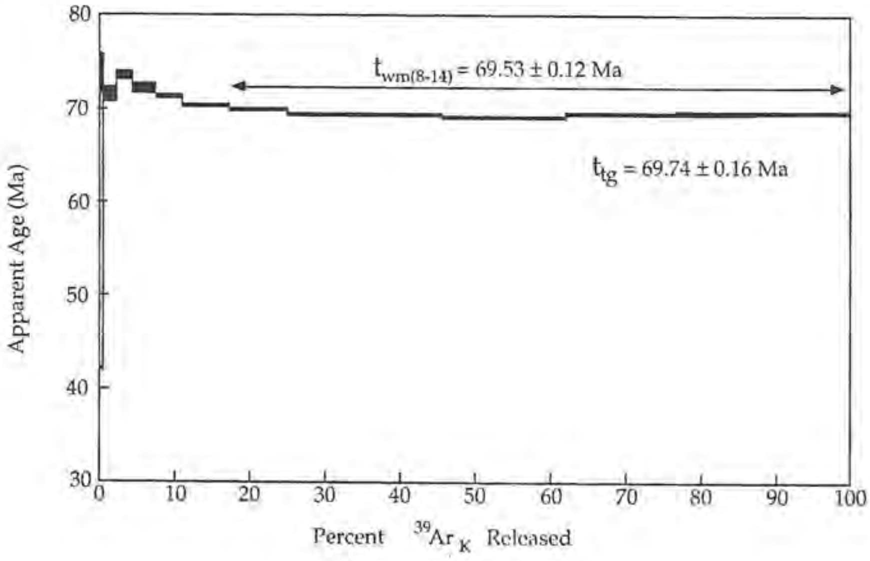

Figure 9. *Ar^{40}/Ar^{39} age spectrum for sample M95NY-01 muscovite from Pinto shear zone. t_{wm} weighted mean age for pseudo-plateau increments shown; t_{tg}, total gas age.*

Conclusions

Three north- to northwest-striking faults cut the Teutonia batholith in the northeastern Mojave Desert. We correlate these faults as segments of the East Mojave fault because each has down-to-the-west separation and each was active between 80 and 20 Ma. The East Mojave fault is 70 km long and may be greater if it extends under Quaternary alluvium farther to the south and north. Down to the west separation was greater than 2.3 km, and faulting took place at about 70 Ma. Lateral variations from ductile to brittle behavior along the East Mojave fault may be due to (1) different thermal regimes in different levels of the crust, (2) transient thermal effects, and/or (3) different strain rates. The spatial and temporal coincidence of fluid-rich alteration with mylonitic rocks in the New York Mountains suggests that latest Cretaceous thermal alteration influenced conditions for plastic behavior. Further chronologic studies can test whether a once-continuous belt of Cretaceous extensional structures spanned the eastern Mojave Desert.

The proposed East Mojave fault appears to have been active at the time that mid-crustal extension unroofed areas to the south and the north, strongly suggesting that latest Cretaceous extension affected a 250-km long zone of the southern Cordillera at ~70 Ma. The gravitational collapse of the region near the end of the Cretaceous was apparently the last major tectonic event before a 50-million-year interval of tectonic quiescence, during which erosion formed widespread pediments that were not to be disrupted until the middle Miocene.

Acknowledgements

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The Small Horse from Valley Wells, San Bernardino County, California

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Abstract

Fossils representing a minimum of seven (7) individuals of small horse have been recovered to date from late Pleistocene spring deposits at Valley Wells, San Bernardino County, California. These fossils are reported to have been associated with other late Pleistocene megafauna including *Mammuthus* sp. cf. *M. columbi* and *Camelops* sp. cf. *C. hesternus*. Only one species of small horse is represented from this assemblage; this species has been previously reported to be *Equus conversidens* Owen (1869). A review of the pertinent literature reveals that at least three different morphologic diagnoses are presently available for *E. conversidens*; this confusion stems in part from the incomplete nature of the holotype and the lack of diagnostic topotypic material. Nevertheless, the morphology of the horse from Valley Wells matches *none* of the available diagnoses for *E. conversidens*. This extinct equid, which exhibits characters suggesting affinity with either the asses or the kiangs, must be referred to some other taxon.

Introduction

The late Quaternary sediments of the southeastern Shadow Valley, west of the Mescal Range and east of the Halloran Hills, are frequently referred to as the Valley Wells "lake beds;" these sediments have previously produced vertebrate fossils of Plio-Pleistocene age (Reynolds and Jefferson, 1971; Reynolds and others, 1991). These light green to buff, carbonate-rich clays, silts and tufa deposits, formerly considered to be lacustrine in origin (Reynolds and others, 1991), are presently thought to represent sediments deposited in a zone of ancient spring discharge (Quade and others, 1995). The fossil assemblage recovered from these sediments can be subdivided into at least three apparently discrete biostratigraphic units that are correlated with the stratigraphic sequence established by Reynolds and Jefferson (1988): 1) late Pliocene Epoch fossils, which are derived from the Unit "B" peat; 2) early Pleistocene Epoch fossils, which are reported from green siltstones in the lower portion of Unit "D;" and 3) late Pleistocene fossils that occur in the upper part of Unit "D" (Reynolds and others, 1991).

The specimens under study were derived from the upper part of Unit "D," and were attributed by previous authors (Reynolds and others, 1991) to the taxon *Equus conversidens* Owen (1869), a small form of extinct Pleistocene horse. The validity of *E. conversidens* has recently been challenged (Winans, 1985, 1989; MacFadden, 1992) on the basis that the holotype specimen "possesses no unique features" (Winans, 1985, p. 116). However, as noted by Simpson (1945), it is not necessary for a holotype to be unique or even typical in order for it to be valid; holotypes are simply the "name-bearers" of the species. The lack of uniqueness in the holotype of *E. conversidens* is an insufficient reason to reject the validity of the taxon. *E. conversidens* is herein considered a valid taxonomic species of indeterminate phylogenetic relationships.

Description of the Material

The equid material from the upper half of Unit "D" at Valley Wells is listed in Table 1. These fossils were recovered from localities SBCM 01.001.001 and 01.001.036, and are reported (Reynolds and others, 1991) to have occurred in association with remains of *Mammuthus* sp. cf. *M. columbi* and *Camelops* sp. cf. *C. hesternus*. Specimens representing these other taxa are preserved similarly to the equid fossils. Only one species of equid appears to be represented from these localities.

The horse represented in this assemblage is small in size. A minimum of seven (7) individuals are present in the sample. The upper teeth are hypsodont and slightly curved buccolingually. The morphology of the upper cheek teeth is not consistent; this is not unusual, since upper cheek teeth of fossil horses "are individually variable and, with few exceptions...of slight value in taxonomy" (Dalquest and Schultz, 1992, p. 209). The enamel plications of the fossettes (see Figure 1 for explanation of dental terminology) range from very simple throughout the tooth in the isolated upper premolar (AE 20-341) and the isolated upper molars (AE 20-342-3 and AE 20-631) to complex in the premolars and molars of specimen AE 20-340. The protocones are generally long and angular with moderately-developed anterior heels and either a lingual groove or a broad, shallow lingual trough. On the premolar (AE 20-341), the protocone is short and triangular, with a slight, angular anterior projection (*not* a full anterior heel) and a well-defined lingual groove that grows less distinct towards the tooth root. The presence of a pli caballin is variable; it is present in both premolars and molars of specimen AE 20-340, but absent in the isolated premolar and molars.

The morphology of the lower cheek teeth is more consistent than that of the uppers. The lower cheek teeth are hypsodont and relatively straight buccolingually. The molars generally exhibit V-shaped linguaflexids, full isthmuses, and shortened ectoflexids. The presence of the pli caballinid is variable; two specimens from high in the stratigraphic section (AE 20-761 and AE 20-762) lack a pli caballinid, while all of the remaining molars in the assemblage exhibit strong development of this feature.

The shape of the linguaflexid in the lower dentition is variable. Specimens AE 20-342-1 and AE 20-342-2 (left and right portions of the mandible from one individual) exhibit somewhat narrowly U-shaped

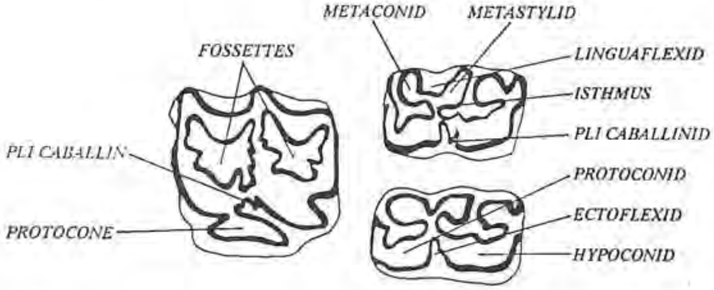

Figure 1. Diagram of the occlusal surfaces in horse teeth. The figure on the left represents an upper left cheek tooth; the two figures on the right are lower left cheek teeth. Anterior is to the left of the figure. The lower cheek tooth depicted on the upper right exhibits a U-shaped linguaflexid like that of *E. conversidens*; the tooth beneath it possesses a V-shaped linguaflexid like that observed in the Valley Wells horses. The ectoflexids shown are short; the isthmuses are full. (After Schafer and Dalquest, 1991).

Table 1. Skeletal elements of small *Equus* from upper Unit "D", Valley Wells

Element	Accession #	Locality #
Lt & rt P^{2-4}, M^{1-3} (sectioned)	AE 20-340	SBCM 01.001.001
Lt P^3	AE 20-341	SBCM 01.001.001
Lt dentary w/ symphysis (incl. lt & rt I_{1-3}, lt P_{2-4}, M_{1-3})	AE 20-342-1	SBCM 01.001.001
Rt dentary; same individ. as AE 20-342-1 (incl. rt P_{2-3}, M_{1-3})	AE 20-342-2	SBCM 01.001.001
Lt M^1	AE 20-342-3	SBCM 01.001.001
Rt P_{2-4}, M_{1-3}	AE 20-342-4	SBCM 01.001.001
Lt calcaneum, astragalus	AE 20-342-5	SBCM 01.001.001
Lt navicular and ectocuneiform	AE 20-342-6	SBCM 01.001.001
Rt astragalus, incomplete	AE 20-342-7	SBCM 01.001.001
Rt calcaneum, incomplete	AE 20-342-8	SBCM 01.001.001
1st phalanx	AE 20-342-9	SBCM 01.001.001
Rt ?P^3	AE 20-342-x	SBCM 01.001.001
Rt scapula	AE 20-342-x	SBCM 01.001.001
Broken, incomplete long bones (associated in one jacket)	AE 20-342-x	SBCM 01.001.001
Lt & rt I_{1-3}, rt P_{2-4}, M_{1-3}	AE 20-630	SBCM 01.001.001
Lt M^1 or M^2 (sectioned)	AE 20-631	SBCM 01.001.001
Lt P_{2-4}, M_{1-3}	AE 20-632	SBCM 01.001.001
Rt dentary fragment w/ P_{2-4}, ?M_1	AE 20-633	SBCM 01.001.001
Lt P_{2-4}, M_{1-3}	AE 20-723	SBCM 01.001.001
Lt P_4 or M_1	AE 20-761	SBCM 01.001.036
Rt M_1	AE 20-762	SBCM 01.001.036
Rt M_1 or M_2	AE 20-763	SBCM 01.001.036
Proximal lt metatarsal III	---	SBCM 01.001.001
2nd phalanx	---	SBCM 01.001.001
Rt P^4	---	---

Abbreviations: "lt" = left; "rt" = right; "P" = premolar; "M" = molar

linguaflexids in the right M_{2-3}, but have V-shaped linguaflexids on the remaining molars. Such variance in linguaflexid morphology in one individual is not uncommon in North American Pleistocene horses. As observed by Dalquest and Schultz (1992), "the Pleistocene horses of North America are not...easily separated by this character. Some lower linguaflexids are difficult to classify as U-shaped or V-shaped. Both shapes may occur in one jaw." Since the somewhat U-shaped linguaflexids in specimen AE 20-342-2 are narrow and very nearly V-shaped, and *not* the broad, shallow U-shape reported for other North American caballine horses (Dalquest and Schultz, 1992), the morphology of the Valley Wells horses will be herein termed V-shaped.

No upper incisors are present in the collection. In the lower incisors, the I_{1-2} possess infundibulae; the I_3 does not.

Associated postcranial elements are listed in Table 1. Of these, only the 1st phalanx (AE 20-342-9), the proximal left metatarsal and the 2nd phalanx (accession numbers not assigned) were sufficiently well-preserved to acquire approximate measurements. The results are presented in Table 2.

Discussion

The taxonomic history of Pleistocene horses from North America is complicated. As observed by many, numerous species of fossil horse have been named on the basis of inadequate type material. Early descriptive efforts in the late 1800's and early 1900's were often based upon isolated fossil teeth; these studies generally did not consider potential ranges in size and morphologic variation resulting from species diversity, geographic distribution, and individual ontogenetic age and/or sex. As a result, there are currently far more technically-correct taxonomic names for North American Pleistocene horses than there ever were biologically valid species. Interpretations of phylogenetic groupings based upon morphologic characters and subsequent taxonomic determinations are not likely to ever be determined to the satisfaction of all.

The taxon *Equus conversidens* is a case in point. The holotype for this species, recovered from the slopes of Tepeyac Mountain, Guadelupe, Mexico (Mooser and Dalquest, 1975), consists of a palate containing all teeth. This specimen possesses moderately complex infoldings (plications) of the enamel in the fossettes of the upper cheek teeth; there are few other distinctive features. No topotypic lower teeth were reported with the holotype of *E. conversidens.* Subsequent studies that referred equid fossils to this taxon were (by necessity) based upon comparison of upper dentitions; lower teeth were referred on the basis of their association with referred upper teeth.

Recent studies of equid phylogeny have indicated that the lower cheek teeth are generally more taxonomically diagnostic than the upper cheek teeth (Skinner, 1972; Dalquest, 1978; Eisenmann 1981, 1986). For this reason, many discussions on the systematic and phylogenetic relationships of *Equus conversidens* have therefore been pursued using lower teeth as the basis for comparison. Since topotypic lower teeth and jaws have yet to be reported from the type locality at Tepeyac Mountain, phylogenetic interpretations have been based upon referred material. Unfortunately, there are varying interpretations as to which teeth and jaws are correctly referred to *E. conversidens.*

At present, at least three different, but potentially valid, interpretations of the morphology and relationships of *Equus conversidens* are present in the literature. These interpretations are defined as follows:

1.) *Equus conversidens* as a small, stout-limbed equid. This is the most common interpretation employed (Skinner, 1942; Stock, 1950; Hibbard, 1955; Slaughter, 1966; Devin, 1968; Mooser and Dalquest, 1975; Dalquest, 1978, 1988; Harris and Porter, 1980; Kurtén and Anderson, 1980; Carranza-Castañeda and Miller, 1991; Azzaroli, 1992; Dalquest and Schultz, 1992). The defining characteristics employed by these authors are presented in Table 3. While some of the authors who utilize this characterization differ markedly in their interpretations of the phylogeny of this equid (for example, whether *E. conversidens* should be placed in the subgenus *Asinus, Amerhippus* or *Equus*), it is noteworthy that the morphology itself, as employed by these authors, remains consistent. Important here is the lack of infundibulae, or enamel-lined "cups," in *all* of the lower incisors.

2.) *Equus conversidens* as a small, stout-limbed equid possessing infundibulae in the lower incisors. This interpretation has been advanced by Lundelius and Stevens (1970) and Lundelius (1972), based upon analysis of material from Canyon, Randall County, Texas. This material was originally referred to *Equus conversidens* by Dalquest and Hughes (1965), which suggests that these authors also interpreted *E. conversidens* to have infundibulae in the lower incisors. However, subsequent works (Mooser and Dalquest, 1975; Dalquest, 1978, 1988) clearly indicate that a *lack* of infundibulae is considered by Dalquest to be one of the hallmarks of *E. conversidens.* The relationship of the small horse

Table 2. Measurements of *Equus conversidens* and small horses from Valley Wells

	San Josecito Cave Mexico[1]	Slaton Quarry Texas[2]	Dry Cave, New Mexico[3]	Aguascalientes, Mexico[4]	VALLEY WELLS
Metatarsal III:	(N=70)	(N=2)	(N=4)	(N=4)	
Proximal breadth	43.0 - 52.0	46.7, 49.0	44.3 - 47.7	42.9 - 46.0	*48.2*
Proximal depth	39.0 - 46.0	---	40.0 - 45.6	37.5 - 41.8	*43.1*
1st Phalanx:	(N=313)	(N=3)	(N=2)		
Proximal breadth	40.1 - 54.7	38.8 - 41.7	45.7, 49.0		*50.5*
Midshaft breadth	25.2 - 32.8	23.8 - 28.2	27.9, 29.3		*34.5*
Distal breadth	34.3 - 42.1	31.3 - 34.0	38.1, 38.3		*37.6*
2nd Phalanx	(N=25)	(N=2)	(N=5)		
Proximal breadth	26.9 - 31.5	37.1, 37.8	40.5 - 44.8		*36.2*
Distal breadth	—	34.5, 35.0	36.9 - 42.2		*32.0*

Footnotes: 1 = after Devin (1968).
2 = after Dalquest and Hughes (1965).
3 = after Harris and Porter (1980)
4 = after Mooser and Dalquest (1975)

from Canyon with specimens referred to *E. conversidens* from other localities is indeterminate.

3.) *Equus conversidens* as a stilt-legged, "hemionine" equid. This opinion was initially advanced by Skinner (1972) as a reinterpretation of his earlier (1942) analysis of fossils from Papago Springs Cave, Arizona. Postcranial elements originally assigned to *E. conversidens* (Skinner, 1942) were later determined to "represent another form of *Equus* for which we found no dentition" (Skinner, 1972, p. 125), while a slender phalanx originally referred to *Equus tau* Owen (1869) (Skinner, 1942) was reassigned to *E. conversidens* based upon "studies of living and extinct *Equus* in the American Museum of Natural History Mammal and Frick Collections" (Skinner, 1972, p. 125). No additional diagnosis or rationale for this new interpretation was advanced. However, Downs and Miller (1994) employed the "expertise, information, and written comments provided by Morris F. Skinner in the late 1980s" (Downs and Miller, 1994, p. 9), as well as Skinner's (1972) work, to establish characters for living and fossil subgenera of *Equus*; this work undoubtedly presents the morphologic criteria upon which Skinner's (1972) efforts were based. Downs and Miller (1994) listed *E. conversidens* as "*Equus (Hemionus) conversidens,*" a small, stilt-legged equid; additional features that further defined this interpretation of *E. conversidens* are presented in Table 3. It is unfortunate that specimens upon which this diagnosis was based have not been published.

It is beyond the scope of the present study to unravel the complex systematic and phylogenetic relationships of *Equus conversidens*. However, by presenting all of the possible diagnoses advanced for *E. conversidens*, the relationship of the small horses from Valley Wells may be better assessed.

It is apparent from Table 3 that the morphology of the Valley Wells horses does not fit that of *any* of the available diagnoses for *Equus conversidens*.

Table 3. Morphologic diagnoses for *Equus conversidens* and small horses from Valley Wells

Character	"Classic"*	Lundelius & Stevens '70 Lundelius '72	Skinner '72; Downs & Miller '94	VALLEY WELLS
Fossette plications	COMPLEX	COMPLEX	MODERATE	SIMPLE-COMPLEX
Linguaflexid	"U"	"U"	"U"	"V"
Isthmus	FULL	FULL	FULL	FULL
Ectoflexid	SHORT-MODERATE	SHORT	SHORT	SHORT
$I_{1,2,3}$ infundibulae	NNN	YYY	YYY	YYN
Metapodials	SHORT	SHORT	LONG	?

Definitions:

Fossette plications: the degree of infolding of the enamel of the fossettes of the upper molars.
Linguaflexid: the shape of the linguaflexid of the lower molars; can be either "U" or "V" shaped.
Molar isthmus: the presence of an "isthmus" between the metaconid/metastylid column and the protoconid/hypoconid column in the lower molars. "Full" designates a complete and unobstructed isthmus.
Ectoflexid: the relative length of the ectoflexid. "Short" designates an ectoflexid which does not enter into the molar isthmus. "Moderate" designates an ectoflexid which closely approaches but does not penetrate the isthmus.
$I_{,2,3}$ infundibulae: the presence of "cups" or infundibulae in the lower incisors. A "Y" denotes the presence of cups; an "N" designates a lack of them. Thus, for example, a "YYY" designation would indicate the presence of infundibulae in all three lower incisors. A "YYN" designation, in contrast, would indicate the presence of infundibulae in the first two lower incisors, but a lack of them in the third lower incisor.
Metapodials: the relative length of the metapodials.

Footnote: * = based upon definitions of *Equus conversidens* provided by Skinner (1942), Stock (1950), Hibbard (1955), Dalquest and Hughes (1965), Slaughter (1966), Devin (1968), Mooser and Dalquest (1975), Harris and Porter (1980), Dalquest (1978, 1988), Carranza-Castañeda and Miller (1991), Dalquest and Schultz (1992) and Azzaroli (1992).

Comparisons of upper teeth from Valley Wells with the holotype of *E. conversidens* are inconclusive, given the variable nature of the morphology of the Valley Wells specimens and of equid upper teeth in general (Dalquest and Schultz, 1992). The V-shaped linguaflexids in the lower molars and the lack of an infundibulum in the I_3 are characters that are not possessed by any of the published fossils referred to *E. conversidens*. It is presumed that the Valley Wells horse was identified (Reynolds and others, 1991) as *E. conversidens* based exclusively upon the small size of the animal; there is little else to suggest any affinity. The Valley Wells equid must be some taxon other than *E. conversidens*.

The V-shaped linguaflexids and the non-penetrating ectoflexids in the lower molars, as well as the pattern of infundibulae in the lower incisors suggest affinity with the subgenus *Asinus*, which has been characterized (Dalquest, 1978; Bennett, 1980; Downs and Miller, 1994) as having this morphology. However, it is noted that the Mongolian kiang, a hemionine or "stilt-legged" equid, also exhibits V-shaped linguaflexids in its cheek teeth and occasionally lacks an infundibulum in the I_3 (Downs and Miller, 1994). The primary difference between asses and kiangs is the length of their metapodials: asses have short, stout metapodials while kiangs have long, slender metapodials (Downs and Miller, 1994). Given that the assemblage from Valley Wells did not include any complete equid metapodials, it is presently impossible to determine whether these horses more closely resembled asses or kiangs.

Fossil equids referred to *Equus conversidens* have been reported from other localities in the Mojave Desert (Jefferson, 1991). Of these presumed records, the largest single assemblage has been recovered from Bitter Springs Playa, Fort Irwin National Training Center, San Bernardino County (Reynolds and Reynolds, 1994; Scott, 1996, in review). The equid remains from this late Pleistocene assemblage closely resemble the "classic" morphology reported by many authors for *E. conversidens* (e.g. Skinner, 1942; Hibbard, 1955; Mooser and Dalquest, 1975; Dalquest, 1978; Harris and Porter, 1980; Dalquest and Schultz, 1992). This morphology includes moderately complicated fossettes in the upper cheek teeth and broadly U-shaped linguaflexids in the lower molars (Scott, 1996, in review). These specimens are clearly morphologically distinct from the Valley Wells horses. If the geologic and biostratigraphic associations reported for the equid remains from Valley Wells (Reynolds and others, 1991) are correct, it is apparent that at least two species of small horse were present in the Mojave Desert region during the late Pleistocene Epoch.

Conclusions

Specimens representing a minimum of seven (7) individuals of a species of small horse have been recovered to date from the late Pleistocene Valley Wells spring deposits in the Mojave Desert, San Bernardino County, California. These horses have been previously referred to the taxon *Equus conversidens* Owen (1869). This assignment is in error. The horses from Valley Wells all clearly exhibit a morphology that is different from any of the published diagnoses for *E. conversidens*. The Valley Wells horse morphology includes V-shaped linguaflexids, non-penetrating ectoflexids and a lack of infundibulae in the I_3, features which suggest affinity with asses or kiangs. Given the presumed late Pleistocene age of the equid remains from Valley Wells, the small horse represented from this site was one of at least two species of small horse occupying the Mojave Desert region during the last Ice Age.

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The Blue Bell Claims and the Mohawk Mine:
Two Prolific Mineral Localities in San Bernardino County, California

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Introduction

Of all the various mineral deposits within San Bernardino County, the Blue Bell claims and the Mohawk Mine have produced by far the most extensive assemblages of minerals. Both are lead, zinc, copper sulfide deposits with a limited suite of primary minerals. Late stage hydrothermal and weathering oxidation produced about forty secondary minerals at each locality. Interestingly, however, the two suites of secondary minerals are quite different.

The purpose of this article is to compare the two suites secondary minerals, and to discuss reasons for the differences.

Locations of the Mineral Deposits

The Blue Bell claims are located in the Soda Mountains about six miles northwest of the Zzyzx Road exit of I-15 about 6 miles southwest of Baker. The claims were developed from about 1920 until the late 1950s with a relatively small amount (less than 100 tons) of low grade ore being shipped. Lead, copper, and silver were smelted from this ore. Maynard et al (1984) provide a review of the history of claim ownership and mining activity.

Figure 1. Wulfenite from the Blue Bell claims. *Sugar White photograph.*

Figure 2. Caledonite from the Blue Bell claims. *Sugar White photograph.*

The Mohawk Mine is located on the south side of Mohawk Hill about 5 miles east of the Cima Road exit from I-15 (26 miles northeast of Baker). These deposits were discovered in the early 1900s, and during the first World War produced about 2900 tons of ore, yielding lead, zinc, copper, and silver. Mining was resumed again during the second World War, and produced nearly 17,000 tons. See Wise (1990) and Hewett (1956) for reviews of the mining history.

Primary Ore Deposits
Blue Bell Claims

The primary ore minerals were emplaced largely as replacement veins, controlled by faults and fractures in Pennsylvannian limestone beds, during intrusion by Cretaceous quartz diorite (Grose, 1959). Hot fluids from the intrusion converted limestone to skarn, composed mostly of garnet and diopside.

Table 1. Secondary minerals from the Blue Bell claims

MINERAL	COMPOSITION	CRYSTALLINITY	OCCURRENCE
anglesite	$PbSO_4$	m	rare
apatite	$Ca_5(PO_4)_3Cl$	X	common
aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	XX	rare
brochantite	$Cu_4(SO_4)(OH)_6$	XX	rare
calcite	$CaCO_3$	XX	rare
caledonite	$Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$	XX	rare
cerussite	$PbCO_3$	XX, m	rare
chalcanthite	$CuSO_4.5H_2O$	XX	rare
chlorargyrite	$Ag(Cl,Br)$	XX	rare
chrysocolla	$(Cu,Al,Fe)_2H_2Si_2O_5.nH_2O$	m	common
dioptase	$CuSiO_3.H_2O$	XX	rare
fluorite	CaF_2	XX	common
goethite	$Fe^{3+}O(OH)$	xx, m	v.common
gypsum	$CaSO_4.2H_2O$	XX	rare
hematite	Fe_2O_3	XX	common
hemimorphite	$Zn_4Si_2O_4(OH)_2.H_2O$	XX	rare
jarosite	$KFe_3(SO_4)_2(OH)_6$	XX	rare
kaolinite	$Al_2Si_2O_5(OH)_4$	m	rare
kettnerite	$CaBiO(CO_3)F$	xx	rare
leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$	XX, m	v.rare
linarite	$PbCu(SO_4)(OH)_2$	XX	rare
malachite	$Cu_2(CO_3)(OH)_2$	xx	rare
minium	$Pb^{2+}Pb^{4+}O_4$	m	v.rare
murdochite	$PbCu_6(O,Cl,Br)_8$	xx	rare
perite	$PbBiO_2Cl$	XX	rare
plattnerite	PbO_2	xx	rare
plumbogummite	$PbAl_3(PO_4)_2(OH)_5.H_2O$	m	v.rare
pyrolusite	MnO_2	m	rare
pyromorphite	$Pb_5(PO_4)_3Cl$	XX	rare
quartz	SiO_2	XX	common
rosasite	$(Cu,Zn)_2(CO_3)(OH)_2$	xx	rare
smithsonite	$ZnCO_3$	ps	v.rare
tsumebite	$Pb_2Cu(SO_4)(PO_4)(OH)$	xx	rare
vauquelinite	$Pb_2Cu(CrO_4)(PO_4)(OH)$	xx	rare
willemite	$ZnSiO_4$	XX	v.rare
wulfenite	$PbMoO_4$	XX	common

Crystallinity: *XX - crystals or groups easily discernable with standard microscopes; xx - crystalline, but individual crystals are too small to see easily; m - occurs as masses with crystals much too small to see except with the scanning electron microscope; and ps - form occurs but has been pseudomorphed (replaced) by a later mineral.*

Occurrence: *common - mineral is easily found in workings or on dumps; rare - mineral can be found, but only in a few specific localities; v.rare - only a few specimens have been found.*

As the temperature of fluids decreased retrograde skarn minerals (tremolite, epidote, and fluorite) replaced most of the earlier garnet and diopside. At this stage base metal sulfide minerals galena, sphalerite, chalcopyrite, and pyrite were precipitated in replacement masses and veins. Several small ore bodies have been exposed by mining (Maynard et al, 1984).

Mohawk Mine

Ore veins were emplaced along west-dipping faults and breccia zones between quartz monzonite and pre-Cambrian dolomite and limestone beds. These veins appear to have been mostly fissure filling rather than replacement deposits. (See Wise, 1990, for a discussion of the relationships between the geology and the ore deposit.) Primary vein minerals include quartz, ankerite, rhodochrosite, chalcopyrite, gaelna, sphalerite, arsenopyrite, and gold. The larger portions of these veins have been exposed by three major adits (Wise, 1990).

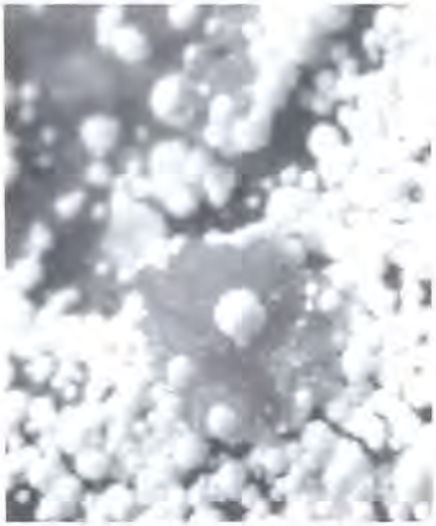

Figure 3. Tsumebite, kaolinite, and pyromorphite, Blue Bell claims. *Sugar White photograph.*

Figure 4. Beudantite from the Mohawk Mine. *Sugar White photograph.*

Secondary Minerals

Both deposits have been extensively oxidized to gossan, replacing the primary veins and extending into the wall rocks. All of the minerals discussed below occur in cavities or fractures of the gossan as microcrystals or masses. The studies of these two deposits (Maynard et al ,1984, and Wise, 1990) included mineral identification with x-ray powder diffraction and, as needed, electron microprobe analysis.

Table 2. Secondary minerals from the Mohawk Mine

MINERAL	COMPOSITION	CRYSTALLINITY	OCCURRENCE
adamite	$Zn_2(AsO_4)(OH)$	XX	common
agardite-(Y)	$(Y,Ca)Cu_6(AsO_4)_3.3H_2O$	xx	rare
anglesite	$PbSO_4$	m	rare
aragonite	$CaCO_3$	XX	common
arseniosiderite	$Ca_3Fe_4(AsO_4)_4(OH)_6.3H_2O$	xx	rare
aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	XX	rare
austinite	$CaZn(AsO_4)(OH)$	xx	common
azurite	$Cu_3(CO_3)_2(OH)_2$	XX, xx	common
beudantite	$PbFe_3(AsO_4)(SO_4)(OH)_6$	XX	common
brochantite	$Cu_4(SO_4)(OH)_6$	XX	rare
calcite	$CaCO_3$	XX	rare
carminite	$PbFe_2(AsO_4)(OH)_2$	xx	rare
cerussite	$PbCO_3$	XX	rare
chalcanthite	$CuSO_4.5H_2O$	XX	v.rare
chlorargyrite	Ag(Cl,Br)	XX	rare
chrysocolla	$(Cu,Al,Fe)_2H_2Si_2O_5.nH_2O$	m	common
conichalcite	$CaCu(AsO_4)(OH)$	XX, m	rare
copper	Cu	m	v.rare
cuprite	Cu_2O	m, ps	rare
delafossite	$CuFeO_2$	m	rare
duftite	$PbCu(AsO_4)(OH)$	XX	common
epsomite	$MgSO_4.7H_2O$	xx	v.rare
fluorite	CaF_2	XX	common
fraipontite	$(Zn,Cu,Al)_3(Si,Al)_2O_5(OH)_4$	xx, m	rare
goethite	$Fe^{3+}O(OH)$	xx, m	v.common
hemimorphite	$Zn_4Si_2O_4(OH)_2.H_2O$	XX	rare
hetaerolite	$ZnMn^{3+}{}_2O_4$	XX	rare
hidalgoite	$PbAl_3(AsO_4)(SO_4)(OH)_6$	xx	rare
hydrohetaerolite	$Zn_2Mn^{3+}{}_4O_8.H_2O$	xx	rare
jarosite	$KFe_3(SO_4)_2(OH)_6$	XX	rare
malachite	$Cu_2(CO_3)(OH)_2$	xx	rare
mawbyite	$Pb(Fe^{3+},Zn)(AsO_4)_2(OH,H_2O)_2$	xx	rare
mimetite	$Pb_5(AsO_4)_3Cl$	XX	common
olivenite	$Cu_2AsO_4(OH)$	xx	rare
pyrolusite	MnO_2	m	rare
quartz	SiO_2	XX	common
rosasite	$(Cu,Zn)_2(CO_3)(OH)_2$	xx	common
sauconite	$Ca_{0.5}Zn_3(Si,Al)_4O_{10(}OH)2._4H_2O$	m	common
smithsonite	$ZnCO_3$	ps	common
Use of symbols for crystallinity and terms for occurrence are the same as in Table 1.			

Blue Bell Claims

The secondary minerals identified from the various mine workings and prospect pits are listed in Table 1. Individual mineral descriptions and occurrences are given by Crowley (1977) and Maynard et al (1984).

Figure 5. Hidalgoite over cuprite from the Mohawk Mine. *Sugar White photograph.*

The list in Table 1 is dominated by carbonate, sulfate, and phosphate minerals, which reflects the skarn environment into which the primary minerals were emplaced. There are two different local environments of secondary mineral formation, the main Blue Bell mine and the southern group of prospect pits and adits (Maynard et al, 1984).

In the main mine the secondary minerals are mostly sulfates, e.g. anglesite, linarite, caledonite, and contain some of the phosphates, tsumebite, plumbogummite, and vauquelinite. Although some carbonate minerals also occur here, this group largely represents those minerals stable in slightly acid waters, a result of limited circulation of vadose water.

Figure 6. Smithsonite from the Mohawk Mine. *Sugar White photograph.*

The gossan of the southern pits is in carbonate or altered skarn wall rocks. The minerals here are wulfenite, carbonate minerals, and chlorargyrite along with fluorite, probably recrystallized from the retrograde skarn. In general these minerals are stable in neutral to slightly alkaline waters, suggesting this gossan may have formed through extensive washing by vadose water, amply charged with carbonate from the surface.

Figure 7. Mimetite from the Mohawk Mine. *Sugar White photograph.*

Mohawk Mine

The secondary minerals identified from the gossans of the various mine workings are listed in Table 2. Individual mineral descriptions, occurrences, and distribution are given by Wise (1990). None of the mine workings reached unoxidized ore.

The secondary minerals are dominated by arsenates of lead, zinc, and copper, such as adamite, conichalcite, beudantite, and duftite. Arsenic commonly occurs in base metal sulfide deposits either as enargite (Cu_3AsS_4) or as arsenopyrite (FeAsS). Neither of these minerals was found in the Mohawk workings, but a few zones of scorodite, an iron arsenate, has been found leading to the assumption that they originated from arsenopyrite. I also assume that arsenopyrite accounts for all the arsenic in the Mohawk Mine veins.

Zones of secondary minerals, rich in arsenates suggest formation from slightly acidic waters, and others, dominated by carbonate minerals show ample circulation of slightly basic surface waters.

Conclusions

The secondary mineral of these two deposits formed during the oxidation of galena, chalcopyrite, and sphalerite bearing veins, probably under the same kinds of weathering conditions. Yet the mineral assemblages show some remarkable differences between the two deposits. Arsenic clearly accounts for most of these differences. Thirteen of the 41 minerals in Table 2 are arsenates, and none occur at the Blue Bell claims. Not only is the presence of arsenic an essential constituent of these minerals, but there is good evidence from other arsenate localities in the western U.S. that arsenates are more stable than most other compounds. For example, the presence of arsenate ions in a solution will prevent the formation linarite, a Pb-Cu sulfate, forming duftite, Pb-Cu arsenate, instead. Similarly mimetite occurs in place of wulfenite or anglesite. Note that at the Mohawk Mine anglesite is rare and wulfenite has not been found, but mimetite is common.

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Structural and Stratigraphic Controls on the Emplacement of Mineralization at the Mohawk Mine, San Bernardino County, California

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Introduction

The Mohawk Mine lies within the western portion of the Ivanpah Mining District, five kilometers east-northeast of the Cima Road exit from Interstate 15 (Fig. 1). The mine was worked briefly during World War I (1916-1918). Three hundred tons of hand cobbed ore were shipped yielding four ounces of gold, 20,000 lbs. of copper and 250,000 lbs. of lead. The property lay idle until its acquisition in 1942 by the Ivanpah Copper Company. Production records are incomplete, but from 1942 to 1952 Ivanpah Copper reported the shipment of 16,700 tons of ore which produced 206 oz. of gold, 92,802 oz. of silver, 183,600 lbs. of copper, 2.9 million lbs. of lead and one million lbs. of zinc (Hewett, 1956). Mapping of the existing underground workings, which consist of seven adits, nine shafts and five prospect pits, suggests that significant unreported production may have occurred after 1952. The mine has been inactive since 1957 (Evans, 1958).

Hewett (1956) published a reconnaissance-scale map of the Ivanpah district mentioning the Mohawk Mine in the context of ore reserves and general geology. Evans (1958) mapped the Mescal Range to the south, briefly discussing the Mohawk Mine. Dobbs (1961) mapped Mohawk Hill in greater detail and recognized the presence of both Tapeats and Bright Angel strata. Burchfiel and Davis (1971) prepared the first comprehensive structural map of the Mescal Range, Clark Mountains and Mohawk Hill. This paper presents a structural interpretation of the ore deposits near the west end of Mohawk ridge. While relying on previous work, we have based much of our interpretation on detailed surface and underground mapping and thin section petrology. We present a model for emplacement of the ore mineralization and Mesozoic/early Cenozoic tectonics of Mohawk Hill.

Stratigraphy

All productive mine workings on Mohawk Hill lie within the Bonanza King Formation (Fig. 2). The Mesquite Pass thrust which marks the contact between the upper plate Cambrian Bonanza King and lower plate Devonian Sultan Formation lies two kilometers east of the property. The Winters Pass thrust is thought to lie approximately three kilometers west of Mohawk Hill, but its presence has never been verified with certainty.

The Bonanza King, in the vicinity of the mine, consists essentially of two units; thin-bedded, blue-gray and tan-white limestone and brown to white, dolomitic marble. Hewett (1956) and Evans (1958) report that regionally the Bonanza King strikes northwest and dips 20-30° to the southwest. Our mapping along Mohawk ridge suggests strikes from N 20° W to N 50° W with highly variable dips, generally to the southwest (see Fig. 2). Near the crest of the ridge, immediately above the West Adit, extreme variations in dip and strike were noted. Preliminary mapping suggests folding along a nearly east-west axis related either to intrusion of a sill-like mass of granite (discussed below) or drag folding accompanying faulting.

Figure 1. Index map showing the location of Mohawk Hill.

The thin bedded limestone, which is best exposed to the west of the mine workings, closely resembles outcrops of Bonanza King Formation (formerly Goodsprings) described by Hewett (1931) from the southern Spring Mountains. The dolomitic marble, well exposed on the high hill east of the East Adit, was examined in thin section (CNL) and found to consist of an equigranular (~2.0 mm) mosaic of subhedral to euhedral calcite (96%) cut by veinlets of opaque minerals (hydrated oxides of iron and manganese) (4%). Locally, the unit is both dolomitized and silicified. In general, the two units are in fault contact, (see below) but careful examination of the hillslope above the mine workings reveals small patches of thin-bedded limestone which are gradational to marble, suggesting the dolomitic marble represents recrystallized Bonanza King.

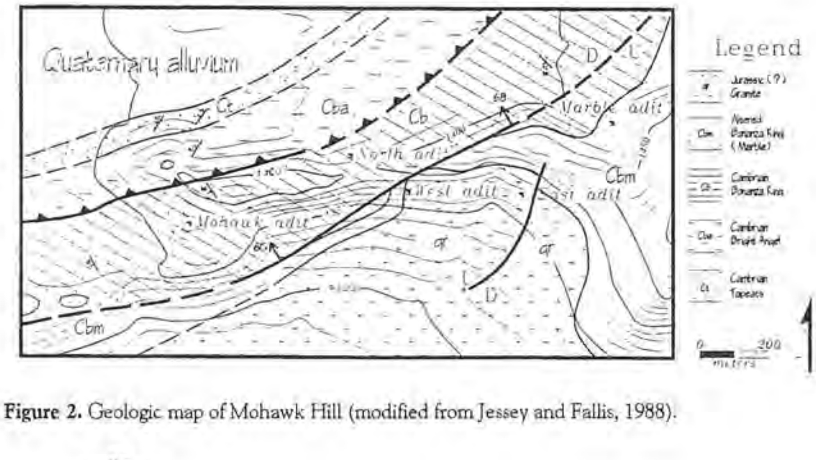

Figure 2. Geologic map of Mohawk Hill (modified from Jessey and Fallis, 1988).

Figure 3. Contact between granite (white) and recrystallized Bonanza King (above hammer head).

Dobbs (1961) was the first to recognize the presence of a small outcrop of Tapeats Quartzite at the west end of Mohawk Hill. Since this juxtaposes Tapeats and Bonanza King, Dobbs concluded a fault must be present. Burchfiel and Davis (1971) mapped the fault as the Mohawk thrust. The present authors have remapped the area in detail and concluded that not only is the Tapeats present, but also the Bright Angel (Carrara). Furthermore, the Tapeats-Bright Angel contact is conformable.

The Tapeats is the more resistant of the two units. It has been extensively recrystallized into hard, blocky quartzite. Relict bedding indicates the unit strikes N 50-60° E and dips 40-45° NW. The Bright Angel is a gray-green, moderately fissile shale. Its attitude is similar to the Tapeats. The Bright Angel weathers readily making its contact relationship with the Bonanza King unclear. This is unfortunate since apparent outcrop thickness suggests the unit has either been remarkably attenuated near Mohawk Hill, or lies in fault contact with the Bonanza King. The latter interpretation is favored due to the difference in strike of the Bonanza King (northwest strike) and Tapeats-Bright Angel (northeast strike). One additional observation can be made regarding the Bright Angel. Near its contact with the Tapeats the unit is only weakly metamorphosed. To the east, metamorphic grade increases, to phyllite and eventually talc schist.

A coarse-grained, igneous intrusive, previously termed Teutonia batholith, outcrops along the south flank of Mohawk Hill. Thin section analysis (CNL) suggests the rock is a granite comprised of 45% quartz, 30% perthitic feldspar, 10% mica, 15% alteration minerals (talc, serpentine and sericite) and opaques. The contact of the granite with the Bonanza King strikes generally east-west and dips 30° to the south (Fig. 3). Drilling indicates the intrusive is sill-like, averaging 40 meters in thickness (Wiebelt, 1949). Wise (1990) suggests the intrusive lies in fault contact with the Bonanza King. Our mapping (DWT, DRJ) indicates the contact is intrusive. Evidence includes extensive recystallization of the Bonanza King to the north and east of the intrusive; presence of minor calc-silicate minerals including epidote, chlorite, idocrase and diopside and hydrated calc-silcates such as talc and serpentine along the intrusive-Bonanza King contact, and a lack of features normally associated with a kinematically emplaced pluton such as brecciation or localized shearing in adjacent rocks. Further, Hazelton (1991) studied sill-like intrusives along the south margin of Clark Mountain and discovered several west-northwest trending, south plunging fold axes related to emplacement of the sills. Limited mapping (DRJ) suggests the presence of a comparable west trending, south plunging fold near the crest of Mohawk Ridge, possibly, related to emplacement of the Mohawk sill. It should be noted that a similar controversy regarding the contact relationship between intrusive and carbonate host has raged for over fifty years in the Goodsprings District, 25 kilometers to the east. The recent excavation of a gold prospect in upper Keystone Wash has created a spectacular exposure along 100 meters of the intrusive-carbonate contact, clearly showing the intrusive relationship of the pluton.

Recent research (Walker, Burchfiel, Davis, 1995) has resulted in a reinterpretation of ages for many of the intrusives in the Clark Mountains and Mescal Range. Crosscutting relationships near Pachalka Springs, seven kilometers northwest of Mohawk Hill, constrain initial thrusting to between 146 and 142 Ma and also provide evidence for a late Jurassic magmatic event. Since compositional and structural similarities exist between intrusives of the southern Clark Mountains and Mohawk Hill, it seems reasonable to postulate a late Jurassic age for the Mohawk granite.

A massive quartz "vein" was first reported by Hewett (1956) at the intrusive-Bonanza King contact. The vein trends N 60° E along the south flank of Mohawk Hill. Several smaller quartz veins lie to the east, wholly within the intrusive. Sampling indicates the quartz is unmineralized. Joseph (1984) suggests that the quartz "vein" of Hewett is a skarn zone formed during intrusion of the Clark Mountain stock. Our mapping does not support this conclusion, but suggests the quartz vein may be related to more recent Tertiary extension. Evidence includes the proximity of the vein to a nearby normal fault and the presence of quartz crystals up to 15 cm in length within the vein, an open-space texture consistent with dilation during extensional tectonism.

Structure

Dobbs (1961) states that a low angle northeast-trending, northwest dipping thrust fault (Mohawk Thrust) has transported Tapeats Quartzite to the southeast onto Bonanza King. Our mapping reveals the presence of Bright Angel (Carrara) between Tapeats and Bonanza King removing the need for a fault (see Fig. 2). However, several aspects of the stratigraphic relationships have lead the authors to continue to map the Bright Angle and Bonanza King in fault contact. Both Tapeats and Bright Angel strike northeast and dip northwest while the Bonanza King strikes northwest and dips southwest. The Bright Angel section appears greatly attenuated at the west end of

Figure 4. Footwall marble and juxtaposed hanging wall mylonitic Bonanza King. Plane of the fault lies just above the hammer head.

Mohawk Hill when compared to exposures five kilometers to the northwest. Furthermore, Walker, Burchfiel and Davis (1995 indicate the Bright Angel-Bonanza King contact is marked by a similar small thrust fault near Pachalka Spring.

A second fault lies just to the west of the West Adit mine workings on the south slope of Mohawk Hill (see Fig. 2). Its trace closely parallels that of the prominent quartz vein near the base of the ridge and a well defined zone of mylonitic deformation near the crest of the ridge (Fig. 4). The fault strikes N 60-80° E and dips moderately to the northwest. Both the footwall and hanging wall of the fault lie within the Bonanza King Formation. Footwall carbonates have been moderately to completely recrystallized to a medium-grained marble while hanging wall rocks are unmetamorphosed. Mapping suggests dip-slip motion with the hanging wall (northwest) block down. The fault cuts recrystallized Bonanza King and a N 50° E trending splay offsets the prominent quartz vein (Fig. 5). Additionally, the fault is unmineralized and appears to down-drop a portion of the west ore body. We conclude the fault is related to Tertiary extension.

Mapping of the West Adit has revealed a shear set trending N 30-50° W. The shears offset the intrusive causing brecciation of both the granite and the Bonanza King immediately adjacent to the contact. Intensity of shearing decreases eastward along the contact and outward from the intrusive. Ore body geometry suggests the shear zones acted as loci for initial hypogene mineralization.

Exact timing of the shearing is enigmatic. It postdates intrusion, but predates mineralization and Tertiary normal faulting. Hazelton (1991) mapping near the Copper World Mine recognized a series of fold axes related to east-directed thrusting. Such east-directed thrusting would cause ductile deformation of carbonates and brittle deformation of intrusives. Thus, the northwest-trending shear zones of Mohawk Hill may be a manifestation of thrust faulting. If the work of Walker, Burchfiel and Davis (1995) can be extrapolated to the south, the Mohawk granite is younger than the late Jurassic Winters Pass/Pachalka (Mohawk) thrust. Therefore, shearing might have occurred during Cretaceous compression related to the Mesquite Pass or Keaney-Mollusk Mine thrust.

Ore Mineralogy and Alteration

In as much as the purpose of this paper is to detail stratigraphic and structural relationships at the Mohawk Mine, only a brief discussion of ore mineralogy and alteration is included. For a more detailed discussion the reader is referred to Wise (1990) and Fallis (1990). The ore mineralogy at the Mohawk Mine is complex. Cerrusite is dominant, however smithsonite is common. Minor malachite, azurite and chrysocolla can be seen on the mine dumps. Galena and sphalerite were reported by Hewett (1956), and native silver and gold by Evans (1958). Gangue consists of abundant iron and manganese oxides in a matrix of coarsely-crystalline quartz and calcite. Minor jarosite, and pyrite are also present.

Hypogene alteration consists of silicification, widespread recrystallization of the Bonanza King Formation, skarnification and local sericitic and argillic alteration of granite. Weathering has produced a prominent secondary gossan of iron oxides overlying the ore zone.

Ore mineralization lies within a zone of moderately silicified and recrystallized limestone and dolomite of variable thickness (2-10 meters). Previous workers (Joseph, 1984) have characterized this zone as a tactite or skarn adjacent to the intrusive. Indications of the typical calc-silicate alteration associated with skarn mineralization include a small block of talc-tremolite schist on the north side of Mohawk Hill

Figure 5. View of Mohawk ridge looking to the northeast. Quartz vein (right center) is offset (left center) and down thrown along a northeast-striking normal fault.

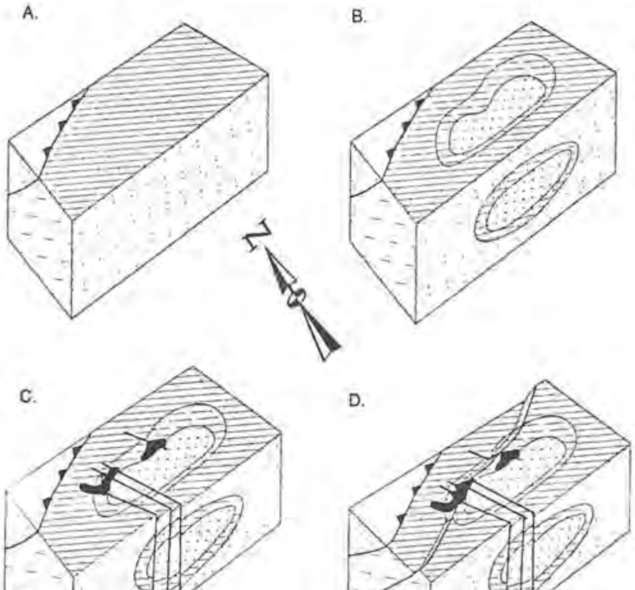

Figure 6. Tectonic setting of Mohawk Mine. A. Jurassic thrusting; B. Intrusion of the granite sill; C. Cretaceous compression, northwest shearing and emplacement of ore bodies; and D. Tertiary extension and normal faulting.

and local grains of epidote, diopside and idocrase in extensively recrystallized Bonanza King. Granite adjacent to ore zones has been subjected to moderate to strong sericitic alteration and weak argillic alteration. Biotite has altered to chlorite and a mixture of iron oxides while feldspar has altered to sericite + clay. Locally, up to 3% of the granite is comprised of serpentine and talc. Since the latter are typical hydration products of calc-silicate minerals, it seems probable the granite was characterized by a zone of endoskarn mineralization which subsequently underwent hydration.

Conclusions

Figure 6 presents a model for emplacement of mineralization at the Mohawk Mine. The first structural event was late Jurassic thrusting (Fig. 6A) resulting in formation of the Mohawk thrust. Evidence for this event includes structural discontinuities between the Bonanza King Formation and juxtaposed Bright Angel/Tapeats; attenuation of the Bright Angle section; and the presence of a similar thrust fault to the northeast near Pachalka Springs. Thrusting was closely followed by intrusion of the granitic pluton (Fig. 6B). A similar granitic intrusive seven kilometers to the northwest yielded an age of 142 Ma (late Jurassic). The intrusive nature of the contact with the Bonanza King is supported by extensive recrystallization of the Bonanza King, calc-silicate alteration of the carbonate and intrusive, folding related to ductile deformation of the Bonanza King during intrusion and a general lack of a brecciation and shearing along much of the contact.

Cretaceous compression, perhaps related to formation of the Mesquite Pass or Keaney-Mollusk Mine thrusts caused the formation of northwest striking shear zones within the granitic sill and associated brecciation of the intrusive-Bonanza King contact (Fig. 6C). Mineralization occurred when pore waters were expelled from the sedimentary host rock into zones of low pressure (i.e. breccia zones) as a consequence of the compression. While the timing of mineralization is uncertain, it clearly postdates the intrusive and northwest shearing, but predates Tertiary normal faulting. The final event depicted (Fig. 6D) is Tertiary extension which resulted in the northeast-striking normal fault that offsets mineralization, alteration and the quartz vein.. Not shown is the subsequent Quaternary denudation and oxidation of the ore deposits.

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The Occurrence of Monticellite-Clintonite-Vesuvianite Skarns at Clark Mountain, San Bernardino County, California

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Introduction

A diverse group of high temperature calc-silicate skarns are associated with a small quartz monzodiorite pluton (Fig. 1) that is located 300 meters northwest of the Copper World Mine on Clark Mountain, San Bernardino County, California. A number of these skarns are significant in that they represent only the fourth reported occurrence of monticellite coexisting with the uncommon trioctahedral brittle mica, clintonite (Adams, 1979; Adams and Anderson, 1979). This paper describes the various skarn mineralogies and environments at this locality and estimates the conditions of their formation.

Regional Geology

Clark Mountain, with an elevation of 2440 meters, occurs along the northeast margin of the Mojave Desert physiographic province and is located north of Interstate 15 at a distance of 100 kilometers southwest of Las Vegas, Nevada. This portion of the Mojave Desert is characterized by a north-south trending belt of mountain blocks which rise above alluvial slopes or pediments (Shadow Valley on the west, Ivanpah Valley on the east).

Hewett (1956) was the first to recognize that the Clark Mountains lie in the southern extension of the Cordilleran foreland thrust belt. Burchfiel and Davis (1971, 1988) refer to the Clark Mountain, Mesquite, Mescal, and Ivanpah Ranges collectively as the Clark Mountain thrust complex, which consists of three major eastwardly directed thrust plates. From east to west, the thrust faults, which have a combined minimum displacement of 60 to 80 km, are the Keaney/Mollusk Mine, Mesquite Pass, and Pachalka/Winters Pass thrusts.

During the Mesozoic, magmatic activity along the western margin of North America resulted from the eastward subduction of an oceanic plate (Hamilton, 1969). Isolated intrusives, presumably associated with plate convergence, are present in the Clark Mountain thrust complex and help to distinguish at least two major groups of Mesozoic deformational events associated with the formation of the complex (Walker, et al., 1995).

During the intrusion of a quartz monzodiorite pluton (Fig. 2), near the Copper World Mine, adjacent grey and white limestones of the Upper Cambrian Bonanza King Formation were transformed, by flowage, into a highly folded and foliated marble sheath which envelops the pluton (Burchfiel and Davis, 1973). Structures in this sheath are highly discordant to those in the surrounding country rock. The formation of the sheath from the grey and white limestones can be attributed to calcite having greater ductility and lower yield strength than the associated dolomite units. The boundary between sheath and

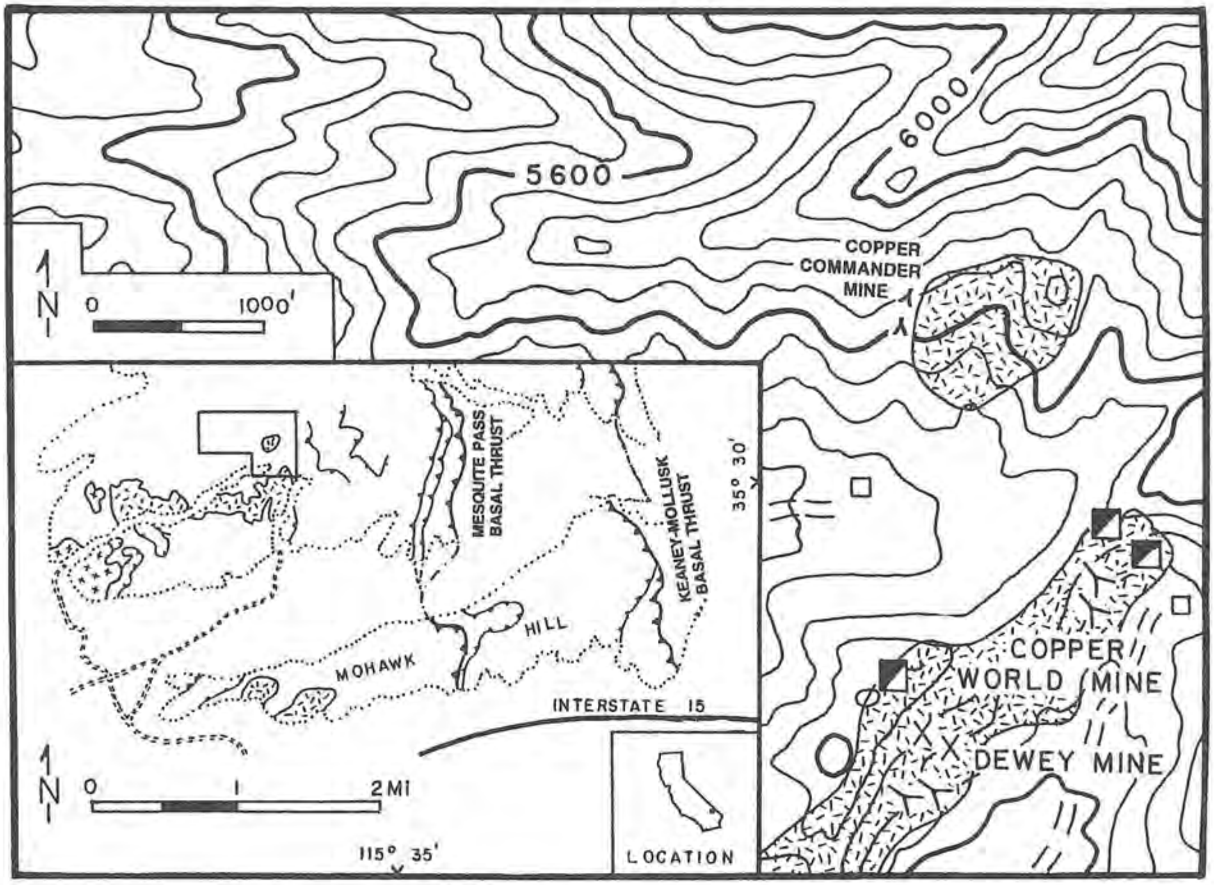


Figure 1. Index map showing the location of the quartz monzodiorite pluton that produced high temperature calc-silicate skarns. Pluton is 300 m NW of the Copper World Mine.

Figure 2. Quartz monzodiorite pluton and enclosing marble sheath. View looking north from the ridge immediately above the Dewey Mine.

country rock can easily be recognized as a fault when separating contrasting lithologies but grades into a zone of flowage between juxtaposed marbles. In addition to large open to isoclinal folds, small scale intrafolial folds can be recognized in some portions of the sheath. During folding, grey and white marbles have been recrystallized and display a pervasive flow structure. With the exception of additional grain growth during recrystallization, there is no direct evidence for contact metamorphism in the sheath. However, subsequent infiltration of metasomatic fluids along sheared zones in the sheath and alteration of included blocks have led to the development of calc-silicate skarns.

Description of Skarns

Figure 3 depicts the various skarn environments, outlined by Kerrick (1976), which have been observed in association with the quartz monzodiorite pluton. These include: roof pendants and included blocks, magmatic skarn (exoskarn and endoskarn), and vein skarn. Table 1 lists the calc-silicate minerals (with formulas) found in included blocks and vein skarns. Figure 4 shows the distribution of skarn types within roof pendants and sheath marbles.

Roof pendants and included blocks range from 125 m to 10 cm in length and represent marble or dolomite blocks which have been engulfed by magma and undergone intense pyrometasomatic alteration. The three fundamental rock types found as included blocks are named after the predominant mineral and are; prograde monticellite rock, prograde diopside rock, and retrograde vesuvianite rock. The bulk compositions of these rocks (refer to Table 1 for mineral formulas) are significantly different from the sheath marbles (which contain negligible Al_2O_3 and $< 3\%$ SiO_2) and indicate the addition of significant amounts of Si and Al from metasomatic fluids. Monticellite rock (monticellite + perovskite + calcite ± vesuvianite ± clintonite ± spinel) forms the majority of roof pendants and small included blocks. Outcrops have a characteristic light reddish-brown colored weathering surface and display a layering (Fig. 5) that is defined by poikiloblasts of vesuvianite (2-15 mm) and clintonite (2-10 mm). Fresh surfaces of monticellite are grey to yellowish tan in color and display a vitreous to sub-vitreous luster. Monticellite is less resistant to weathering than the poikiloblasts, and as a result, outcrops and talus are frequently studded with iron-stained, pseudo-cubic crystals of vesuvianite (Fig. 6) or dark green pseudo-hexagonal books of clintonite (Fig. 7). The surfaces of the vesuvianite crystals are typically pock-marked as a result of monticellite inclusions having been weathered out.

Monticellite from this general area was first noted by Schaller(1935) who described it occurring with spinel, garnet, and fassaite from the Dewey Mine, which is adjacent to the Copper World Mine(Fig. 1). The coexistence of clintonite with monticellite is somewhat unique and only three other occurrences have been reported. These are the Crestmore Quarry in Riverside Co., CA (Burnham, 1959), the Adamello Massif, Italy (Ulmer, 1982), and Green Monster Mountain, Alaska (Leavens and Thomssen, 1977).

The clintonites from this locality are among the most silica-poor and alumina-rich ever described from natural occurrences, and exhibit minor compositional variation dependent on mineral assemblage (Adams, 1979). The rarity of clintonite-bearing skarns has been attributed to the unique combination of a metasomatically produced silica-undersaturated alumina-rich bulk composition associated with H_2O rich fluids (Olesch and Seifert, 1976).

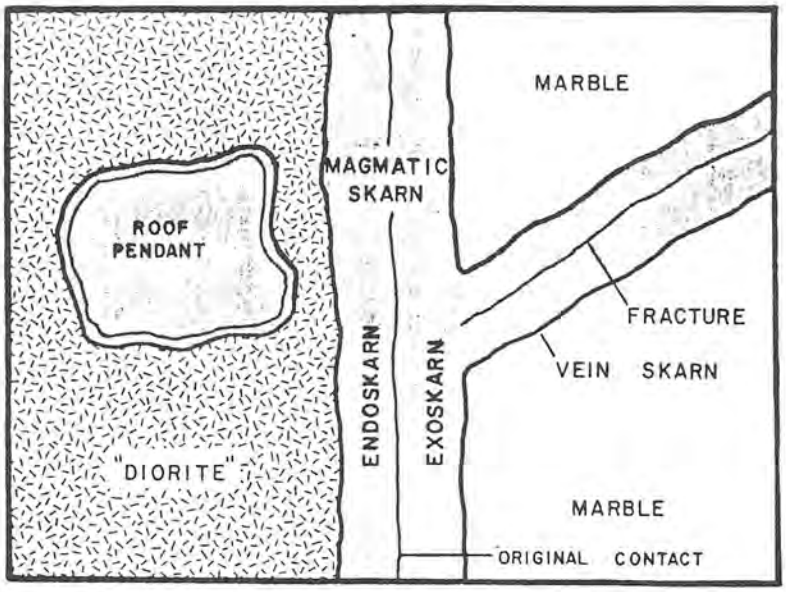
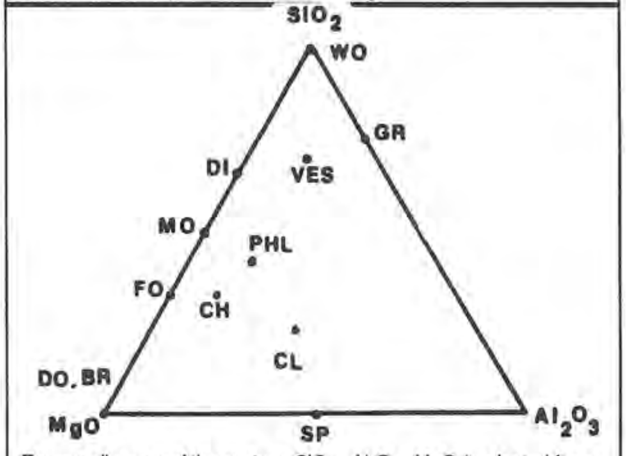


Figure 3. Schematic diagram depicting skarn types associated with quartz monzodiorite pluton.

Alteration products of monticellite rock that have been observed in thin section include: (a) rims of intergrown vesuvianite and brucite (and/or Fe-free clinochlore) often separate monticellite from clintonite, (b) afwillite(?) occasionally forms rims around monticellite in primary vesuvianite, (c) minute fibrous thaumasite(?) is an alteration product of some primary vesuvianite pseudo-cubes, (d) scaly brucite and anhedral andradite occur in clintonite-free monticellite rock, (e) retrograde vesuvianite often forms rims on primary vesuvianite and occasionally replaces monticellite inclusions therein, (f) frequently fibrous hillebrandite has formed along fractures or is intergrown with brucite, (g) in localized areas, intergrown fine-grained vesuvianite and iron-free clinochlore form pseudomorphs after monticellite and iron-free clinochlore or aluminian lizardite pseudomorphs after clintonite have

Table 1. Calc-silicate minerals (and formulae) identified from monticellite skarns and vein skarns

PRIMARY MONTICELLITE SKARNS	
calcite (CC)	
clintonite (CL)	$CaCO_3$
monticellite (MO)	$Ca(Mg,Al)_3(Al_3,Si)_3O_{10}(OH)_2$
perovskite	$CaMgSiO_4$
spinel (SP)	$CaTiO_3$
vesuvianite (VES)	$MgAl_2O_4$
	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
ALTERATION PRODUCTS OF MONTICELLITE SKARNS	
afwillite	$Ca_3Si_2O_4(OH)_6$
andradite	$Ca_3Fe_2(SiO_4)3$
brucite (BR)	$Mg(OH)_2$
clinochlore	$(Mg,Fe)_5Al(Si_3Al)_{10}(OH)_8$
hillebrandite	$Ca_2SiO_3(OH)_2$
lizardite	$Mg_3Si_2O_5(OH)_4$
thaumasite	$Ca_3Si(CO_3)(SO_4)(OH)_6 12H_2O$
vesuvianite (VES)	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
VEIN SKARNS	
calcite (CC)	$CaCO_3$
clinochlore (CH)	$(Mg,Fe)_5Al(Si_3Al)_{10}(OH)_8$
diopside (DI)	$CaMgSi_2O_6$
dolomite (DO)	$CaMg(CO_3)_2$
forsterite (FO)	Mg_2SiO_4
grossular (GR)	$Ca_3Al_2(SiO_4)_3$
phlogopite (PHL)	$KMg_3Si_3AlO_{10}(F,OH)_2$
spinel (SP)	$MgAl_2O_4$
vesuvianite (VES)	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
wollastonite (WO)	$CaSiO_3$



Ternary diagram of the system: $SiO_2 - Al_2O_3 - MgO$ (projected from CaO + fluid) showing relative compositions of calc-silicate phases.

both been observed. Tentative (?) identifications are based on cation stoichiometry derived from electron microprobe analyses.

Prograde diopside rock, consisting of nearly pure diopside, forms the majority of one large roof pendant. Outcrops are light grey in color and often have a layered appearance due the presence of retrograde vesuvianite veins.

Retrograde vesuvianite rock is found as a major constituent of some small roof pendants and as veins in monticellite and diopside rock. This retrograde assemblage consists of vesuvianite + diopside + chlorite + calcite. Outcrops are light green-grey in color and light green crystals of vesuvianite (to 2 cm) with complex morphologies are often prominent.

Magmatic skarn includes endoskarn and exoskarn, both metasomatic rocks, which have formed between fresh quartz monzodiorite and marble. Endoskarn represents igneous material which has interacted with marble. One specimen studied in detail consists of epidote, acmite-augite, garnet, and calcite. Rocks with an igneous parentage (quartz monzodiorite, endoskarn) are at all times separated from sheath marbles and included blocks by several centimeters to one meter of exoskarn. Exoskarn is light green to chocolate brown in color and contains the assemblage vesuvianite + diopside ± chlorite ± calcite ± garnet.

The sheath was formed totally from the Upper Cambrian Bonanza King Formation and consists of grey and white layered marbles. Sheath marbles contain the assemblage calcite ± dolomite ± quartz ± phlogopite ± chlorite, which is nearly identical to that found in the country rock. Vein skarns are restricted to the sheath, and were produced by metasomatic fluids from the quartz monzodiorite pluton infiltrating along fracture zones. Generally vein skarns are readily identified in outcrop by the presence of porphyroblasts of vesuvianite (to 2 cm), garnet or wollastonite. These porphyroblasts are more resistant to weathering than the enclosing marbles and protrude from the surface of outcrops (Fig. 8). Commonly grey sheath marbles have turned yellow or white in the vein skarns, although the absence of this coloration does not necessarily indicate an absence of metasomatism.

Vein skarns commonly display a simple zonation symmetrically disposed around the fractures which channeled metasomatic fluids. In one such example the following sequence of assemblages was observed outward from the fluid supplied fracture: (1) calcite + vesuvianite + diopside (diopside zone); (2) calcite + vesuvianite + wollastonite (vesuvianite-wollastonite zone); and (3) calcite + wollastonite + phlogopite (phlogopite zone). The diopside zone consists of yellow marbles which contain (40%) subhedral poikiloblasts of vesuvianite (2-5 mm), and 30% fibrous diopside (0.05-0.15 mm). The marbles in the vesuvianite-wollastonite zone are yellow to white and contain 20-25% subhedral vesuvianite poikiloblasts (0.2-1 mm) and twinned euhedral wollastonite (0.05-0.3 mm). The onset of the phlogopite zone is marked by a change in color of the marble from yellow or white to grey. Euhedral twinned wollastonite [0.05-0.3 mm) and euhedral phlogopite (0.05-0.15 mm) each form 10% of the marbles in this zone. At distances up to tens of meters from readily identifiable vein skarn, medium-grained marbles containing the assemblage calcite + forsterite ± dolomite ± spinel ± phlogopite ± chlorite have been observed. These marbles are also thought to be metasomatic in origin but are not recognizable as vein skarn in outcrop because of the low percentages (<10%) and small size (0.1 mm) of the metamorphic phases.

Retrograde vein skarns have also been observed along the western margin of the sheath. These are recognized by cross-cutting relationships with primary vein skarn or lower temperature mineral assemblages (calcite + orthoclase + amphibole). Lower temperature hydrothermal veins containing the assemblage calcite + quartz ± dolomite ± magnetite ± kaolinite are also relatively common in the sheath and country rock. The majority of these veins are relatively small and warrant no further attention but one unique concentration of hydrothermal activity has led to the replacement of sheath marbles by a 2-3 meter wide tabular magnetite body. The major portion of this body trends north-south along the western margin of the pluton and consists of nearly pure magnetite. Northward extensions of this body, though, are less magnetite rich and form 10-20 cm wide veins which intrude primary vein skarn. There is also copper and zinc mineralization in the vicinity of the magnetite body that has been explored by several adits (Copper Commander Mine) but these were not studied in detail.

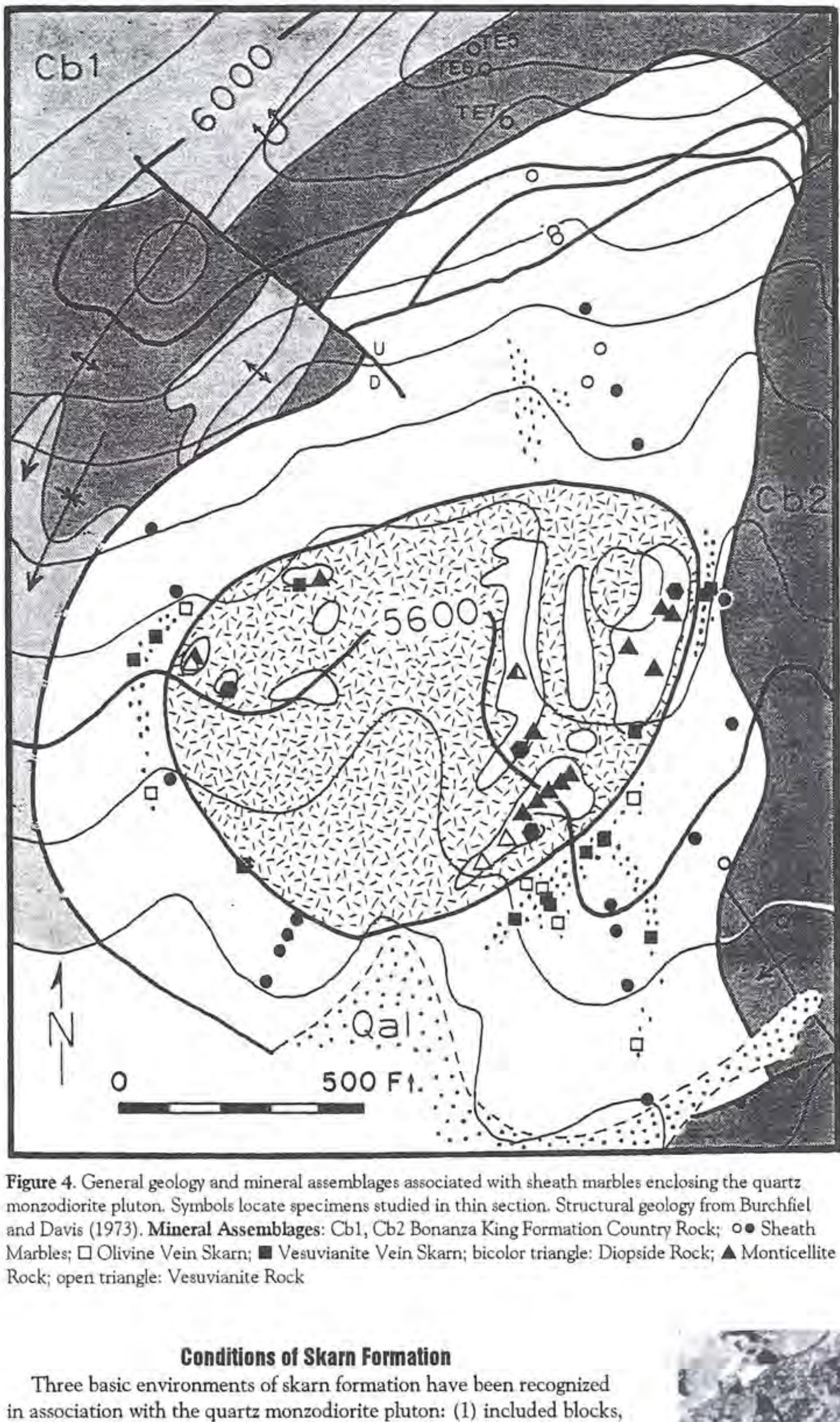


Figure 4. General geology and mineral assemblages associated with sheath marbles enclosing the quartz monzodiorite pluton. Symbols locate specimens studied in thin section. Structural geology from Burchfiel and Davis (1973). **Mineral Assemblages**: Cb1, Cb2 Bonanza King Formation Country Rock; ○● Sheath Marbles; □ Olivine Vein Skarn; ■ Vesuvianite Vein Skarn; bicolor triangle: Diopside Rock; ▲ Monticellite Rock; open triangle: Vesuvianite Rock

Conditions of Skarn Formation

Three basic environments of skarn formation have been recognized in association with the quartz monzodiorite pluton: (1) included blocks, (2) magmatic skarn, and (3) vein skarn. Skarn from each of these environments formed from Si and Al metasomatism of calcite and dolomite marbles, and have characteristic mineralogies and textures. As a result of retrogressive metamorphism, skarns have formed over a wide range of temperatures (and possibly fluid compositions). No evidence has been observed for a simple contact aureole in the sheath marbles which surround the pluton, but sheath and country rock marbles have been subjected to a very low grade of regional metamorphism. This regional metamorphism has transformed clays in the original sediments to chlorite, phlogopite and muscovite and may have been a result of deep sedimentary burial or thrusting. The only fundamental difference between sheath marbles and country rock lies in the larger grain size that sheath marbles have attained during recrystallization.

The highest temperature skarns are represented by the assemblage monticellite + calcite + perovskite ± clintonite ± vesuvianite, and are restricted to roof pendants and included blocks. Limited experimental and thermodynamic data on monticellite, clintonite and vesuvianite allow an estimation of the temperature and fluid phase composition (X_{CO_2}) during the highest grade of metamorphism (Adams, 1979). Stabilities and phase relations for monticellite, clintonite, and vesuvianite have been reported by Walter (1963), Olesch and Seifert (1976) and Ito and Arem (1970), respectively. While the experimental data is somewhat incomplete, it is possible, using the methods outlined in Skippen (1971), Skippen (1977), and Tracy (1978), to estimate approximate T vs X_{CO_2} diagrams at various pressure, for the various reactions involving monticellite, clintonite and vesuvianite (Fig. 9). These reactions include (see Table 1 for abbreviations, MEL=melilite, AN = anorthite, $_{ss}$=solid solution):

$(2)\ CC + FO + DI = (3)\ MO + (2)\ CO_2$:
Monticellite "in"
$VES = MEL + WO \square MO + H_2O$:
Vesuvianite "out"
$CL = SP + DI_{ss} + FO + CL_{ss} + H_2O$
$CL = SP + MEL_{ss} + AN + CL_{ss} + H_2O$

Discontinuous and continuous reactions involving these phases restrain the maximum temperature to be below 650-750° C and the minimum temperature to be above 550-724° C over a pressure range of 0.5-3 kilobars (Adams, 1979). An upper pressure limit of 3 kilobars is inferred based on stratigraphic thicknesses in the Clark Mountain thrust complex (G. A. Davis, personal comm.). Similarly the X_{CO_2} of the fluid phase must have been below 0.07 (i.e. $X_{H_2O} > 0.93$) during the formation of the skarns in the included blocks. These conditions are

Figure 5. Outcrop of monticellite rock. Metamorphic layering is defined by vesuvianite and clintonite poikiloblasts.

Figure 6. Macrophotograph of vesuvianite poikiloblasts (to 7 mm) in monticellite rock.

Figure 7. Macrophotograph of clintonite poikiloblasts (to 3 mm) in monticellite rock

taken from the very limited stability field outlined by the monticellite "in" and vesuvianite "out" reactions. The very high H_2O content of the fluid phase indicated by these reactions provides positive proof of the metasomatic nature of these skarns, which was originally inferred based on their bulk compositions. The reactions involving clintonite do not constrain the T - X stability field any further but they do serve as a check on the validity of the assumptions used in estimating the vesuvianite "out" reaction. In particular, this reaction could not be extrapolated with accuracy very far from $X_{CO2} = 0$ because of the very limited experimental data of Ito and Arem (1970).

Figure 8. Outcrop of vesuvianite bearing vein skarn in sheath marble.

The coexistence of vesuvianite with wollastonite in vein skarns also allows an estimation of their conditions of formation. Using the method outlined by Skippen (1977) (and thermodynamic data presented therein), along with stability data reported by Greenwood (1967), it was possible to plot the wollastonite "in" reaction in T-X space (Fig. 9). Unlike the case of vesuvianite coexisting with monticellite, vesuvianite coexisting with wollastonite is stable over a much larger region of T-X space. At 1000 bars, for example, the temperature of formation may have ranged from 450-700°C while X_{CO2} may have ranged from 0-0.60. There may be considerable error, however, in the values of X_{CO2} since they can not be accurately estimated very far from $X_{CO2} = 0$, as stated earlier.

Retrograde metasomatic activity continued over a wide range of temperature (and X_{CO2} ?) as evidenced by the development of thin rims of vesuvianite + brucite, or clinochlore, on clintonite in monticellite rocks and in some cases the complete replacement of these rocks by vesuvianite + diopside + chlorite + calcite. Similarly, prograde vein skarns are occasionally crosscut by calcite + orthoclase + amphibole veins, and along the western margin of the pluton a large tabular body of magnetite has replaced sheath marbles. Coexisting quartz-calcite--dolomite in portions of this magnetite body indicates that the conditions of formation for this final metasomatic event were below the talc isograd.

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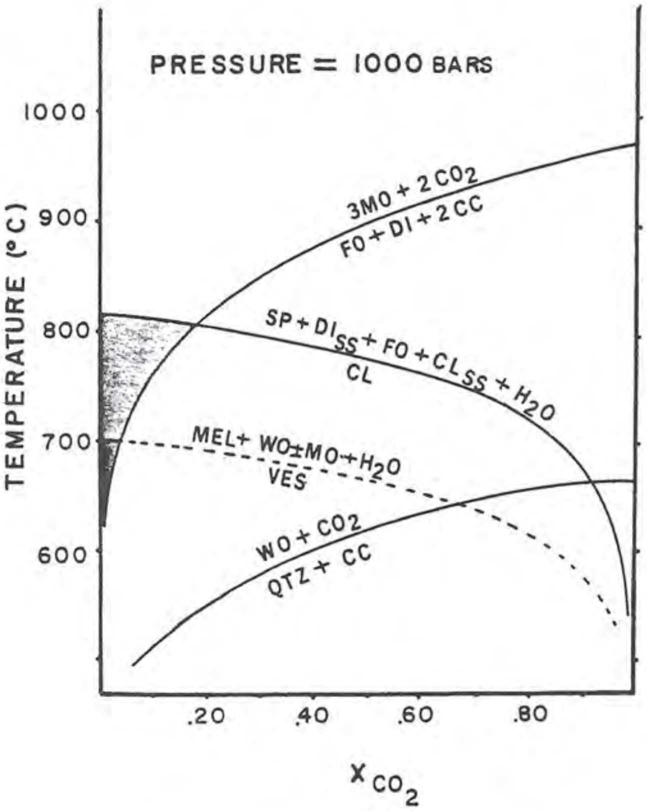

Figure 9. Temperature - X_{CO2} phase diagram, at a total pressure of 1000 bars, for reactions involving the stabilities of monticellite, clintonite, vesuvianite, and wollastonite. See Table 1 for abbreviations. DI_{ss} = DI solid solution, CL_{ss} = CL solid solution, MEL = melilite.

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Timing and Significance of the Pachalka Thrust, Clark Mountains, Southern California

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Abstract

Age data from the Clark Mountain area, show that Sevier-belt thrusting started in the Clark Mountain thrust complex in Late Jurassic time. The Pachalka thrust, structurally the highest fault in the complex, carries Late Jurassic plutonic rocks eastward above Cambrian rocks. Hanging wall and footwall rocks are mylonitic near the thrust contact. Hanging wall plutonic rocks are dated at 146 ± 2 Ma and thus are Late Jurassic. Folds kinematically related to thrusting in footwall metasedimentary rocks are overturned eastward and cut by the Pachalka pluton dated at 142 ± 7 Ma. These ages bracket thrusting and related deformation in structurally high levels of the complex to be latest Jurassic.

Introduction

The Clark Mountain area of southern Nevada and California forms the easternmost part of the Cordilleran fold and thrust belt at this latitude. In addition, it intersects the structural belt associated with the northwest-trending Mesozoic magmatic arc. The structural style within the Clark Mountain thrust complex is a blend of both foreland and hinterland deformational styles (Burchfiel and Davis, 1971, 1981, 1988). The complex, over a cross-strike distance of less than 10 km, contains both brittle, thin-skinned thrusts, that carry miogeoclinal and cratonal strata, and older, more ductile thrusts which are structurally higher and involve Precambrian basement rocks and Mesozoic plutons. North from the Clark Mountains, typical thin-skinned, east-directed thrusts along the eastern margin of the Cordilleran fold and thrust belt are separated from more ductile structures within the coeval magmatic arc that lies 10's to 100's of km to the west. To the south of the Clark Mountains, all contractile structures involve Precambrian basement rocks and Mesozoic plutons.

The Clark Mountain thrust complex contains: 1) an eastern autochthon of Precambrian basements rocks and a cratonal sedimentary succession that ranges in age from Cambrian (Tapeats Sandstone) to Cretaceous (volcanic and sedimentary rocks); and 2) allochthons of Precambrian basement rocks, Precambrian to Cretaceous sedimentary and volcanic rocks, and Mesozoic plutonic rocks. A more detailed stratigraphic description is presented elsewhere (Burchfiel and Davis, 1971, 1981; Fleck et al., 1994). The thrust belt is intruded by numerous Jurassic and Cretaceous plutonic rocks in the southern and western parts of the complex. Cretaceous plutons are part of the Teutonia batholith and its outliers, dated between 71 and 97 Ma (Beckerman et al., 1982; DeWitt et al., 1984).

Mesozoic structures in the Clark Mountain thrust complex include east-northeast-directed thrust faults, folds, and high angle faults. Faults related to Tertiary extension are also present in the area. Major thrust faults in ascending structural sequence (and from east to west) include the Keaney/Mollusk Mine (formerly, but erroneously, correlated with the Keystone thrust of the Spring Mountains, Nevada), Mesquite Pass, Mescal, Pachalka, and Winters Pass thrust faults (Fig. 1). The latter two faults are considered correlative (Burchfiel and Davis, 1971, 1988). These faults vary in

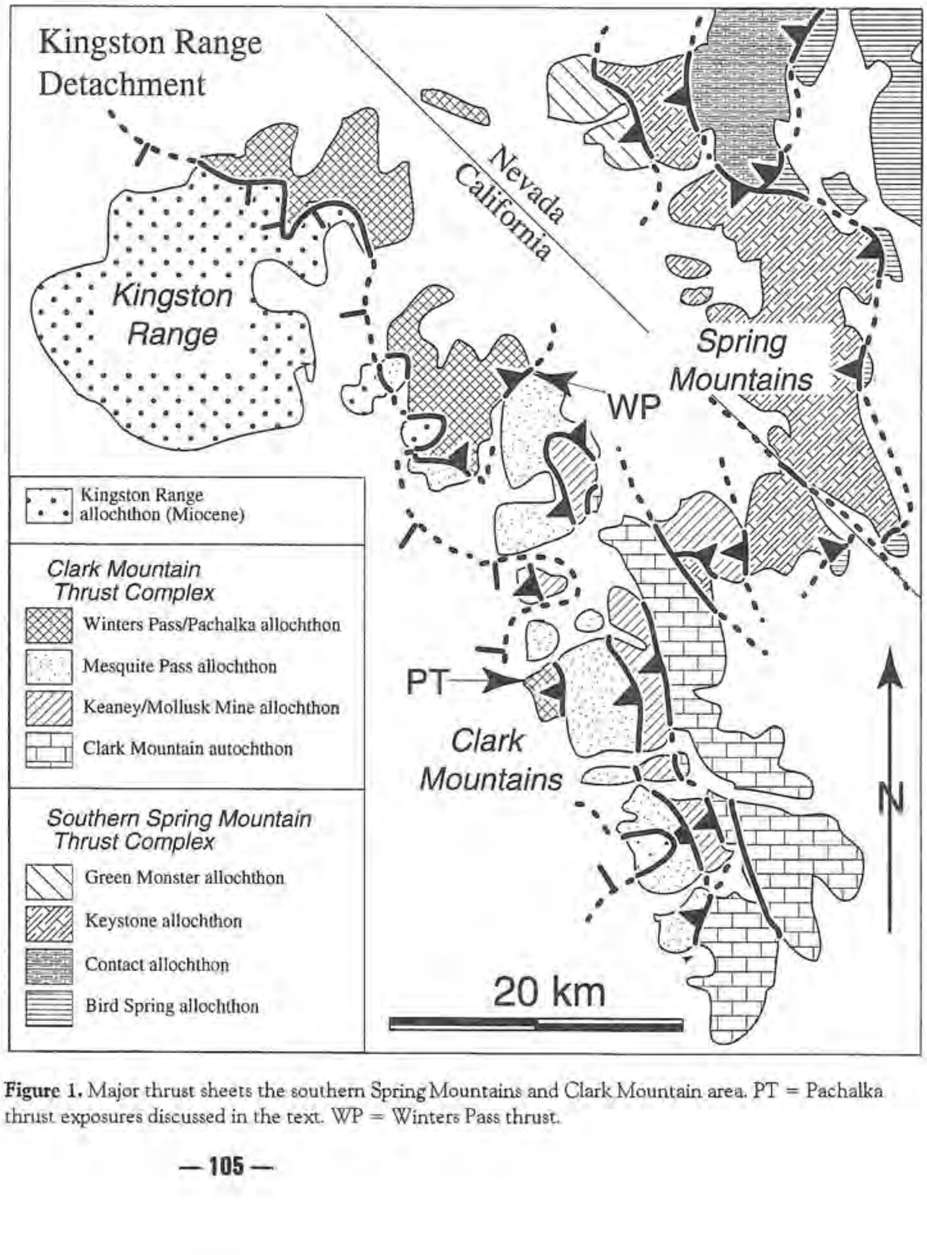

Figure 1. Major thrust sheets the southern Spring Mountains and Clark Mountain area. PT = Pachalka thrust exposures discussed in the text. WP = Winters Pass thrust.

structural style from brittle décollement thrusts, that involve only sedimentary rocks (Keaney/Mollusk Mine), to ductile thrusts that carry crystalline basement and plutonic rocks (Mesquite Pass, Pachalka/Winters Pass). The Pachalka/Winters Pass thrust is the structurally highest thrust in the Clark Mountain thrust complex and carries Jurassic plutonic and Precambrian crystalline basement rocks in its hanging wall. Major Mesozoic high-angle faults include the Kokoweef and South faults that juxtapose eastern Precambrian cratonal basement rocks against Cambrian to Cretaceous strata.

Tertiary structures that strongly overprint Mesozoic structures in the Clark Mountain complex include the Kingston Range detachment fault and several low-angle normal and strike-slip faults (Burchfiel and Davis, 1989; Davis and others, 1993). Extensional faults can be distinguished from contractile ones based on their structural style and westward sense of displacement. The normal faults, although locally subparallel to the thrust faults, have brecciated and shattered hanging walls, hanging wall-down-to-the-west sense of shear, and extensively deform Tertiary sedimentary and igneous rocks. The normal faults do not greatly disrupt the arrangement of the Mesozoic contractile structures.

Structural Geology of the Pachalka Thrust

The Pachalka thrust is a ductile east-directed thrust fault exposed on the west side of Clark Mountain (Fig. 1; Burchfiel and Davis, 1971, 1988). The thrust places granitic rock on folded Cambrian strata. The thrust contact is sharp and mylonitic rocks associated with the thrusting extend more than 100 m into the hanging wall and more than 30 m into the foot wall. The mylonitic stretching lineation plunges shallowly S80W, and S-C fabrics in mylonitic gneisses record top-to-the-east sense of shear.

Footwall rocks have a well-developed axial plane cleavage and contain folds overturned to the east both below and east of the thrust contact. About 1.5 km east of the thrust trace, the folds become more upright and cleavage is less well developed. All of these folds are interpreted to be related to emplacement of the Pachalka thrust, because of similar trend, continuity, and eastward gradation from overturned to upright. About 2 km east of the thrust trace, one of the synclines within the footwall rocks is intruded by the post-kinematic Pachalka pluton. The contact aureole of this pluton overprints fabrics related to folding and, by our interpretation, related to the Pachalka thrust.

The age of thrusting may be bracketed by the ages of the pre-kinematic granitic rocks in the hanging wall of the Pachalka thrust and the post-kinematic Pachalka pluton which cuts folds and fabric related to the thrust. Hanging wall plutonic rocks were previously considered to be Precambrian (Burchfiel and Davis, 1971, 1988), however, these rocks give an age of 146 ± 2 Ma (Walker et al., 1995). The Pachalka pluton gives an age of 142 ± 7 Ma (Walker et al., 1995). Because both the deformed and undeformed plutons yield similar ages (within error), we interpret these data to mean that the emplacement of the Pachalka thrust and the associated mylonitization and folding was active at about 144 Ma (latest Jurassic).

The Pachalka thrust age may also apply to other structures in the Clark Mountain area. The Pachalka thrust correlates with the Winters Pass thrust to the north. West of Striped Mountain in the southwestern part of the thrust complex, a 650m-thick section of folded and mylonitized upper Precambrian sedimentary rocks are interpreted to be in the footwall of the Pachalka thrust (Burchfiel and Davis, 1988). These correlations suggest that a significant amount of the shortening within the thrust complex, as well as the involvement of crystalline basement rocks and Mesozoic plutons in thrust faulting, is of latest Jurassic age.

Discussion

The data presented above allow us to better bracket the age of the contractile deformation within part of the Clark Mountain thrust complex and to place it in a regional context. Because the Clark Mountain thrust complex lies at the intersection of the Sevier fold and thrust belt and the Mesozoic magmatic arc and its associated structural features, the Clark Mountain area is an ideal region to compare timing of arc, thrust belt and foreland deformational events. In the central part of the Clark Mountains thrust complex, the Pachalka thrust formed as a ductile thrust, carrying plutonic rocks of the magmatic arc in its hanging wall. Farther north, it becomes a basement-involved, thin-skinned Winters Pass thrust. The Pachalka thrust slipped late in the history of the east Sierran contractile belt associated with the magmatic arc (Dunne and Walker, 1993) but early in the history of the Sevier thrust belt (Armstrong, 1968, Royse, 1993). For this reason, and because of the style of the Pachalka and Winters Pass thrusts, we consider the Pachalka thrust to be transitional in age as well as structural style between the two thrust systems.

Acknowledgments

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Tectonic Controls on Evolution of the Miocene Shadow Valley Supradetachment Basin, Southeastern California

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Introduction

Miocene strata of the Shadow Valley basin rest unconformably on the upper plate of the Kingston Range – Halloran Hills detachment fault system in the eastern Mojave desert, California (Fig. 1; Davis and others, 1993; Burchfiel and others, 1983). The depositional and structural evolution of the basin occurred in two broad phases that can be related to development of the underlying detachment fault. During the earliest portion of basin development ("phase one" — 13.4 to 10 Ma in the Shadow Valley basin; 13.4 to 12.8? Ma in the Kingston Range), 500–3000 m of concordantly-bedded sedimentary and volcanic strata were deposited onto the subsiding upper plate of the detachment fault. At this time, the upper plate translated southwestward as an intact block with only limited internal deformation. During later portions of basin development ("phase two" — 10 to 8.5 Ma in the Shadow Valley basin; ~12.8? to 12.4 Ma in the Kingston Range) the detachment fault upper plate and overlying Tertiary strata were extended and tilted by predominantly west-dipping normal faults. Phase two strata were deposited synchronously with upper-plate normal faulting; they unconformably overlie phase one deposits and display progressive shallowing in dip and intraformational onlap. Below, we briefly summarize Miocene geologic relations in the Shadow Valley basin and Kingston Range and relate basin development to the dynamic response of extending continental crust. For more detailed treatments of Shadow Valley basin sedimentation and tectonics, the reader is referred to Davis and others (1993), Bishop (1994), Fowler (1992), Fowler and others (1995), Fowler and Calzia (in press), and

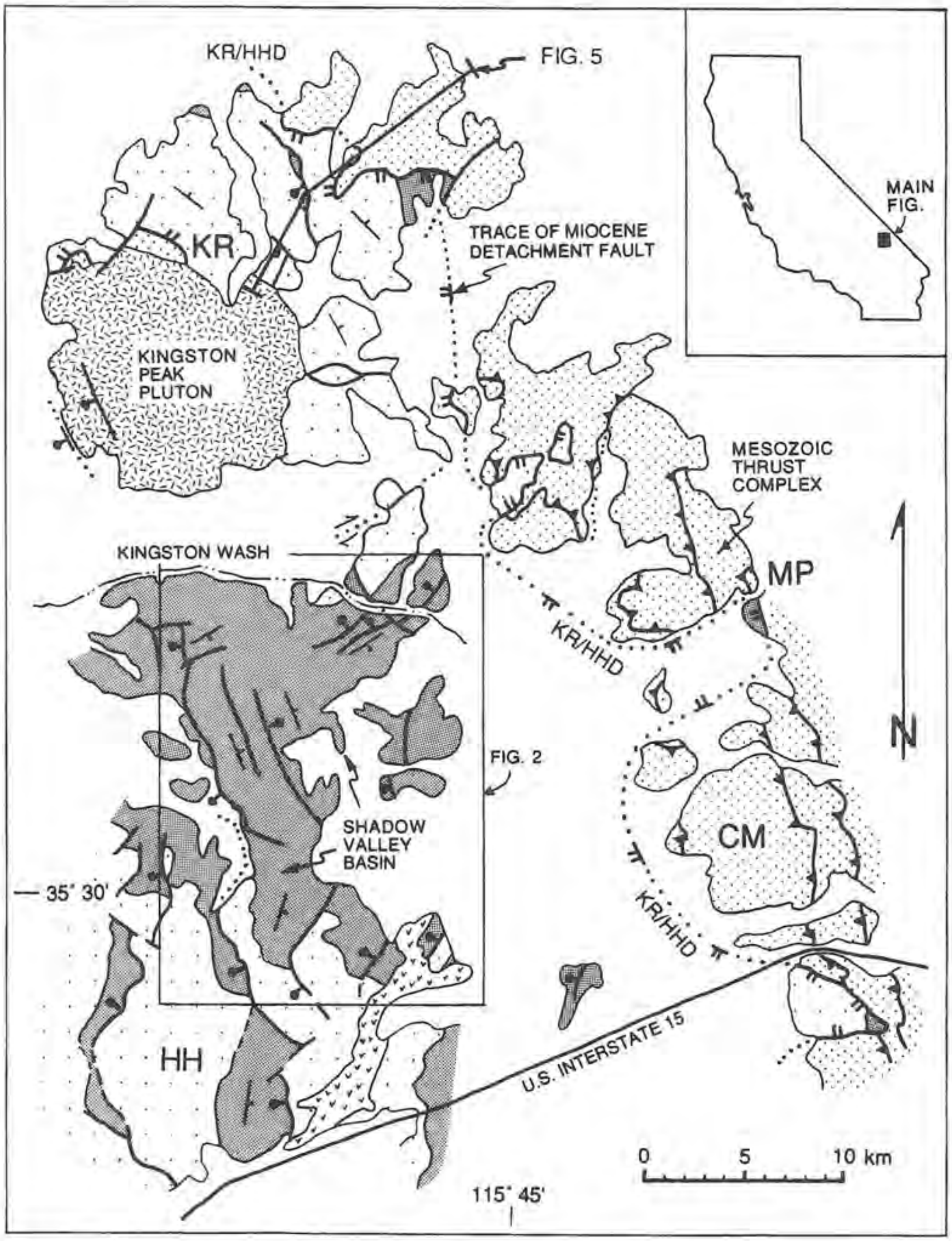

Figure 1. Location map of Shadow Valley basin. KR/HHD = trace of Kingston Range-Halloran Hills detachment fault; dark stipple = Miocene Shadow Valley basin and equivalent strata; medium stipple = pre-Tertiary rocks of KR/HHD lower plate; light stipple = pre-Tertiary rocks of KR/HHD upper plate; KR = Kingston Range; MP = Mesquite Pass; CM = Clark Mountain. Figure after Davis and others (1993).

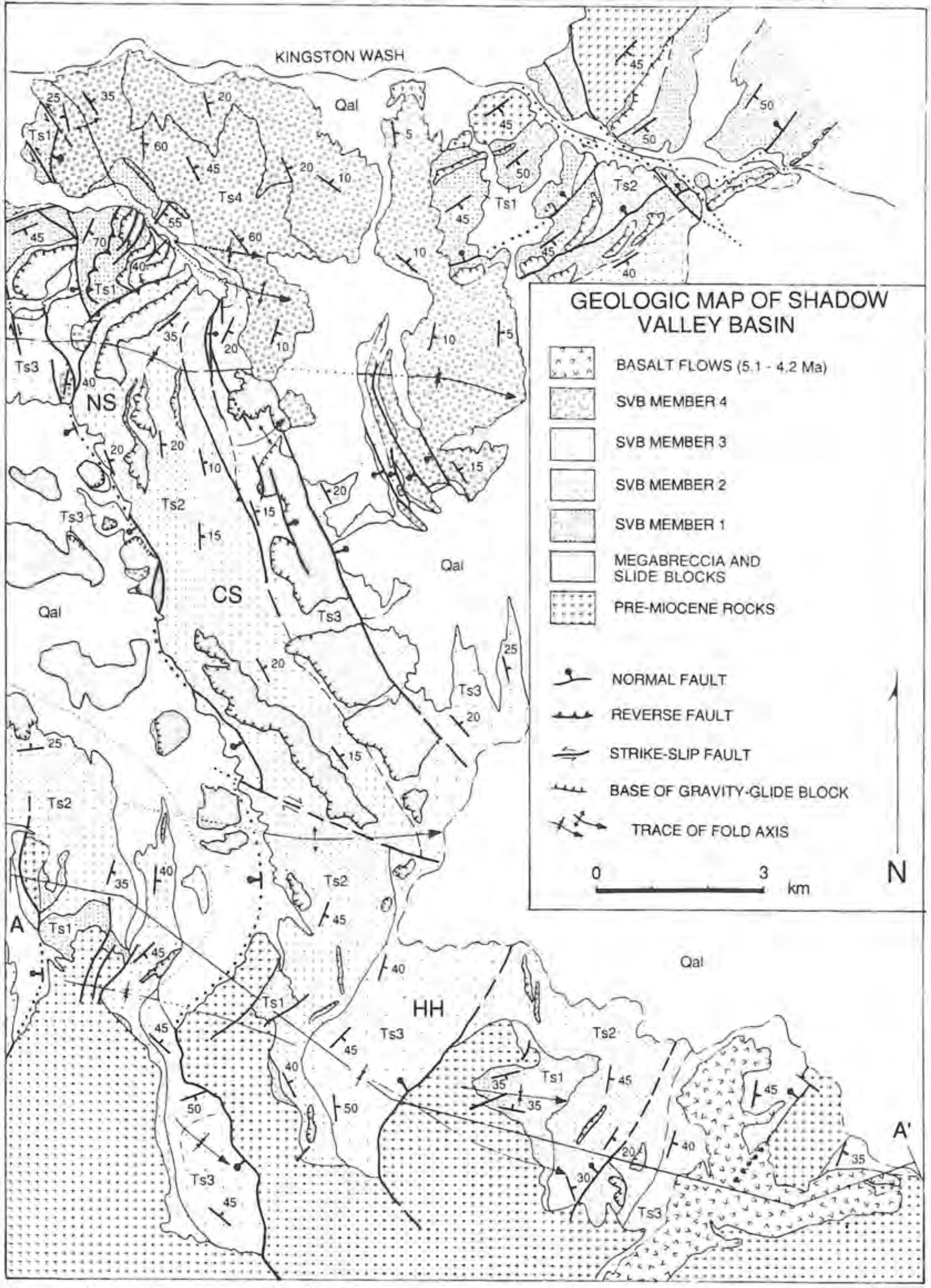

Figure 2. Simplified geologic map of the Shadow Valley basin. Compiled from 1:12,000 scale mapping by K. Bishop (Halloran Hills), G. Davis (northern Shadow Mountains), K. Fowler (eastern Shadow Mountains and Kingston Wash), J. Friedmann (Kingston Wash), and M. Parke (central Shadow Mountains). Details of Shadow Valley basin stratigraphy can be found in Friedmann and others (in press; 1994), Davis and others (1993), Bishop (1994), and Fowler (1992). Figure from Fowler and others, 1995.

Friedmann and others (1994, and in press).

Phase One

Shadow Valley basin phase one began shortly after 13.4 Ma, with nearly synchronous initiation of rapid basin sedimentation, proximal volcanism, and detachment faulting. In the northern Shadow Mountains, phase one strata are approximately 2,200 m thick (Figs. 2, 3). They comprise a lower section of carbonate-clast fanglomerate, carbonate and quartzite megabreccia, lacustrine silt and clay, and mafic to felsic volcanic flows, breccias, and tuffs (SVB unit 1), and an upper section (SVB units 2 & 3) of interfingering fanglomerates, lacustrine silts and clays, megabreccias, large gravity-glide blocks (up to 100 km^2), and minor volcanic ash. At any single location, phase one strata are bedded sub-parallel to one another and pre-date the main phase of extensional faulting within the detachment fault upper plate (Figs. 3, 4). Seven $^{40/39}$Ar ages recently obtained from phase one volcanic rocks fall between 13.1 ± 0.2 Ma ($^{40/39}$Ar biotite) and 10.8 ± 0.2 Ma ($^{40/39}$Ar biotite; Friedmann and others, in press). Miocene strata in the Kingston Range were named the Resting Springs Formation by Hewett (1956) and are correlative with Shadow Valley basin unit 1 strata to the south in the Shadow Mountains and Halloran Hills. Radiometric ages from the two sections overlap and the two localities are tied stratigraphically by a distinctive porphyritic andesite flow (Fowler, 1992; McMackin, 1992; Friedmann and others, 1994). Regionally, phase one strata generally rest disconformably (Hewett, 1956) above rocks that range widely in age, including Precambrian to Cambrian miogeoclinal strata, Mesozoic plutonic rocks, and locally, slightly older pre-basinal Tertiary strata (Friedmann, this volume).

Several lines of evidence strongly support the hypothesis that phase 1 sedimentation was controlled by detachment faulting. Faulting and sedimentation are spatially and temporally related. The detachment fault trace lies immediately east of, and dips gently southwestward beneath the basin, whereas basin deposits are largely confined to the detachment fault upper plate (Fig. 1). Sedimentation in the Shadow Valley basin began shortly after 13.1 Ma (Friedmann and others, in press). Detachment faulting began between 13.4 Ma and 12.4 Ma; in Mesquite Pass, the detachment fault

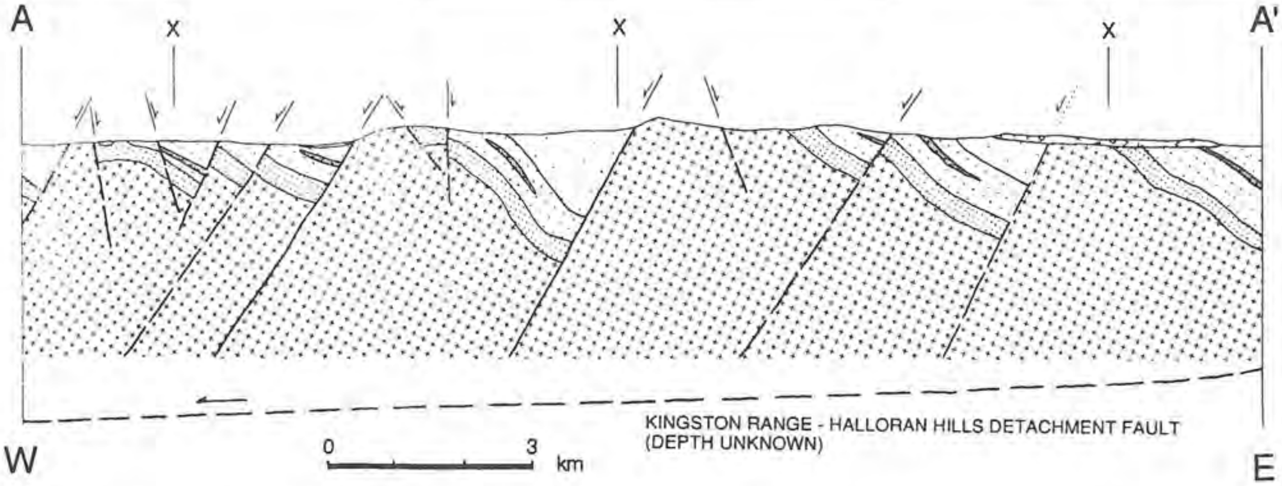

Figure 3. Geologic cross section A to A'. Patterns same as in Figure 2. X denotes bend in section. After unpublished cross section by K. Bishop.

cuts a felsic hypabyssal sill (13.4; K-Ar, hornblende; R. Fleck, pers comm. to G.A. Davis, 1992) whereas in the Kingston Range, the detachment fault is cut by the 12.4 Ma granite of Kingston Peak (Wright, 1974; Calzia, 1990; Davis and others, 1993). The sudden onset of rapid sediment accumulation (1 m/1,000 years) in the Shadow Valley basin followed tens of millions of years of erosion (Hewett, 1956), suggesting that sedimentation was controlled by fault initiation. Abundant mass wasting deposits in the basin, including both megabreccias and large gravity-driven slide blocks, suggest fault scarp-related sedimentation. The detachment breakaway apparently controlled sediment supply and drainage patterns for the basin; phase one sediments were largely derived from the footwall and transported westward across the breakaway onto the hanging wall (Friedmann and others, in press).

Structural reconstruction of the detachment fault suggests that geometry of the fault can account for phase one basin geometry. Although the Kingston Range – Halloran Hills detachment fault currently dips 0° to 15° SW (Figs. 1, 5), the fault did not initiate with this shallow orientation. In the Kingston Range, middle Miocene and older strata in both the upper and lower plates of the detachment fault

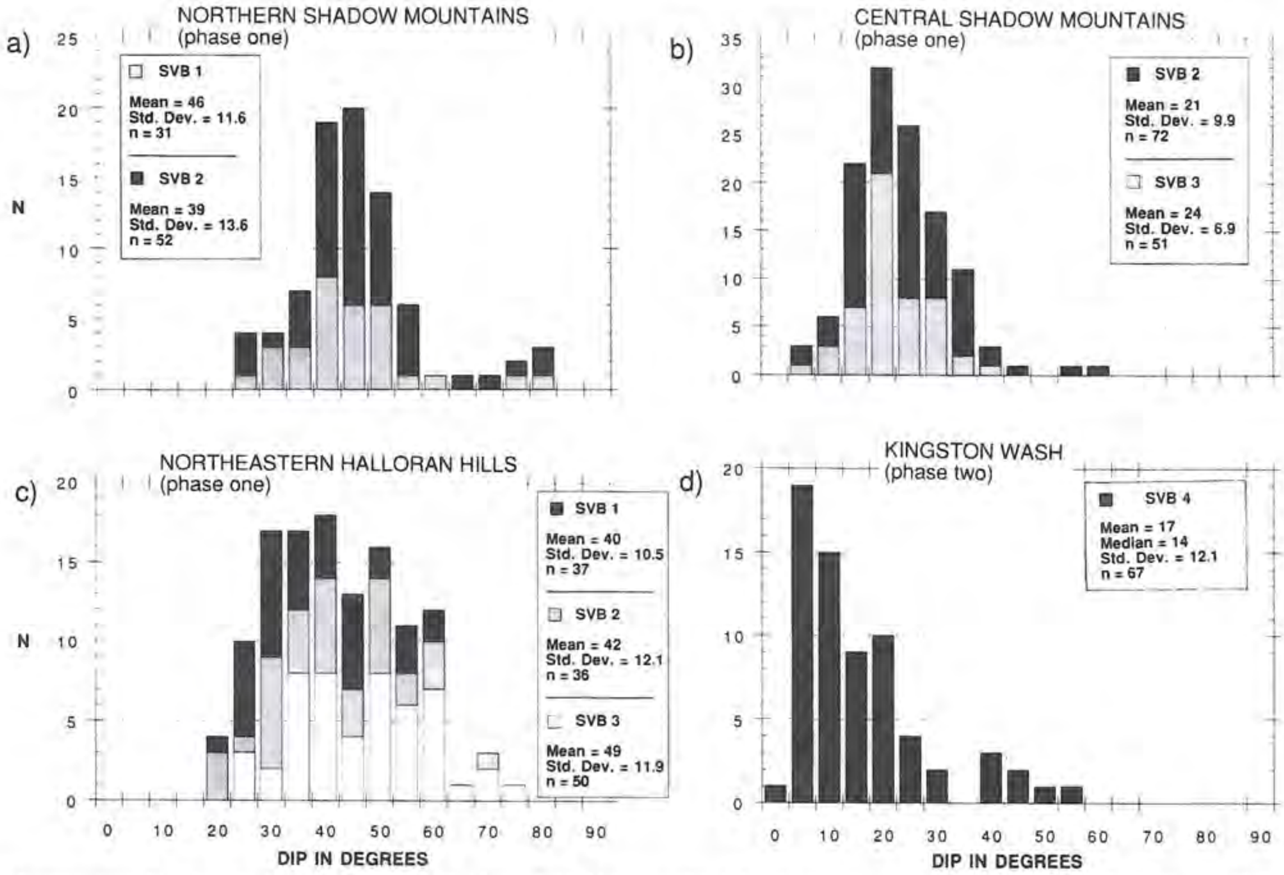

Figure 4. Histograms of bedding dip data from Shadow Valley basin divided by geographical domain. Note rough parallelism of bedding dips in Shadow Valley basin units 1-3 in any given domain. Unit 4 shows broad range of bedding orientations with an asymmetrical distribution that is skewed toward shallow dips. Figure from Fowler and others, 1995.

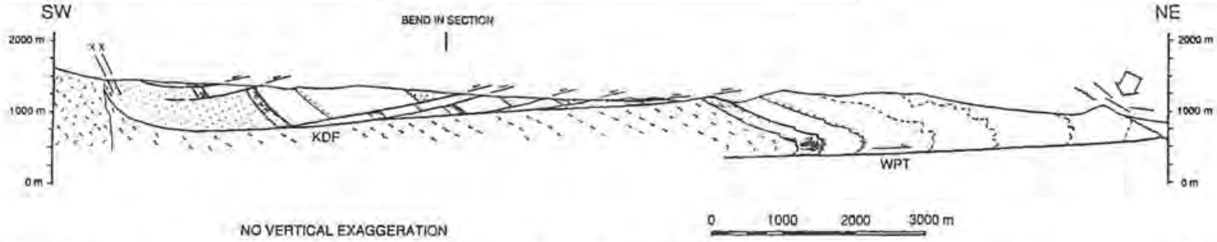

Figure 5. Simplified geologic cross section of the northeastern Kingston Range. Representative dips of lower plate Tertiary strata have been projected approximately 500 m onto the line of section (indicated below open arrow). Unit patterns are (from oldest to youngest): wavy dash = Precambrian gneiss; dots = Precambrian Pahrump Group; shaded = Precambrian Noonday Dolomite; white = Precambrian to Cambrian miogeoclinal strata; random stipple = Tertiary Resting Springs Formation; random dash = granite of Kingston Peak. Solid line with dots above is marker horizon in the Johnnie Formation. Dashed lines in lower plate miogeoclinal rocks are form lines showing geometry of Mesozoic folding. WPT = Winters Pass thrust fault; KDF = Kingston Range detachment fault. Figure from Fowler and Calzia (in press).

currently dip northeastward, indicating that the fault has been tilted (Fowler and Davis, 1992; McMackin, 1992; Fowler and Calzia, in press). Limited paleomagnetic data suggest that the granite of Kingston Peak is tilted 15°NE (Jones, 1983). When middle Miocene and disconformably underlying Cambrian strata are restored to their original orientation, the fault/bedding cutoff angle with upper- and lower-plate rocks indicates that the average initial fault dip was 38° ± 9° SW between the Earth's surface and 4 km depth (Fig. 6; Fowler and Calzia, in press). Dip-slip displacement of 2 – 9 km (magnitude constrained by surface mapping) along an initially 38°-dipping detachment fault would create 1 – 5 kilometers of structural relief, consistent with the observed thickness of phase one strata and providing a steep mountain front from which to derive the mass wasting deposits.

Phase Two

Following the above described period of upper-plate translation and concordant deposition of basin strata (phase one), the upper plate of the Kingston Range – Halloran Hills detachment fault was internally extended and tilted by normal faults (phase two). A set of northeast- to northwest-striking, primarily west-dipping brittle normal faults cuts the Shadow Valley basin, repeating basin strata and the basal Tertiary unconformity at least five times across the northern Halloran Hills (Figs. 2, 3; Bishop, 1994; Reynolds and McMackin, 1988; Reynolds, 1991). Cross-cutting relationships with basin strata indicate that these normal faults initiated after deposition of Shadow Valley basin unit three and during deposition of Shadow Valley basin unit four, which consists predominantly of alluvial fan deposits containing boulders of the granite of Kingston Peak (Fig. 2; Fowler, 1992; Bishop, 1994). Dip data indicate eastward tilting during unit four deposition (Fig. 4); strata within unit four show a fanning dip distribution that is skewed toward very shallow dips (0° to 10°). Additionally, unit 4 strata characteristically overlie tilted strata of units one through three with angular unconformity (Fig. 2).

Although direct age determinations on phase two strata do not exist, phase two deposition is bracketed by underlying 10.8 ± 0.2 Ma phase one strata, and by a 5.1 ± -.2 Ma (K-Ar; Turrin and others, 1985) basalt flow in the Halloran Hills which unconformably overlies normal faults that were active during phase two deposition (Fig. 2). Upper-plate extensional faulting (phase two) occurred earlier in the Kingston Range (prior to 12.4 Ma granite of Kingston Peak) than in the Shadow Mountains and Halloran Hills. This difference in the duration of basin development apparently relates to position with respect to the detachment fault breakaway; basin exposures in the Kingston Range occur adjacent to the breakaway (0-15 km) whereas exposures in the Shadow Mountains and Halloran Hills occur far from the breakaway (20-40 km). At both locations, available age constraints indicate that detachment fault initiation and upper-plate break-up were separated in time (0.5 – 3.5 million years).

Summary

Fowler and others (1995) suggest that the change in structural and depositional style represented by the phase one to phase two transition

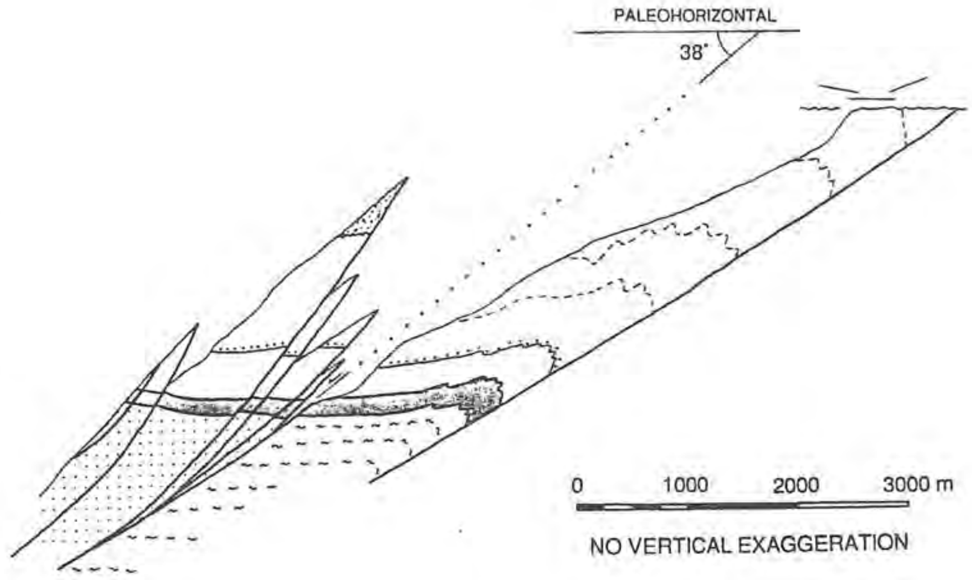

Figure 6. Structural reconstruction of cross section in Fig. 5 immediately prior to inception of Miocene detachment faulting. See Fowler and Calzia (in press) for constraints.

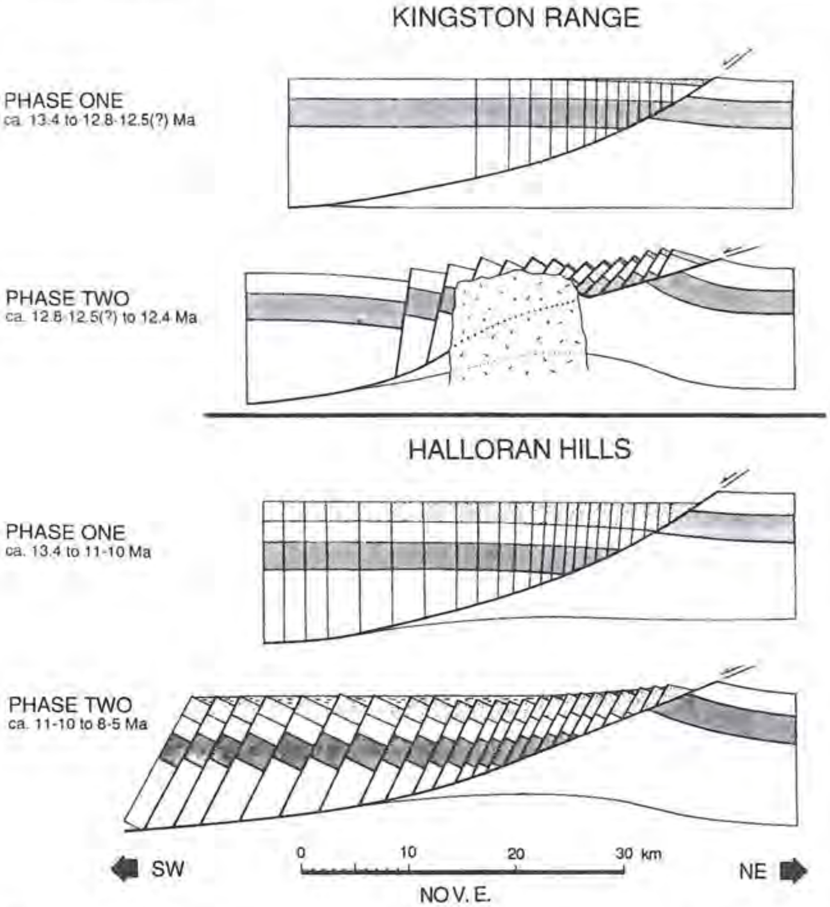

Figure 7. Balanced, schematic cross sections showing model for two-phase evolution of the Shadow Valley basin. Shaded bar is idealized, initially horizontal marker. Stipple pattern shows phase one strata. Horizontal dash pattern shows phase two strata. Random dash pattern is granite of Kingston Peak. Upper-plate translation, extension, and basin thickness is constrained by surface geologic data. The detachment fault initial dip is constrained by geologic relations in the Kingston Range. Detachment fault geometry below ca. 4 km depth is conjectural. Figure from Fowler and others, 1995.

may record a change in lower-plate mechanical behavior (Fig. 7). They argue that during phase one, the detachment fault lower plate remains an essentially intact ramp, allowing smooth translation of the upper plate with overlying deposition of largely concordant phase one strata. At this time the mechanical behavior of the lower plate may be analogous to an elastic plate with high flexural rigidity, and any initial isostatic response to detachment faulting is distributed across a broad region. As the upper plate continues to translate, tectonic denudation and unloading of the lower plate exceeds lower plate strength (exceeds the elastic limit of strain?) and rapid lower-plate isostatic uplift begins, thus rotating the detachment fault into a shallow configuration (c.f. Spencer, 1984; Buck, 1988). As the dip of the detachment fault decreases, the normal stress component across the fault increases, strengthening frictional coupling between the upper and lower plate and inhibiting translation. The upper plate may then behave as a supercritical Coulomb wedge, unable to translate without also reducing wedge taper to the critical angle by extending internally (Xiao and others, 1991). Thus, the birth and death of a supradetachment basin images a cycle, from initial mechanical strength to ultimate mechanical failure, of the dynamic response of continental crust to rapid extension.

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Tertiary Breccias in the Halloran Hills, North-Central Mojave Desert, California: Characteristics of Catastrophic Rock Avalanche Deposits

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Abstract

Large breccia bodies within Tertiary Shadow Valley basin fill are exposed in the Halloran Hills of southern California. These breccias display characteristics suggesting two different emplacement mechanisms operated. Large breccia sheets within the upper basin unit have a basal mixed zone which incorporates underlying material, coarsen upward, and display crackle and jigsaw brecciation. These features are characteristic of catastrophic rock avalanche deposits. The catastrophic rock avalanche deposits are interbedded with proximal alluvial fan deposits, suggesting deposition within a few kilometers of the source area. Deposition occurred during the final stages of detachment-related basin development. The mountain-sized Squaw Peak block does not display features characteristic of catastrophic rock avalanche deposits. Brecciation is relatively rare, and is distributed throughout the body in isolated zones. The base of the block is relatively sharp, and there is not concentration of brecciation near the base. The block therefore is interpreted as having been emplaced by a non-catastrophic gravity glide mechanism. Emplacement of glide blocks in the Shadow Valley basin was approximately coeval with emplacement of massive catastrophic rock avalanche deposits in the Amargosa Chaos basin in southern Death Valley, and may have been related.

Introduction

Monolithologic breccia deposits resulting from gravity-driven mass movement have been reported from many extensional basins in the southwestern United States. Most are interpreted as resulting from catastrophic rock avalanches, while others are thought to result from slow downslope creep. Structural controls play a major role in the genesis of both types of deposits, and thus the breccias can provide significant information about paleotopography and structural activity at the time of emplacement.

Several large monolithologic breccias occur within deposits in the Tertiary Shadow Valley basin exposed in the Halloran Hills of southern California. Descriptions of two very different large breccia bodies are presented in this paper, along with an interpretation of the mechanisms responsible for their emplacement.

Characteristics of Sedimentary Breccias

Types of Monolithologic Breccias

Breccia deposits are seldom described in sufficient detail to determine depositional mechanism. Many workers refer to all large breccia bodies simply as "monolithologic breccias," with no further description, assuming a landsliding origin. However, "monolithologic breccia" is a generic term that can refer to any coarse-grained sedimentary rock composed of angular fragments that are pebble-sized or larger, derived from a lithologically homogenous source. The term conveys no information about matrix abundance or internal organization, and thus no depositional mechanism is implied. Strata that can be described as monolithologic breccias include fluvial, debris flow, catastrophic rock avalanche, and gravity glide deposits. This paper is concerned with the latter two breccia types.

Catastrophic Rock Avalanche Deposits

Catastrophic rock avalanche deposits generally originate as huge rockfalls that traverse gently inclined slopes below at high speeds. Single large blocks fracture on impact and subsequently are not much deformed (Shreve, 1968). Large-volume rock avalanches may travel as much as 10-15 kilometers from their source, with the travel distance dependent on the mass of the rock body (Shreve, 1968; Hsü, 1975). Eyewitness accounts of historical events indicate that rock avalanches move faster than a person can run (Heim, 1882).

Yarnold and Lombard (1989) identified a number of features that are characteristic of large-volume rock avalanche deposits formed in dry climates. These include (from bottom to top):

(1) **Deformed substrate:** Sediments immediately underlying avalanche deposits locally display folding and contortion that die out downsection from the avalanche-substrate contact. The upper surface of the substrate may be scoured to depths of 5-10 m or more. Substrate deformation is characteristically found in the distal parts of deposits.

(2) **Discontinuous mixed zone:** The lowermost part of rock avalanche deposits is a discontinuous mixed zone composed of material from the substrate mixed with material derived from the avalanche breccia. The zone is structureless to banded in appearance, and commonly is dominated by substrate material. The undulatory bands tend to be subparallel to the base of the deposit, and in places exhibit cross-cutting relations that reveal the lowermost bands to be the youngest.

(3) **Disrupted zone:** The lower part of the breccia mass is dominated by a matrix-rich breccia facies. Clasts usually range from a few centimeters to several meters in maximum dimension, and are derived almost solely from avalanche debris. The zone is internally sheared and locally intruded by clastic dikes derived from the discontinuous mixed zone.

(4) **Matrix-poor zone:** The matrix-rich material in the disrupted zone grades upward into the matrix-poor zone. The matrix-poor zone is dominated by highly shattered but coherent large avalanche blocks. Crackle breccia (internally fragmented blocks with little to no separation and rotation between fragments) and jigsaw breccia (fragmented blocks with separation between fragments without significant rotation) dominate. Blocks may be many tens of meters in maximum dimension. The matrix-poor zone, commonly refereed to as "megabreccia," comprises most the thickness of the rock

avalanche deposit.

Characteristic lateral trends were also reported by Yarnold and Lombard (1989). In general, well-developed clastic dikes and significant deformation in the substrate are observed mainly beneath the distal reaches of deposits. Total thickness, thickness of the mixed and disrupted zones, and the degree of development of shear-related features appear to increase distally. No systematic lateral trends in clast size occur. Proximal-type avalanche features are usually associated with near-source coarse-grained substrate sediments. In contrast, features typical of the distal margin usually overlie lacustrine or floodplain sediments.

Gravity Glide Deposits

"Gravity gliding" is a poorly understood mechanism that has been invoked to explain emplacement of very large blocks which lack features characteristic of catastrophic emplacement. Glide blocks are thought to move downslope by slow creep over periods that may range from weeks to thousands of years. The term has even been applied to some tectonic-scale features, such as rootless thrust faults, which may have experienced motion over time periods as long as millions of years (Voight and Pariseau, 1978). Glide blocks lack the pervasive internal brecciation that characterizes catastrophic rock avalanche deposits. Basal contacts are sharp, and commonly resemble fault surfaces with slickensides and grooves. Because of the slow emplacement of the slide mass, underlying strata to not display deformation and are not incorporated into the base of the slide mass.

Tertiary Breccias in the Halloran Hills

General Geology

This summary of events that affected the Halloran Hills is summarized from Reynolds (1993; personal comm., 1996).

A deeply weathered erosional surface developed in the Halloran Hills area until about 20 Ma. Lag gravels were deposited in areas of low relief on this surface. Fine-grained lacustrine sedimentary rocks deposited between 18.5 – 11 Ma recorded subsidence and sedimentation into the Shadow Valley basin north of the Francis Spring – Squaw Mountain area. Coarse-grained arkosic fanglomerate grades from Halloran Spring northward into the uppermost part of these lacustrine sedimentary rocks. The fine-grained rocks were folded and faulted after 11 Ma. The basin then filled with coarse debris derived from the southeast, northeast, and south, herein referred to as the "upper basin unit." The basin was broken up by southeastward tilting along normal faults, probably above a detachment surface with upper-plate displacement to the west. Another erosional surface developed, followed by emplacement of several large rock masses, including the block that forms Squaw Peak.

Breccia Sheets within the Upper Basin Unit

Near Squaw Mountain, two large breccia sheets and several small breccia bodies are interbedded with the upper basin unit. The outcrop extent of the two large breccia sheets is about 3.5 km long. The skeets have a maximum thickness of about 30 m. The breccias are composed predominantly of dark grey dolomite and white marble, with minor white quartzite. The sheets display crackle brecciation and jigsaw brecciation.

The bases of the two breccia sheets are undulatory and locally indistinct, with the conglomeratic sandstone underlying each breccia grading up into a zone where sheared and pulverized breccia material is mixed with varying amounts of material from the underlying bed. This mixed zone exhibits a characteristic banded appearance, with indistinct lenses of monolithologic material oriented subparallel to the basal contact. Short, discontinuous slip surfaces and zones of shear are common locally. Parts of the mixed zone exhibit a deep red color, suggesting zones of fluid movement. Grain size increases from the mixed zone up into the main body of the deposit, with the largest clasts being a few meters in diameter.

The breccia sheets are interbedded with moderate reddish brown, very coarse-grained sandstone and conglomerate. Maximum clast size in the conglomerates ranges from fine pebble to small boulder. The clast assemblage is heterolithologic, including variable amounts of Tapeats sandstone, garnet gneiss, dolomite, and granite. Two different types of deposits are present.

(1) Beds display crude stratification, with the coarsest clasts segregated into layers and thin lenses. Clasts display a preferential orientation, although imbrication (stacking of clasts) is rare. Sedimentary structures include crude horizontal stratification and poorly defined large-scale trough cross-stratification. Bedding planes are poorly defined. Erosional surfaces, such as channels and scours, are present but are rare. These beds are interpreted as rapidly aggrading streamflood (confined in a channel) and sheetflood (not confined in a channel) deposits. Paleocurrent indicators such as clast imbrication show derivation from the southeast.

(2) No internal organization is apparent, and clasts do not display a preferred orientation. The sediment is unsorted, with rare "outsized" (anomalously large) clasts. In general, the largest clasts in the section occur in these beds. Bedding planes are poorly defined, although the edges of the beds commonly can be readily identified. These beds are interpreted as debris flow deposits.

Coarse-grained streamflood and sheetflood deposits interbedded with debris flow deposits suggest deposition in the proximal part of an alluvial fan.

Squaw Peak Block

The Squaw Peak block is a mountain-sized block of carbonate rock with some diorite, probably derived from the Pahrump Group. The basal contact of the Squaw Peak block is sharp and relatively planar. In the few localities where the base is exposed, the underlying strata display no disruption and the basal part of the block lacks the characteristic banded mixed zone present in the older breccia sheets. Although the block contains reddened brecciated zones throughout its thickness, it is not pervasively brecciated, and the base of the block is no more brecciated than the rest of the body. Classic crackle and jigsaw brecciation are not present. The block sits on top of weathered Teutonia quartz monzonite and on the Shadow Valley basin sedimentary and volcanic strata.

Discussion and Conclusions

The breccia sheets within the upper basin unit exhibit many of the features described by Yarnold and Lombard (1989) as being characteristic of catastrophic rock avalanche deposits. The association of the breccia sheets with proximal alluvial fan deposits is consistent with the lack of deformation in underlying strata and the absence of clastic dikes, based on the lateral trends in rock avalanche deposits reported by Yarnold and Lombard (1989). These features indicate deposition very near the source of the deposits, probably within a few kilometers. Deposition of the breccia sheets occurred during the latter part of detachment-related basin development, similar to Miocene large-volume rock avalanche deposits in the Colorado River extensional corridor in the easternmost Mojave Desert. The breccias in the extensional corridor are thought to have originated from the steepening flanks of the rising metamorphic core complexes (Beratan, in press). It is possible that the breccia sheets in the Halloran Hills may have had a similar origin.

In contrast, the Squaw Peak block does not display features characteristic of catastrophic rock avalanche deposits. Instead, the sharp, straight basal contact of the block strongly resembles the movement surface of a thrust fault. This interpretation is unlikely, however, because the block appears to have been emplaced at the surface, and a significant thrust fault is inconsistent with extension or with the strike-slip regime that gradually took over following extension. The Squaw Peak block therefore is interpreted to be a gravity glide deposit. No inference about distance to source can be made, due to the general lack of knowledge about gravity glide deposits. Reynolds and Calzia (this volume) infer that the Squaw Peak block was emplaced during a 1 - 2 m.y. time period.

The Amargosa Chaos basin was an asymmetric, dominantly two-sided, 15 - 20 km-wide basin between the Kingston Range and the southern Panamint Mountains. At least six episodes of major landsliding occurred between about 90 and 5 Ma (Topping, 1993). These breccia deposits typically exhibit features characteristic of rock avalanche deposits. The breccia mass was derived from Kingston Range, now located 50 km southeast of the Amargosa Chaos basin (Topping, 1993). Paleozoic strata on the northwestern flank of the Kingston Range were tilted down to the northwest by post-detachment uplift of the range core, eventually becoming gravitationally unstable. The bedding planes were oriented appropriately to act as glide surfaces, and an unusually large number of rock avalanche deposits resulted. Emplacement of the Squaw Peak block in the Halloran Hills occurred approximately coeval with breccia emplacement in the Amargosa Chaos basin. The two depositional events thus may be genetically related in some way.

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Miocene Rock-Avalanche Deposits in the Halloran Hills area, Southeastern California

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Introduction

Although not as common as other types of mass wasting processes, rock-avalanches are a fascinating phenomenon because of their catastrophic nature and the volume of rock often involved in the movement. For example, the largest recorded Quaternary rock-avalanche in California, derived from Mt. Shasta, was emplaced in a manner of only a few minutes and involved 26 km^3 of rock that covered an area of 450 km^2 and had a maximum runout distance of 40 kilometers (Crandell and others, 1984). In the Halloran Hills are the remnants of at least four rock-avalanche deposits with magnitudes comparable to that of the Mount Shasta avalanche. These deposits occur interbedded with Miocene sedimentary rocks of the Shadow Valley basin (Bishop, 1994).

The Shadow Valley basin occupies the region extending from the Halloran Hills of the south to the Kingston Range on the north (Fig. 1). Deposition in the basin began approximately 13 Ma (Fowler and others, 1995) and was completed to 5 ma (Bishop, 1994). During basin evolution the area was extensively deformed by block faulting, rotation of fault blocks, and folding. Today, basin sediments are strongly tilted and dissected by erosion.

In addition to the four rock-avalanche deposits in the Halloran Hills area, many others are found in Shadow Valley basin strata to the north in the Shadow Mountains and Kingston Range areas (Friedmann and others, 1995). The deposits form sheet-like layers that are lithologically distinct from other basin strata and form the most prominent beds within the basin sequence because of their resistance to erosion.

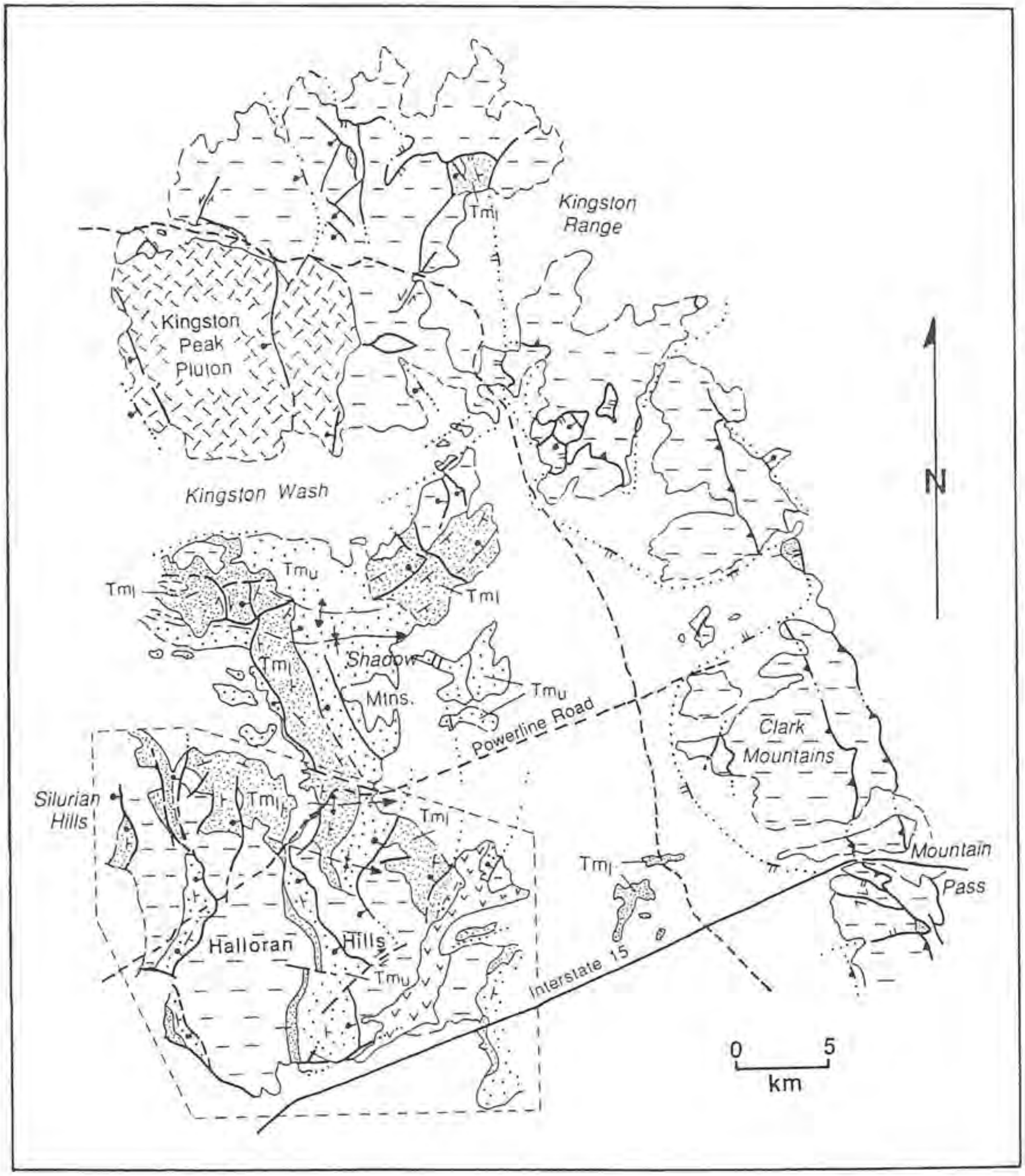

Figure 1. Map of the Halloran Hills -Kingston Range area showing distribution of Shadow Valley basin deposits. Tm$_l$ and Tm$_u$ indicate lower and upper units, respectively, of the basin sequence. Horizontal dashed pattern indicates Mesozoic and older basement rocks. The area outlined by the dashed line in the southwest part of the map shows the area of the Halloran and eastern Silurian Hills presented in Figure 2. (Modified from Davis and others, 1993).

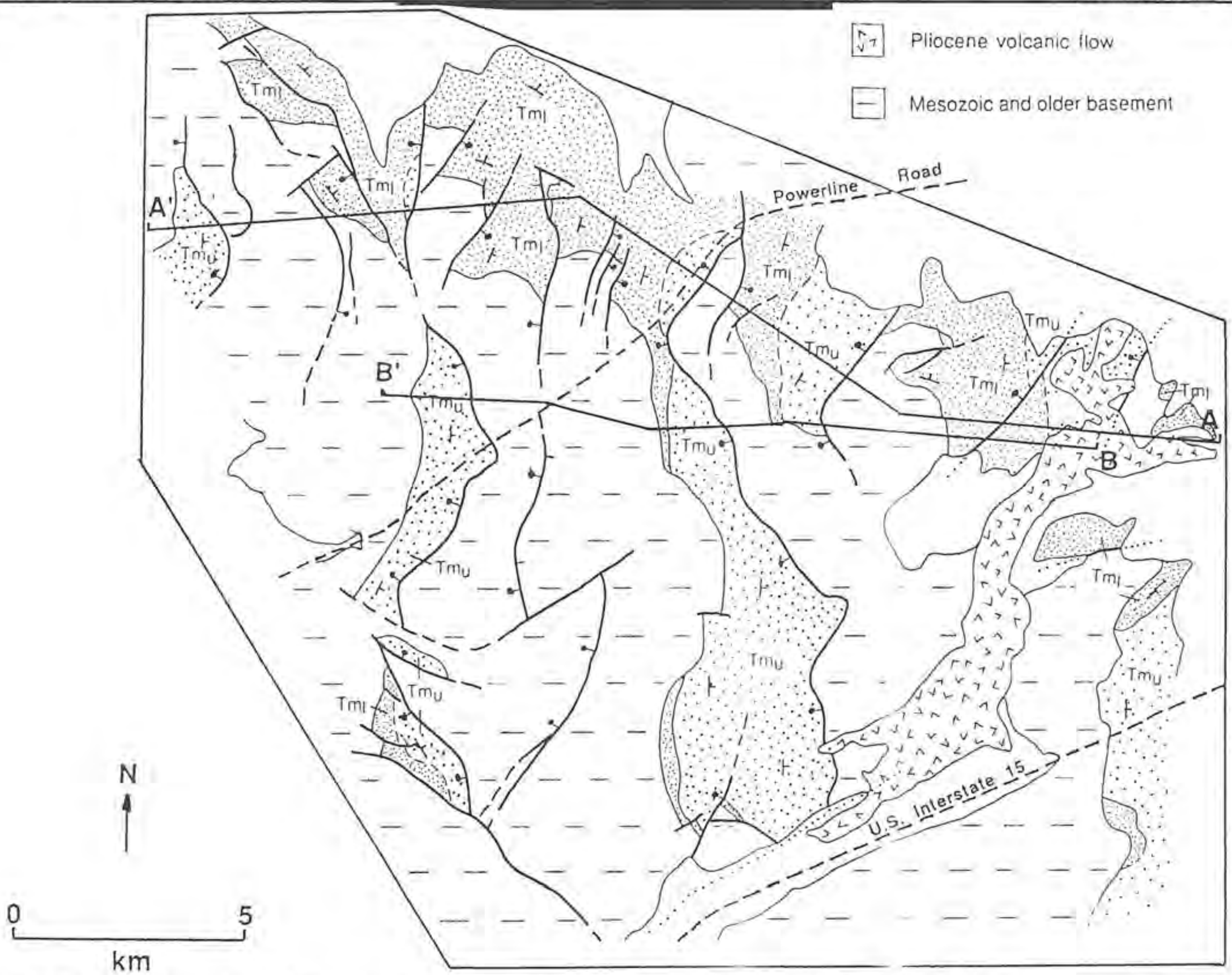

Figure 2. Simplified geologic map of Halloran Hills and eastern Silurian Hills showing outcrop distribution of Shadow Valley basin deposits. Tm$_l$ and Tm$_u$ indicate lower and upper units, respectively, of the basin sequence. Ball and stick symbols indicate dip direction of normal faults.

Shadow Valley Basin Stratigraphy and Structure

The Shadow Valley basin sequence in the Halloran Hills is a variegated terrestrial sequence that includes conglomerate, megabreccia, volcanic flows, volcanic breccia, sandstone, siltstone, mudstone, and limestone, which nonconformably overlies Mesozoic and older basement. Mudstone and limestone units represent lacustrine deposition, whereas conglomerate, sandstone, siltstone, and megabreccia deposits constitute alluvial fan deposition (Bishop, 1994). It is the megabreccia units that are interpreted as avalanche deposits and described in this report.

Based on lithologic characteristics, the Shadow Valley Basin sequence is divided into upper and lower units (Figs. 1 and 2) (Davis and others, 1993). In the Halloran Hills, the units are distinguished in the basis of conglomerate clast source area.

The lower unit contains conglomerate clasts with lithologies identical to basement lithologies present in the Clark Mountain/Mountain Pass area to the east (Fig. 1), which is identified as a unique source area for the clastics (Bishop, 1994; Reynolds and Nance, 1988). During deposition of the lower unit, clastics from the Clark Mountain/Mountain Pass area were spread across the entire Shadow Valley basin area indicating broad subsidence. In the Halloran Hills,

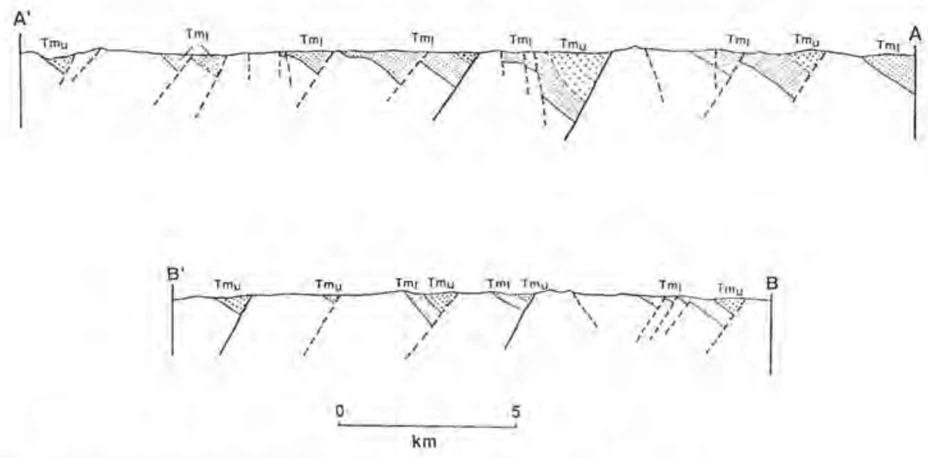

Figure 3. Cross-sections of the Halloran Hills and eastern Silurian Hills area. The locations of the cross-sections are shown on Figure 2.

the thickest deposits of the lower unit occur in the northern part of the area, where the unit is up to 1500 m thick. Most of the lower unit in the Halloran Hills consists of red-bed conglomerate. The avalanche megabreccia deposits occur interbedded with the conglomerate.

In contrast to the lower unit, the upper unit was deposited during a time of block faulting that divided the initial large basin into a series of small, north-south trending basins separated by basement uplifts. Strata of the upper unit were deposited in these localized basins and consist of clastic debris derived from the adjacent uplift zones.

Structurally, the fault blocks active during deposition of the upper unit are 2 to 5 km wide and are bounded by west dipping, down-to-the-west normal faults (Fig. 2). Basin strata on each block dips an average of 35 and 45 degrees to the east (Fig. 3). Because of the tilted fault block structure, the base of the Shadow Valley basin sequence is exposed six times in the east-west direction across the Halloran Hills (Fig. 3). This structure allows for three dimensional study of the two units in the Shadow Valley basin and, in particular, the megabreccia deposits of the lower unit.

Avalanche Deposits

As mentioned previously, at least four megabreccia sheets interpreted to be avalanche deposits occur interbedded with the lower unit red-bed conglomerate. Lithologic characteristics of the megabreccia ascribed to avalanche deposition include: monolithologic composition, crackle and jigsaw breccia textures, 5-15 percent matrix content, clastic dikes, and basal striations. Similar characteristics have been described from rock-avalanche deposits in other parts of the southwest United States (Yarnold, 1988).

Throughout the Halloran Hills, the avalanche sheet outcrops are laterally discontinuous because of faulting and burial by colluvium. In addition, local erosion shortly after deposition but prior to burial by overlying sediments may have removed portions of the deposits Support for this interpretation is the presence of megabreccia clasts in the overlying conglomerate. The four sheets are best delineated in the northwestern Halloran Hills. In the northeastern Halloran Hills, structural complexities created mainly by faults render correlations of outcrops in the area to those in the northwest uncertain.

The lower three avalanche sheets range between 5 to 10 m thick. In contrast, the uppermost sheet is over 75 m thick. Each sheet thins toward the south and none extend into the southern half of the Halloran Hills,. The avalanche deposits generally crop out as rugged-appearing cliffs or very steep slopes and commonly form the tops of ridges. In contrast, the red-bed conglomerate crops out with rounded, gentle slopes.

Each megabreccia deposit is composed primarily (>95%) of angular carbonate fragments set in a fine=grained carbonate matrix. The matrix generally comprises 5 to 15 percent of the deposit by volume. The carbonate clasts range between gray and light gray and are weakly recrystallized. Lithologically, the carbonate is identical to the carbonate of Paleozoic basement exposed in the Clark Mountains area to the east. Although Paleozoic carbonate basement rocks crop out in the Halloran Hills as basement beneath the Shadow Valley basin strata, this rock could not be the source for the avalanche sheets because it is mostly buff to cream color and strongly recrystallized. Other clast lithologies in the avalanche deposits include quartzite, gneiss, and to a lesser extent, shale. The clasts composed of these lithologies do not occur intermixed with carbonate clasts; instead, they are found in monolithologic zones within the deposits. These quartzite, gneiss, and phyllite breccia zones are more abundant in the southern part of the avalanche deposits, but the reason for this is unclear.

In the three lower thinner sheets, the clasts in the megabreccia are typically only a few centimeters in diameter, but clasts up to a meter are locally present. Although the majority of the upper thicker sheet is brecciated and contains textures similar to the thinner sheets, it locally contains non-brecciated zones tens to hundreds of meters wide. These zones contain intact bedding, which from a distance appear as large blocks of basement rock. If one does not recognize the blocks as being interstratified with conglomerate, they can easily be mistaken for in-place basement.

In some outcrops, the megabreccia sheets contain crackle breccia texture, where blocks of rock have been shattered but the clasts have little or no separation. In other areas, where brecciation is more intense, textures are found in which clasts are separated by thin bands of matrix material but the clasts have not been rotated relative to one another. This texture has been defined as "jigsaw" texture (Yarnold and Lombard, 1989). Light and dark bands in the megabreccia deposits reflect color banding inherited from the source rocks. Thickening and thinning of these bands is interpreted to be the result of internal shearing during sheet emplacement.

Striations have been found where the base of sheets are exposed at two locations. One of these locations is in the northwestern Halloran Hills at the base of the thick sheet. Here, the striations are a few millimeters in relief and ubiquitous on the basal surface. The other location is the bottom of one of the thin sheets in the northeastern part of the study area. Here, the striations occur as grooves a few centimeters in relief and spaced at ½ to 1 meter. In both locations, the striations trend nearly east-west, which is consistent with an easterly source area for the sheets.

Rare clastic dikes consisting of red-bed conglomerate material are present in the thicker sheet and one of the thinner sheets. The dikes range between ½ and 2 meters wide and several meters long. They occur in the lower part of the sheets and are oriented at high angles to the bases. Emplacement of the dikes is interpreted to have occurred at the time of avalanche deposition. Differential pressures caused by the weight of the sheets as they moved across the surface presumable forced unconsolidated underlying sediment up into the fractures within the avalanche bodies.

An impressive feature of the avalanche deposits is the size of the

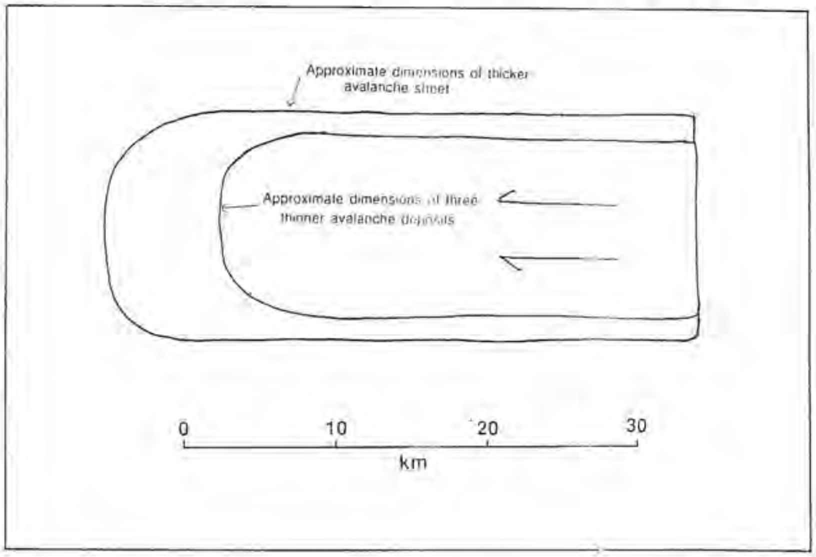

Figure 4. Reconstructions showing approximate original dimensions of the rock avalanche sheets in the Halloran Hills and eastern Silurian Hills area.

area they cover. Outcrops of the three thinner sheets occur in an area that extends from the northeastern Halloran Hills westward to the eastern Silurian Hills (Fig 1). Outcrops of the thicker, upper sheet occur another 10 km west of the thinner sheets to the western Silurian Hills. Based on the present distribution of the avalanche deposits and taking into account approximately 20 percent post-deposition tectonic extension (Bishop, 1994), each of the three thinner sheets covered about 300 km^2 and the thicker sheet covered about 400 km^2. Runout distances for the three thinner avalanche sheets is about 30 km and for the thicker sheet, about 40 km (Fig. 4). In volume, the three thinner sheets are on the order of 5×10^9 m^3 and the thicker sheet is on the order of 4×10^{10} m^3.

Thickness to runout ratios for the deposits vary from 0.002 for the thicker sheet to 0.0004 for the thinner sheets. The value for the thinner sheets is significantly lower than the lowest value of 0.001 calculated from dimensions of avalanche deposits described by Yarnold and Lombard (1989) from other areas of southwest North America. The small thickness to runout ratios imply very low frictional stresses along the basal slip plane during emplacement.

Discussion

The avalanche deposits in the Shadow Valley basin sequence are not anomalous features. Similar deposits occur in Miocene terrestrial basin sediments of nearby areas including the Avawatz Mountains (Spencer, 1990) and Death Valley (Topping, 1993) to the northeast, the Soda Mountains to the west (Grouse, 1959), and the Old Dad Mountains to the south. The sediments in each of these areas were deposited in basins created by regional extensional tectonics that resulted in active faulting and localized subsidence. Apparently, conditions favorable to avalanche deposition were widespread during the Miocene extension. Whether or not rock avalanches occurred more frequently than they occur in other active orogenic belts is unknown. Perhaps the rock avalanches were triggered by earthquakes and are simply the result of subsiding basins being adjacent to highlands during a time of seismic activity. However, the initiation of the avalanches could also be related to more subtle processes, such as the characteristics of seismic shaking created during extensional tectonics as opposed to shaking created during compressional or transformal features.

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Miocene Strata below the Shadow Valley Basin Fill, Eastern Mojave Desert, California

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Abstract

Several sections of Miocene sediment crop out beneath rocks of the Shadow Valley basin. Such strata in the Halloran Hills are characterized by limited sections, 20-13 Ma in age, which include distinctive volcanic rocks, conglomerates, lacustrine carbonates, or mudstones. Along Kingston Wash, a thick volcaniclastic package of undetermined age, though probably mid-Miocene, underlies Shadow Valley fill. Several hundred meters of lacustrine carbonates and fluvial conglomerate lenses in the northeast Kingston Range in both the footwall and hangingwall of the Kingston Range detachment fault, and thus antedate Shadow Valley deposition. The strata in this region have an upper age limit of 16 Ma. The great variety in age and lithology, the thinness of many sections, and the spottiness of preservation suggest that Middle Miocene sediments below the Shadow Valley basin fill do not constitute a linked stratigraphic unit and are depositionally unrelated.

Introduction

The Shadow Valley basin (Friedmann et al., 1994; in press) is a tectonostratigraphic package deposited during slip along the Kingston Range-Halloran Hills detachment fault (Davis et al., 1993; Reynolds, 1990). Detachment faulting which produced the basin began at approximately 13.4 Ma., and all the strata in the basin are 13.4 Ma or younger (Friedmann et al, in press). In defining the Shadow Valley basin, Friedmann et al. (in press; in review) separated the Shadow Valley strata from other older Tertiary units within the Ivanpah 1° X 2° quadrangle (Hewett, 1956; Reynolds and Nance, 1988). New stratigraphic data from mapping, measured sections, other outcrop examinations, and radiometric age dating suggest that the Miocene sediments pre-dating Shadow Valley strata are distinctly different than those of the overlying basin and do not have a common history, with the basin or each other. Their preservation was coincidental and governed by local effects, and attempts to group them into a coherent stratigraphic package may prove groundless.

Nomenclature

Hewett (1956) originally mapped and named the Tertiary strata in the Ivanpah 1° X 2° quadrangle. He grouped together all Tertiary sediments and volcanics within the Kingston Range to form the Resting Springs Formation, and all Tertiary units south of the Kingston Range, east of the Avawatz Mountains, and north of the Cima Volcanic Field into the Shadow Valley basin (Fig. 1). This nomenclature has stood as the regional stratigraphic framework for most other workers (Reynolds and Nance, 1988; McMackin, 1992; McMackin and Prave, 1991). In most locations, however, a good case can be made for a hiatus of 2-6 Ma between Shadow Valley strata and other Mid-Miocene units.

The Shadow Valley basin unconformably or disconformably overlies strata ranging in age from Neoproterozoic to middle Miocene. Although in general this contact is easily recognized, the proximity between Shadow Valley strata and various subjacent Miocene units has produced some confusion in nomenclature and geology. This problem is compounded by the fact that in most locations Shadow Valley and subjacent strata are sub-parallel (Fowler, 1992). The term "*pre-detachment*" strata will be used in this paper to refer to all Tertiary sediments found unconformably or disconformably below Shadow Valley basin units.

Pre-basinal Stratigraphies

The following descriptions and subdivisions are based on the mapping of Kim Bishop (1994), G. Davis (unpublished), two M.I.T.

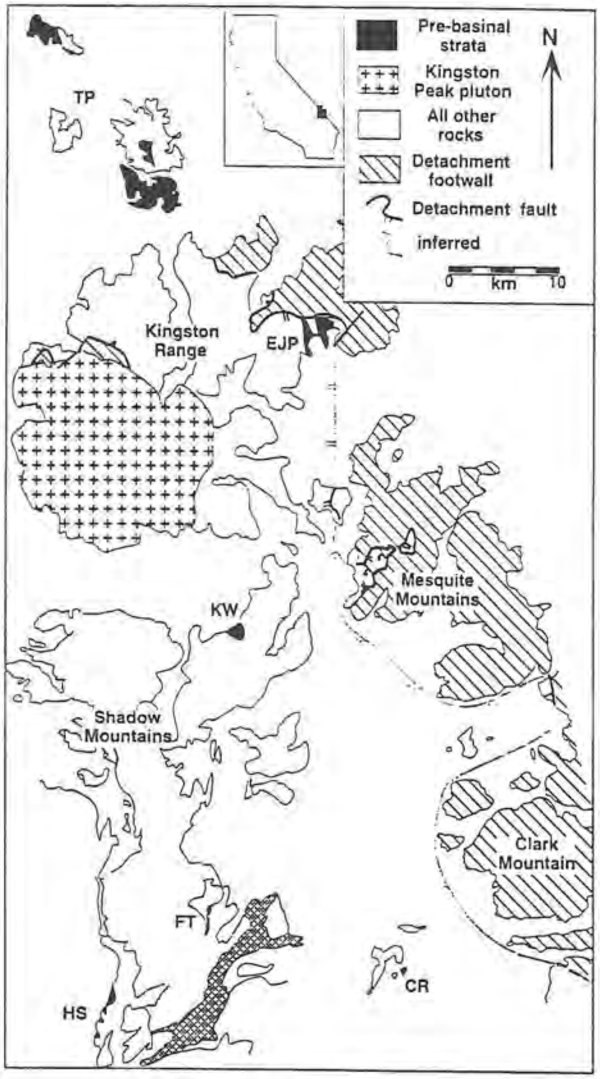

Figure 1. Location map of the Shadow Valley basin and surrounding region showing distribution of pre-basinal outcrop. Kingston/Halloran detachment fault indicated as thick solid or grayed line (gray where inferred in subsurface). EJP=Eastern Jupiter Peak; FT=Francis Tank; HS=Halloran Springs; KW=Kingston Wash; TP=Tres Picos.

field camps (1985, 1989; unpublished), mapping presented in this paper, and descriptions from Reynolds and McMackin (1988), Reynolds and Nance (1988), and Reynolds (1990; 1991). Locations for each section are shown in Fig. 1.

Halloran Springs (10-15N-10E)

A 20 m thick pyroxine andesite breccia lies above a deeply weathered granitic basement (Reynolds and McMackin, 1988; Dohrenwend, 1988; Reynolds, 1991) and below Shadow Valley basin strata in several locations. Clasts of the breccia appear in the overlying course sandstones and conglomerates. The breccia is undated, although there is a possible correlation (H. Wilshire, pers. comm. to R. Reynolds, 1989) to a volcanic breccia further south (K/Ar on plagioclase, 12.8 Ma; J. Nakata, pers comm. to H. Wilshire, 1989). It is intruded by an undated felsic, hypabyssal dike, which is truncated by the unconformity at the base of Shadow Valley member one (13.4-12.5; Friedmann, in press), and clasts of both the andesite and sill can be found in the overlying strata.

Cima Road

A package of subvertical to overturned, coarse sandstones-cobble conglomerates approximately 50 m thick can be found along a wash close to the Cima Rd (Fig. 1). The majority of the predominantly angular clasts comprise black, quartz sandstones, probably shed from the Kingston Peak Formation. This clast composition is unusual, as clasts of Kingston Peak Formation appear neither in any other pre-detachment assemblage nor in the Shadow Valley basin's lowest members. This unit is of undetermined age, although the outcrop character suggests that the sediments are probably Neogene.

Francis Tank (18-16N-11E)

The Tertiary section at Francis tank is difficult to measure and map due to complicated faulting and erosional relationships (Fig. 2). The lowest obvious unit is a welded quartz-plagioclase ignimbrite, 0-15 m thick. It has been tentatively correlated with the Peach Springs tuff (18.5 Ma) based on an unpublished sanidine date (19.1 Ma, pers. comm. C. Swisher to R. Reynolds, 1991). Various authors report a white ash which overlies the ignimbrite, which has mineralogical and geochemical ties to the Peach Spings tuff as well (R. Reynolds, pers. comm, 1996).

A lacustrine section ~ 50 m thick overlies the tuff. It contains fine grained carbonates, some containing possible onkolites and other unidentified allochems, with poorly exposed interbedded fine siltstones and claystones. Although the lacustrine section has not been dated radiometrically, the rodent *cupidinimus lindsayi* ,collected from these units, indicates a Late Barstovian-Early Clarendonian age(R. Reynolds, 1991).

Above the lacustrine section (Fig. 2), two different units lie at approximately the same stratigraphic horizon. Outcrop does not permit relative age determination. To the north, a breccia bed of Bonanza King 3-5 m thick overlies the lacustrine section; to the south, a fine grained, aphanitic tuff of 0-2 m thickness. Both units are then overlain by red conglomerates of Shadow Valley basin member two (12.0 to ~11.0 Ma). Correlation of these beds to other units within the Halloran Hills region suggests an age close to 13.0 Ma, by links to the pyroxen3e andesite breccia (see *Halloran Springs* section above).

Kingston Wash (19-18N-11E)

Within Kingston Wash, and at the base of the Blacksmith Hills, a section of volcanic rock ~500 m thick underlies the base of Shadow Valley member one. The section is subvertical, and it is bounded by a dextral fault on the north, a sinestral fault to the south, and cut by several small sinestral faults.

A series of enigmatic beds ~60 m thick lie below the main part of the section. These bed include orange, algal lacustrine carbonates, volcanic breccias, gun-powder-grey volcanic sandstones, and large blocks and breccias of Bonanza King Fm. Intense faulting, folding, and limited outcrop prevent further clarification of the section.

The bulk of the section comprises over 400 m of amalgamated volcanic breccias that overlie the other beds. They are of likely mafic-intermediate composition. A series of reworked felsic ash beds ~100 m thick serves as a key marker horizon about half-way up the section. The section is preserved at least in part by the steep faults which placed it between basement blocks.

East of Jupiter Peak (16-20N-11E)

Within the Kingston Range, the basal Tertiary assemblage is probably part of Shadow Valley member I in most locations. However, east of Jupiter Peak over 300 m of pre-detachment sediment are preserved below basal Shadow Valley beds. The contact between member I strata and subjacent middle Miocene strata is discordant both in strike and dip; the contact, however, does not crop out and is inferred from map patterns.

Carbonate rocks constitute most of the section. Most beds are fine-grained and contain algal structures (stromatolites, onkolites, algal bedding), teepee structures, and some thin planar lamination. Beds are typically 10-50 cm thick. In addition, carbonate sandstones and mixed quartz/CO_3 sandstones are common, usually with carbonate cement. Towards the top of the section, channels with up to 2 m paleo-relief incise the lacustrine strata and are filled with pebble-cobble conglomerates. Clasts are predominantly derived from the local, surrounding Cambrian quartzites, and the conglomerates are carbonate cemented.

A fine grained ash from the top of the section yielded a suite of biotite crystals which were dated at 16.0 ± 0.2 Ma (Sample 5194 on Fig. 4; Friedmann et al., in press). This ash has appeared in the literature with different ages (14.1 Ma, P. Tilke pers. comm. to B.C. Burchfiel; 12.5 Ma, B.C. Burchfiel pers. comm. to J. Calzia), all unpublished. The new age strongly suggest an hiatus of about 3 m.y. between the top of the Jupiter Hill stratigraphy and the base of Shadow Valley member one (~13.0 Ma)

Tres Picos
(35-21.5N-9E)

North of the Kingston Range and southeast of the Nopah Range, three hills crop out near the Old Spanish Trail (Fig. 1). These hills consist of strata that lie within the footwall of the

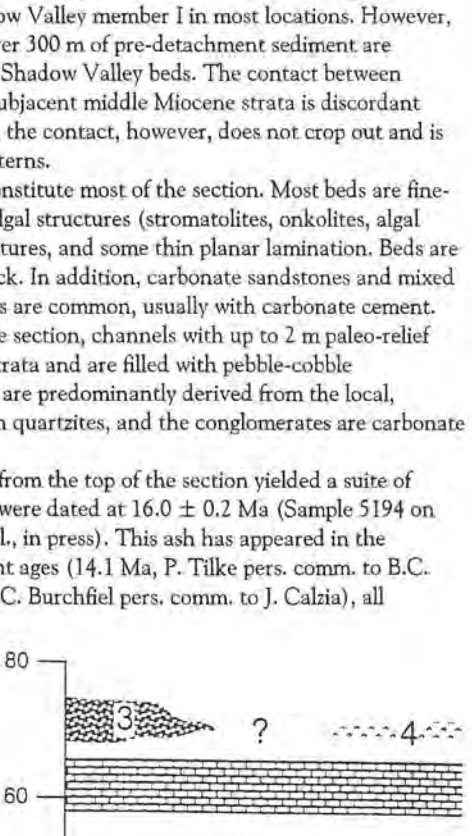

Figure 2. Schematic cross section of Francis Tank area stratigraphy. 1=welded ignimbrite, 2=interbedded limestones and shales, 3=Paleozoic carbonate breccia, 4=fine grained aphanitic tuff.

Kingston Range detachment fault and hold no Shadow Valley units. However, they are unconformably overlain by volcaniclastic strata, chiefly volcaniclastic sandstones and conglomerates with thin intercalated flows and breccias. Although there are no chemical analyuses on the sediments or volcanics, their composition appears to be mafic-intermediate, sujggesting a source terrane in the Kingston Range. The unconformity between the volcaniclastic strata and the underlying pre-detachment units is well exposed and 20-40° discordant. Based on their discordance and stratigraphic character, we believe that these younger beds were shed northward from the Kingston Range across the detachment fault after slip had ceased, about 12 Ma.

The older Miocene strata are 200-300 m thick and very similar in character to the pre-detachment strata east of Jupiter Peak. They consist primarily of fine grained pink-grey-yellow limestone and dolostone. Much of the carbonate is detrital, though some carbonates may be algal or precipitated. They host a wide array of shallow to subaerial sedimentary structures, including oscillation ripples, desiccation cracks, fenestrae, burrows, parallel lamination, and trough cross-stratification. Beds are typically 10-50 cm thick. Coarse carbonate sandstones and conglomerates are relatively common, predominantly containing clasts shed from local Paleozoic carbonates and quartzites. Near the top of the section, calcified reeds appear in beds ~ 90 cm thick. Channels occur throughout the section, with up to 6 m paleo-relief near the top.

J. Calzia has produced a number of K-Ar dates from this area (unpublished data). Although most of the ages are between 12.5 and 12.0 Ma, these samples were taken from the overlying volcaniclastic sections; however, biotite crystals from the tuff at the base of the Tertiary carbonates yield a K-AR age of 16.5 Ma. This age is chronostrati-graphically consistent with the 16.0 Ma tuff near the top of the carbonates East of Jupiter Peak. Base on the radiometric, stratigraphic, and sedimentological data, we correlate these beds to those found east of Jupiter Peak.

Discussion

The Mid-Miocene sediments found unconformably beneath Shadow Valley basin fill are dramatically different from location to location. It is likely that this lack of similarity is a function of the caprices of preservation. Irregular paleotopographies, enhanced by structural features, either by local preservation within down-dropped fault blocks (Kingston Wash) or by structural controls on the sedimentation itself (North Kingston Range), combined to produce a patchwork of seemingly unrelated outcrop belts.

Halloran Hills

Within the Halloran Hills, pre-detachment strata are most likely scattered remnants of localized deposits, based on their restricted geography and thinness. Each has a different lithostratigraphy, ranging from an andesite breccia to lacustrine mixed carbonates and mudstones to fluvial conglomerates with exotic clasts. They are probably not of the same age, and the lithologic heterogeneity strongly suggests that they were never linked by a common depositional system. Since the three sections in the Halloran Hills are relatively thin (< 100 m), they may have been preserved locally within paleotopograhic lows.

Work by Reynolds (1994) suggests that despite the irregular paleodrainage, some units were connected. The discovery and examination of fossil minnows argues strongly for a linked drainage from the ocean to many places in the Mojave. Ages of fossil fish in the Halloran Hills are between 16 and 12 Ma , though Reynolds (1994) believes that they are older than 13.4 Ma and occur within the units below Shadow Valley fill.

Kingston Wash

Unlike the Halloran Hills pre-detachment stratigraphy, the two packages in Kingston Wash and the northern Kingston Range are several hundred meters thick and require further explanation. The thick package of volcanic rocks found in Kingston Wash appears nowhere else in the region beneath Shadow Valley strata. However, they are similar in character to rocks preserved in the Owlsheads Mountains (G. Davis, pers. comm.), which were deposited 15-13 Ma. This tempting, though tentative, correlation is consistent with palinspastic reconstructions of the Death Valley region (e.g., Wernicke et al., 1988; Topping, 1993) which place the southeastern Owlsheads very close to Kingston Wash. Unfortunately, the Kingston Wash section remains undated; examination of biotite suites from the thick, reworked felsic ash revealed overwhelming xenocrystic contamination (J. Friedmann, unpublished data).

The Northern Kingston Range

Due to the common occurrence of shallow subaqueous (oscillation ripples, calcified reeds, algal lamination) and subaerial (mudcracks, channels, intraclasts) features, the pre-detachment strata of Tres Picos and east of Jupiter Peak probably were deposited near the edge of a relatively long-lived lake. The most common depositional environments were playa-sabkha, carbonate sandflat, and deep (1-6 m), narrow river channels. The remarkable predominance of carbonate detritus, deposition, and cement, argues for an ephemeral lake which was saturated with respect to carbonate.

The lacustrine units were deposited before detachment slip, as they were cut and separated by the Kingston Range detachment fault. However, their similarity in age and lithologic character suggests that they were initially a continuous depositional unit. Due to the relative thickness, continuity, and homogeneity of section, it is likely that these strata accumulated due to local subsidence. Possible cause of subsidence-induced deposition are (1) fault-controlled subsidence related to movement on the hypothetical Spring Mt. detachment (Wernicke et al., 1988), (2) regional thinning due to incipient formation of the Kingston detachment, and (3) deposited in a regional sag, possibly related to Oligo-Miocene deformation in the Death Valley area or pre-detachment thinning of the lower crust. The first interpretation is preferred, although there is little data to constrain the timing, geometry, or throw of a Spring Mt. detachment fault. If the first hypothesis is correct, then the detachment fault was active close to 16.0 Ma; independent calibration of Spring Mt. detachment history would test this hypothesis. The second hypothesis, though possible, is unlikely due to the lack of deposits within several million years of Kingston Range detachment faulting. The third interpretation is extremely difficult to test.

Conclusions

Middle Miocene strata lie unconformably and disconforma bly below Shadow Valley basin fill, and as a rule are several million years older than overlying sediments. The pre-detachment sections vary substantially from location to location in both lithology and age, each reflecting a different set of depositional environments.

Acknowledgments

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Dead Fish Tell Tales

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Abstract

Distribution of Miocene fossil minnows (Cyprinidae) across the Mojave desert may, in part, reflect time-gransgressive drainage development during and following the Mojave block becoming dismembered by extensional tectonics. The oldest Miocene record of minnows (16.1 Ma) is in the central Mojave desert at localities around Barstow. The youngest Miocene minnow localities (13.2 - 12.8 Ma) are in the Halloran Hills east of Baker in the eastern Mojave desert. In the Halloran Hills, lacustrine sediments containing minnows predate chaotic basin fill by coarse debris and avalanches. Stickleback fish (Gasterosteidae) first appeared near Barstow at 16.1 Ma. Their appearance in the central Mojave desert may be explained with palinspastic reconstruction of San Andreas fault movement. Sticklebacks and minnows survived the uplift of the Transverse Ranges and repopulated Ice Age lakes in the Mojave desert.

Fish are important indicators of waterways that allow their distribution. The fossil fish in the late Tertiary of the Mojave desert may have occasionally lived in lakes, but minnows and sticklebacks are often found in slow moving, intermittent streams and poorly-connected ponds and marshlands. The presence of fossil fish (Figs. 1 and 2) offers insights to drainages that may have connected inland basins to the coast. Although not conclusive, the absence of fish in lacustrine sediments may indicate that these sediments were deposited in closed basins that did not drain externally to other basins which did contain fish. Two types of Miocene fish are recorded from the Mojave desert: the sticklebacks (Gasterosteidae), of which modern relatives live in well-aeriated, relatively fast moving clear water (McGinnis, 1984), and the minnows (Cyprinidae), which live in slow-moving water and ponds.

The Mojave desert today is bounded on the south by the Transverse Ranges, on the southwest by the San Andreas Fault, on the northwest by the southern Sierra Nevada, and on the northeast by the Garlock Fault the southern Sierra Nevada. The geomorphic signature of the Mojave desert is mountain ranges that run northwesterly as a result of activity on northwest-trending faults roughly parallel to the San Andreas system. Today no major drainages leave the Mojave desert in the direction of the Pacific Ocean. The major river system draining the Mojave desert is the Mojave River, running northeasterly and connecting with the Amargosa River which runs into Death Valley. The Bristol-Danby trough connects the southeastern portion of the Mojave desert to the Colorado River, but proposed drainage systems during Pleistocene times that connect to the Colorado River have been discredited (Brown and Rosen, 1992). Southeastern portions of the Mojave desert drain to the Colorado River.

During late Early and Middle Miocene times, the Mojave desert was a highland covered by a well-developed erosional surface. We can see evidence that drainage systems evolved on the Mojave block as early as 17 to 18 Ma (Lindsay, 1972; Reynolds, 1991; Woodburne and Golz, 1972) and that the southwestern Mojave drained toward the Pacific Ocean. Distinctive clasts were shed southwestward from a highland at Victorville between 18 and 17 Ma and appear in the Cajon and Crowder formations (Woodburne and Golz, 1972). Perhaps as early as 16 Ma, a cohesive drainage system from the Pacific Ocean reached inland and allowed stickleback to enter the Mojave block and disperse through the drainages into basins created by crustal extension (Dokka, 1986). Today, anadromous forms of stickleback are not found south of Monterey Bay (Miller and Lea, 1972) so the entry of sticklyback into the Mojave desert from southern latitudes may relate to right lateral movement between the North American Plate and the Pacific Plate along the San Andreas Fault. Although fossil minnows may not have originated in the Pacific ocean, their distribution followed the developing drainages across the Mojave desert.

One of the oldest occurrences of fish in the Mojave desert is that of stickleback at Yermo, dated at 16.1 Ma (Roeder, 1985). Other records of fish are of minnows. These, in order of age in the central Mojave desert, occur at Daggett Ridge south of Barstow (16.1 Ma), in the Cronese Basin at 15 Ma, in the Cajon Fm at about 14.5 Ma and in the Barstow Basin at 13.5 Ma. In the eastern Mojave desert, fossil fish in the Halloran Hills are located in sediments associated with volcanic breccias dated between 13.2 Ma (Calzia, writ. comm. 1987) and 12.8 Ma (Wilshire, 1991), slightly younger than the youngest record to the west in the central Mojave desert.

Established minnow populations could survive in any perennial fresh water drainage. Lacustrine and playa sediments in apparently isolated basins in the southeastern and eastern Mojave desert do not have a record of fish: the Cady Mountains (Hemingfordian Hector Fm, Woodburne, Miller and Tedford, 1985), the Little Piute Range (Reynolds and Knoll, 1992) south of Essex, and the Hackberry and Wild Horse Mesa areas (Reynolds and others, 1995), for example. These localities, all approximately 18 to 16 Ma, have produced other vertebrate fossils including small mammals and reptiles, and invertebrate fossils and gastropods. Fine-grained sediments associated with extensional basins along the Colorado River corridor in eastern California and western Arizona, and in the extensional corridor in the Horse Springs Fm near Las Vegas (Bohannon, 1984; Nielson and Reynolds, this volume), ranging in age from 18 to 14 Ma, apparently do not contain fossil fish. Fossil fish are known west of the Mojave desert in the Clarendonian Dove Springs Fm. (10-9 Ma, Whistler and

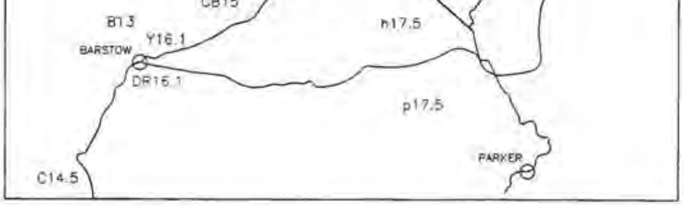

Figure 1. Mid-Miocene fish localities in southern California and southern Nevada within the Hemingfordian and Barstovian land mammal ages. Localities designated by lower case letters have no record of fish fossils. DR, Daggett Ridge (16.1 Ma); C, Cajon Pass (14.5 Ma); Y, Yermo (16.1 Ma); B, Barstow (13.5 Ma); CB, Cronese basin (15.0 Ma); HH, Halloran Hills (13.0 Ma); h, Hackberry (17.5 Ma); p, Little Piute (17.5 Ma); hs, Horse Springs (15 Ma)

Figure 2. Late Miocene to Pliocene fish localities in southern California, southern Nevada, and western Arizona. Selected Pleistocene localities are shown in lower case letters. D, Dove Spring Fm, Ridgecrest CA (9 Ma); R, Ridge Basin, Gorman CA (8 Ma); G, Muddy Creek, Glendale NV (7 Ma);P, Bouse Fm, Parker AZ (4.5 Ma); m, White Narrows Fm, Moapa NV (4.4 Ma); t, Lake Thompson, Mojave CA; m, Lake Manix, Barstow CA; d, Lake Manly, Death Valley CA

Burbank, 1992). In the Ridge Basin sticklebacks are known from approximately 8 Ma (David, 1945; Bell, 1973). The Muddy Creek Fm in Nevada has fossil minnows recorded in the upper portion of the section, between 8 and 6 Ma. Along the Colorado River trough, the oldest fossil fish is found in the Bouse Fm, approximately 4.5 Ma (SBCM collections; Buising, 1992). The ancestral Colorado River drainage may have reached the area of Moapa by about this time. Suckers and sunfish as well as minnows had entered that basin (J.D. Stewart, LACMNH, writ. comm. 1992) and are found in sediments referred to as the White Narrows Fm, formerly the White Narrows Mbr (D. Schmidt, p.c. 1992; Gardner, 1968; Kowallis and Everett 1966).

The distribution of these fossil fish is significant because it indicates interconnecting drainage patterns that we cannot see due to tectonic disturbances. The sticklebacks at Yermo indicate that drainage to the Pacific Ocean had occurred by 16.1 Ma. The record of minnows throughout the Mojave desert indicates that they thrived, perhaps in poorly-connected, intermittent, slow-moving streams and ponds, from 16 Ma to their youngest known occurrence at approximately 12.8 Ma at Squaw Peak and along the powerline road outcrops in lacustrine sediments in the Halloran Hills.

The extensive drainage system needed for these fish to radiate during the mid-Tertiary indicates that the Mojave highland had begun to break apart. This corresponds to models for extension presented by Dokka (1986) and Glazner and others (1989). The subsidence which allowed for interconnecting drainages preserved lacustrine sediments and volcanic rocks which have been dated radiometrically. The time-transgressive subsidence perhaps heralded breakup of extending upper plates throughout the Mojave desert.

In the Halloran Hills, these basins may not have contained a single extensive lake but a patchwork of ponds and marshlands developed over time across the geography. Dates of the volcanic rocks in basins containing fine-grained sediments in the Halloran Hills range from 13.2 Ma (Calzia, wr. comm. 1987) to <12.8 Ma (Wilshire, 1991.).

Cupidinimus lindsayii, a late Barstovian ancestral kangaroo rat, is found in the fine-grained sediments (Reynolds and Whistler, 1990) and its presence supports these dates. The Halloran silts and limestones may have been deposited over a period of 500,000 to 700,000 years.

Tertiary minnow populations in refugia may have survived the extreme tectonic breakup of the Mojave desert until the Pleistocene, when fish populations fluorished in extensive lakes (Blackwelder and Ellsworth, 1936; Hubbs and Miller, 1942; Miller, 1948). When lakes dried out at the end of the Pleistocene, populations were forced to retreat to springs and ponds. Today the minnow in the Mojave desert survives only in the Mojave River (McGinnis, 1984).

Acknowledgments

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Punctuated Chaos: a Depositional/structural Model in the Halloran Hills and Shadow Valley Basin

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Introduction

Most sedimentary basin show continuous depositional historys locally interrupted by structural events that create erosional gaps. The Tertiary sedimentary history of the Halloran Hills area, however, records nearly 12 million years of chaotic sedimentation punctuated by volcanism and extreme crustal extension. This paper presents a model that summarizes the sedimentary and volcanic history of the Halloran Hill, extension along the Halloran Hills detachment fault and dismemberment of its upper plate.

Geologic Background

The Kingston Range-Halloran Hills detachment fault marks the eastern margin of the Death Valley extensional terrain (Davis and others, 1993). This detachment fault trends southward from the Kingston Range along the western side of the Mesquite Mountains, Clark Mountain, and the Mescal Range (Fig. 1). The upper plate of the detachment fault may be divided into northern and southern portions separated by the Shadow Valley Basin. The northern portion consists of Early Proterozoic gneiss, Middle Proterozoic Pahrump Group, and Late Proterozoic to Paleozoic clastic and carbonate rocks of the Cordilleran Miogeocline. This portion of the upper plate was intruded and immobilized by the 12.4 Ma (Calzia, 1990) granite of Kingston Peak and is not involved with our model.

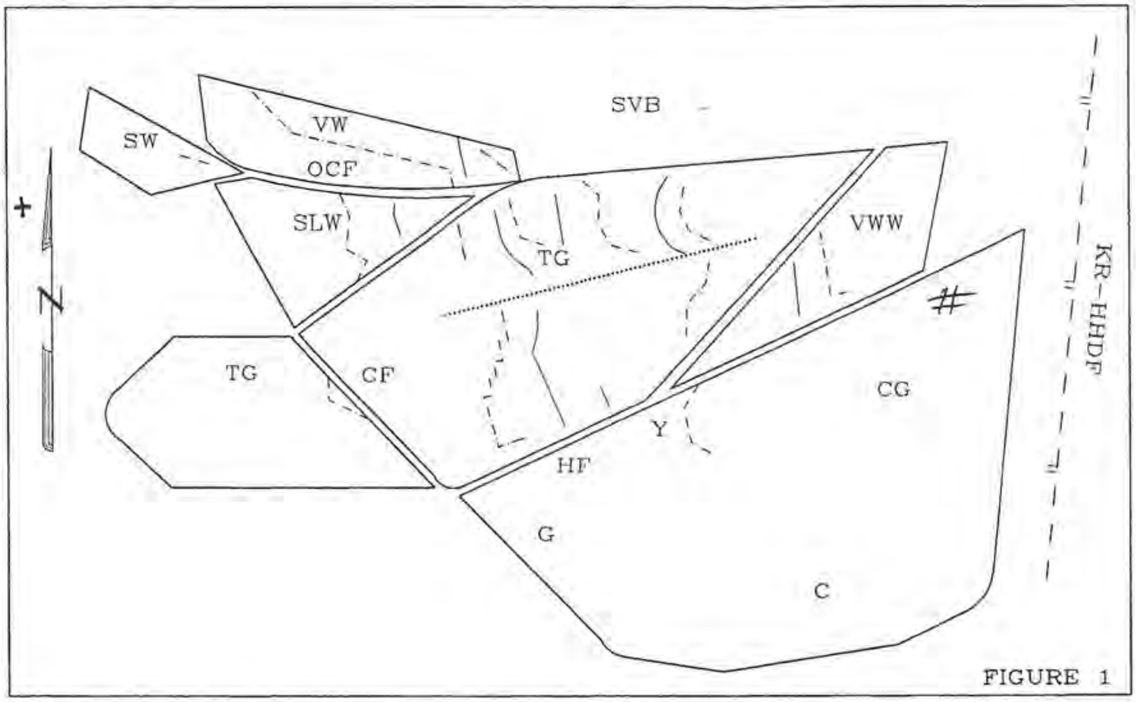


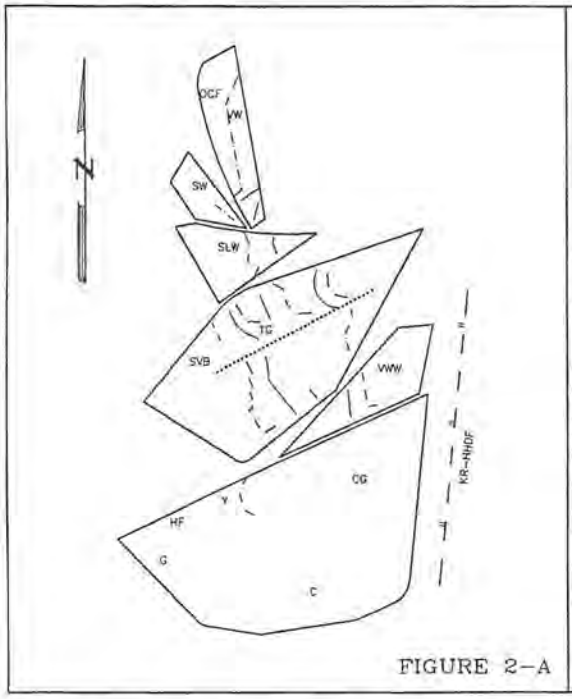
Figure 1. Present-day configuration of the granitic terrain of the Halloran Hills/Cima Dome area. + = intersection of Highway 127 and the road to Riggs. # = intersection of Cima Road and Interstate 15. Faults include: KR-HHDF, Kingston Range-Halloran Hills detachment fault; HF, Halloran Fault; OCF, Owl Canyon Fault; CF, Cree Fault. The Cima Group (CG) includes the Yucca block (Y), the granite block (G), and the Cima Dome blocks (C). The Turquoise group (TG) sits between the Valley Wells wedge (VWW) and the Silver Lake wedge (SLW), the Silurian wedge (SW) and the Valjean wedge (VW). Shadow Valley basin *s.s.* (SVB) lies to the north.

The southern portion of the upper plate is best exposed in the Halloran Hills and Cima Dome and consists of Cretaceous granitic rocks (Beckerman and others, 1982) overlain by Tertiary sedimentary and volcanic rocks. These granitic rocks and overlying sediments moved westward along a low angle fault herein called the "Halloran Hills detachment fault." This portion is divided into a northern and southern section by the northeast-trending Halloran Fault (Jennings, 1961) (Figs. 1, 2). This fault separates crustal blocks that have different extensional histories. Rocks north of the Halloran Fault are highly extended and east-tilted whereas rocks south of this fault have undergone only minor extension and minor tilting.

Tertiary sedimentary and volcanic rocks in the northern portion, here named the Turquoise complex, consist of the Turquoise Group flanked counterclock-wise from north to south by the Valjean, Silurian, Silver Lake, and Valley Wells wedges (Figs. 1, 2). The Turquoise Complex includes lacustrine sediments, andesite flows, and volcanic breccia that strike north to northwest; the volcanic breccias thin to the east and are absent in the Valley Wells wedge. The lacustrine sediments thin to the south and consist of silt with petrified wood overlain by pyroxene andesite. The south margin of the Turquoise Group is overlain by 2,500 m of arkosic fanglomerate, monzodiorite slide blocks, and reworked pyroxene andesite from the Cima Group south of the Halloran Fault.

The Valjean granitic wedge is overlain by sediments which strike west to northwest, dip north, and consist of a 13.2 Ma latite flow overlain by silificied lacustrine sediments, siltstone, shale, and sandstone. These relatively fine-grained sediments are overlain by a thick conglomerate characterized by abundant clasts of Cambrian Tapeats Sandstone. Approximately 330 m upsection, the sandstone clasts are mixed with garnet gneiss and rocks from the Jurassic Delfonte Volcanic Series in the Mescal Range.

The Silurian granitic wedge is overlain by a basal section of coarse-grained arkosic sandstone giving way to fine-grained sandstone, a



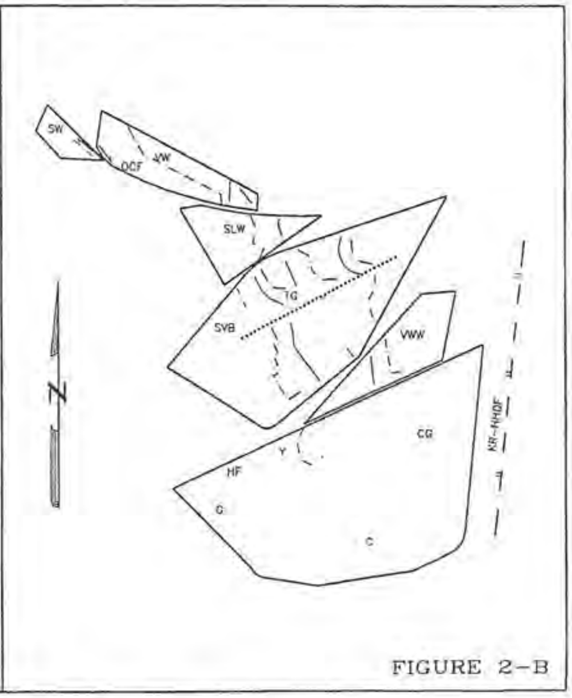


Figure 2A. 13.2 Ma configuration of granitic rocks near the Kingston Range/Halloran Hills detachment fault (KRHHDF) shows alignment of lacustrine sediments and restoration of the Valjean wedge (VW) to a position near the source of Tapeats Sandstone. **Figure 2B.** 13.0-12.8 Ma. The Valjean wedge (VW), Silurian wedge (SW), and Silver Lake wedge (SLW) moved westward and Shadow Valley basin (SVB) began to fill with coarse sediment from sources to the east.

pyroxene andesite, and sandy siltstone with flamingo tracks. These sediments strike east-west and dip northerly.

The Silver Lake granitic wedge is overlain by pyroxene andesite, siltstone, and silifiied lacustrine sediments, and then by gravels derived from the Mescal Range. Sediments in the Silver Lake wedge are similar to rocks in the Valjean wedge.

The Valley Wells granitic wedge is overlain by green lacustrine siltstone which is in turn overlain by coarse gravels and avalanche debris derived from Mountain Pass. The coarse gravels contain a prominent marker bed of quartz monzonite boulders derived from the Cima Group to the south.

Tertiary rocks in the southern block, here named the Cima Group, consist of a relatively thin Tertiary sequence of gray siltstone and pyroxene andesite overlain by thick, coarse-grained granitic and gneissic fanglomerates derived from a southerly source. The siltstone and andesite dip to the east; the fanglomerate deposits dip 12°-20°E.

Pre-detachment Geography

Fine-grained sediments in the Valjean Wedge north of the Turquoise Group contain clasts of the Cambrian Tapeats Sandstone that were derived from a point source near Mesquite Pass on the north side of Clark Mountain. The eastern half of the Turquoise Block and the Valley Wells wedge align with the Valjean Wedge to form a N-S trending trough filled with fine-grained sediments. These sediments overlie 13.2 Ma (Calzia, p.c., 1987) latite in the Silurian Hills and 12.8 Ma (Wilshire, 1991) pyroxene andesite near Halloran Summit associated with silts and lacustrine limestone. Fossil minnows in the lacustrine sediments (Reynolds, this volume) indicate a drainage connection to the west where similar minnows are present in mid-Tertiary (16-13 Ma) basins in the central Mojave Desert. Based on the age and composition of the volcanic detritus, the development of the depression was time transgressive. The fine-grained sediments in the easternmost tilt blocks do not contain andesite breccias and may be younger than fine-grained sections containing volcanic rocks.

The west half of the Turquoise Group aligns with Yucca in the Cima Group. The east portion of the Turquoise Group aligns with the Valley Wells wedge. The Turquoise Group was displaced westward along the left-lateral Halloran Fault; drag folds in the north-striking contacts and marker beds, and clast-to-source relations suggest 5 km of left-lateral offset along the Halloran Fault.

Geologic Model

Prior to Peach Springs tuff time (18.5 Ma, Nielson and others, 1990), a mid-Tertiary erosional surface developed across granite that would become the Turquoise and Cima groups in the upper plate of the Halloran Hills (Reynolds, 1991, 1993). Locally, crustal extension was heralded by subsidence, capturing 13.2-12.8 Ma volcanic rocks and silts in a drainage system that connected with previously developed basins to the west in the central Mojave Desert.

In the early history of movement of the upper plate complex, extension included dismemberment of the upper plate with westward counterclock-wise rotation of the Valjean Wedge and westward translation of the Silurian Wedge along, east-west trending (Owl Canyon Fault) left-lateral faults. It is important to note that this and

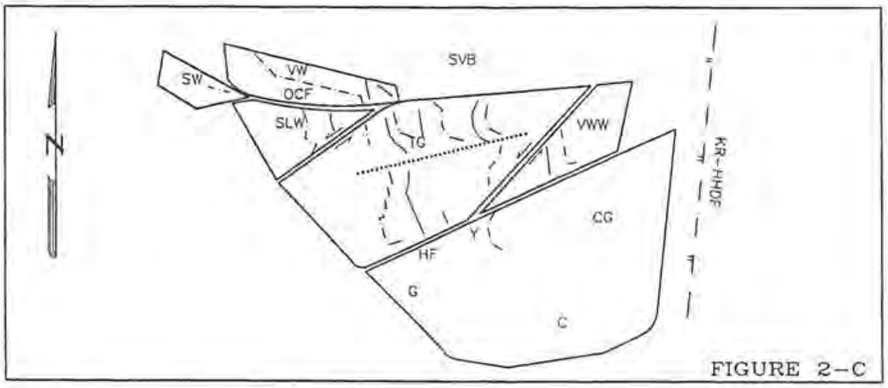


Figure 2C. <12.8 - ca. 11 Ma. The Owl Canyon Fault (OCF) shed debris onto the Silurian wedge (SW). Shadow Valley basin (SVB) fill covered the Valjean wedge (VW), the Turquoise group (TG), and the Valley Wells wedge (VWW). The Halloran Fault (HF) transferred TG left laterally west of VWW.

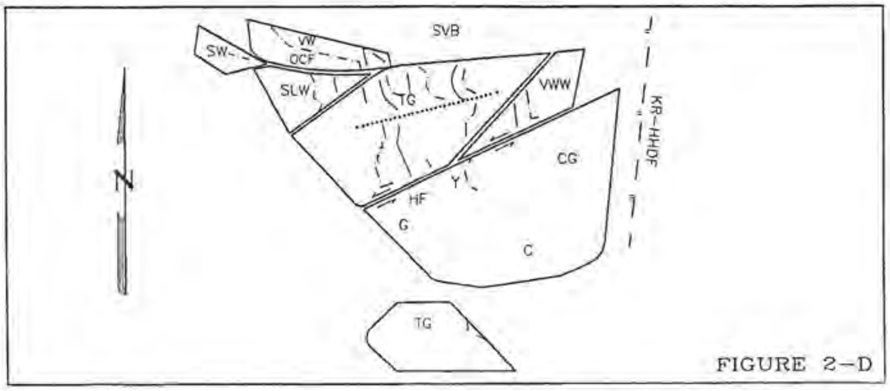


Figure 2D. 11 - <10.8 Ma. Halloran Fault (HF) activity continued and granitic debris was shed across the fault scarp from the Cima group (CG) onto the Turquoise group (TG). The granitic upper plate north of HF was severely extended by north-striking normal faults that tilted blocks easterly. The Cima group (CG) remained modestly extended.

other left-lateral faults adjoining the Turquoise Group were active at about the same time as the left-lateral displacement on the Garlock Fault. Granitic blocks and the fine-grained sediments were buried by coarse gravels and landslide breccias associated with the early deposits in the Shadow Valley basin.

The fine-grained sediments of the Valjean wedge now strike east-west and dip north in contrast to a similar sequence of sediments that strike north and dip east in the Turquoise Group. The Valjean wedge with Tapeats Sandstone clasts is now 30 km west of the point source at Mesquite Pass. The unique orientation and lithology of these sediments suggest counterclock-wise rotation and westward translation of the Valjean Wedge along the northern margin of the granitic upper plate of the Halloran Hills detachment fault.

Using a recent model (Fowler and others, 1995), the Turquoise Complex (including granitic wedges) has undergone two phases of deformation. Phase I involved volcanism and concordant sedimentation between 13.2 Ma (Calzia, p.c. 1987) and 10.8 Ma (Friedmann and others, in press). Phase II encompasses dismemberment of the upper plate by normal faulting and east tilting of fault blocks producing extreme keps, followed by deposition of sediments with modest easterly dips. In contrast, the Cima Block has undergone only Phase II deformation consisting of deposition of a shallow cover of gravels, and modest east tilting of fault blocks to produce shallow east dips.

Phase II deformation of the upper plate is characterized by normal · faulting and east-tilting of each block. Faulting and tilting was followed by interblock sedimentation characterized by modest E dips.

Between 10.8 and 10 Ma, erosion planed a surface across the extensional structures in the Halloran Hills and Shadow Valley basin. This post-extension erosional surface may have extended southward from the Kingston Range and may be coeval with an erosional surface in the southern Death Valley region to the northwest (Topping, 1993, this volume; Holm and others, 1994). This erosional surface was the start of granitic dome development as erosion modified granitic scarps on eastward-tilted normal faults. Large glide blocks of Proterozoic and early Paleozoic sediment are sitting on the post-extension erosional surface. This model suggests that the source of these blocks best fits the Pahrump Group that is exposed in the Kingston Range north of the Halloran Hills.

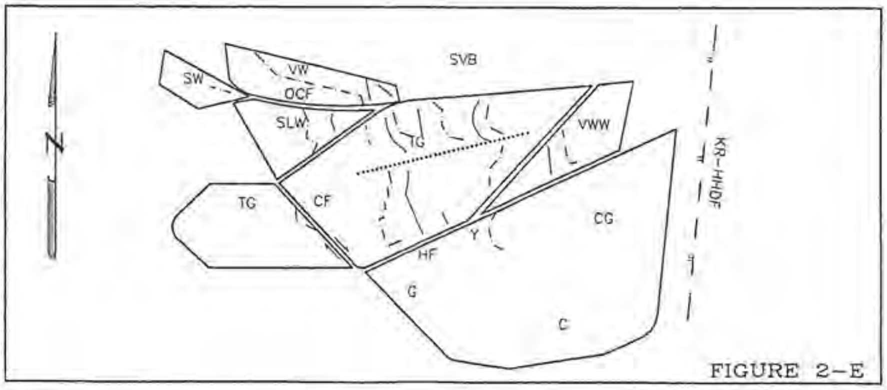


Figure 2E. 10.8 - <9 Ma. Erosion planed the surface of the upper plate. Proterozoic glide blocks were emplaced prior to 10 Ma. The northwest-trending Cree Fault (CF) translated the western Turquoise group right laterally against the main Turquoise group after 9.9 a.

Strike-slip Regime

Left-lateral faults disrupted the 10 Ma erosional surface and cut the Squaw Mountain glide blocks at Willow Wash (Reynolds and others, this volume). The northwest-trending, right lateral Cree Fault cuts a 9.9 Ma andesite breccia (Calzia, pers. comm. 1987) in the western Halloran Hills. This aspect of right lateral faulting may coincide with initial activity of the Eastern California Shear Zone (Brady and Dokka, 1989; Richard, 1992).

Deformation of the upper plate of the Halloran Hills detachment fault presumably is constrained by late Miocene to Pliocene volcanic flows (7.6-4.5 Ma; Turrin and others, 1985) in the Cima Block. There is new evidence, however, that 4.2 Ma basalts flowed in drainages 70 m below the older basalt flows. This evidence suggest that base levels were not stable and topography was still evolving as recently as 4 Ma ago.

Acknowledgments

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History of Mining in the Halloran Hills, Shadow Mountains, and Silurian Hills.

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Abstract

The Halloran Hills, Shadow Mountains and Silurian Hills lie within an area circumscribed by Interstate 15 on the south, State Route 127 on the west, Kingston Wash on the north, and Clark Mountain on the east. As depicted by early maps, this area was devoid of mines, and there are no contemporary reports of mining activity before 1900. As early as the 1870s a road passed through here, running from Soda Lake via Halloran and Francis Springs, to the mining town of Ivanpah, northeast of Clark Mountain. The Solo or Reil Mining District, established February 18, 1889, embraces the portion of this area south of a line from Halloran Spring to the north end of Silver Lake. The Solo Mining District extended from the north end of Cronese Lake southwest to Crucero, northeast to Marl Spring, northwest to Halloran Spring, west to the northwest end of Silver Lake then southwest back to Cronese Lake. The mining district was established by miners working properties just a few miles due west of Baker. However there may have been mines near Halloran Spring at this early date. According to a 1908 account the Riggs mine was worked continuously from about 1875, the first discoveries in the Shadow Mountains were made in 1894, and turquoise was found about 6 miles northeast of Halloran Spring in 1896. Gold was discovered near Halloran Spring shortly thereafter and by 1911 the talc mines east of Silver Lake were first worked.

Riggs Mine

Frank Riggs was born in Michigan in 1845. In 1875 he married Sarah and soon after made the first discovery in the Silurian Hills at the Alta Mine. They had four children. Riggs became somewhat a celebrity with his incredibly rich silver mine, and unorthodox method of shipping ore. A 1908 article by the American Mining Review reported,

> When Riggs had found the first ore, instead of seeking to interest capital in his find, as most prospectors would have done, he decided that the mine should be owned by himself alone. The first shipment that Riggs sent out went to San Francisco and the returns enabled him to build a home at the mine, where he has lived since while working the property. Since then shipments have left the Riggs mine consigned to Selby's by express. These enabled Riggs to live well and improve his property.

Prior to construction of the California Eastern Railroad in 1893 he brought the ore to Daggett for shipment, but with completion of the California Eastern he brought it to the railhead at Manvel. One 1904 shipment, which wasn't out of the ordinary, was noted by the Los Angeles Mining Review,

> Mr. Frank Riggs shipped another small lot of specimen ore to the Selby Smelting and Lead Company, San Francisco, last week - about twelve sacks. The last lots ran something like $10,000 to the ton, and as this lot was again shipped by express it may be supposed that it was of about the same value. It is almost pure silver.

To add to the mystique of the mine was Riggs' secrecy. The Redlands Citrograph in 1903 reported,

> No living man today knows just what Riggs has. Parties who have been at his place have seen a shaft, and down this shaft there is a drift fitted by a heavy massive door. What lies behind this door is a mystery.

Sarah was a full partner in this enterprise. Her role and reward for this spartan life on the Mojave was well described.

> Together they do all the work. Their shipments are prepared with great care. After the ore has been mined it is carefully broken and sorted... Riggs and his wife lead a dual existence. About half the year they work their property, Mrs. Riggs working side by side with her husband. Then, after they have made a few shipments they travel. To paraphrase, [the] object is no money to them. They can enjoy their outings secure in the knowledge that there is more where the present comes from. (Redlands Citrograph, June 20, 1903).

Frank continued to mine here until the death of his wife on April 11, 1914, shortly after her seventieth birthday in February. She was buried in Michigan. Frank, six months younger than his wife, was no youngster himself. In June he leased the mine to the Riggs Mining Company and it immediately began shipping ore via the Tonopah and Tidewater Railroad. It has been stated that before 1914 the mine had produced $100,000 in silver and by 1920 another $100,000 had been produced. The mine was active between 1939 and 1943 when a 1,700 foot crosscut was driven to intersect the vein, and a 1,500 foot tram was constructed.

Shadow Mountain

In early 1894, there was a brief gold rush to Shadow Mountain. As the Mining and Scientific Press reported, quoting the Vanderbilt Shaft, "Of all the mineral producing districts contiguous to Vanderbilt...none have attracted more attention in mining circles here during the last two months than the Shadow Mountain country."

"...'Shadow Mountain,' says a prospector of that section, 'is the poor man's country, for the reason that there is rich rock from the grass roots down. The veins are large and the ore rich, and it is bound to be a good place. There are more men coming in every day now, and very few are going out. Everyone is doing well.'" The Redlands Citrograph noted that several deeds for mining property have been filed. In January, 1895, the Shadow Mountain Mining District was listed with new mining districts of San Bernardino County. However, just a year later the district is summed up by the California Mining Bureau, "The small size of the veins, some of which are faulted, the great distance from supply points, and scarcity of water, have retarded the development of the mines, and the district is practically deserted."

In February, 1895, Mr. Stewart, former owner of the store at Keystone, bought the 5-stamp Shadow Mountain mill, located at Valley Wells, and was soon to start milling ore from the Shadow mines. At the same time, Gus William and Pete Wagner were working their mine here, having shipped 10 tons to the Campbell's mill at Vanderbilt. Thirteen years later in 1908, H. Amos Perkins purchased William's mine, and began working a force of 16 men sinking two shafts, and erecting a new mill at Valley Wells. After this report there is no way to correlate the properties which sporadically were mentioned over the next 10 years. In 1910 E. William Johnson employed with the Golden Eagle Copper Company worked a mine here. Julian Douglas and his brother, natives of New York, had interest in the Black Beauty mine between 1911 and 1914; Julian's arrival in Cima in January 1914 received a note in the Barstow Printer. In May, 1913, Arthur and Scheff Henrie were working their mine, and began shipping small lots of high grade ore containing nearly 3 ounces of gold per ton and a little silver, copper and lead. About a year later the Barstow Printer mentioned Dan Henrie's son Kenneth, had recently come from Salt Lake City "en route to Shadow Mt. where he expects to work their gold mine." D. F. Hewett indicates this mine, known as the Henry or Dan Henry, was first worked as early as 1895.

By the late teens the mines of Shadow Mountain were consolidated by E.D. Foster. Foster located 22 claims, known the Glory Group or Foster Mine. But the original mine names also were used including the Dan Henrie, Gold Hill, Grey Copper, and the Foster Mine - a copper mine in the low hills that form the western part of Shadow Mountain. By 1926 there was a 250 foot adit at the Foster mine and two shafts, 60 and 80 feet deep. Prior to 1937 Foster drilled the property, only to discover the granitic gneiss host rock was emplaced over unconsolidated clay and sand of middle Tertiary age. In the late teens 35 tons of ore had been shipped from the Dan Henrie mine, which by 1926 had a 750 foot long adit. The Gold Hill mine, a lead mine, was leased in the late 1930s to Marty Herbst of Los Angeles. A 600 foot deep well was sunk 2 miles from the mine - a 55 foot deep inclined shaft, and a simple gravity concentrating mill was erected at the well. Foster died in 1946.

Halloran Spring Turquoise Mines

In 1905, G. F. Kunz described the discovery of turquoise in the Halloran Spring area:

> Mr. T. C. Bassett had observed in this neighborhood a small hillock where the float rock was seamed and stained with blue. On digging down a few feet, he found a vein of turquoise - a white talcose material inclosing nodules and small masses of the mineral, which at a depth of 20 feet showed fine gem color. Two aboriginal stone hammers were met with, as usual at all the turquoise localities in the southwest, and from this circumstance the location was named the Stone Hammer mine.

The first claim, the Gem, was located May 20, 1896, one mile due west of Solomons Knob. Three addition claims were located August 9, 1896 adjacent to the Gem. Reports of these ancient turquoise mines reached San Francisco, and an exploring party was organized by the San Francisco *Call* newspaper, with Gustav Eisen, an archeologist from the California Academy of Sciences accompanying the party. They departed in March, 1898 going via rail to Manvel, then to the prospects.

Early operations are vague. In April, 1898 the Mining and Scientific Press noted the greater part of the turquoise had been shipped to Amsterdam, with the largest piece weighing 210 carats. Due to the soft rock, all work was done with pick and shovel. Eventually two companies acquired the mines. One, the Toltec Mining Company headed by J.B. Wood of New York, purchased three groups of claims in October, 1898. The claim groups, known as East Camp, Middle Camp, and West Camp, were located one mile due west of Solomons Knob, on Turquoise Mountain, and about one and one-half miles due west of Turquoise Mountain. At East Camp, a well was sunk and a boarding house and frame house were constructed.

The other company, known as the Himalaya Mining Company, was headed by Lippman Tannenbaum and Benedict Lederer. The Himalaya Claim, located August 7, 1899, adjoined the Toltec Company's claims at West Camp on the south. Tannenbaum purchased four claims in this

Figure 1. West Camp, Halloran Turquoise mines, in *1913. U.S. Geological Survey photograph.*

Figure 2. Silver Lake in the early 1900s. *Larry Vredenburgh collection; Steele photograph.*

group in March, 1901. An office/boarding house was located on the millsite claim in the wash just south of the Himalaya Claim. At this same time Woods patented Halloran Spring and Francis Spring as millsite claims.

The turquoise from these operations was shipped to New York. In 1900, an estimated $28,000 worth of turquoise was shipped. In 1904 it was reported, "The Tannenbaum turquoise camp locally known as the Himalaya group..closed last week after a run of seven months. Julius Goldsmidt, the manager and Martin Keane, superintendent started for New York today." There is no mention of mining at these deposits after 1904.

Halloran Spring Gold Mines

The first evidence of gold mining in the Halloran Spring area is provided by a 1902 miners' map of the desert. This map shows "Hyten's" at the site of James Hyten's Wanderer Mine, and the "Mammoth" just southeast of Halloran Spring.

James Hyten, a resident of San Bernardino, continued to work the mine throughout the years, occasionally leasing it out. By 1930 there were a number of shallow shafts, the deepest being 125 feet. There was also a 20 ton per day capacity mill. With revived interest in the district following the discovery of gold at the Telegraph Mine in 1930, the group of 15 claims were leased to American Hellenic Gold Mining Co. of Las Vegas.

The Telegraph Mine was discovered November 9, 1930 by A. A. Brown and Ralph Brown of Salina, Utah. One sample showed free gold in calcite and quartz and assayed up to $800 per ton in gold. The Browns returned to Utah and interested Vivian and Robert Burns, who located a large number of claims. O. Perry Riker of Long Beach, California, leased the property from December 1932 to 1935. During this period, 220 tons of ore were mined and milled at Yucca Grove, three miles northeast of the mine. An additional 990 tons of ore were shipped for smelting. Total production was $35,200. The mine was idle in 1943 and by 1953 all equipment had been removed.

Silver Lake Talc Mines

Ten miles northeast of Silver Lake a two-mile long discontinuous outcrop of talc schist has been mined at six locations. The Amos brothers of Silver Lake made the first shipment of talc from their mine in 1911. At this time G. E. Gould located claims here as did M. E. Stearns who organized the Western White Talc Company. In 1918 Gould sold two claims to the Robert W. Glendenning of the Pacific Coast Talc Company. The Pacific Coast Talc Company built a mill in Los Angeles. The original shaft, known as the Gould, was sunk at a point high on the most extensive talc exposure. In 1925 the shaft was intersected by the Gould tunnel driven east on the talc-bearing zone. By 1934 additional working had been developed and by 1935 85,000 tons of talc had been produced. The Sierra Talc Company purchased the holdings of Pacific Coast Talc Company in 1941, and by 1953 an additional 90,000 tons of talc had been mined.

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Mines and Miners of the Silurian Valley

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The Riggs

Along the eastern border of the Silurian Valley north of Baker, California is the small mountain range known as the Silurian Hills. The first mines to be opened on the east side of Silurian Valley date to the 1880s and were known as the Riggs Mines. The origin of the Riggs name in the area is traced back to Frank and Sarah Riggs, husband and wife, apparently the first permanent settlers in Silurian Valley, about whom little is known although their name appears everywhere on the landscape. For example, in 1918 after the Riggs themselves had both gone, the north end of the Silurian Valley was known as "Riggs Valley." The wash south of the Silver Lake Mine is still called "Riggs Wash," a 1914 road map attests to the existance of "Riggs (dry) Lake," the Tonopah & Tidewater named their local siding "Riggs Station," and the 1938 Automobile club *Map of Southern California* pinpoints "Riggs Well" for desert travelers in need.

The first mention of Frank and Sarah Riggs in San Bernardino County records is found on notice of location for the North Wind claim for December 19, 1882 [Mines C:344]; their first deed was recorded on May 21, 1885 [Deeds 41:316]. The last entry, for Frank Riggs alone three years after Sarah's death, was dated Oct. 11, 1917. Thus the Riggs' paper trail through the deeds and mining records spans a full 35 years. During this long career they recorded over 152 official documents in support of their various prospecting activities, primarily in the Silurian Valley, but also in Randsburg and the Tecopa area. Many of their claims were followed by proofs of labor, and in several cases a mill was located in association with developed claims, but curiously, the Riggs never patented a claim.

Personal information about these two is in short supply. No photograph of their dwelling or representation of their likeness has been found to date. Frank and Sarah Riggs were shown living together in the Silurian Valley on both the 1900 and the 1910 Population Census. Of the two, the 1900 Census contains the most information. Frank M. Riggs was listed as having been born in November, 1845 in Michigan; both parents were born in New York state. He gave his occupation as mining expert. The figure of Sarah Riggs seems particularly mysterious; her pioneering life suggests many questions. It appears she was at Frank's side through the years, living with him at their remote desert mining camp, often the only female for many miles and filing many mineral claims on her own, in her name only. One of their richer mines, for example, the Raymond Marble, was Sarah's alone. Like Frank, Sarah was also born in Michigan, on February 26, 1844, thus making her almost two years older than Frank. Although it was reported that she was the mother of four children, all of whom were living at the time of the 1900 enumeration, no children resided with them at that time or in 1910.

The last notice of location filed in Sarah's name was dated January 13, 1914 (Mines 106:327) Her death certificate states she died at age 70 on April 11, 1914 of an "acute intestinal obstruction;" she had been ill for 14 days. Her father's name was Lyman Milliman and he was a native of New York. Her mother's name is not given [Certificate #289]. Frank Riggs did not long outlive her, succumbing to heart disease three years later. He died in Redlands on October 19, 1917 [Deaths 11:366].

The tantalizing question of what became of Frank and Sarah Riggs' children is rekindled when the first mention of Mary Montague Riggs shows up in the Index to Mines. Although no documentation found to date confirms or denies it, it seems likely she was their daughter. Frank filed his last Proof of Labor on Oct. 11, 1917, eight days before his death. Not quite two months after his death, Mary Montague Riggs began filing claims and Proofs of Labor on mines previously owned by Frank and Sarah. Mary continued to file on the Alta Group through Feb. 26, 1921 before leasing the property to Chris Baker (Mines 150:311).

Perhaps because so little was known of the Riggs, an air of mystery developed around them. They were said to have made a fortune from their silver mines, yet no one knew what they spent it on. L. Burr Belden took advantage of the mystery when writing his "History in the Making" column for the San Bernardino SUN in 1959. Belden's "Johnny" Riggs, as described below, is a composite of fact and fancy, based in part on the real Frank Riggs.

> Some 10 miles north of Silver Lake is the ghost town of Riggs... Riggs was a station on the Tonopah & Tidewater. Riggs was named for Johnny Riggs, who for years served as railroad employee in between his mining. Riggs' mine, a small but reliable ore producer, was in the Silurian Hills, a couple of miles beyond the mine [station?]. Riggs Well was back of the town also, a reliable water supply known to every burro man on the Mojave. Riggs and his wife operated their mine for years.
>
> Occasionally Riggs would hire a man to help him. On such occasions it was usually someone who drifted past and was in need of work, food and a bed. The quality of mining done by such workers may have left something to be desired but Johnny Riggs liked to help people. His wife expressed concern over the amount of gold her husband kept around their little place but as far as is known he was never robbed though the desert fraternity knew he cashed and converted his bullion checks into gold coin. Banks were just too far away by early day transport.
>
> Riggs today is little but a memory. Back near the hills the well is intact but no ore has been hoisted since the depression days. When Johnny Riggs died his little one-man empire just faded back into the desert. Now there isn't even a sign-post marking the turnoff to Riggs (Belden 1959:B-10).

A count of the claims filed by the Riggs in San Bernardino County by year suggests peaks in their mining activity. The Riggs' most energetic years interestingly appear to coincide with the most active years for the Silurian Valley as a whole. There is a predictable peak in the number of Riggs claims filed from 1906 through 1908, just after the arrival of the Tonopah and Tidewater Railroad and during the years of the Crackerjack boom.

Based on a count of the number of documents filed by the Riggs for a single mining property, the Alta Group was by far their most valuable mine. In fact, the Alta Group is the longest worked of any mine in the area. One source places the Alta mine in the Silurian Hills very close to the border in T17N R8E, Sec. 24 [Dept. of Natural Resources 1953:96]. The current topo map, however, shows no roads or other indications of development at this location. What seems more likely is that the Alta is the actual, official name of the Riggs' mine located at T16N R8E, Section 2. This location, marked "Riggs Mine" on the current topo, shows evidence of considerable development.

Frank Riggs' first Notice of Location on the Alta Mine was dated Aug. 30, 1892 (Mines M:289) and his final entry for the Alta Group

Table 1. Number of claims per year filed by Frank and Sarah Riggs. *from San Bernardino County records*

1882	3	1894	2	1906	27
1883	0	1895	1	1907	32
1884	8	1896	32	1908	23
1885	6	1897	0	1909	2
1886	0	1898	2	1910	17
1887	0	1899	9	1911	21
1888	1	1900	0	1912	18
1889	5	1901	4	1913	8
1890	0	1902	11	1914	6
1891	18	1903	7	1915	7
1892	11	1904	4	1916	4
1893	1	1904	1	1917	1

was recorded Oct. 11, 1917, a span of 25 years. In 1898, the Alta Group of mines consisted of the Alta, Etna, Carmelita, Esmeralda, Fleidermaus, Banner, Plumosa and Copper Rivet claims (Deeds 252:224). By 1908, the American, Fairview, Vedette, Last Chance and Grandpa mines were also considered part of the Alta Group. The wealth of the mines was legendary. A trip through the Silurian Valley was made on the Tonopah and Tidewater Railroad on August 11, 1907 mentions the Riggs mine.

> The next station, Riggs, 60 miles from Ludlow, is noted for the fact that here is located one of the richest mines in the whole district. It is a silver property and belongs to old man Riggs, after whom the station is named, and who has lived here and worked this property for 25 years, hauling his ore, which runs $2000 to the ton, with a two-horse team to Barnwell, on the Search Light branch of the Santa Fe, a distance of 60 miles. The old fellow calls his property the Poor Man's Mine, but he has taken ore out of it for years that paid him a dollar a pound [San Bernardino Daily SUN, 1907 Booster Edition].

Another version of the Alta/Riggs Mine history provides contradictory details but paints the same general picture.

> The Alta Silver Mine established by [Frank] Riggs was incredibly rich. Invariably he made all of his shipment by express, which, in 1903, cost him $135 per ton. In the early 1890s, before the construction of the California Eastern, he brought this ore to Daggett and then shipped it by express.
>
> In 1914, it was reported that no ore less than $500 per ton was shipped. Some of the shipments were an incredible $4,000 per ton. Riggs jealously guarded his rich mine with a heavy massive door that gave his mine the resemblance of a safe deposit vault. Riggs, with occasional employees, worked the mine fairly consistently until April, 1914.
>
> In April, 1914, Sarah Riggs, Frank's wife, died. Shortly after, in June, 1914, William Polland of the Riggs Mining Company leased the mine and almost immediately shipped seven sacks of ore by express and seven tons via the Tonopah and Tidewater Railroad.
>
> Before 1914, $100,000 worth of silver was said to have been taken from the Alta, and by 1920, another $100,000. In 1920, Christopher Baker of Silver Lake leased the mine, employing 4 men. The mine was reported idle in 1931, but in 1939 a 1,700 foot tunnel was driven to intersect the vein. Also at that time a 1,500 foot tram connected the upper workings with the ore bin near camp. In 1943, three men were working there [Vredenburgh, Shumway and Hartill 1981:64].

Silurian Camp

The Riggs' established several base camps through the years. One of the first was located near Soda Lake Station, another from the year 1885 was called "Solo Mining Camp," located ten miles northeasterly from Soda Lake Station [Mines B:316]. By 1898, the Riggs camp was known as "Silurian Camp" and was located near their mines in the Silurian Hills [Mines 252:224]. By 1908, the same or nearby location was called "Thos. Cunningham Camp," situated 2 3/4 miles east from Riggs Station on the Tonopah and Tidewater Railroad [Mines 66:390]. The site of Riggs "Station" or siding is clearly shown on the modern topo map. Riggs Well was located at the camp and "was reported in July, 1919, to contain a good supply of water" [Thompson 1921:264].

For the 1910 Census, the residents of Silurian Camp were enumerated together.

The narrative of a visit to the site of Riggs Siding and an abandoned mining camp, possibly Silurian, was published in Desert Magazine in January, 1977. The description and accompanying map help to picture the terrain. The writer was driving north toward Riggs from the Silver Lake Talc Mines. The adobe structure mentioned in the article suggests that a Tonopah and Tidewater section house was located at this camp.

> We decided to follow one [road] heading north toward the Silurian Hills and hoped we would join a road at their base which would lead downslope to Riggs Siding. If the

Table 2. Silurian Camp at the 1910 Census

NAME	COLOR	AGE	TRADE	MARITAL STATUS
William Polland	W	16	miner	single
William Redlied	W	37	miner	single
Charles King	W	38	miner	single
Frank Riggs	W	65	miner	married
Sarah Riggs	W	50	—	married
James Best	W	50	miner	single
Thomas Cunningham	B	57	laborer	single
James Howell	B	40	miner	single
Ollie Johnson	W	50	miner	single
Rose Johnson	W	18	—	single
Percy McCabe	W	35	miner	single

road dead-ended we could always backtrack. It was slow going because fast-moving water had cut small washes across the road...

> At the base of the hills we joined a newly graded road and headed west. Several mines were passed before we reached Riggs Siding. Only a cement slab, piles of talc and old cans mark the site which was once a busy loading point for a number of mines. Forty years of occupancy make these old sidings--Silver Lake, Riggs, Valjean--of special interest, if your hobby is metal detecting. Such sites, generally, yield some good finds.
>
> We headed north from Riggs Siding toward a pass in the Silurian Hills... as we entered the pass, some ruins appeared on our left. Not much was left of what seemed to have been a fair-sized building - just the foundation and a partial corner section. The adobe brick construction was similar to the ruins at Sperry Siding in Amargosa Canyon so we assumed it was built for the railroad. Bits of purple glass and soldered cans indicate the site as pre-1915.
>
> Behind the ruins, a short road led up to a mine in the hills. The adit seemed to have been used for living quarters in more recent times. Rock work supported paths and a fancy, two-hole privvy was built over a minor ravine.
>
> Continuing north, our road joined the T & T railbed which had almost been covered with blow sand. A short distance beyond, an east-west road crossed the right-of-way and lead east to the Annex Silver Mine. By turning left at this point, the road skirts another mine, goes down a short canyon, crosses Silurian Dry Lake and joins Highway 127.
>
> We looked over the Annex Mine then continued our journey north...to the site of Valjean siding. The large amount of debris here seemed to indicated a considerable occupancy over along period of time. Yet, we didn't see any foundations. Perhaps this area had been a base camp for railroad workers when pushing the [Tonopah and Tidewater] tracks through the Dumont Dunes region (Strong 1977:35-36).

The Annex Mines

The Annex Mines are another important mine complex located due north of the Riggs/Alta Mine. Apparently there were two Annex Mines, the Annex/Silver Hills was located in T17N R8E, Sections 26 and 27. The Annex/Mammoth was located in T17N R8E Section 35 and was adjoined by the Berryhill Mines. Both the Annex/Mammoth and Berryhill complexes were talc mines and both of were patented, the Berryhill first. The Mineral Survey Plat for the Berryhill as drawn by Clarence Rasor was filed September 5, 1917. In addition to the shafts, cuts, stope, drifts and tunnel, this plat map shows the location of a "cabin" at Berryhill #2 Mine [MS 5321].

The Mineral Survey Plat for the Annex Mines was filed on August 22, 1947. It shows the location of two "automobile roads" and two ore bins on the property, but no other structures [MS 6384]. The Annex mines were described in 1953.

> Since the Annex Mine [Silver Hills] was first seriously worked in 1947 it has yielded a modest tonnage of high-grade silver ore. This was mined by lessees. Silver minerals have been noted along the length of two claims. The principal zone of veinlets, the "Memorial Day vein," is several hundred feet long... It ranges from a few inches to as much as 10 feet in exposed width. It has been mined by means of an irregular open cut about 35 feet long, joined to several short adits.
>
> Early in 1948 eighty-one tons of high-grade ore had been shipped from the open cut. The ore was hand-sorted, sacked and hauled by means of a light aerial tram a distance of 1400 feet, where it was loaded into trucks and hauled to Dunn, a shipping point on the Union Pacific Railroad. A road half a mile long has since been constructed to a loading bin on the property. By mid-1952 development work consisted of the workings noted above with numerous prospect holes and shallow cuts...In mid-1952 the mine was idle... Ownership: George Peterson and Albert E. Barton own 4 claims [Dept. of Natural Resources 1953:139].

The Uncle Tom Mines

On the 1910 census at the same house location as Frank and Sarah Riggs, three single miners were also counted, apparently boarders. Their names were James Best, Thomas Cunningham and James Howell. What was somewhat unusual about Thomas Cunningham and James Howell was that both were black men. It would appear that black men rarely engaged in mining in this part of the world, as the documents never mention their presence. Blacks are not common desert residents even to this day. These two men, however, spent at least ten years in the desert and eventually patented a rich mine in the Silurian Hills.

The first filing for Thomas Cunningham found so far is dated June 27, 1903 and consists of three claims for the Lone Star, the Bessie and the Lady Bountiful [Mines 36:16]. His last was a proof of labor was on the Yankee Gal Nos. 1 and 2, dated May 1, 1915 [Mines 98:308]. Thomas may have had a brother named John, as both were found the Great Register as voters in San Bernardino County in 1908. Thomas Cunningham was listed as "age 50, 5'11" in height, from Kentucky, living in Silver Lake, finger on right hand mashed." John Cunningham was "age 45, 5'7" in height, from Michigan, living in Silver Lake, broken nose" [Great Register 1908 Vol. 1]. Perhaps John left the area soon after, as no further mention is made of him in the documents.

Clearly, Thomas Cunningham had a sense of humor. With partners A. Stevenson, and Gilbert Bailey, he formed the "Uncle Tom Mining Company." The Uncle Tom mines were located in T16N, R8E, Section 3. Location Notices were first filed on claims in the Uncle Tom Group by the partners in May, 1908 [Mines 66:390]. All the locations were referenced in terms of "Cunningham Camp, on the south side of Silurian Mountain and about 2 1/2 miles easterly from Riggs Station." The roster of mines included in the group fluctuated; among those consistently listed were: Happy Hooligan, Cashier, Smith, Gulch, Hattie, Bessie, Opera, J.S., Florence (sometimes Folorence), February, Mesa, Butte, Deep Discovery Extension, and Granite.

The year 1910 was particularly active for the Uncle Tom Mining Company.

> January 11, 1910 -- A. Stevenson filed a proof of labor "consisting of crosscutting, timbering shafts, and trails upon the Well group of claims including the Deep Discovery, Granite, Uncle Tom, Smith, Gulch, Mesa and Deep Discovery Extension mining claims. Filed at the expense of A. Stevenson and Thomas Cunningham for the benefit of A. Stevenson, T. Cunningham and G. E. Bailey." Mines 74:95.
>
> January 12, 1910 -- Thomas Cunningham and Wallace Wilson filed a claim on the Yankee Girl No. 2 "which joins Yankee Girl No. 1 on the west." Mines 78:60.
>
> February 15, 1910 -- Thomas Cunningham filed a proof of labor on five claims, Joplin No. 1, Joplin No. 2, Yankee Gal, Ned and Griszella "all situated in the Silver Lake Mining District." Mines 57:477-478.

On January 12, 1911, a Proof of Labor was filed by A. Stevenson and Thomas Cunningham for work done in 1910. Stevenson stated that "At least $4,000 worth of labor or improvements was done, consisting of machinery and work on a main crosscut tunnel and road" (Mines 79:291). At an unknown date probably near this time, one of the Uncle Tom mines had "a 1,200 foot tunnel" and "employed 3 men" (Vredenburh, Shumway and Hartill 1981:65). In order to patent their claims, in July, 1912, the Uncle Tom Mining Company paid Samuel J. Paul to formally survey their properties. The result was Mineral Survey Plat 5020, the "Plat Map of the claim of the Uncle Tom Mining Company known as the Folorence, Happy Hooligan, Hattie, Bessie and Cashier Lodes." In addition to drawing the map, Surveyor Paul certified that "Five Hundred Dollars worth of labor has been expended or improvements made...that consist of 9 cuts, 4 tunnels, 1 upraise, 2 drifts and 2 shafts, Value; $14,605.00".

Also owned by the Uncle Tom Mining Company were the Gulch and February Lodes. Improvements on the Gulch consisted of "1 cut, 2 shafts and 2 drifts, Value; $1305.00" (MS 5021). The February Lode was apparently the least valuable, with "2 cuts and 2 shafts: $580.00" but additonal features are included on this Plat of historical interest. A branching road is drawn running through the claim, dropping down into a dry wash at one point, and "cabins" are located in a curve in the road. The Uncle Tom Mining Company's efforts were successful in establishing their claims, and a patent was issued for the properties on April 22, 1914 (S# 03004, P# 400257).

It appears that Thomas Cunningham and partners left the Riggs area not long after receiving the patent, as there is no further mention of them in the mining records. With the end of the second decade of the 20th Century, the era of the hardrock miner slipped away, as the activity in soft minerals, such as gypsum and talc, increased. There is little left today to indicate the flurry of mining activity that once dominated the area around Riggs and only a few bits of paper to shed light on the lives of men such as Frank Riggs or Thomas Cunningham.

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The Tectonic Significance of the Greater Amargosa Chaos – Buckwheat – Sperry Hills basin

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Introduction

The Greater Amargosa Chaos – Buckwheat – Sperry Hills basin is located on the southeastern side of Death Valley, California and occurs as three tectonically dismembered sub-basins: the Amargosa Chaos basin, the Buckwheat basin, and the Sperry Hills basin. These three sub-basins span the region from southern Death Valley to the Kingston Range; strata in the sub-basins range in age from approximately 10.5 through 4 Ma and record the magnitude and style of extension in the southern Death Valley region (Figure 1). A record of two extensional systems is preserved within the Greater Amargosa Chaos – Buckwheat – Sperry Hills basin: the older extensional system initiated at approximately 10.5 Ma on the western flank of the Kingston Range; the second extensional system initiated at approximately 7.8 Ma on the western flank of the Ibex Hills. Below is a brief synopsis of work in the Amargosa Chaos, Buckwheat, and Sperry Hills basins that I have previously published in Topping (1993) and Holm and others (1994). The summary presented below is only meant as an introduction to the topics covered in these two papers; for more complete overview of the stratigraphic relationships in the basin, read the summary I presented on pages 42-46 of Holm and others (1994). The general timing of depositional and tectonic events recorded in the Greater Amargosa Chaos – Buckwheat – Sperry Hills basin is presented in Table 1.

10.5 – 7.8 Ma Strata in the Greater Amargosa Chaos – Buckwheat – Sperry Hills Basin

Strata ranging in age from 10.5 Ma through 7.8 Ma preserved in the lower portion of the Amargosa Chaos basin correlate with 10.5 – 7.8 Ma strata preserved to the southeast in upper Buckwheat Wash and in the Sperry Hills; these three basins together form the Greater Amargosa Chaos – Buckwheat – Sperry Hills basin or GABS basin (see Figures 9, 10, and 11 and Holm and others, 1994). Noble (1941) originally correlated these GABS basin strata from Death Valley to the Kingston Range as part of the Jubilee Phase of the Amargosa Chaos. Clast-provenance and paleoslope trends indicate that the 10.5 – 7.8 Ma GABS basin records the opening of a half-graben with the footwall being the Kingston Range block on the east and the Panamint Mountains – Alexander Hills – Ibex Hills block being the hanging wall on the west (Topping, 1993; Holm and others, 1994).

The changing clast composition of the 10.5 – 7.8 Ma east-derived sediments in the GABS basin records the tectonic denudation of the

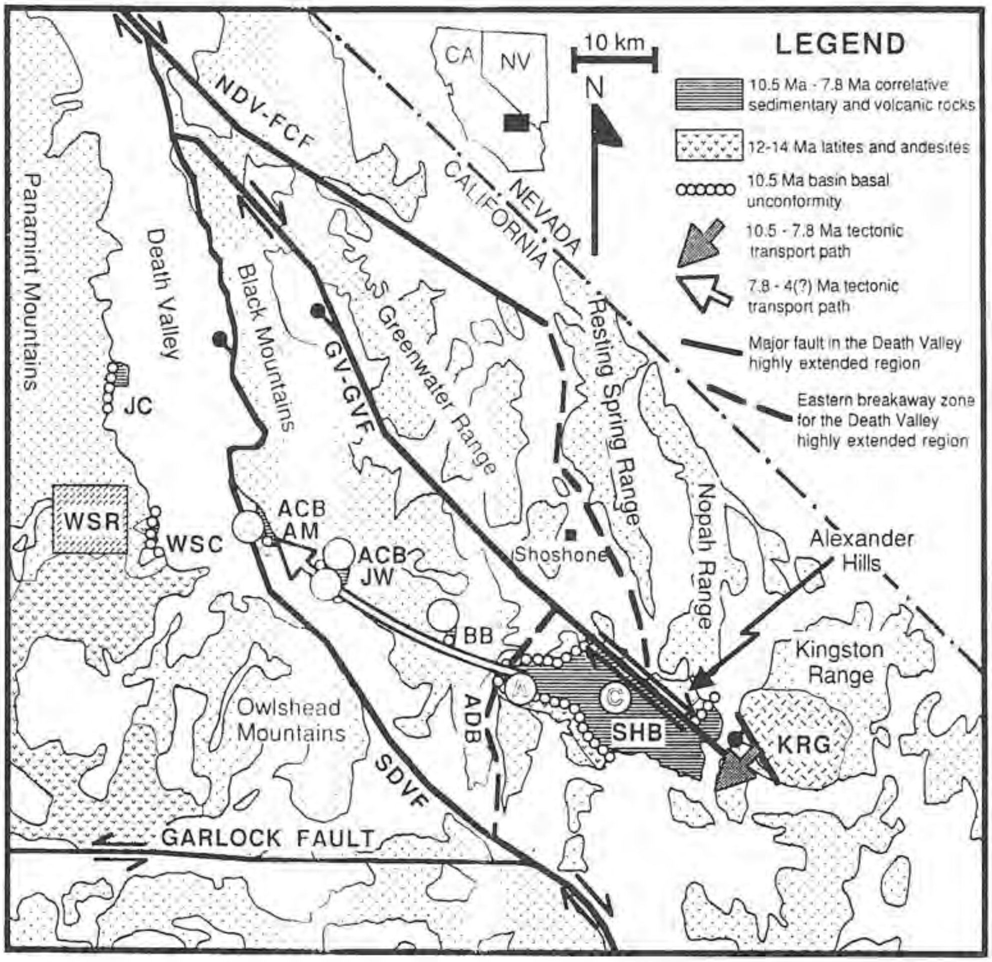

Figure 1. Regional seting of the Greater Amargosa Chaos - Buckwheat - Sperry Hills basin in the Death Valley region. Large arrows depict the three-state tectonic transport path of the Amargosa Chaos basin. (**1**) Southwest-directed extension between the Kingston Range block and the Alexander Hills - Ibex Hills - Panamint Mountains block from 10.5 to 7.8 Ma. (**2**) Northwest-directed extension between the Ibex Hills block and the Panamint Mountains block from 7.8 Ma to the present. (**3**) Fifteen kilometers of dextral strike-slip along the Greenwater Valley - Grand View fault from 7.8 to 3 Ma. Outlined letters A, B, and C refer to the locations of correlative stratigraphic sections in Figures 10 and 11 of Holm and others (1994). Abbreviations: NDV-FCF = Northern Death Valley - Furnace Creek fault; GV-GVF = Greenwater Valley - Grand View fault; SDVG = Southern Death Valley fault; JC = Johnson Canyon; WSR = source region for the **West-derived conglomerate** in the Amargosa Chaos and Buckwheat basins; WSC = Warm Springs Canyon; ACBAM = Amargosa Chaos basin, Ashford Mill area; ACBJW = Amargosa Chaos basin, Jubilee Wash area; BB = Buckwheat basin; SHB = Sperry Hills basin; ADB = 7.8 Ma brittle Amargosa detachment breakaway zone; KRG = Kingston Range granite pluton.

upper Proterozoic sedimentary rocks and the underlying Pahrump Group sedimentary rocks intruded by the 12.5 Ma granitic pluton in the Kingston Range (see Figure 4 in Topping, 1993). These east-derived sediments include: (1) **East-derived conglomerate 1** (a unit composed of clasts derived predominantly from the Johnnie Formation and Stirling Quartzite), (2) **East-derived conglomerate 2** (a unit composed of clasts derived from, in decreasing order of abundance: Kingston Range granite, Beck Spring Dolomite, Crystal Spring Formation, 12 – 14 Ma latite, Kingston Peak Formation, Noonday Dolomite, Johnnie Formation, and Stirling Quartzite), and (3) a series of large rock-avalanche deposits composed of both Kingston Range granite and Crystal Spring Formation and Beck Spring Dolomite intruded by dikes of Kingston Range granite. **East-derived conglomerate 2** unconformably overlies **East-derived conglomerate 1**; this unconformity is a key stratigraphic marker that is beautifully exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin and is always above the 9.2 – 9.8 Ma Rhodes Tuff and below the uppermost 7.7 – 8.6 Ma Shoshone Volcanic tuffs. The first occurrence of Kingston Range granite as clast material in the basin is always above this unconformity and falls at approximately the 9.1 Ma horizon. Paleocurrents determined at numerous sites in both the Amargosa Chaos and Sperry Hills portions of the GABS basin indicate a west to northwesterly transport direction for both **East-derived conglomerate 1** and **East-derived conglomerate 2**. The granitic large rock-avalanche deposits always occur above the unconformity and are interbedded with either **East-derived conglomerate 2**, playa deposits, charophyte limestones, or west-derived conglomerates. Paleoslide indicators measure on 6 slide bases in the Amargosa Chaos portion and 6 slide bases in the Sperry Hills portion of the GABS basin indicate a westerly transport direction for the granitic large rock-avalanche deposits.

Evidence for a Kingston Range pluton source for the large rock-avalanche deposits, summarized from Topping (1993), is as follows:

(1) While the rock-avalanche deposits are interbedded with both the east-derived and west-derived conglomerates, the rock types in the rock-avalanche deposits only match those in the bracketing east-derived conglomerates.

(2) Grooves at the bases of the deposits indicate an east-west transport direction. Grooves unfortunately are bi-directional indicators, but can be used in conjunction with observation (1) to indicate an eastern source.

(3) Fabric asymmetries in the clay gouge beneath the deposits indicate an east-to-west transport direction.

(4) The rock-avalanche deposits contain both granite and Proterozoic Crystal Spring Formation and Beck Spring Dolomite strata intruded by dikes of the same granite. The only Miocene pluton in the southern Death Valley region that intrudes unmetamorphosed rocks of the Crystal Spring Formation and Beck Spring Dolomite is the Kingston Range pluton.

(5) A survey of all the regional Miocene granitic plutons indicates the closest hand-sample and thin-section match between the rock-avalanche deposits and the Kingston Range pluton. The granite in the rock-avalanche deposits contains two rock types, a phase dominated by feldspar phenocrysts and a phase dominated by round quartz phenocrysts. The Kingston Range granite pluton consists of two phases, a feldspar porphyry and a quartz porphyry (J.P. Calzia, pers. comm., 1993); **it is the only Miocene granite pluton in the region containing quartz phenocrysts.**

(6) The Kingston Range pluton is the only regional pluton that matches the rare-earth element pattern of the granite in the rock-avalanche deposits (see Figure 1 in Topping, 1993).

(7) The zircon and apatite fission-track ages in the rock-avalanche deposits only match the ages obtained from the Kingston range pluton (see Table 2 in Topping, 1993).

(8) The portions of the rock-avalanche deposits which remained in the Sperry Hills basins when faulting stepped westward to the brittle Amargosa detachment are still within 20 km of the Kingston Range.

West-derived sediments exposed in both the Amargosa Chaos and Buckwheat portions of the GABS basin can be tied to a unique source area in the southern Panamint Mountains. Unlike the temporally changing clast composition of the east-derived sediments that reflects the erosion of an actively uplifted footwall, the modal clast composition of the west-derived sediments does not change through time and reflects the erosion of a hanging wall dipslope. Clasts in the **West-derived conglomerate** include (a) a suite of volcanic rocks, (b) rocks from the Anvil Spring Formation (a Permian fusulinid packstone exposed in the southern Panamint Mountains), and (c) upper Proterozoic quartzites. The three source units for these clasts have occurred together from 14 Ma to the present only in the vicinity of Warm Springs Canyon in the southern Panamint Mountains (see Figure 5 in Topping, 1993), where 12 – 14 Ma volcanic rocks nonconformable overlie both the Anvil Spring Formation and Proterozoic sedimentary rocks, which are, I turn, in fault juxtaposition along the Mesozoic Butte Valley fault (Johnson, 1957; Topping, 1993).

The paleowidth of the GABS basin can be reconstructed by combining the above stratigraphic observations with an empirical physical analysis of catastrophic landslide runout as a function of landslide volume. Rock-avalanches are catastrophic, inertial events that occur within minutes, reaching peak velocities of 100 m/s, and do experience relatively long runouts over low-gradient surfaces, e.g., alluvial fans. In analyses of runouts of modern landslides, normalized landslide runout, i.e., the horizontal runout divided by the drop height, is usually presented as a function of landslide volume (see Figure 11b in Topping, 1993). However, since the paleorelief of the Kingston Range at 8 – 9 Ma is unknown, an analysis was used that removed the landslide drop height from the problem (see Figure 11c in Topping, 1993) and only required the maximum likely volume of each deposit as input in the calculation. So, since the individual volumes of the Kingston Range granite rock-avalanche deposits in the GABS basin range up to 0.5 – 1.0 km^3, the rock avalanches could have traveled no farther than 10 km from the Kingston Range during the landsliding events. Moreover, since three of these rock-avalanche deposits are also interbedded with west-derived conglomerates, these rock avalanches must have traversed at least half of the basin, so the inferred original basin width could be no more than about 20 km, similar in width and morphology to modern Death Valley. This places the Panamint Mountain block no farther than 20 km from the Kingston Range through 7.8 Ma. Presumable, the Panamint Mountains were immediately adjacent to the Kingston Range at 10.5 Ma prior to initiation of sedimentation in the GABS basin.

Post-7.8 Ma Stratigraphy in the Amargosa Chaos Basin

The post-7.8 Ma section in the Amargosa Chaos basin is approximately 0.9 km thick (see Figure 3 in Topping, 1993, and Figure 9 in Holm and others, 1994). This section is dominated by **East-derived conglomerate 3** (the Black Mountains unroofing sequence) and records the initial breakup of the GABS basin, the exposure of the nonconformity separating the Pahrump Group rocks from the underlying metamorphic basement in the Ibex Hills, uplift of the metamorphic basement in the southern Black Mountains along the Amargosa detachment, and subsequent uplift of the Shoshone Volcanics along higher angle domino faults. The clast composition of **East-derived conglomerate 3** changes rapidly up section: (1) the lowest portion (~7.5 to 6.3 Ma) is dominated by clasts derived from the

Table 1. Timing of events recorded in the Greater Amargosa Chaos - Buckwheat - Sperry Hills (GABS) basin and environs.

TIMING *	EVENT †
14-12 Ma	Eruption of the latites and andesites exposed regionally beneath the basal unconformity of the GABS basin. **AGES**: 12.3 ± 0.6 Ma K/AR *Ibex Pass* (J.P. Calzia, pers. comm., 1992); 13.01 ± 0.42 Ma Ar/Ar *Ashford Mill-Black Mountains* (Topping, 1993); 13.56 ± 1.64 Ma Ar/Ar *Warm Springs Canyon-Panamint Mountains* (Topping, 1993).
12.5 Ma	Intrusion of the Kingston Range granitic pluton. **AGES**: 12.5 ± 0.6 Ma K/Ar (Hewett, 1956); 12.5 ± 0.6 Ma U/Pb (J.P. Calzia, pers. comm., 1994)
12.5 Ma	Cooling of the Kingston Range pluton to below 200°. **AGE**: 12.6 ± 1.0 Ma ZFT (Topping, 1993)
10.5-10.3 Ma	Eruption of dacites and tuffs exposed regionally beneath the basal unconformity of the GABS basin. **AGES:** 10.3 ± 1.2 Ma K/Ar *China Ranch* (Scott et al., 1988); 10.4 ± 1.2 Ma K/Ar *Sheephead Pass-Black Mountains* (Wright and Troxel, 1984); 10.3 ± 1.0 Ma ZFT *Warm Springs Canyon-Panamint Mountains* (Topping, 1993); 10.5 ± 0.6 Ma Rb/Sr *Trail Canyon-Panamint Mountains* (McKenna and Hodges, 1990).
10.5 Ma	Initiation of the GABS basin as a half-graben between the Kingston Range block on the east and the Panamint Mountains-Alexander Hills-Ibex Hills block on the east.
10.5-8 Ma	Deposition of **East-derived conflomerate 1** (dominated by clasts derived from the Johnnie Fm & Stirling Quartzite). Unit is exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin.
10.5-6.5 Ma	Deposition of **West-derived** conglomerate (contains clasts of the 12-14 Ma latites and andesites, Proterozoic sedimentary rocks, and Permian Anvil Spring Fm; these source rocks have only occurred together from ~14 Ma to the present in the southern Panamint Mountains (see Topping, 1993, for discussion). Unit is exposed in both the Amargosa Chaos and Buckwheat portions of the GABS basin.
9.8-9.2 Ma	Eruption of the Rhodes Tuff. **AGES**: 9.6 Ma *Resting Spring Range* (Thompson et al, 1933); 9.81 ± 0.02 Ma Ar/Ar *Sperry Hills basin-China Ranch* (Scott et al., 1988); 9.7 ± 1.0 Ma ZFT, 9.2 ± 0.8 Ma ZFT *Amargosa Chaos basin-Black Mountains* (both from Topping, 1993). Unit is exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin.
9.1 Ma	Cooling of the Kingston Range granitic pluton to below 100°C. **AGE**: 9.1 ± 1.4 Ma AFT (Topping, 1993).
9.1 Ma	First occurrence of Kingston Range granite as clasts in the GABS basin.
9.1-7.8 Ma	Deposition of **East-derived conglomerate 2** (composed of clasts derived from, in decreasing order of abundance: Kingston Range granite, Beck Spring Dolomite, Crystal Spring Fm, 12-14 Ma latite and andesite, Kingston Peak Fm, Noonday Dolomite, Johnnie Fm, and Stirling Quartzite). Unit is exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin and unconformably overlies **East-derived conglomerate 1.**
9 Ma	Beggining of period of major landsliding of Kingston Range granite and Pahrump Group rocks intruded by Kingston Range granite into GABS basin from the east. These rock-avalanche deposits are interbedded with both **East-derived conglomerate 2** and **West-derived conglomerate** and are exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin.
8.6-7.7 Ma	Eruption of the Shoshone Volcanic tuffs. **AGES:** 7.6-8.4 Ma tephrachronology age *Sperry Hills basin-Alexander Hills* (J.P. Calzia, pers. comm., 1994); 8.35 ± 0.48 Ma Ar/Ar *Sperry Hills basin-China Ranch* (Scott et al., 1988); 8.4 ± 0.8 Ma ZFT, 7.7 ± 0.8 Ma ZFT, 6.6 ± 0.6 Ma ZFT *Amargosa Chaos basin-Black Mountains* (all from Topping, 1993); 8.1 ± 0.8 Ma ZFT *Johnson Canyon-Panamint Mountains* (Topping, 1993).
8 Ma	Deposition of lacustrine charophyte limestone. Unit is typically interbedded with the 8.6-7.7 Ma Shoshone Volcanic tuffs and is exposed in the Amargosa Chaos, Buckwheat, and Sperry Hills portions of the GABS basin.
7.8 Ma	Cessation of major landsliding from the Kingston Range into the GABS basin.
7.8 Ma	Breakup of the GABS basin and the Panamint Mountains-Alexander Hills-Ibex Hills block by the brittle Amargosa detachment fault system and the dextral Greenwater Valley-Grand View fault system. Regional extension direction shifts from wouthwesterly to northwesterly.
7.8-7.5 Ma	Buckwheat basin fragment is stranded in the footwall of the brittle Amargosa detachment fault.
7.5-4 Ma	Continued tectonic transport of the Amargosa Chaos basin to the northwest in the hanging wall of the Amargosa detachment fault. Deposition of **East-derived conglomerate 3** (the Black Mountains unroofing sequence). Unit is exposed in the Amargosa Chaos basin.
7.1 Ma	Deposition of the rock-avalanche deposit that includes Buckwheat and Sperry Hills basin rocks into the Amargosa Chaos basin.
6.3 Ma	Onset of the breakup of the Amargosa Detachment fault by higher-angle domino faults.
6.3 Ma	Deposition of the metamorphic basement rock-avalanche deposit in the Amargosa Chaos basin.
5.5 Ma	Deposition of the Shoshone Volcanic rock-avalanche deposit into the Amargosa Chaos basin.
5.2 Ma	Eruption of the uppermost tuff in the Amargosa Chaos basin. **AGE**: 5.2 ± 0.6 Ma ZFT (Topping, 1993).
4.6 Ma	Eruption of the Funeral Basalt and cessation of motion in the Amargosa detachment in the Virgin Spring area. **AGE**: 4.6 ± 0.6 Ma K/Ar (L. Wright, pers. comm., 1993).
4.6 Ma - present	Continued motion on the Black Mountain frontal fault segment of the Amargosa detachment and associated faults. Tectonic transport of the Ashford Mill portion of the Amargosa Chaos basin into Death Valley proper and continued tectonic transport of the Panamint Mountains block to the northwest.

Note:

* Ages in boldface type are based on the age determinations listed in column 2; ages in italic type are estimated by interpolation between dated volcanic units.

† ZFT = zircon fission-track; AFT = apatite fission-track; locations of samples are listed in italics; all ages are ± 2 σ

Crystal Spring Formation, Beck Spring Dolomite, and the stranded Buckwheat-Sperry Hills basin in the footwall of the brittle Amargosa detachment, (2) the middle portion (~6.3 to 5.8 Ma) is composed only of metamorphic basement clasts, and (3) the upper portion (~5.8 to 4.6 Ma) is dominated by metamorphic basement, Shoshone Volcanics, Sheephead Andesite of Wright and Troxel (1984), and basalt clasts.

Three rock-avalanche deposits occur in this section (see Figure 9 in Holm and others, 1994). The lowermost is composed of Sperry Hills - Buckwheat basin strata and is dominated by Kingston Range granite rock-avalanche deposit material, west-derived conglomerate, and charophyte limestone. The second is composed of metamorphic basement and is inferred to have occurred at approximately 6.3 Ma as interpolated from bracketing volcanic units. The uppermost rock-avalanche deposit is composed of rocks from the Shoshone Volcanics. A 5.2 ± 0.6 Ma (ZFT, Topping, 1993) ash layer occurs approximately 70 meters upsection from this rock-avalanche deposit. The investigated section is capped by the Funeral basalt dated at 4.6 ± 0.3 Ma (K/Ar, whole rock, L. Wright, pers. comm., 1993) east of Virgin Spring Canyon and 4.9 ± 0.1 Ma (Ar/Ar, Holm and Lux, 1991) in the Copper Canyon basin to the north. A potential feeder dike for this flow cuts the Amargosa detachment east of Virgin Spring Canyon (Noble, 1941; Wright and Troxel, 1984) indicating cessation of movement on the detachment by 4.6 Ma in the western Black Mountains. Finally, the timing of unroofing of the Black Mountains core that is bracketed by the dated volcanic horizons within **East-derived conglomerate 3** is in general agreement with the zircon and apatite fission-track cooling-age transects in the metamorphic basement from Holm and Dokka (1993).

Tectonic Reconstruction

The following tectonic history of the region between the Kingston Range and the southern Panamint Mountains can be reconstructed by combining the stratigraphic analysis summarized above with: (1) the observation that the dextral Greenwater Valley – Grand View fault has cut the Sperry Hills portion of the GABS basin in two with 15 km of offset on the basin basal unconformity occurring between 7.8 and 3 Ma (Figure 1), and (2) cross-sections that I have constructed across the southern Black Mountains (see Figure 12 in Holm and others, 1994).

(1) Prior to about 10.5 Ma the Kingston Range block and the Alexander Hills – Ibex Hills – Panamint Mountain block were adjacent.

(2) From 10.5 to about 7.8 Ma, approximately 15 km of southwest-directed extension occurred on the normal (to oblique) slip fault system on the western flank of the Kingston Range.

(3) From approximately 7.8 to 3 Ma, the GABS basin was disrupted by 15 km of dextral strike-slip motion along the Greenwater Valley – Grand View fault system.

(4) From approximately 7.8 to about 6.3 Ma in the eastern Black Mountains and from 7.8 to 4.6 Ma in the western Black Mountains, 15–18 of northwest-directed normal slip occurred on the brittle Amargosa detachment fault.

(5) From about 6.3 Ma to somewhat younger than 4.6 Ma, 10 km of northwest-directed normal slip occurred on the domino faults that cut the Amargosa detachment in the southeastern Black Mountains.

(6) From about 4.6 Ma to the present, 15 km of northwest-directed normal slip occurred on the modern Death Valley fault system.

Thus, the total tectonic transport between the Kingston Range and the southern Panamint Mountains is about 70 – 73 km, a value in close agreement with the hypothesis of Stewart (1983).

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Appendix: Field and laboratory methodologies used in this investigation

In order to accurately determine the distribution of alluvial fan conglomerates and rock-avalanche deposits in the GABS basin, I remapped the Amargosa Chaos basin and the Ibex Pass and China Ranch portions of the Sperry Hills basin at a scale of 1:8000 building on the work of Wright and Troxel (1984). In the Amargosa Chaos basin, I measured detailed stratigraphic sections at 16 different locations; in the Buckwheat basin, I measured stratigraphic sections through the entire basin a 2 locations; and, in the Sperry Hills basin, I measured detailed stratigraphic sections at 3 different locations. All of these sections included grain-size and clast provenance data collected by means of a point-counting grid. At each location, paleocurrent data were collected by measuring orientations of imbricated clasts in the fluvial conglomerates. Where possible in the GABS basin, I determined rock-avalanche paleoslide direction by measuring groove orientations on the base in combination with fabric asymmetries in the underlying clay gouge.

During the course of this investigation, I used fission-track dating both for determining the ages of the tuffs in the basin and as one of several fingerprinting methods for determining the provenance of the rock-avalanche deposits. To this end, 32 zircon fission-track and 6 apatite fission-track ages were processed. The ^{40}Ar-^{39}Ar method was used to determine the age of latite flows beneath the basin sediments in southern Death Valley. The Inductively Coupled Plasma Emission Spectroscopy method was used as another fingerprinting tool to compare trace- and rare-earth element data collected from 4 different granitic rock-avalanches in the Amargosa Chaos and Sperry Hills basins to trace- and rare-earth element data collected from all of the Miocene granitic plutons in the region. I determined the paleoslopes of the fluvial alluvial fan conglomerates in the Amargosa Chaos basin by (1) calculating the critical shear stress for D_{84} of the grain-size distribution measured at the outcrop, and (2) determining the paleoflow depth from the scale of stratification in the outcrop.

Abstracts from the 1996 Desert Research Symposium

San Bernardino County Museum, April 26-29, 1996

Jennifer Reynolds (compiler), *San Bernardino County Museum Association, Redlands, CA 92374*

An early Barstovian cat: *Pseudaelurus sinclairi,* Robbins Fossil Quarry, Barstow, California

Mary A. Aruta, *Earth Science Volunteer*, and **Robert E. Reynolds**, *Section of Earth Sciences, San Bernardino County Museum, Redlands, CA 92374*

Research and collection of fossils in the Barstow Formation has been ongoing by the University of California and the Frick Laboratories for 80 years. Robbins Fossil Quarry is a horizon high in the Barstow Fm.. that has been quarried by the SBCM intermittently for almost 30 years. During the last two major excavations (1984 and 1994) SBCM volunteers and students from Berkeley plotted and removed hundreds of specimens. Several specimens are notable, particularly the recovery of *Pseudaelurus sinclairi.*

During the 1984 excavation, 14 diagnostic specimens were identified and catalogued as Felidae. In 1994, left and right associated *Pseudaelurus* mandibles were collected. In 1995, adjacent to the previous finds, a complete skull of *Pseudaelurus* was uncovered. Richard H. Tedford, American Museum of Natural History, used dental measurements to refer the skull and jaws to *P. sinclairi.*

The closely associated but incomplete skeleton of the felid indicates the possibility that it died elsewhere and was washed to the site partially articulated. At the site it was disarticulated, then buried and compressed. Dimensions of the skull, and size and shape of the teeth, indicate that its size approximated that of a small mountain lion. It appears to be approximately 10 percent smaller than the *Felis concolor* specimen in the SBCM collection.

While still encased in the matrix, the San Bernardino County Hospital did a computerized tomography (C-T) scan on the skull. The results were spectacular, showing what appeared to be a complete skull including cranium, maxilla, orbits, palatine bone, parietal bone, frontal bone, temporal bone, malar bone, nasal bone, one broken and one partial canine, and partially intact premolars and molars. Even the semicircular canal in the auditory bulla could be viewed while in the matrix.

The skull and associated mandibles may be the most complete known for *Pseudaelurus sinclairi.* The stratigraphic position of the specimen sub-adjacent to the Hemicyon Tuff (14 Ma) suggests an approximate 14.3 Ma date.

Foraging ecology and dietary overlap of desert tortoises (*Gopherus agassizii*) and range cattle in the Mojave Desert: Implications for wildlife conservation and land management.

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Animals experience great seasonal and annual variation in food availability in the Mojave Desert. The magnitude and frequency of this variation can greatly affect rates of food acquisition and nutrient assimilation, which have important short- and long-term consequences for survivorship, fecundity, and population viability. By removing plant biomass from the environment, cattle grazing can potentially impose further limitations on food availability. I examined if the desert tortoise (*Gopherus agassizii*), a generalist herbivore, alters foraging behavior to compensate for the effects of cattle grazing. Rates of food acquisition and forage preference were compared for free-living tortoises in grazed and protected habitat in the eastern Mojave Desert of California. I also measured food preferences for undisturbed range cattle, to quantify their food preferences and dietary overlap in relation to tortoises.

In 1992 and 1993, biomass of spring annuals was similar in grazed and ungrazed plots. Biomass of annuals exceeded 200 lbs acre^{-1} in 1992, and was approximately 70 lbs acre^{-1} in 1993. Tortoises consumed green annual forbs (80% of intake in both years) and cacti (17% to 20% of intake). Perennial shrubs and grasses, and annual grasses constituted less than 2% of tortoise diets in both years. Tortoises foraging in protected and grazed areas acquired food at similar rates in both years. In 1992, duration of foraging bouts were similar for tortoises foraging in grazed and protected areas, but in 1993 duration of foraging bouts were greater for tortoises foraging in a grazed area compared to those in a protected area.

Stocking rates of cattle during spring of 1992 and 1993 (0.66 Animal Unit-Month km^{-2}mo^{-1}) did not cause changes in the foraging ecology of desert tortoises. Although dietary overlap between cattle and tortoises was great, food abundance was sufficient in spring of both years to prevent food competition. During years when spring annuals are lacking, livestock grazing may have a more observable effect on tortoise foraging and nutrition, when tortoises must rely on perennial grasses that are likely to be over-utilized by cattle. Findings from this study suggest that regulating cattle consumption of perennial plants, rather than utilization of annual forage, may be more important to the conservation of desert tortoise populations.

An Inventory of Museum Specimens of Amphibians and Reptiles from Riverside and San Bernardino Counties, California: A Work in Progress

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The topic of biodiversity and its preservation has generated considerable interest in recent years. Documentation of biodiversity requires detailed knowledge of the numbers of species that occur in a particular area. However, community composition is dynamic and continued monitoring is required to chronicle fluctuations in species composition. Museums play an important role in documenting changes in biodiversity by maintaining collections of voucher specimens.

Riverside and San Bernardino Counties have high herpetofaunal diversity with approximately 19 species of amphibians and 68 species of reptiles. Included are numerous threatened, endangered, and candidate species and several endemic and spatially limited taxa. The high diversity of reptiles is partly attributable to the diversity of habitats in the region including coastal sage scrub, montane (to alpine), and two desert bioregions (Mojave and Colorado). The last review of the distribution of the herpetofauna in the region was a compilation of the distribution of amphibians and reptiles in Riverside County published in 1970. Although some locality data has been published for the area, there has been no systematic attempt to compile all the museum and literature records of the herpetofauna in the region. In addition, the ranges of many species have been reduced due to intense urbanization in the western portion of the region. The purpose of this project is to assemble a database listing all readily available records of amphibians and reptiles in the region. Our preliminary estimate suggests that records are available for over 20,000 specimens. A significant end product is an electronic database on the distribution of the herpetofauna in the region. To date over 3,000 records have been entered and several thousand more have been received from museums in electronic format for inclusion into the database. Over 57% of the records available to date are for lizards with another 29% representing snakes.

Common raven populations in the Mojave Desert

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Common raven (*Corvus corax*) populations have increased considerably in recent years (<1000% over 26 years) in the deserts of southwestern United States. The increases are probably caused by an rise in human population densities in the desert and they may be responsible for increased raven predation on juvenile desert tortoises (*Gopherus agassizii*). The potential exists for ravens to impact other native populations as well. As subsidized predators, ravens benefit from food, water, and other subsidies provided by human activities. To determine the extent to which raven populations are influenced by human-based resources during the summer, we studied ravens at Edwards Air Force Base (EAFB), Kern Co., California. We found that significantly more ravens used landfills than any other resource type ($F = 7.27$; $df = 4{,}90$; $P = 0.0090$). We are also studying the movements of radio- and wing-tagged ravens to determine the influence anthropogenic resources have on raven presence and densities in the desert.

A Victorian collector's sojourn in Southern California

James M. Bryant, *Riverside Municipal Museum, 3580 Mission Inn Avenue, Riverside CA 92501*

Franklin Tanner Pember was a successful, 19th century New York businessman whose life-long hobby involved the collecting of natural history specimens. A portion of both his collecting and business careers brought him to Riverside, California, during which time he explored areas of California from Marin County southward. His activities included exchanges of specimens with a number of other naturalists in the region. Today, the bulk of these samplings of California plants and vertebrates have been preserved at the Pember Museum of Natural History in Granville, New York and may prove invaluable as science pieces together a record of California's changing environment over the past 150 years.

Report on continuing investigations of the Sespe Formation (Oligocene/ Miocene: Terrestrial) in the San Joaquin Hills of Orange County, California.

Steven W. Conkling, *LSA Associates, One Park Plaza Suite 500, Irvine, CA 92714*

In Orange County, the Sespe and Vaqueros formations represent terrestrial (Sespe) and marine (Vaqueros) facies of an interfingering lithostratigraphic unit (the Sespe/Vaqueros Formation). Work by Savage and Russell (1983) indicates that the Sespe Formation is Whitneyan(?) to Arikareean in age. Lander (1994) reports a Hemingfordian age for the Sespe facies in the Santiago Canyon Landfill area. Sespe Formation sediments from Orange County may correlate in age with faunas from Black Butte Mine (Hector Formation), the Tick Canyon Formation, Baker Ranch (Round Mountain Silt), Tropico Group, Caliente Formation, and Kinnick Formation of the Mojave Desert area.

LSA Associates, Inc. (LSA) has been involved in an extensive monitoring project in the San Joaquin Hills of Orange County. Excavations in the Sespe Formation exposed approximately 2,400 feet of section, and produced a wide diversity of vertebrate remains. In the course of monitoring activities, five standard samples (approximately 6,000 pounds each) were collected and washed to 20 mesh. Approximately 500 pounds of matrix were washed to 30 mesh and examined for diagnostic remains. Palynomorphic, foraminiferal and calcareous nannoplankton studies of the sediments yielded no age diagnostic remains. Microvertebrates indicate that the sediments are probably Hemingfordian in age. Complete measured sections for each formation exposed on the project were developed.

Additional work in the Sespe/Vaqueros Formation is continuing. Faunas have recently been collected from the western and middle Santa Ana Mountains. Earlier work by Belyea and Minch (1994), Lander (1994), and others will be discussed as it relates to these faunas.

Use of Global Positioning Systems (GPS) and Global Information Systems (GIS) in cultural and paleontological resource mitigation.

Steven W. Conkling and **John M Staight**, *LSA Associates, One Park Plaza Suite 500, Irvine, CA 92714*

LSA Associates has recently employed GPS and GIS technologies in the management and mitigation of cultural and paleontological resource sites. GPS units can be used to provide field way points for localities, locate isolated sites, promote field safety, and provide reference points for surveys in remote locations. In the field, GPS units provide precision mapping (from 5 to <0.01 meter resolution) of sites, individual finds, excavation units, and other site information. In addition, through the use of portable computers and cellular telephones, GPS units can be field corrected to provide accurate, to scale mapping while in the field. Individual finds or site locations can be immediately recorded with latitude/longitude or UTM readings, and site elevation above mean sea level is automatically recorded. Analysis of locality acreage, boundary discrimination and specimen concentrations can also be readily made using this technology. The individual pieces of machinery are relatively small and collector error in readings is minimized.

Integration of GPS and GIS technologies allows importing of topographic base maps for the production of accurate site maps. Raster images of USGS maps or aerial photographs can be scanned, or engineering drawings from CAD and GIS programs can be used to provide base maps for GPS data.

The impact of rodents on desert fan palm (*Washingtonia filifera*) populations

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The composition of rodent communities of sixteen desert fan palm oases in California and Baja California Norte were determined by live-trapping over a five-year period (1982-1987). Eight species of rodents were captured. The cactus mouse, *Peromyscus eremicus*, was the most abundant species and accounted for 58.1% of all captures. The spiny pocket mouse, *Perognathus spinatus*, was the second most common rodent and accounted for 32.3% of captures. All other species of rodents were rare. Both rodent species occurred in lesser densities in the creosote- and mesquite-dominated habitats in the vicinity of palm groves. Contrary to popular accounts (Jennings, 1979; Olin, 1977), woodrats (*Neotoma* spp.) were exceedingly rare in palm oases, being captured only three times in 1,834 trap days. However, woodrats were one of the most frequently-captured rodents in nearby mesquite-dominated habitats.

Captive feeding trials were conducted to discover which rodent species might impact palm populations by feeding upon seeds and/or seedlings. No captive rodents fed upon palm seedlings and field work failed to reveal any palm seedlings which had been browsed. Desert fan palm seeds are exceedingly hard and captive rodents preferred any variety of commercial grain over palm seeds. Only when given no other food alternative would rodents attempt to feed upon palm seeds. Typically, the flesh or pericarp of the entire fruit was consumed but the seeds were left intact. Only the spiny pocket mice regularly attempted to gnaw into the seeds and even this species was unable to maintain normal body weight for five days when given a restricted diet of whole palm fruits and water.

A single mature desert fan palm can produce up to 600,000 seeds annually (Cornett, 1987a). Even if rodents did regularly utilize this food resource they could not destroy even one-fourth of the annual production of palm seeds in an oasis. This calculation assumes a production of 150,000 fruits annually per tree at 8 calories per fruit, a generous estimate of eight rodents per palm and an annual energy requirement of 20,000 calories per rodent (see Cornett, 1987b).

In conclusion, the present research suggests that rodents do not have a significant negative impact upon the ultimate number of palms in an oasis.

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Gravel dispersion on a granitic pediment (East Mojave Desert, California): A short term look at erosional processes.

Susan Edinger-Marshall, *Centers for Water and Wildland Resources, University of California, Riverside CA 92521*; and **Lanny J. Lund**, *Department of Soil and Environmental Sciences, University of California, Riverside CA 92521*

Location: Sweeney Granite Mountains Desert Research Center (Lat. 34°, Long. 115°45').

Gravel dispersion patterns were characterized on a shallowly dissected portion of the Granite Cove Pediment after about 50 mm cumulative precipitation over a four-month time period. Gravels (2 to 20 mm diameter) from the study area were painted with fluorescent paint. Circular piles (30 g each) were placed at 117 nodes on a 6 m x 3 m grid superimposed on an area with a shallow wash and two bordering interfluves. Six landscape units were identified (summit, shoulder, backslope, footslope, toeslope, and wash.) The following one-time observations were made for each node: surface shape, frequency of granitic stones and cobbles, number of rounded basalt clasts, relative abundance of laminar petrocalcic fragments and vegetative cover. Vectors are used to indicate the magnitude and direction of gravel movement and represent a normalized center of mass. Ellipses with variable ratios of major to minor axes are used to depict gravel dispersion patterns.

In general, summits and shoulders have a significantly higher frequency of stones and cobbles at the surface compared to other landscape units. Summits and shoulders may exist as high points on the landscape because of the armoring effect of coarse fragments at the surface. Finer materials may be selectively removed from summits and shoulders and/or may bury coarse fragments at lower positions.

Vector lengths for all nodes averaged 19 cm (±15 cm). Individual gravels moved as far as 50 m downslope from one of the lower wash sites. No significant differences were found when vector lengths were compared between surface shapes (convex, flat, or concave). When vector lengths were compared between paired landscape units, only one pair was significantly different: summit gravels ($n=34$) moved an average of 24 cm while backslope gravels moved an average of 14 cm ($n=27$ sites). Vector lengths were significantly greater on Class 3 (no vegetative cover) sites when compared to either Class 2 (indirect cover) or Class 1 (direct cover) sites. Analyses of elliptical shapes are ongoing.

Preliminary findings concerning increase in size through time of the clupeiform teleost, *Xyne grex*.

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Xyne grex is probably the most common of the teleosts whose skeletons are found in Late Miocene marine rocks in central and southern California. Skeletons of this species are frequently found in monospecific mass mortality layers. We segregated nine mass mortality layers into two temporal groups, based on our understanding of the stratigraphy of the Modelo, Monterey, and Puente formations in which they occur. Some of the six localities within the younger group are assignable to the *Denticulopsis katayamae* diatom zone (late Mohnian). We do not yet have a definitive diatom zone assignment for any of the three localities of the putatively older group.

The largest individuals of *Xyne grex* are found in the geologically younger group. A t-test of the lengths of the first ten caudal vertebrae of 58 individuals from the younger group and of 36 individuals from the older group indicates a difference at the .001 level of significance.

We tentatively conclude that *Xyne grex* underwent a size increase during Late Miocene time. Additional identification of diatom floras from the rocks that produced these fossils are pending. This conclusion is therefore subject to revision.

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Evolution and biogeography of the orange-throated whiptail lizards (*Cnemidophorus hyperythrus*) in Baja California and the Gulf of California, México

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The *Cnemidophorus hyperythrus* group currently contains six subspecies: the peninsular *C. h. hyperythrus*, *C. h. espiritensis* from Islas Espíritu

Santo and Partida Sur, *C. h. franciscensis* from Isla San Francisco, *C. h. danheimae* from Isla San José, *C. h. pictus* from Isla Monserrate, and *C. h. caeruleus* from Isla Carmen. A phylogeny of this group results in a polytomy of four lineages. In one lineage, *C. h. hyperythrus* and *C. h. espiritensis* are sister species and on another lineage *C. h. pictus* and *C. h. caeruleus* are sister species. The remaining lineages of the polytomy are *C. h. danheimae* and *C. h. franciscensis*. The possession of the derived character state of an orange throat in *C. h. hyperythrus* and *C. h. espiritensis* indicates that the ancestors of *C. h. franciscensis, C. h. danheimae, C. h. pictus,* and *C. h. caeruleus* had blue throats and colonized the islands before the ancestor of *C. h. espiritensis* colonized Isla Espíritu Santo and Partida Sur. This also indicates that orange-throated whiptail lizards were originally blue-throated. Most of them still are. Thus, the common name is based on a recently derived, distributionally limited feature and is historically inaccurate. The diagnosability and allopatry of these taxa demonstrates that they are lineages and should all be accorded full species status.

Ecological correlates of protein polymorphisms in a desert and non-desert population of *Belonia saturata* (Odonata: Anisoptera)

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Two populations of *Belonia saturata* (Odonata: Anisoptera) were studied to determine the thoracic temperatures maintained during flight, the presence of polymorphic enzyme systems and to determine the differences in activity of Glycerol-3-phosphate dehydrogenase between a desert and non-desert population of *B. saturata*. Thoracic temperatures were measured in 57 desert and 26 non-desert individuals. The body temperature data suggest that the non-desert population maintains a significantly higher thoracic temperature than the desert population. Starch gel electrophoresis was used to determine the presence of polymorphisms in Glycerol-3-phosphate dehyrogenase (G3PD). G3PD was assayed at seven temperatures (30° - 60°C) to determine the relative activity of this enzyme in flight muscle tissue between both populations of *B. saturata*. The desert population maintained a higher initial activity (activity from 0 - 5 minutes) of G3PD at 40° - 60°C. The data reported here may suggest that the life history strategy of *B. saturata* may be to maintain elevated thoracic temperatures (>45°C) regardless of the environment they are inhabiting.

Is the geomorphic development of washes in the Death Valley region during historic time similar to alluvial valleys of the southern Colorado Plateau?

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In the semiarid southern Colorado Plateau, ephemeral and perennial streams with basin areas larger than about 10 km^2 have near-channel valleys that formed in the past 80-120 years. The geomorphology of these alluvial valleys is distinctive, consisting of an entrenched channel partly filled with sediment. Channel deepening from a higher floodplain level happened during the 1880s and early 1900s. Known as arroyo cutting, this entrenchment resulted from frequent large floods during a period of unusually heavy precipitation, although grazing may have exacerbated erosion locally. Channels began to fill in the late 1930s and early 1940s in response to somewhat drier conditions that reduced the frequency of large floods. Several washes in the Death Valley region have near-channel valleys that resemble and may have developed at about the same time as those of the Colorado Plateau. These washes show evidence of historic entrenchment and subsequent channel filling. Although tree-ring dating and most other dating methods are precluded by the lack of vegetation, truncation of early trails and roads at stream crossings shows that entrenchment post-dates the 1880s; "tin-can archeology" indicates that channel filling may have begun around the 1950s. This similarity in timing and of channel shape might have resulted from the same flood-related processes that caused arroyo cutting and channel filling on the Colorado Plateau. Additional studies are needed in the Death Valley region to verify these observations. Presently, archival ground-based photography, time-sequential aerial photography, journals of early desert travelers, and field studies are being used to determine the timing and extent of geomorphic change in the washes of the region.

Chasing the rat

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The oldest published occurrence of woodrats, *Neotoma (Paraneotoma.) minutus*, is from the latest Hemphillian Coffee Ranch fauna in Texas. However, the Crowder Formation in the Cajon Pass, San Bernardino County, California, has produced a tantalizing fauna of mid-Miocene age which also contains a *Paraneotoma*.

The purpose of this project was to sample stratigraphic superposed paleosols to locate additional *Paraneotoma* remains; to locate temporally diagnostic taxa; and to locate paleosols which contain restricted concentrations of heteromyids and cricetids.

Over the past two years, 14,650 pounds of matrix have been collected and washed. Calcareous paleosols were broken down using detergents and kerosene, then washed through 20 and 30-mesh stacked screen sets in motorized washing machines. Initial volume was reduced to 1.7% which necessitated the manual sorting of 250 pounds of concentrate.

Six paleosols were sampled. These consist of arkosic sand giving way to a brown, fining upward sequence of silts. They contain pedogenic carbonate that has been redeposited as kernels.

Certain taxa appear to be common to several paleosols while heteromyids and leporids are concentrated in Unit A, shrews are known only from Unit C. This may reflect procurement practices by owls and raptors, or it may reflect grassland or xeric conditions.

This additional work recovered teeth representing the complete dentition for *Paraneotoma*, except for M^2. The other taxa recovered, particularly *Parapliosaccomys, Copemys,* and *Cupidinimus* reinforce the previously assigned early Clarendonian age.

Internet Accessible Bio-informatics Databases for Desert Ecological Studies

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Computer accessible databases which influence ecology can be divided into two broad categories: (1) those which reflect conditions in the environment and the species present and (2) those which reflect human-based activity modifications to the environment.

(1) Specific types of databases which are available include

A. Short term weather
B. Long term climate
C. Seismic activity
D. Geology (including hydrology)
E. Habitats
F. Indigenous and introduced vegetation and their ranges
G. Parasites and infectious agents
H. Indigenous and introduced animals and their ranges
I. Species status (endangered, threatened, etc.)
J. Genomic and other molecular biology identifiers

(2) Current human based activities are more difficult data to obtain, particularly when economic activity (profits) are at stake. Some of the required data is posted by agencies such as the US EPA and state agencies of similar purpose. These databases include air pollution, ground and surface water pollution, ground and surface water diversion or loss, soil erosion, land fill, agricultural, and industrial use data. Much of the data, however, is not available; this particularly is true when adverse ecological effects would present limitations to short term profits or investment returns.

Specific Internet accessible sites will be examined, along with those sites which maintain indices of other sites. Data acquisition and search methods will be outlined. Suggestions for a greater availability, uniformity, and construction of environment databases important to understanding desert ecology and preserving the desert environment will be discussed.

Faunal differences and microhabitats east of Panaca, Nevada

Kyle Karnes and **Martyn Smith**, *Earth Science Volunteers*, and **Robert E. Reynolds**, *Curator, Earth Science Section, San Bernardino County Museum, Redlands, CA 92374*

Mio-Pliocene sandstone and siltstone east of Panaca contain a prolific small mammal assemblage with associated reptiles, birds, artiodactyls, and carnivores. Collecting since 1991 by the San Bernardino County Museum at two different localities has produced different ratios of rodents and lagomorphs which suggest varying microhabitats. The west facing site produces a greater number of lagomorphs to rodents while the south facing site produces the opposite. Though both sites contain many taxa in common, the south facing site produces more artiodactyls and the west facing site produces more carnivores. The differences in the two sites allow for a study of the two microhabitats.

This study is concerned with the west facing site. The most abundant taxa are lagomorphs with one genus the size of modern *Lepus*. The sediments have also yielded two species of *Repomys*. Low crowned cricetids are uncommon, but do occur at this site. Other taxa include *Ophiomys*, *Prodipodomys*, *Perognathus*, *Geomys*, *Bassariscus*, lizards, and raptors. This site is considered early Blancan Land Mammal age. The presence of *Ophiomys mcknighti* suggests an age of >4 m.y.

As part of this study, MNI percentages will be compared to determine mesic and xeric habitat and environmental differences between the two sites.

Characteristics of desert tortoise burrow locations at an industrial site in the southeastern San Bernardino Mountains

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The western limit of desert tortoise distribution in the northern Colorado Desert is found in the Whitewater Hills of the southeastern San Bernardino Mountains. The area is a transition zone for four major plant communities including cismontane, coastal, Mojavean and Sonoran elements. As such, the plant assemblage is a diverse admixture of species not often found in such close association, or in desert tortoise habitat, including chamise, condalia, juniper, California sagebrush, teddy-bear cholla, spiny hop-sage, mesquite and creosote bush. The steep topography of the area is also atypical of desert tortoise habitat throughout most of California. In addition to the natural features noted above, the area is distinguished by a major wind energy development (established in the 1980's) superimposed on a cattle grazing allotment operated under lease from the Bureau of Land Management.

Given that a relatively large number of tortoises occupy this unusual site, we were interested in characterizing the environment in which they located their burrows. Thirty-two burrows were located during searches of the site in 1995, most prior to the Verbenia Fire in August. Distances from the mouth of the burrow to various natural features and plant species were measured with a flexible tape. Burrow locations exhibited a mean slope of 16.5 degrees and ranged from 0-45 degrees. Mean elevation was 775 m with a range of 731-844 m. The modal aspect of burrow openings was southward with a significant remaining proportion facing westward. Several burrows were located in or near disturbed areas and artificial structures. One burrow, occupied by the same tortoise for three consecutive years, was located directly beneath a concrete pad supporting a transformer. Another burrow was located in a road cut. Distances from burrows to roads ranged from 0-101 m with a mean of 20 m. Distances to wind turbine pads ranged from 0-98 m with a mean of 28 m. As in other areas, burrows were often located under shrubs. Distances to creosote bushes ranged from 0-100 m with a mean of 18.4 m. Distances to four species of cactuses ranged from 0-73 m. Most burrows were relatively shallow (less than 1 m), but measurements of depth were not taken. Features of burrow habitat we observed were similar to those reported for other areas. Our data, based on a single site, challenge the paradigm of the desert tortoise as being extremely sensitive to human activities. However, continued monitoring will be required to verify the long-term persistence of tortoises exposed to these impacts.

Pleistocene distribution of the ground sloth *Nothrotheriops shastensis* (Xenarthra, Megalonychidae)

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Nothrotheriops remains have been identified from at least 55 localities distributed throughout the western and southern U.S. and Mexico. These occurrences range in age from middle Irvingtonian (about 1.9 Ma BP) to latest Rancholabrean (about 11 Ky BP). Most sites are late Pleistocene in age, and many occur in cave deposits. The Rancholabrean geographic range of *Nothrotheriops* appears to have shrunk in comparison to an earlier, wider Irvingtonian distribution (Akersten and McDonald, 1991).

Localities that yield *Nothrotheriops* remains occur as far north as 40°55'N latitude in northern California (Samwell Cave, Shasta County) and as far south as 18°30'N latitude in southern Mexico (Rancho de La Ollas, Michoacan). The elevation of localities ranges from 2250 m (San Josecito Cave, Nuevo León, Mexico) above mean sea level to near sea level in California and Florida. A bivariate plot of the latitude/elevation of localities yields a distribution with a definite limit relative to elevation. A similar pattern is found when *equatorial equivalent elevation* (ee) in meters (ee = elevation of the site + [107 x latitude of the site], see Harris, 1985) is plotted against latitude. Northern localities always occur at elevations lower than the southern localities, and the relationship is directly proportional to ee.

Given an apparently low basal metabolic rate for *Nothrotheriops shastensis* (Ho, 1967), McNab (1973) suggested that the lower temperature limit for *N. shastensis* was 20.5°C. Akersten and McDonald (1991) point out that climate and specifically minimum temperature may have been a significant limiting factor in the geographic distribution of *Nothrotheriops*. This site elevation analysis confirms their assertion.

The extinct vampire bat, *Desmodus stocki*, is associated with *Nothrotheriops shastensis* at four late Pleistocene localities: Potter Creek Cave, Shasta County, California; Rampart Cave, Mohave County, Arizona; U-Bar Cave, Hidalgo County, New Mexico; and San Josecito Cave, Nuevo León, northern Mexico. Modern *Desmodus rotundus* ranges through coastal northern and southern Mexico, and is temperature restricted to 10°C minimal winter isotherm (McNab, 1973). The association of *N. shastensis* and *D. stocki* in a number of faunas suggests a similar restriction for both species by the distribution of minimal winter temperatures.

Although the number of pre-Rancholabrean II sites is very limited (N=10), the distribution of all age sites through time relative to elevation exhibits an increased frequency of higher elevation localities with decreasing age. This apparent trend suggests that *Nothrotheriops* may have become more tolerant to cooler conditions, adapting (physiologically or behaviorally) to higher elevation environments throughout the Pleistocene.

Open sites that yield *Nothrotheriops* range in ee from about 2900 to 4900 m and the ee of cave sites that yield *Nothrotheriops* ranges from about 3800 to 5800 m, with an overlap in the ee distribution between 3800 and 4900 m. The observation that most low ee sites are open and most high ee sites are caves is not easily explained taphonomically, but may suggest that *Nothrotheriops* more frequently occupied caves at cooler, higher altitudes during later Pleistocene time.

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Results of recent archaeological surveys near Kramer Junction, San Bernardino County, California

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McKenna et al. has recently completed a series of archaeological surveys south of Kramer Junction, San Bernardino County, California. Investigations into previous research and a compilation of data from both the San Bernardino County Museum Archaeological Information Center and the Bureau of Land Management has provided McKenna et al. with the necessary data to argue that an area of "Critical Environmental Concern" exists within this area. McKenna et al. has found that the cultural remains identified to date reflect a spectrum of relatively early materials to relatively late items identified in the prehistoric record of the Mojave Desert - despite the limits of research conducted to date.

The shorelines of Death Valley

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New closed-circuit leveling measurements of the main shoreline features in Death Valley have led to several important discoveries about the paleolakes in the basin. The highest lake in Death Valley peaked just below 135.4 m, had a surface area approximately 1851 km^2, a volume of 245.9 km^3, and predates the Illinoian (OIS 6) lake. The Illinoian lake peaked at about 94.7 m on Shoreline Butte, had a surface area approximately 1606 km^2, and a volume of 176 km^3. The Late Wisconsinan (OIS 2) lake probably peaked about 5 m above sea level, had a surface area approximately 940 km^2, and a volume of 58 km^3. Closed-circuit leveling measurements of shoreline sequences at Mormon Point and Shoreline Butte permit two possible correlations. The conservative interpretation is that no significant vertical tectonic offsets have occurred between these sites since the Illinoian glaciation. The more speculative correlation of major shoreline features requires a relative lowering of Mormon Point by ≈26 m with respect to Shoreline Butte. Surveying across the valley floor revealed a basin-wide doming (≈1 m) of the salt flat in the vicinity of Mormon Point.

Unique features of envenomation by the Mojave green rattlesnake (*Crotalus scutulatus*).

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Envenomation by rattlesnakes found in the southern California ecosystems will be compared and contrasted. A slide presentation case report of a snakebite involving the Mojave green rattlesnake will be delivered. Other Crotalidae discussed will include: sidewinder (*Crotalus cerastes*); western diamondback rattlesnake (*Crotalus atrox*); red diamond rattlesnake (*Crotalus ruber*); speckled rattlesnake (*Crotalus mitchellii*); and southern Pacific rattlesnake (*Crotalus viridis helleri*).

A new arvicoline species (Mammalia: Rodentia) from the Pliocene Panaca Formation, southeast Nevada

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In the Basin and Range province of southern Nevada, the deposits after extension in the Meadow Valley are recognized as the Panaca Formation. In 1921, three large mammal species, including a horse, a rhino and a camel, were found from this area. Based on these fossils, the Panaca beds were considered to be Pliocene deposits, and this mammalian fauna was placed in the Hemphillian Land Mammal Age (middle Pliocene). In the early 1940s and 1960s, the American Museum of Natural History (AMNH) collected a large number of mammal fossils near the town of Panaca, including rodents, lagomorphs, carnivores, perissodactyls, artiodactyls and proboscideans. However, only some small mammals have been reported in literature. Based on the two arvicolid rodents in the AMNH collection, *Mimomys (Ophiomys) magilli* and *Pliopotamys meadensis*, the fauna has been considered middle Blancan land mammal age (late Pliocene).

Since 1993, the Laboratory of Paleontology at the Department of Geosciences, University of Arizona, has collected sediments from Panaca. The screen washing technique recovered abundant small mammal fossils from several sites, most of which are arvicoline rodents. Since arvicoline rodents have a number of evolutionary trends in their dental morphology, they have proven to be an important source for Tertiary biochronologic study. The arvicoline rodents from one site to the northeast of Panaca present a number of primitive characters. The molars are hypsodont, but have roots and lack cementum in their reentrant angles. The first lower molar has three alternating triangles and a very low dentine tract on the labial side, with an enamel islet present on the anteroconid complex of most slightly or moderately worn specimens. Nearly 50% of the last upper molars retain three roots. An enamel islet occasionally exists on the anterior or posterior lobe of the last upper molar. This population is recognized as a new species of *Mimomys (Cosomys)*, ancestral to *M. (C.) primus* from the middle Blancan Hagerman local fauna in Idaho. This new species is placed in the early Blancan. Compared to the other two early Blancan *Mimomys* species, it is differenciated from *M. (Ophiomys) mcknighti* in having the last upper molars with an enamel islet and/or three roots, and from M. *(Ogmodontomys) sawrockensis* in smaller size, the occlusal outline of the first lower molar, and the presence to two-rooted last upper molars.

The arvicoline rodents from the Panaca area strongly suggest that there is probably a sequence of sites in this area, spanning Hemphillian and Blancan land mammal ages. The fossil samples from other sites are under study. Further work will try to recover biostratigraphic and geochronologic data in this area, hoping to obtain resolutions of the early *Mimomys* history in North America and on the Hemphillian-Blancan Land Mammal Age boundary.

A review of procyonids (Carnivora, Procyonidae) from the Blancan and Irvingtonian Vallecito Creek local fauna of Anza-Borrego Desert State Park, California

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The fossil procyonids from Anza-Borrego Desert State Park (ABDSP) have been mentioned by several authors in publications over the past 30 years (Downs and White, 1968; Kurtén and Anderson, 1980; Anderson, 1984). Although these materials have never been described or identified by catalog number, they do indeed exist. *Bassariscus* (cacomistle or ringtail), *Nasua* (coati), and *Procyon* (raccoon) are each represented by two specimens. All ABDSP specimens were recovered from the upper part of the informal Huesos member (Cassiliano, 1994) of the Palm Spring Formation and are assigned to the Vallecito Creek Local Fauna. This portion of the stratigraphic section falls within the early to mid-Matuyama chron and is about 2.5 to 1.6 ma BP.

Anza-Borrego ringtail material includes an edentulous right dentary with C_1 of *Bassariscus casei* Hibbard (1941) (ABDSP 42/V175) and dentary fragments identified to *Bassariscus?* (LACM 1506/6757). The identification of ABDSP V175 was made by E. Anderson (pers, comm., 1978).

Although the occurrence of *Nasua* in ABDSP recently appeared in the literature (Cassiliano, 1994; Remeika and others, 1995), the original source of this identification can not be confirmed, and the taxon was not reported from ABDSP by Kurtén and Anderson (1980). A partial mandible with incomplete dentition (ABDSP 90/V356) and an edentulous left dentary and associated right distal humerus (ABDSP 101/V5509) are here referred to *Nasua* sp. These specimens compare favorably with modern *N. narica*.

Raccoons are represented by a partial right dentary with fragmentary and well worn P_4 to M_2 (ABDSP 161/V634) identified as *Procyon* sp. cf. *P. rexroadensis* Hibbard (1952), plus a distal tibia identified to *Procyon?* (LACM 1766/20608). ABDSP V634 is robust and slightly larger than available comparative specimens of *P. lotor*.

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Huge dinosaurs from Argentina

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The public learned of great discoveries in Argentina in 1995. The largest sauropod, *Argentinosaurus*, and the largest carnivorous dinosaur, *Gigantosaurus*, were made know. The specimens are housed in the tiny Museum Carmen Funes in Plaza Huincal, Neuquen Province. We went to Plaza Huincal and made casts of the skull parts. We are assembling the skulls and sculpting the missing parts.

Arid land degradation processes and monitoring in the Mojave: a progress report

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Humans populate all but the harshest areas of the globe and our activities inevitably have an impact on the environment. Arid regions are no exception and, although they are widely thought to be areas of low economic productivity, deserts areas serve as livestock rangeland and agricultural land. Desert areas are more vulnerable to land degradation than their wetter counterparts, and land degradation is prevalent where arid lands have been used in these ways.

Significant land degradation has been reported in the Manix Basin of the Mojave Desert, 30 miles east of Barstow, California (Ray, Terrill W., Remote Monitoring of Land Degradation in Arid/Semiarid Regions, Ph.D. Thesis, CalTech, 1995). Here, circular fields abandoned in the seventies and eighties show differences in plant distribution from the surrounding undisturbed desert. Most striking is the relative absence of creosote bush (*Larrea tridentata*) and the abundance of white bursage (*Atriplex polycarpa*). We have also observed significant sand mobilization off of the abandoned fields into the surrounding desert in the direction of the prevailing west winds.

These observations point to three interesting directions of field-based research which are being pursued by the Arid Region Land Use and Change Group at CalTech. First, we are attempting to determine the important variables in the biological succession of the abandoned circular fields. Second, we are attempting to model wind flow and sand mobilization over the fields. Third, we would like to couple these models to determine the feedback relationships between the biological succession and wind effects.

Finally, in an effort to provide inexpensive, fast, and accurate land change analysis, we are developing methods to monitor long-term change in this area through the use of satellite remote sensing data.

Restoration of the Foxtrot petroglyph site

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The Foxtrot petroglyph site, located at the Marine Corps Air Ground Combat Center near Twentynine Palms, has been adversely affected by visitors since the early 1900s, when carved names first began to appear at the base of a lava flow where over 490 rock art panels are located.

Over the years, more people have added their names, slogans and drawings, some of them over the rock art. The site is located in a wash, along an historic trail and now frequently-used unpaved military "main supply route." This paper will describe ongoing efforts to preserve the site by removal and re-integration of graffiti, repositioning of signage, and regular site-monitoring.

Seeds and seed-eaters in the eastern Mojave desert.

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The availability of critical resources, such as food, molds many ecological processes. Yet we know relatively little about the availability of resources to consumers in nature, even for well-studied systems such as the granivorous animals of North American deserts. What we think we know about seed resources in deserts is based primarily on the abundance of seeds extracted from samples of the soil, or the "standing crop." Many desert plants produce seeds that can lie dormant for many years in the soil, patiently awaiting the next year of good rains. This "seed bank" may, however, provide a distorted view of what is actually available to seed-eaters if animals rely on newly-produced seeds that are harvested and stored before they enter the soil seed bank. We compared characteristics of seeds in the soil with those of newly-produced seeds by simultaneously monitoring standing crop and seed production over a two-year period in the eastern Mojave desert. Standing crop averaged 110,000 seeds/m^2 and 40 g/m^2, much higher than values reported for other North American desert sites. Large seeds comprised a greater fraction of production than standing crop, suggesting that such seeds are differentially depleted by granivores before they enter the soil seed bank. Because seed production was seasonal, temporal variation comprised a significant component of among-sample variance in seed production, but was smaller in the standing crop, presumably because granivores harvested most of the production. On the other hand, spatial variance was a significant component for standing crop, but not production, perhaps as a result of spatial patterns of seed harvest or seed caching by granivores. By virtue of these differences in variance patterns as well as other attributes, seeds in the standing crop present different challenges to granivores than newly-produced seeds. For example, if granivores depend primarily on new production, then a premium is placed on the ability to harvest seeds rapidly and store them securely for use during periodic lean times, rather than on the ability to locate and extract a temporally stable but patchily distributed resource. Our understanding of desert granivore foraging and community ecology, and of granivore seed interactions, thus depends critically on choosing the appropriate measure of seed availability to granivores.

Late-Cenozoic deformation history of the Chuckwalla Valley and Pinto Basin — a geologic test of competing tectonic models of the Eastern Transverse Ranges, Southern California

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Models of the late-Cenozoic tectonic history of the Eastern Transverse Ranges, Southern California, differ as to the geometry and timing of crustal block rotation and about the nature of any subsequent tectonism (Carter and others, 1987; Dickinson, 1994; Dokka, 1992; Dokka and Travis, 1990; Jagiello, 1991; Matti, 1993; Powell, 1993; Richard, 1993). It is important to understand the tectonic evolution of the Eastern Transverse Ranges because of its relationship to the geology of the western North American plate boundary (Dokka and Travis, 1990) and to seismic activity on the adjacent San Andreas Fault (e.g., Harris, 1992; Sieh, Jones, and others, 1993). Dissertation work in progress is aimed at testing these models using geomorphic and structural mapping. Data gathering focuses on the style and timing of deformation over the past 10 m.y. in a kinematically key region: the Chuckwalla Valley and Pinto Basin. Recent field work has revealed new evidence of late-Cenozoic deformation.

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Ecology of mesquite patch gardens

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Anthropologists focusing on progressive evolutionary models of social development have been accused of winnowing variability out of history. Attempts to generate comprehensible models of the development of social complexity fail to consider the unique challenges faced by people living in extremely variable environments such as the Mojave desert. However, it is the contention of this paper that unpredictable fluctuations in environmental conditions may generate variations in methods of subsistence rather than intensified agricultural efforts. The examination of one agricultural modification — the planting of cultigens in association with *Prosopis glandulosa* Torr. var. *torreyana* — is intended to demonstrate that Cahuilla and potentially Chemehuevi, agriculture was not necessarily a "less evolved" form of the Colorado River agricultural complex, but a highly adaptive response to uncertain environmental conditions. The feasibility of growing crops in association with *Prosopis glandulosa* Torr. var. *torreyana* is being tested by using *Phaseolus acutifolius* var. *latifolius* in trial plantings amidst *P. g. torreyana* during spring and summer, 1996 and 1997. Measurements of reduced temperatures, light penetration, soil water content and available nitrogen under *P. g. torreyana* are being determined for correlation with productivity of *P. a. latifolius*.

The Systematics of the colubrid genus *Chilomeniscus* (Serpentes: Colubridae)

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The colubrid genus *Chilomeniscus*, as currently constituted, consists of four species (*Chilomeniscus cinctus, C. punctatissimus, C. savagei*, and *C. stramenius*) and is distributed across the Baja California Peninsula, several islands associated with it, as well as throughout southern Arizona, Sonora, and northern Sinaloa. Banta and Leviton (1963) were the last to review the taxonomy of this genus based upon an analysis of 185 specimens. They considered the dorsal banding pattern of *C. cinctus, C. punctatissimus*, and *C. savagei* as a diagnostic character that separated these from the bandless *C. stramenius*. I have undertaken a reanalysis of their characters and based on preliminary data, it is hypothesized here that the banded and unbanded dorsal patterns are the character states of a polymorphic character shared by one species. This is based upon the lack of discrete characters to differentiate between these species as well as on the presence of clear intermediate forms for the dorsal pattern banding and coloration. No taxonomic changes are yet proposed due to the need for further study.

San Bernardino County Museum Association
Information for Authors

The San Bernardino County Museum Association publishes articles and monographs on subjects pertaining to the cultural and natural history of San Bernardino County and surrounding regions. We welcome submissions of such manuscripts.

Subject Matter: articles and monographs pertaining to San Bernardino County, inland Southern California, and surrounding regions, in history, anthropology, archaeology, paleontology, mineralogy, zoology, botany, ornithology, and related disciplines. Manuscripts considered for *Quarterly* publication should be written toward the well-educated non-specialist. Technical research will also be considered for publication. All manuscripts should reflect original work which furthers knowledge in their fields.

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