Get your kicks!

Trails Across the Mojave

David M. Miller & Stephen M. Rowland, editors

2024 Desert Symposium Field Guide and Proceedings

April 2024

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We greatly appreciate the support given to the Desert Symposium by the Leighton Group.

We also thank the Bureau of Land Management, National Park Service, and Desert Studies Center for their assistance with this year's meeting and field trip.


The 1994 MDQRC field trip, "Off Limits in the Mojave Desert." Photographs by Greg Stewart (left) and Robert E. Reynolds

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Captions

***Front cover**: near Danby Dry Lake, 1972. Bob Reynolds photo.*

***Title page**: Soda Lake during the 2014 Desert Symposium.*

The Desert Symposium is a gathering of scientists and lay people interested in the natural and cultural history of arid lands. The meeting comprises scientific presentations followed by a field trip. The Desert Symposium and its field trip take place annually, usually in April. The Desert Symposium publishes a volume of papers and a field trip road log. Safety, courtesy, desert awareness, and self-reliance are expected of all participants.

A color version of this and past volumes may be viewed at www.desertsymposium.org/pages/publications

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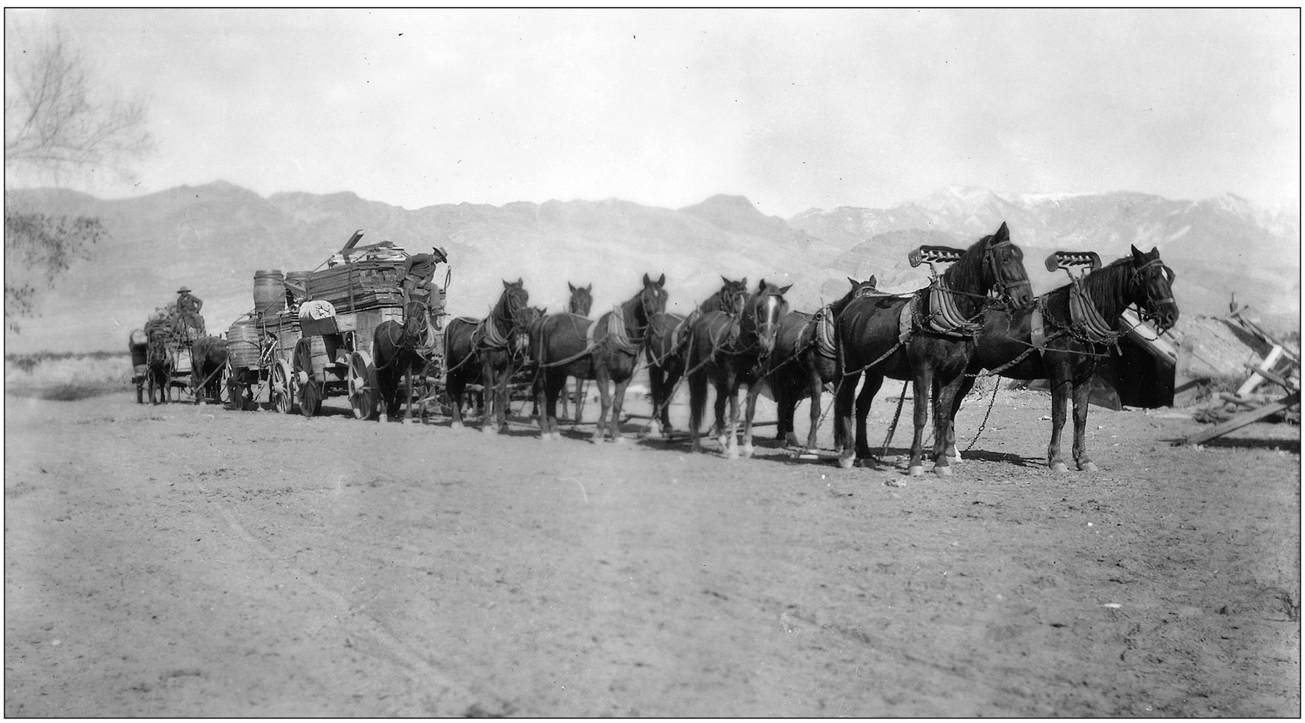
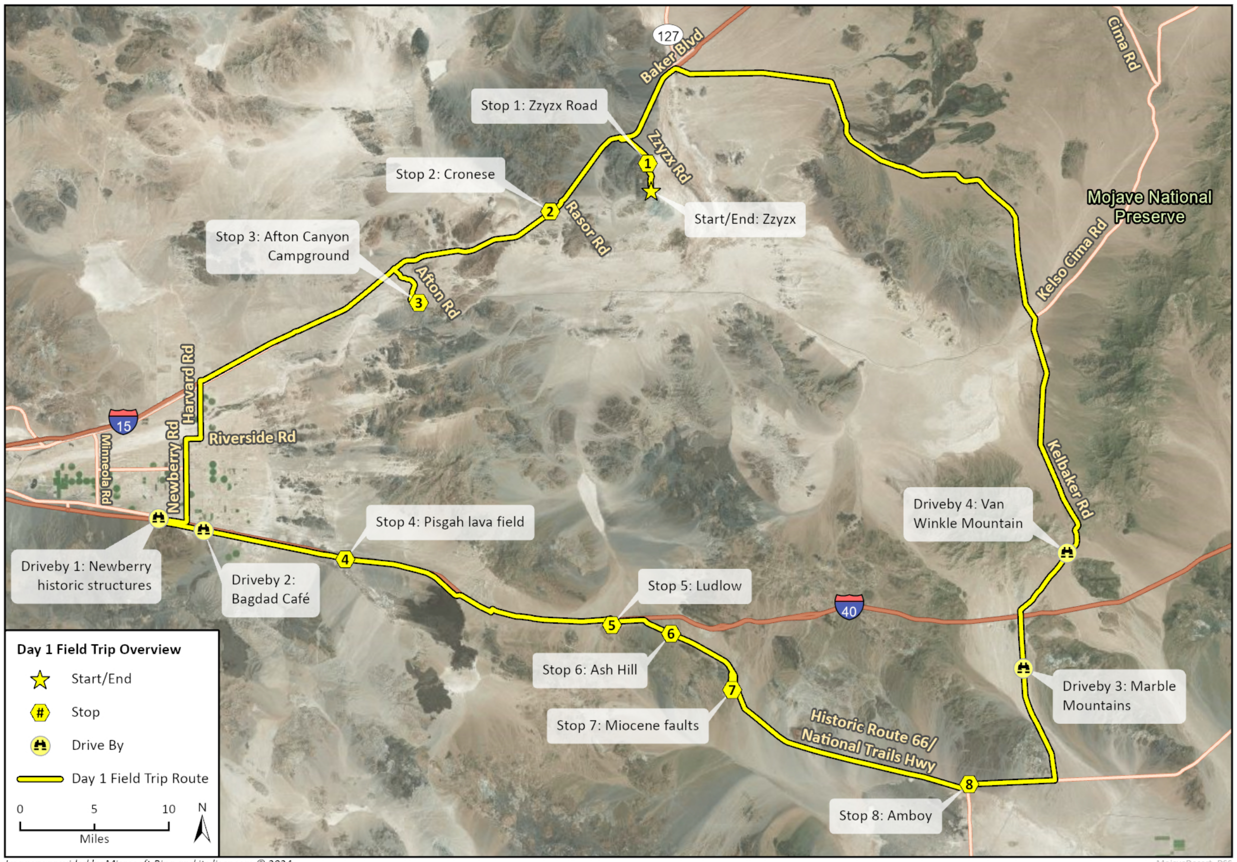


A ten-horse hitch and a loaded freight wagon. Reynolds collection.



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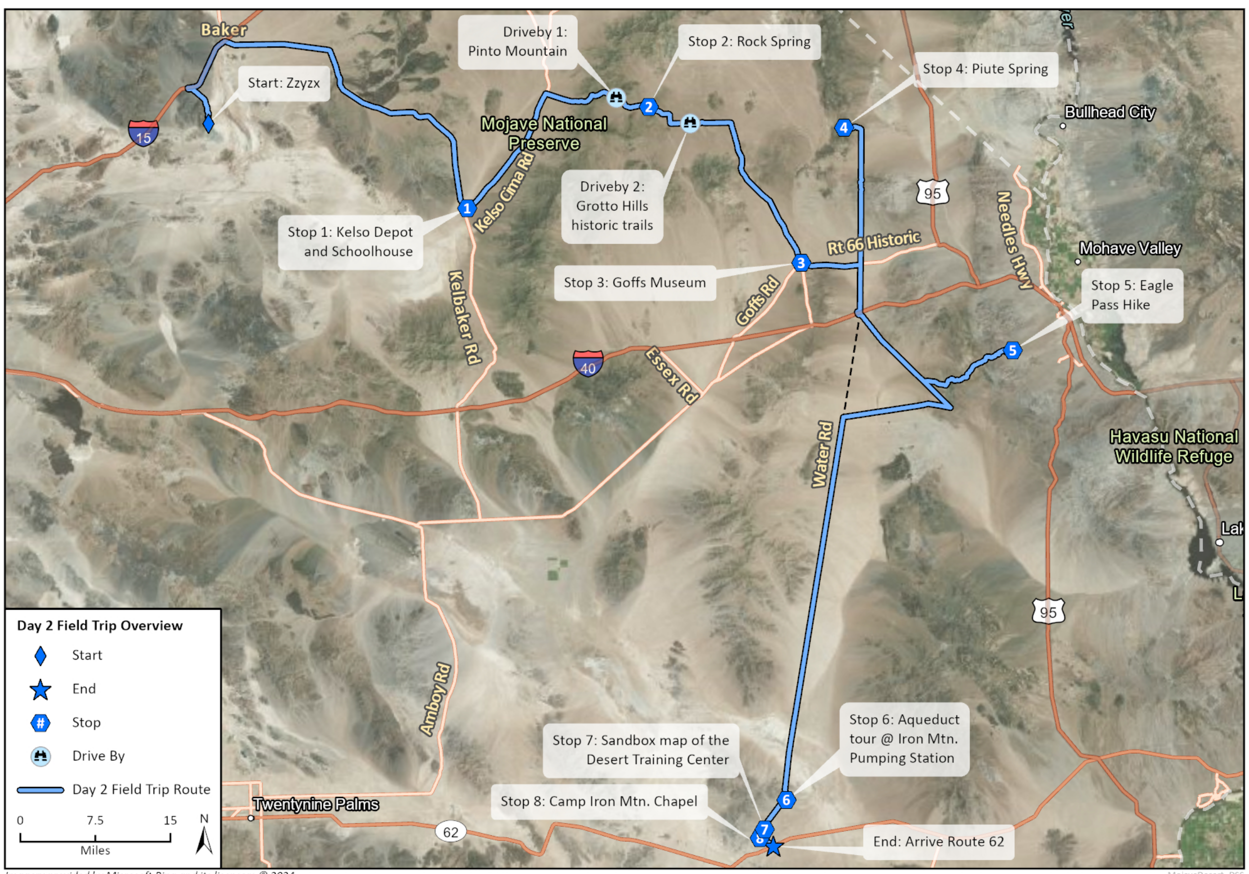
MojaveDesert_DSS Day 1 Overview



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MojaveDesert_DSS Day 2 Overview

Get your kicks: Trails across the Mojave

The 2024 Desert Symposium field trip road log

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The Mojave Desert has served for millennia as home for animals that make and use trails, including humans. As humans increasingly populated the margins of the desert, they had a need to cross the desert for trade and for access to resources. It was the large populations in these nearby areas that brought advancing technology to the task of building trails, and eventually developed means to largely avoid arduous desert travel. Today most travel across the desert is by airplane, train, and vehicle; these transient visitors tend to miss the features of the desert that its wildlife and early human inhabitants were drawn to and with which they interacted.

We plan to introduce trails from a few millennia old to the modern on this field trip. Each trail has its story thread that, if woven well, forms part of a tapestry that illustrates life in the Mojave Desert. Participants on the trip are encouraged to contribute to the tapestry with their knowledge and their own history.

Day 1, Sunday, April 13

Convene at the Desert Studies Center. Make sure vehicles are packed with personal gear and each has a full tank of gas. Check your spare tires. Carry water and snacks, plan your clothing for the conditions. Wear sturdy shoes. Bring hats and sunscreen. Watch for harmful plants and animals. Note that some stops are on private property and others are on Federal lands managed by the Bureau of Land Management and National Park Service. Respect the land and leave it as you found it: no rock or artifact collecting, digging, or harming of plants and wildlife is allowed. Part of this day's route is within the Mojave National Preserve where special use permits are required for field trips with more than a limited number of vehicles or visitors.

Carpooling is mandatory today. Make carpool arrangements at the symposium on Friday or Saturday. We will return to Zzyzx Sunday night.

Today we will examine several kinds of trails, historic buildings, and the history and prehistory of the area west and south of Zzyzx. We hope to create a knowledge and appreciation of travel in the Mojave, whether by foot, horseback, wagon, vehicle, or train. Common themes include the need for water supplies, avoiding difficult terrain, and circumventing water bodies, as well as the continued decay of unused trails and the establishments they once connected.

Acknowledgments

Several people have been tremendously helpful in constructing this road log. David Nichols (NPS) suggested stops and provided material for them, including intricately detailed reports. David Buesch (USGS) contributed text and images for stops and drive-bys. Tracy Popiel created maps and a site to which participants can upload photos while on the trip. Gregg Wilkerson and Larry Vredenburgh contributed historic photographs. Several authors in this volume unknowingly contributed by writing about topics pertinent to the road log. Last but not least, Jenny Reynolds contributed several historic photographs along with her encyclopedic knowledge of this part of the desert.

Introduction

The 2024 Desert Symposium field trip on Day 1 will drive west from Zzyzx to stops for archeology, history, and prehistoric trails at Zzyzx, Cronese Lake, and Afton Canyon. It then will proceed south to historic U.S. Route 66, one of the arterial highways from Santa Monica, California, to Chicago, Illinois. We will proceed east on Route 66, passing historic buildings and enjoying stops to view challenging road-building terrane, towns, and geology along the route. We will finish the trip by crossing the Mojave National Preserve and back to Zzyzx.

Depart Zzyzx

MILEAGE

INCREMENTAL CUMULATIVE

0 0 Depart Zzyzx, located at Soda Spring, an important water source for travelers on the Mojave Road and earlier.

The Tonopah and Tidewater Railroad passed through here, with the railbed still visible where it crosses the Soda Lake playa north of Zzyzx. A reliable water supply was necessary for historic travelers (Haenszel, 2024) as well as Doc Springer (Vredenburgh, 2023), not to mention wildlife such as desert bighorn and aquatic species. The Soda Springs Rockshelter yielded corn cobs at the Desert Studies Center in 1987, possibly indicating that agriculture was practiced near the spring; a cob was dated at approximately AD (CE) 500–1200 (Joesink-Mandeville, 1988).

The area of Soda Lake was inundated by Pleistocene Lake Mojave until about 10 ka (thousand years ago) (Campbell and others, 1937; Wells and others, 2003; Warren and Schneider 2003; Honke and others, 2019). Evidence for human occupations along the margin of Soda Lake exist south of Zzyzx, where they have been defined (Ore and Warren, 1971; Knell, 2016): 1) the Lake Mojave period from 8 to 12 ka on the basis of distinctive stemmed points; and 2) the Archaic period from 8 to 1.5 ka. Native Americans knew the trails and camp spots of this area when Spanish explorers arrived in the 1770s, so it is safe to say that at least occasional occupations continued after 1.5 ka. When Father Garcés was led from the Colorado River and across the desert by Mohave guides in 1776, he traveled south of Soda Lake to Afton Canyon.

2.1 2.1 Arrive at Stop 1.

STOP 1. Historic inscriptions
UTM 11S 581105 | 3892271

We will examine a few very early historic inscriptions written in wagon wheel grease on rocks along Zzyzx Road (Figure 1). These were created by wagon bosses (one inscription actually reads "wagon boss") in 1859: one is so dated. The wagon bosses evidently had to circumvent north around the wet or flooded playa at times when the Mojave Road was not usable.

Continue north to I-15.

2.8 4.9 Enter Interstate 15. Turn left, entering southbound lanes.

5.0 9.9 As we approach the Rasor Road exit area note the change from broad piedmonts to hilly topography. Low hills in this area are underlain by Miocene volcanic rocks ranging from rhyolite to dacite. Part of the volcanic field is perched high on the Soda Mountains to the north. The field is virtually unstudied. Dune sand sourced from Lake Manix and the Cronese Lakes mantle most rock south of Rasor Road, making it an off-road bonanza.

0.8 10.7 **Exit** I-15 at Rasor Road (exit 233) and proceed north to the paved frontage road; turn left and drive west on BLM road CL8834.

0.6 11.5 Pass outcrops of Miocene dacite. Continue to a viewpoint overlooking East Cronese Lake and Cave Mountain where the frontage road meets a pipeline road. Take care when turning around; it is sandy and soft here!

1.0 12.5 Arrive at Stop 2.

STOP 2. Cronese Lake and the Mojave River: travelers over the past 9000 years
UTM 569703 | 3887245

We have a good view to the southwest of East Cronese Lake and flanking Cave Mountain on the south (Figure 2) and an unnamed 'north cave mountain' on the north. The latter is decorated with a falling sand dune named Cat Dune. Stretching north from East Cronese Lake is a broad valley that leads upslope to Bitter Spring (an important stopover on the Old Spanish Trail) to the right of a dark low hill affectionately termed The Whale by Army personnel, and a large drainage basin that is largely within Fort Irwin. To the north are the western Soda Mountains, capped in some places by flat-lying volcanic rocks. Leading to the playa from the south is one main channel of the Mojave River, where it cuts through Cave Mountain at the Basin exit of I-15. Red rocks west of that exit are conglomerate and volcanic rock that lies on rock avalanche deposits sourced by mountains with rocks similar to those of modern Cave Mountain. Other Mojave River channels splay out across a broad distributary fan

Figure 1. Photographs of historic inscriptions along Zzyzx Road, 2024. D.M. Miller photos.

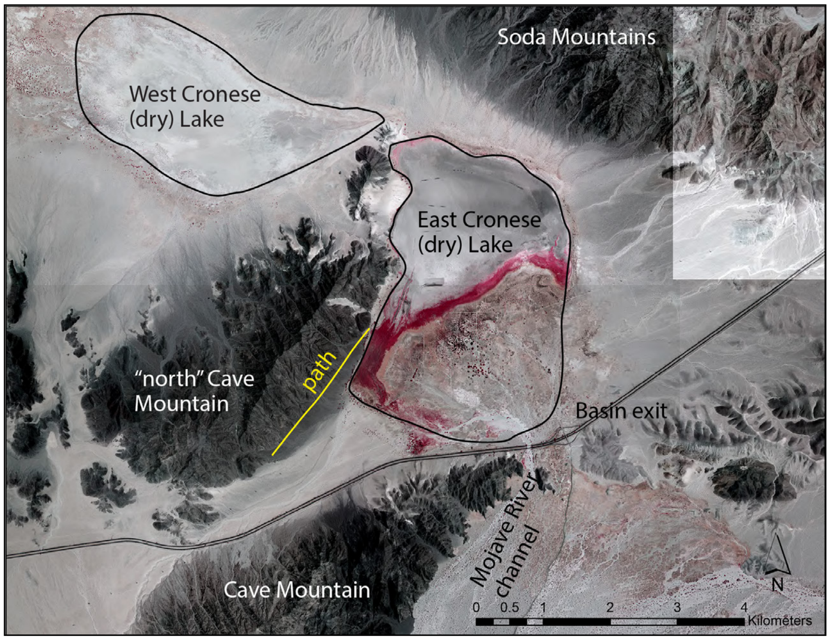


Figure 2. Map of the Cronese Lake area showing main physiographic features and recently discovered human pathway.

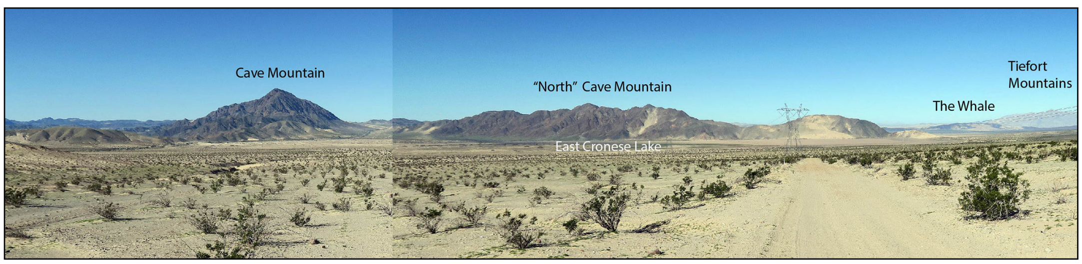


Figure 3. Panoramic photographs of Cronese Lake area, 2024. D.M. Miller photo.

from the mouth of Afton Canyon and lead to Soda Lake. East Cronese Lake thus is at the confluence of several drainage systems and has a record of persistent lakes in the late Pleistocene (Wells and others, 1989; Enzel and others, 1989).

Shallow lakes result from Mojave River flow during modern floods and abundant evidence for prehistoric persistent lakes exist. The evidence is chiefly in the form of sand beaches, lagoons, and aquatic pelecypods in growth position within these deposits. Two periods of persistent late Holocene lakes are recognized (Figure 4) by AMS radiocarbon dating (Miller and others, 2010): the Little Ice Age (~AD 1650) and an interval late in the Medieval Warm Period (~AD 1290). The aquatic fauna require lake durations of decades (Enzel and others, 1989). These dates are more precise than previous dates on shells, but entirely consistent with the previous archeological and geologic interpretations, described below.

Humans apparently interacted with these lakes. Malcolm J. Rogers, pioneer archaeologist of the desert west, was the first to report the archaeology of the Cronese area in 1939. Shell mounds and charcoal hearths are associated with the LIA shorelines, as are burials and artifacts of many kinds. Early Puebloans (formerly termed the Anasazi) evidently travelled across or past East Cronese Lake, based on trade items (such as turquoise from nearby mountain mines and in the Pueblo region of New Mexico as well as shell beads from the Pacific Ocean) found at both Cronese and further east beyond the Colorado River.

A study of the mussel *Anodonta* at East Cronese Lake by Schneider (1994) analyzed the largest intact shells in middens. The large shells indicate that the animals were fully grown and were in place a minimum of 12 years after their 2-year larval stage during which they were parasitic on fish. This evidence convincingly points to extended periods of fresh oxygenated water. Presence of fossil pelican and fish-eating duck also suggest that fish were present. Sedge, cattail, and pond turtle fossils also indicate aquatic habitat. Dates on the mussel shells ranged from ~1200 to ~560 and less than 150 years, possibly modern (Drover, 1979). Today, we see tremendous hatches of fairy shrimp when the lake fills. There is good evidence that these invertebrates were also sought-after food for humans and waterfowl (Schneider and others, 2017; Henrickson and others, 1998).

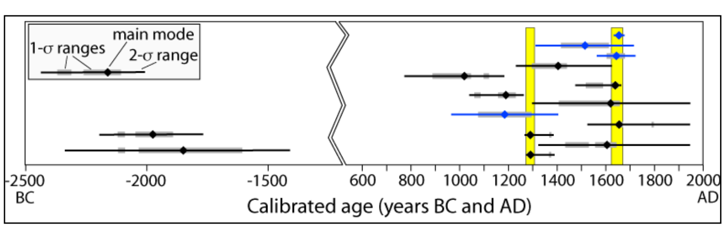


Figure. 4. Plot of luminescence and AMS radiocarbon dates in several sites of the Mojave Desert, including lake settings in three places that are highlighted by the two yellow bars (Miller and others, 2010).

Although trails to and from East Cronese Lake are not mapped because of the influence of eolian sand in the area, a newly discovered trail is present along the base of the unnamed mountain (Figure 2). This trail is nearly level, traverses the upper parts of short alluvial fans near the rock outcrop of the mountain, and is well preserved except for short stretches where the most recent streamflow has obliterated it. The path is built on an undated Holocene fan that is similar in surface characteristics and soil development to fans dated elsewhere as ~6 to 3 ka. Why would travelers take that route when a course straight down the Mojave River channel, through Afton Canyon, and on to points east was shorter and had plenty of water? The answer probably is that for extended periods, perhaps seasonal to decades in length, the Mojave River flooded significantly and made travel down narrow Afton Canyon perilous. Since a channel of the Mojave River leads to East Cronese Lake, all routes between Afton Canyon and the playa were also blocked. The alternative was to travel north of the terminal lake of the Mojave River. The trail also could have led directly to resources of East Cronese Lake. It would be fascinating to date this trail and compare the timing to that of artifacts around the shores of East Cronese Lake.

We should also take a moment to appreciate the steep, linear northern front of Cave Mountain, which is caused by the active Cave Mountain fault. Debris flow fans along that front have boulders as big as small busses!

1.6 14.1 Return to the I-15 freeway and proceed southwest.

4.1 18.2 Cross a Mojave River channel a short distance west of the Basin Exit.

8.3 26.6 **Exit** at Afton (Exit 221). Turn left across the freeway and stop along the straight, level barrier beach of Lake Manix. Continue south on Afton Canyon Road when our caravan is complete. Lake Manix filled episodically in a terminal basin of the Mojave River from ~500 ka to 25 ka (Meek, 1989, 2000, 2004; Jefferson, 2003; Reheis and others, 2008, 2012, 2015). This eastern subbasin was dry during most of that time; it was connected to Lake Manix only after the big western subbasins were filled with much sediment, reducing storage space for water, and causing overflow near Buwalda Ridge into this easternmost subbasin.

2.7 29.2 Steep grade through well-cemented alluvial fan gravels with numerous soil horizons. The brown conglomerate of Meek (1990), later termed the fanglomerate of Cave Mountain by Reheis and others (2014), is exposed in walls of the canyon as we descend. This gravel interfingers to the northeast with sandstone that contains two ash beds, neither of which have firm correlations to dated eruptions.

1.0 30.2 Arrive at Stop 3.

STOP 3. Afton campground. Archeology of Afton Canyon

UTM 556305 | 3877458

Park in the wide area before camping spots and prepare to cross the tiny stream named the Mojave River. Crossing is not to be attempted during flood conditions, however! Afton Canyon was the route of Spanish explorers and the later Mojave Road, and a fort was established near here for a short period in the 1850s. The railroad connecting southern California to Salt Lake City was begun in 1903, and in 1904 work on a tunnel at a bend in Afton Canyon was underway. The completed San Pedro, Los Angeles, and Salt Lake Railroad started sending trains through Afton Canyon in 1905 (Krieg, 1994).

Archeology of Afton Canyon mostly represents occupation after AD 500 (Roth and others, 2020). Ceramic wares, projectile points, and groundstone are present as well as numerous lithic scatters (Schneider, 1989). In the area we will walk to, ceramic sherds, projectile points, and faunal remains of big horn sheep and desert tortoise as well as hares and cottontail rabbits were found. Mesquite pods and seeds were also present at this residential site. Apparently, quarrying of local red, yellow, and brown jasper and rhyolite exposed along the Manix Fault within the Cady Mountains was a principal activity at the site, as well as butchering big horn sheep. Hilltop structures along the south rim of the canyon consist of one to three tiers of rocks stacked in eleven circles. These features overlook drainages and possibly were used as hunting blinds. Each of the features could be seen from the others, thus archeological researchers think communication regarding the whereabouts of bighorn sheep herds facilitated success in the hunt (Roth and others, 2020).

Farther upstream near Oro Grande, Rector (1979) reported on human footprints in the Mojave River sediment. Human footprints and an animal trackway in a silty clay layer are preserved. A single radiocarbon date for the trackway places it at about 5.6 to 6.1 ka. A series of radiocarbon dates place an overlying layer at 0.6 to 1.1 ka (Rector and others, 1983).

3.7 33.9 Return to I-15 and enter southbound.

7.8 41.7 At Field Exit (213), we are crossing an active fold that deforms Pliocene and Quaternary sedimentary units.

2.8 44.5 We are passing through the 500 to 25 ka Manix Formation beds of lacustrine and fluvial deltaic deposits (Jefferson, 2003; Reheis and Redwine, 2008; Reheis and others, 2012, 2014, 2015). Alvord Mountain lies to the north. Travelers on the Old Spanish Trail left Bitter Spring some 35 miles distant to the northeast, climbed the gentle slope up Alvord Mountain, and descended from the crest down Spanish Canyon to join the Mojave Road along the Mojave River about 7 miles west of here. At one time a ranch below the foothills of Alvord Mountain provided help to travelers in need of assistance (Beattie, 1958), and a canyon west of Spanish Canyon held the Alvord mining camp. The Alvord spring was a boon to later travelers on the Spanish Trail (Figure 5).

Rocks in Alvord Mountain are Miocene in age on the east (right) and Mesozoic granitic rocks that intrude Paleozoic strata to the west (Byers, 1960).

4.3 48.7 **Exit** Harvard Road (Exit 206). Turn south on Harvard Road. The Old Spanish Trail crossed the valley a few miles to the northwest.

Figure 5. Alvord well, viewed east to south, 1967. R.E. Reynolds photo.

0.4 49.1 **Stop** at US 40 crossing and nearby railroad crossing. Proceed south on Harvard Road. We are driving across the flat fluvial plain of the Mojave River, constructed before the river headwardly eroded across this plain to create the modern entrenched channel. Harvard Hill is on your right, a location of Barstow Formation beds associated with the 18.8 Ma Peach Spring Tuff (Leslie and others, 2010; Miller and others, 2010).

1.7 50.8 At the bluff overlooking the Mojave River channel are two historical plaques that describe Camp Cady and the Mojave Road. Consult Haenszel (2024) as well. Cornerstones for the fort at Camp Cady can be examined.

1.9 52.7 Cross the (usually) dry bed of the Mojave River. More sand moves here during the frequent windstorms than in the infrequent floods. Both are unpleasant and worth avoiding! Examples of homes built near this channel and now buried by dunes can be found a short distance upstream.

1.0 53.7 **Turn right** (west) on Riverside Road.

Historic Camp Cady lies ~ 1 mile downstream, an area in the riverbed with perennial water and the site of military camps and homesteads. The first historic explorers to visit this site were Spanish: Father Garcés noted on March 11, 1776, that the site had a stretch of timber about 6 miles long (Carder, 1994; Haenszel, 2024). Later came Jedediah Smith, whose group travelled the Mojave River west from Soda Spring in 1826 and 1828 (Walker, 1971).

Figure 6. Sand dunes on Harvard Road in the Mojave River channel, May 2013. R.E. Reynolds photo.

Next came the Mojave Road (Government Trail) and after travel on the trails increased with discovery of gold in the Sierra Nevada in 1849, a fort was established to provide security from Native American raids on travelers (Waitman, 1994). Camp Cady was established in April 1860 and named after Albemarle Cady, commander of the Army Post at Fort Yuma (Ruckstahl, 1994). The camp consisted of a fort and partially underground adobe huts. It was abandoned and reestablished three times as treaties were signed and violated. The last establishment of the camp in 1868 was at a site one-half mile west of the original, from which they hauled water because water quality was poor at the new site. The camp was sold to private owners in 1871.

Accounts of ranch life at the Camp Cady site (James, 1994) describe pasture and fields of alfalfa to raise 33 head of cattle. An artesian well existed in the 1930s. The Mojave Road and stage stop buildings remained at that time. In March 1938 all buildings were destroyed by a flooding Mojave River.

1.0 54.7 **STOP and sharp turn left** (south) on Newberry Road. The broad valley ahead had shallow groundwater and was extensively homesteaded. Many properties are still inhabited despite lowering of water levels and the necessity for deeper wells.

5.6 60.3 **Turn right** on Pioneer Road after crossing the railroad tracks. Head west along the freeway. Pass the clay storage of Elementis, the operators of the hectorite mine near Pisgah.

1.0 61.3 **Stop**. You have reached Route 66! Turn left to start our eastbound route on historic Route 66 (renamed the National Trails Highway later but we will ignore that).

Route 66, established in 1926, was one of the first numbered highways in the United States. Route 66 was the first highway to be completely paved, as well—but paving was not completed until 1938. It connected Los Angeles (and later Santa Monica) with Chicago, allowing large numbers of migrants to travel west with relative ease. The travelers brought prosperous conditions for businesses in towns along the way, towns that in most cases were bypassed 30 years later by newer roads and as a result have been decaying for decades.

Figure 7. The famous Route 66 insignia.

Route 66 was more than an early cross-country highway. It was an icon of

Figure 8. Route 66 crossing a railroad spur at Daggett, March 28, 1928. SBd 58-F. California Highway Department.

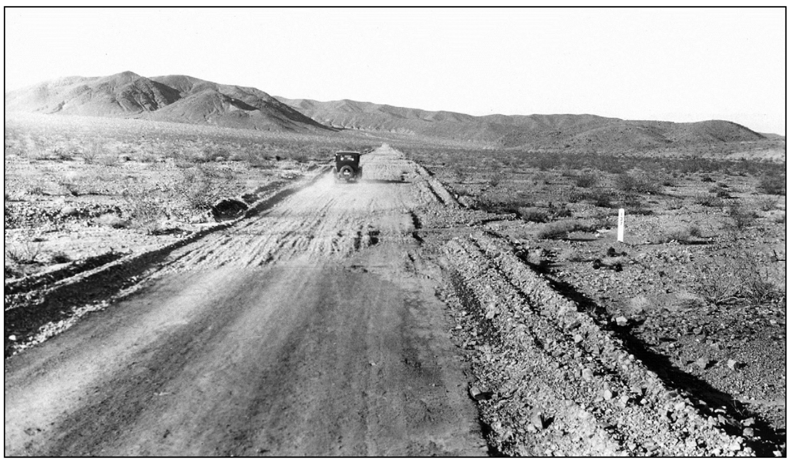


Figure 9. Route 66 at the Oro Grande area (?). Aug. 7, 1929. SBd 31-D. California Highway Department.

American culture, and a colorful part of our history. It has been memorialized by songs and a television series and featured in numerous movies and music videos.

Early conditions on Route 66 were poor, as it was graded by pulling iron weights. The road was near the first railroad to cross the desert, in part because stranded travelers could flag down a train for assistance. Maps in Thompson (1926) probably show early Route 66, also termed the National Old Trails Highway. In several places, perhaps in many, it was re-routed at the time of paving in 1938. And in many places it was later rerouted, so the route we take in several places is not the original.

Pass under I-40, the freeway that usurped the role of Route 66 as the greatest highway west of Chicago. We continue into the town of Newberry Springs, originally named Newberry, which has been and is now a village of dispersed homes and businesses. Slow to enjoy a few historic buildings.

Newberry Springs was founded (as Newberry) about 1910 by the railroad for its water supply, which was used locally to supply steam locomotives as well as carried by railroad cars to dry railroad towns far to the east. The early town consisted of adobe houses that had hand-dug wells to water about 30 feet down (McCoy, 1994). Route 66 to Ludlow prior to paving in 1938 was so rough that coil springs were the most common vehicle repair and the local garage stocked these parts well. The town had a school and post office.

0.5 61.8 **Drive-by old home and barn.**
UTM 528383 | 3853908

On our right are old buildings including two homes and a barn, nestled against the foothills of the Newberry

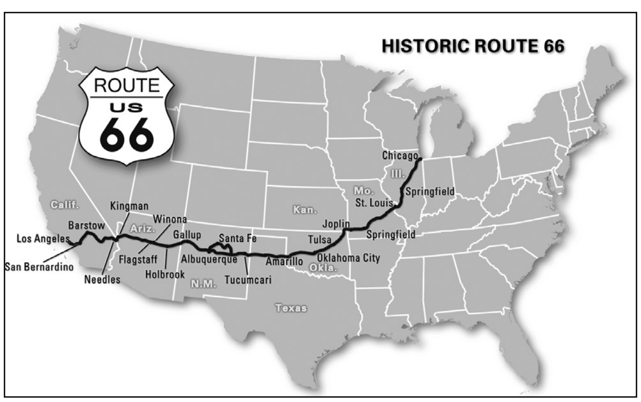


Figure 10. Route 66 map showing road from Chicago to Los Angeles. Source: https://guideandtravel.files.wordpress.com/2013/02/route-66-map.png.

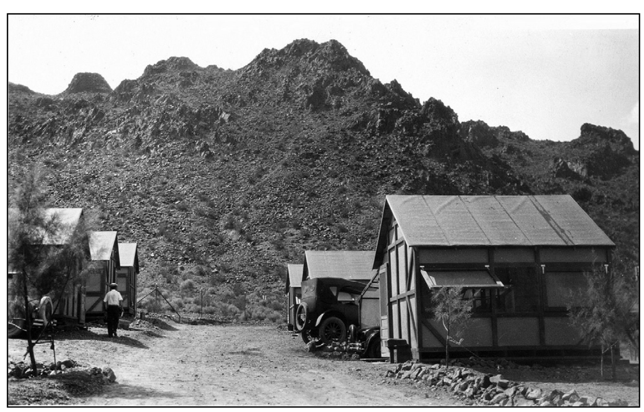


Figure 11. Newberry camp, probably the Highway Department maintenance yard. California Highway Department.

Figure 12. Home and barn in Newberry Springs, 2023. D.M. Miller photo.

Figure 13. Bagdad Cafe in Newberry Springs, 2023. D.M. Miller photo.

Figure 14. Old truck and trailer, Newberry Springs, 2024. D.M. Miller photo.

Mountains. Please do not disturb the residents on this private property. The Cliff House store was near here, apparently.

2.7 64.5 Drive-by Bagdad Cafe. 532623 | 3853074 On our left is Bagdad Cafe, site of the filming for the 1987 cult movie of that name.

0.2 64.7 Abandoned ancient gas station (Whiting Brothers) along the road.

Continue east on Route 66 across flats underlain by Lake Manix muds. Also note the railroad not far to the north. Route 66 was not built along ancient trails and historic wagon roads of the desert, but rather along the railroad passing from Needles to Los Angeles. Our route is probably the paved Route 66 built in 1938. The original route at Newberry swung south and then east before joining the railroad (Thompson, 1926).

6.5 71.2 Pass I-40 rest area on the north side of Route 66 and approach basalt lava flows.

2.8 74.0 Arrive at Stop 4.

STOP 4. Pisgah lava field and nearby hectorite and borate mines
UTM 547943 | 3849778

This stop represents the intersections of three important Quaternary geologic processes—basalt volcanism, formation of lakes and dry lakes, and faulting. Two of these involve the flow of fluids (lava and water) across the landscape and along channels, and the third involves the propagation of fractures within fault systems.

About 10 km southeast of this stop location scoria cones formed at the eruptive centers for the Pisgah basalt field about 23 ka (Phillips, 2003). Sunshine field, about the same age (Wise, 1966), and Lavic field, ~750 ka (Oskin and others, 2008), lie farther south. The Pisgah field had three distinct eruption phases (1, 2, and 3, earliest to latest) that are distinguished by phenocryst composition (Wise, 1966) (Figure 15). Pāhoehoe flows from eruptive phases 1 and 2 traveled ~18 km to the WNW along a paleochannel (two of the longest runout flows in Mojave basalt fields). Phase 1 flows followed a WNW-trending channel, and phase 2 lavas flowed along the southwest side of the phase 1 flows. Both phase 1 and 2 flows developed well organized lateral levees and within-channel flow structures. Near the distal phase 2 flows are structures that can be interpreted as lava platforms (ponded flows) with collapse pits, or lava rise plateaus (Buesch and others, 2022). These flows are visible to the southwest from where we stand.

The Pisgah basalt flows reached the southern (Troy Lake) arm of Lake Manix shortly after the late Pleistocene lake drained at ~25 ka. There are no pillow structures developed in the basalt, as one would expect if warm basalt flowed into lake water.

The eruptive centers for all three basalt fields are close to two faults of the eastern California shear zone (Miller and Buesch, 2022). The Pisgah scoria cone is on the eastern side of a 1.5 km wide band of faults that forms the northern end of the 40 km-long Lavic Lake fault system (Treiman, 2003). Possible minor surface ruptures occurred along the northeastern side of the Pisgah scoria cone during the Hector Mine 1999 earthquake (Sylvester and others, 2002; Treiman, 2002). The scoria cones in both the Lavic and Sunshine fields are within 300 m and 700 m (respectively) of the Pisgah fault, and Dibblee (1966)

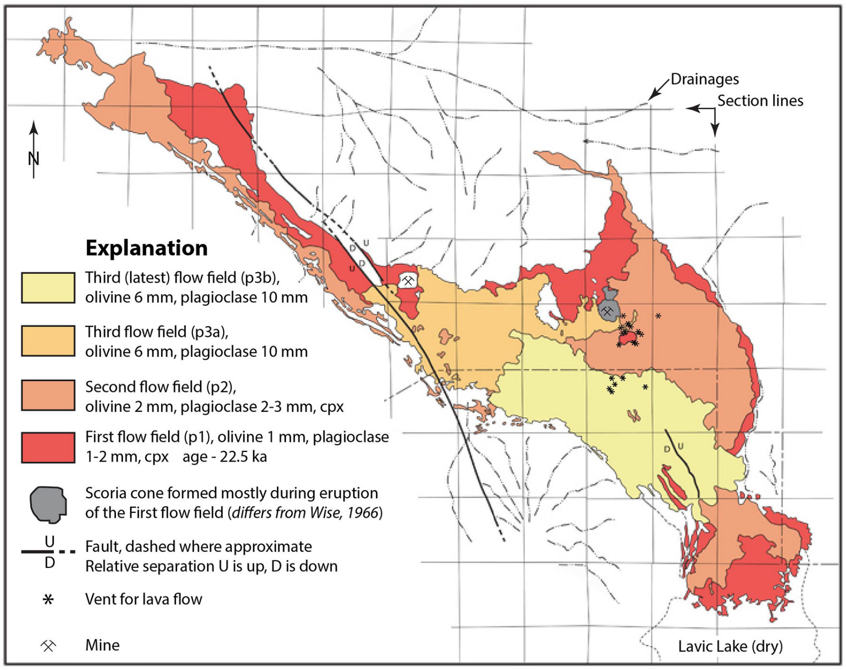


Figure 15. Simplified geologic map of the Pisgah volcanic field showing three phases of basaltic eruptions. In this depiction, phase three is divided into earlier and later flows. The map is after Wise (1966), is public domain, and was posted on the USGS media images website.

mapped these cones along a nearby fault buried by the lava flows and alluvium. Along the Pisgah-Bullion fault strands, Hart (1987) documented numerous geomorphic features along a narrow zone in late Quaternary to Holocene alluvial deposits; these features include linear troughs, closed depressions, right-laterally deflected drainages, faceted spurs, and tonal lineaments. Near the north end of the fault, Hart also interpreted ~2 m of down-to-the-southwest separation of the Pisgah lava flow adjacent to Route 66, where we stopped, and about 15–20 m of right lateral offset of the edge of the lava flow along the north end of the flow (north of the freeway).

Here we can observe large upturned blocks of lava along a linear path, southwest of which the lava field is lower by ~2 m. This could represent a linear compression feature, the edge of a lava lake that collapsed to the southwest, or a fault. The connection of this feature with a linear zone in alluvium that displays fault features is strong support for the last hypothesis. Also, no corresponding margin of a lava lake is evident; the stripe of lava visible far to the southwest is a flow of a different age. If a fault, why don't we see fractures and sheared rock in a narrow zone, as is common along young faults?

How were the railroad bed and the road bed built through lava fields? These are construction challenges even with modern machinery. Construction of routes across the lava fields one century ago must have been arduous and the highway may have been in poor condition in this stretch.

A few miles to the south lie Hector and Fort Cady mines. Hector mine is producing a clay, hectorite, and investigating production of lithium, in an exposed section of rocks similar to the Barstow Formation (Wilkerson, 2023a). Fort Cady is not currently producing but has proposed deep solution mining of borates (Wilkerson, 2023b).

Continue east on Route 66.

10.8 84.8 Sharp left turn to cross over the interstate highway. We are no longer on the original Route 66, which is overprinted by the I-40 freeway. Its trace emerges south of the freeway east of here, and we will meet it again in 'downtown' Ludlow.

0.2 85.0 Sharp turn right to continue east.

7.9 92.9 **Stop** sign. Turn right on Knight Road to cross under the freeway.

0.2 93.1 **Stop** sign. Welcome to Ludlow and Route 66! Turn left on Route 66 and then take an immediate right on Crucero Road (between parking lots). Proceed to Main Street, near the railroad tracks.

0.4 93.5 Arrive at Stop 5.

STOP 5. Old town of Ludlow.
UTM 576718 | 3842375.

Figure 16. Route 66 and Pisgah Crater, probably taken at a location north of here. The photograph was taken before a paved Route 66 was built, and the highway lay to the north near the railroad. One stretch of that road was directed toward Pisgah Crater, unlike the paved Route 66. Photograph February 22, 1935, "View east toward Pisgah Crater." Haenszel collection, San Bernardino County Museum.

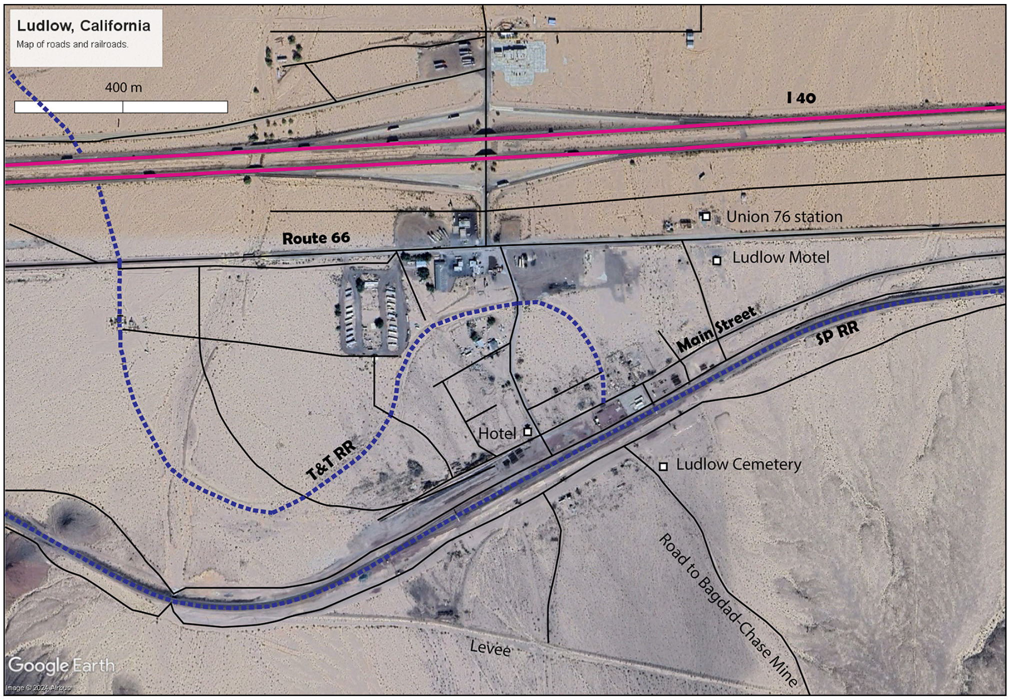


Figure 17. Map of Ludlow. Base is Google Earth image. Black lines are streets and small roads; blue dashed lines are railbeds; red lines are I-40 freeway lanes.

We have stopped at the corner of Crucero and Main streets. Ludlow, currently an exit on I-40 and home to little more than gas stations, fast food, a motel, and a café, had a robust past. Alongside the freeway is old Route 66, but interestingly, its name is not Main Street. Main Street instead borders the railroad and was the original highway through Ludlow. Ruins of several substantial buildings can be found along Main Street and streets that parallel it. As is evident from the map of Ludlow (Figure 17), Main Street and a few other streets lie parallel to and near the railroad. In contrast, streets farther north are parallel to Route 66, and their construction is wood frame with metal and drywall. They include historic gas stations and motels.

There is much to see here so wander around. Where we have stopped at the corner of Main and Crucero streets, a concrete building on the NW corner is the remains of a two-story 1908 Murphys building (Figure 18) that housed a store, hotel, restaurant, and saloon. On the NE corner lay the railroad depot, and farther east was the junction of the Tonopah and Tidewater (T&T) railway with the Southern Pacific tracks. The T&T diverted north in two sweeping curves and apparently became a straight, due-north track several miles north of town.

The hotel has been repainted by expert taggers and shade can always be found next to a tall wall for lunch. The sidewalks here and along the foundation of the depot to the east are signs of a robust town. Wood framed homes south of the railroad tracks offer photography opportunities. A cemetery lies farther east on the south side of the tracks; it hosts over 60 marked graves. Two headstones of granite are dated in the 1920s. A rail line south to the Bagdad Chase mine connected near here but its remnants are not to be found.

The T&T railway junction with the Southern Pacific (SP) railway is obliterated. A curving path marks the railbed.

Evidently, the railroad was the first route across an inhospitable wide valley in 1882, when the town was established (Couch, 1994). The railroad was accompanied by an adjacent road which became Main Street. The history of building and continuing the railroad operations is a complex one, with many sales of both the railroad and the land grant associated with it (Moon and Keeling, 1994; Wilkerson and Vredenburgh, 2024). It was built by Southern Pacific Railroad as a line from San Joaquin to Needles. The railroad reached Ludlow in late 1882 and was completed to Needles in April 1883. A year later it was sold to Atlantic and Pacific Railroad. The railroad town used transported water from Newberry Spring, which was drained from train cars into a cistern three times daily and pumped into a tank. The tank provided pressure for refilling steam locomotives. The town included a railroad shop, housing, a school, and a church. Ludlow grew in 1900 with the opening of the Bagdad-Chase mine about 7 miles south of town, and a short line railroad was built to access the copper and gold ores of the mine. A post office opened in 1902 and continued until 1974. Work crews for the construction of the T&T railroad brought more activity to Ludlow in 1905, resulting in more rooming houses and cafes (Couch, 1994). When the T&T railroad

Figure 18. Two-story Murphy's building along Main Street, 2023. D.M. Miller photo.

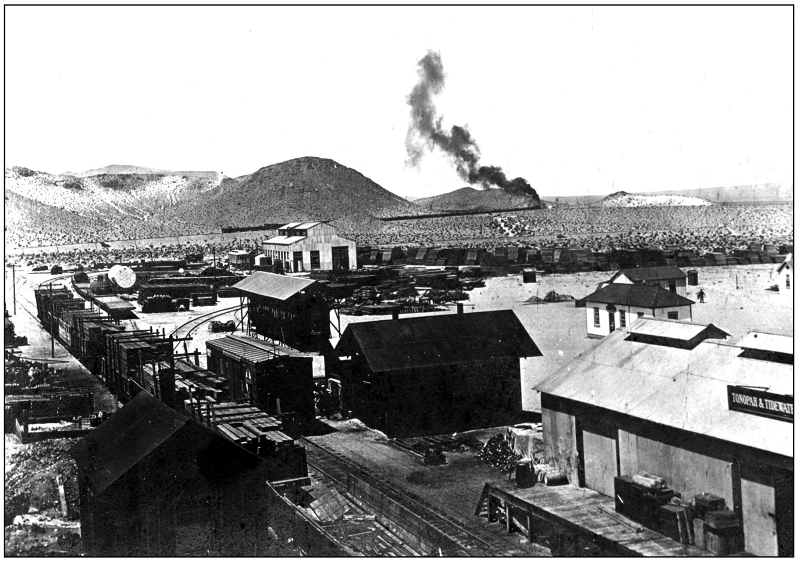


Figure 19. Ludlow buildings near Main Street and the T&T building. Train in background is starting the climb from Ludlow to Pisgah. Frank Green photograph; Rio Tinto – Death Valley National Park Collection.

Return to Route 66 by driving north on Main Street, then left on Elliot Street.

0.3 93.8 **Stop** at intersection of Route 66 with Elliot Street. Notice the historic buildings at the intersection with Route 66; a café and nearby Union 76 Gas station to the north, and the remnants of a main building of the Ludlow Motel to the east (Figure 21). Turn right (east to continue on Route 66.

0.4 94.2 Intersection of Main Street with Route 66. Continue east on Route 66.

1.8 95.9 Cross railroad tracks. This is a busy route, be careful! Some of these trains are as long as three miles, helping the Port of Long Beach distribute shipping containers across the country.

1.8 97.7 Arrive at Stop 6.

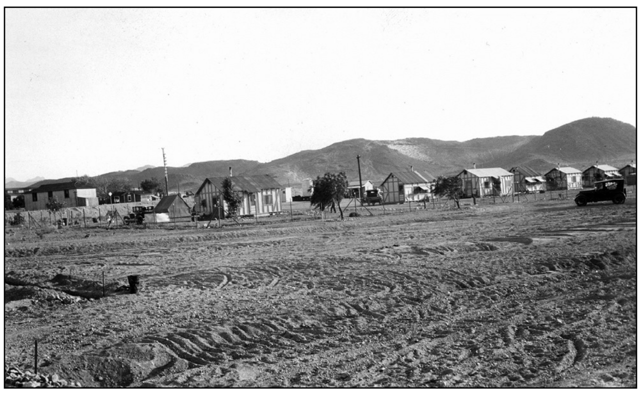


Figure 20. Ludlow highway maintenance yard, ca. 1930. SBd 58-H. California Highway Department.

was completed in 1907, it launched north from Ludlow and employed 80 men. At the time, Ludlow was more populous than Barstow (Keeling, 1994). In 1913 Ludlow boasted two blocks of businesses and a population of about 500.

The development of Route 66 along Main Street brought gas stations, a motel, and related businesses offering services for travelers. In 1931 Route 66 was moved to an alignment north of town, the current position, and the Oasis Motel was moved from Main Street to the new road and renamed the Ludlow Motel. The center of town evidently shifted to the new alignment of Route 66. Gas stations (note the Union 76 gas station location on Fig. 17), motels, and cafés as well as dwellings lined the highway. The T&T ceased operations in 1940, and the population dwindled to less than a dozen. The development of the freeway in the 1950s led to fewer people needing to stop in town, and, coupled with decreases in numbers of railroad workers living there, led to rapid decay of the town. In 1962 a local water supply was developed by drilling wells; water was found at a depth of 650 feet.

Figure 21. (A) Union 76 station. (B) Garage next to station. (C) Ludlow Motel. D.M. Miller photos, 2023.

STOP 6. Route 66 bridge construction and Ash Hill basalt field

UTM 583124 | 3841379

Ash Hill is a railroad "Y" east of here, at the crest of a drainage divide (to Broadwell Lake on the northwest and to Bristol Lake on the southeast). Helper engines stationed at the thriving town of Bagdad, near the Amboy lava field, would help trains up the 400 foot grade to Ash Hill, turn around on the "Y", and return. Like Ludlow, Bagdad was supplied by water delivered by train from Newberry Spring (Kitts, 1994). Ash Hill currently has no dwellings and has four high-speed tracks. It is not uncommon to see three trains moving past one another there!

Walk to the south edge of the road and drop into the stream channel where recently rebuilt supports for the highway bridge are of interest. Compare these with much older (1938?) construction (near Pisgah, Figure 22). The description of these bridges by Caltrans (2023) for a project near Amboy is:

> *"The existing bridges vary in length (40' to 78') but share similar construction components. The typical existing timber trestle bridges are composed of simply-supported timber stringer spans with a laminated timber deck with a concrete deck on it supported on timber strutted abutments and bents consisting of timber piles. The bridges are approximately 28 feet wide with guardrails…"*

The replacements use similar construction but are 34 feet wide. The rebuild has been exemplary in using the architecture of the original bridges, preserving history for Route 66 and Mojave Trails National Monument. Large drums filled with water, for both cars and people, were placed on bridges like this along historic Route 66. They were replenished regularly by the Highway Department.

Walk up onto the levee next to the stream channel and look off to the east. The dark hill that rises abruptly about a half mile to the southeast (on the right) is mantled with basalt flows. Behind it is a major eruptive center (Miller and Buesch, 2022). To the east and northeast are more basalt flows, forming a low rise in the north with two circular scars that look like craters. All this basalt is part of the Ash Hill field, about 5.3 Ma by K-Ar (Miller and others, 2014), and the two craters may be just that: sites of eruptions. They are puzzling for a few reasons: 1) Flows on the margins dip gently away from the craters as if deposited on an eruptive edifice, but no edifice is exposed. 2) Those flows are very extensive laterally, and sag down to the south only to rise again farther south. This indicates post-eruption folding of the flows, so their eruptive source cannot be clearly defined by topography. 3) Although scoria is scattered about in the craters, no thick occurrences of scoria or ash have been found. And 4) a major eruptive center lies in the southern part of the lava field, and is likely the source of most, if not all, of the flows. The gentle dip of flows at the crater margins may have been caused by folding or by flowing down the sides of an ash ring. Scoria cones generally, but not always, have steeper slopes than the observed dips on the basalt flows.

Figure 22. Photographs of Route 66 at an old bridge and stream undercrossing close to Pisgah, November 2023. Compare this construction with the recently rebuilt bridge at Stop 6. What differences do you see? D.M. Miller photos.

There are several road alignments in this area. A graded 2-lane road that was topped by crushed rock lies near Route 66 on the southwest. Farther southwest is a once-graded narrow gravel road. Were these early routes in the evolution of Route 66? In addition, two routes were built to a small clay prospect a few miles south of here. The older route, identified by its wagon-wheel width, hand-dug cuts, and fitted stone supports, follows a ridge and has no stream crossings. The younger route, constructed by bulldozer, is shorter and more direct but crosses several streams where the road is difficult to navigate. Paying attention to roads and trails can yield insight into the historical development of an area.

Continue east on Route 66.

4.8 102.5 **Turn Right**. Take a gentle turn to the right as we start to descend south to a broad, deeply cut stream system. This paved road on the right, in disrepair, may have been an early alignment of Route 66. It leads straight down the piedmont without crossing major streams before it turns east well downslope.

1.3 103.8 Arrive at Stop 7.

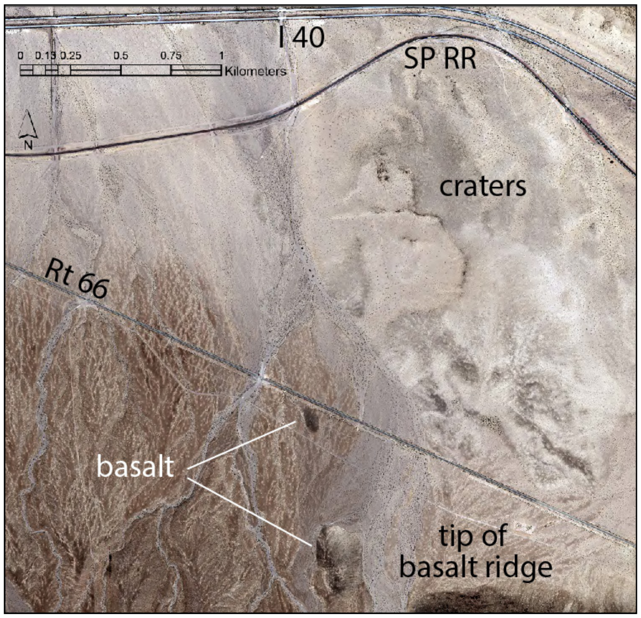


Figure 23. Sketch of the northern part of the Ash Hill lava field with the north end of the high basalt ridge in the south part of the map, and two craters shown between Route 66 and the Southern Pacific railroad. The southern crater has an apparent central peak where two dikes are exposed. Note the light-colored road paralleling Route 66, but south of it.

STOP 7. Old Route 66 and walk to faulted volcanic rocks

UTM 599691 | 3835276

Stop where a faint road leads down into the gully on the west. In this area beautifully displayed fault planes make this an exemplary "field classroom" training site and would be an excellent location for an information display for Mojave Trails National Monument.

1.3 105.1 Return north to and continue east on Route 66.

3.1 108.2 **Drive-by Lava Hills**.

To the west and on the north side of Route 66, sediment and volcanic rocks of early Miocene age lie on basement rocks that are mostly granitic, and of both Jurassic and Cretaceous age (Figure 24).

3.8 112.0 **Drive-by Dish Hill.**

The view to the northeast is of the ~2.0 Ma Dish Hill scoria cone and lava flows, which were summarized by Bridenbecker (2022). The Dish Hill basaltic (basanite) cone and flows were deposited on Jurassic and Cretaceous granitic rocks. After building a large scoria cone, lava breeched the cone and initially flowed to the west before turning to the south, and it carried variously sized rafts of the cone. Dish Hill is a world-renowned site for mantle xenoliths, which as "cargo" in the lava and pyroclastic bombs help constrain the transportation of magma from great depths (Wilshire and others, 1988). Dish Hill is one of three vents near us. To the south in the Bullion Mountains, the Deadman Lake volcanic field is similar in

Figure 24. Oblique aerial photograph of the Lava Hills and Dish Hill, 1980. Miocene sedimentary rocks of the Lava Hills in the foreground present as linear ridges formed by resistant beds. Dish Hill is in the background. D.M. Miller photo.

many respects, raising the possibility that Dish Hill and Deadman Lake fields are parts of a larger field (Howard, 2022).

4.7 116.7 **Crossroad at townsite of Bagdad**

UTM 603962 | 3827152

A town along the railroad near here was named Bagdad, and although little remains, it was once a thriving concern. The town watered locomotives until the 1950s when diesel engines started operation. It sent helper engines up the grade to Ash Hill. The town boasted a school, a Harvey House, a hotel, and many homes (Kitts, 1994).

4.0 120.7 **Drive-by Amboy basalt field**

Lava flows of the Amboy basalt field are next to the highway here. The field consists of a broad set of lava flows surrounding a scoria cone and has attracted much interest. This field was described by Miller and Buesch (2022) and a road log guide to visiting the lava field was presented by Buesch and others (2022). A lava flow in the field was dated at 79±5 ka by ^{36}Cl cosmogenic methods (Phillips, 2003). Despite its youthful appearance, the field is over three times older than the Pisgah field.

2.4 123.2 Intersection with Twentrynine Palms highway.

3.0 126.2 Intersection with and crossing of railroad. Fast and long trains pass through here. Be careful!

0.8 127.0 Arrive at Stop 8.

Stop 8. Amboy.

UTM 615242 | 3824784.

The town of Amboy has a school, post office, and several business and domicile buildings remaining from the heydays of Route 66. Note the vintage cars and buses behind the motel, used in photo shoots and movies.

D.M. Miller recollections: *In the late 1970s Roy's was a strong business operated by Buster*

Figure 25. Oblique aerial photograph of the Amboy scoria cone and lava field, 1980. D.M. Miller photo.

> *Burris with a gas station and a café, as well as an art showcase rumored to be for Buster's girlfriend. The motel next door was available, albeit with few services after Buster closed shop in the early evening. You'd make a reservation by phone, and Buster would leave the door to your bungalow unlocked with the key inside. If you arrived after dark you needed a flashlight because the entire town ws dark. By the late 1980s much of the town had closed and Roy's saw much less business.*
>
> <u>J. Reynolds recollection</u>: *Roy's café had the *best* chili. After one especially satisfying meal in the late 1960s, I asked about the secret of their recipe. I was rewarded with a trip to the kitchen where chili was bubbling in the largest cast iron skillet I have ever seen: it must have taken two people to move it off the stove. "Doesn't work without the pan," I was assured. Amboy was the last gas stop before heading into the Old Woman Mountains and vicinity. Gas could cost as much as 50 cents a gallon*!

Amboy was settled in 1858 and established as a town in 1883. It grew upon the opening of Route 66 in 1926. Roy's Motel and Café opened in 1938 (Wikipedia, Amboy, accessed 2024). During its height, Amboy had some 800 residents enjoying the tourist businesses as well as a post office, school, airport, and mineral operations on nearby Bristol Lake. In 1973, Amboy was bypassed by I-40, which lies far north of Amboy where it crosses the Bristol Mountains at high elevation. Reportedly this freeway route was chosen because an entrepreneur bought the entire town of Amboy, planning to make a financial killing at the remote freeway exit. He feuded with the freeway road barons, however, who chose an expensive and hard-to-maintain route to avoid Amboy. Amboy still sees much traffic when snowstorms blanket the Bristol Mountains and close I-40!

A part of Operation Plowshare was nearly put into action here. When it was decided to route the freeway over, or through, the Bristol Mountains, the idea was floated to blast through the mountain with 23 nuclear bombs! The result would be a trench 2 miles long, 360 feet deep, and about 900 feet wide that would carry the freeway and a re-routed railroad. Project Carryall was begun to accomplish this but was never completed.

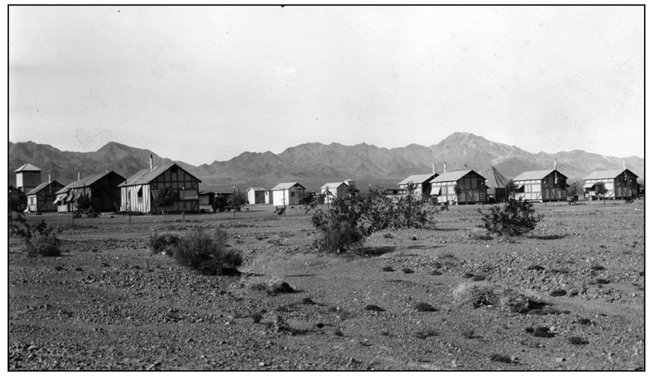


Figure 26. Amboy maintenance yard ca. 1930. SBd 58-K. California Highway Department.

Continue east on Route 66.

5.7 132.7 Turn left (north) on Kelbaker Road. A short distance north we pass the southern Bristol Mountains high purity limestone mine on the left. The white dumps and stored material is calcite mined from specific limestone formations that have been metamorphosed to marble.

Figure 27. Photos of Amboy in 2023. (A) Roy's service station and café. (B) Amboy Motel. D.M. Miller photos.

5.4 138.1 **Drive-by.**

The Marble Mountains lie on the right, and the southern Bristol Mountains on the left. Both are composed of Jurassic plutons and small amounts of Proterozoic gneiss. The Jurassic plutons have intruded and metamorphosed Paleozoic strata of mainly limestone and dolomite composition. The entire complex is overlain unconformably by early Miocene volcanic rocks, most of which are faulted and tilted but overlain by the undeformed Peach Spring Tuff (18.8 Ma).

5.8 143.9 Pass under I-40. Continue north on Kelbaker Road and enter Mojave National Preserve.

5.3 149.3 **Drive-by.**

Van Winkle Mountain volcanic rocks on the right were described by Gans (2022) and the part of the Granite Mountains visible on the left are mostly Cretaceous granite. Continue north on Kelbaker Road, crossing Granite Pass.

9.0 158.3 Kelso Dunes on the left are Holocene in age, and although much of the sand is derived from the Mojave River, which drops its bedload in the southern Soda Lake basin, there are significant components derived from local sources (Muhs and others, 2017).

7.5 165.8 Kelso railroad town and multi-track railroad crossing. We will visit this town on Day 2 of this trip. Continue straight (north) on Kelbaker Road at the intersection just beyond the railroad crossing.

11.8 177.6 We are crossing the divide between the Kelso Wash drainage basin and the streams that drain through the Cima volcanic field and directly west into Soda Lake.

8.6 186.2 The Cima basalt field is on your right, with several tall scoria cones and extensive lava flows visible. The basaltic lava flows issued from scoria cones and flowed west, indicating that the field developed on a west-sloping geomorphic surface. The highest elevation flows and cones visible on the distant skyline are near the north end of the field where they straddle the I-15 freeway near Halloran Summit. The volcanic field is about 13 km x 21 km and has at least 71 vents that resulted in explosive and effusive eruptions from ~7.5 Ma to 12 ka (Turrin and others 1985; Phillips, 2003). The Cima field is also a world-renowned site for mantle xenoliths (Wilshire and others, 1988). Excellent summaries and field trip stops can be found in Buesch and others (2022).

22.2 208.5 **Stop**. Turn left to enter I-15 southbound. Or continue into Baker to fill your gas tanks and resupply snacks and fluids before leaving on the Day 2 part of the field trip tomorrow.

6.3 214.8 Exit at Zzyzx (Exit 239). Turn left over the overpass and continue to Zzyzx.

4.9 219.7 Desert Studies Center at Zzyzx.

Day 2

As with Day 1, prepare your vehicle and your provisions for desert travel. We will be on 2WD roads for most of the trip, and will drop 2WD vehicles at one place to double up in more roadworthy vehicles. Our trip ends near Iron Mountain, and folks wanting to leave a vehicle at Zzyzx in order to carpool should plan on dirt road routes back to Cadiz, then Kelbaker Road through Mojave National Preserve.

Today we tour to the east through Mojave National Preserve, to see historic structures at Kelso. We then drive east along a segment of the Mojave Road to Rock Spring, site of an historic cabin and historic fort. Onward, we will follow the Mojave Road to Lanfair Road and an adjacent old railroad south to Goffs to visit the historic buildings and artifacts. A side trip to Piute Spring is available for travelers to follow later; we won't be able to include it in our trip this time. We continue to historic trails and stunning desert gardens at Eagle Pass. From there we swing south to Iron Mountain to visit the pumping plant and General Patton's historic Camp Iron Mountain.

MILEAGE

INCREMENTAL CUMULATIVE

0.0 0.0 Depart Desert Studies Center at Zzyzx with a full tank of gas.

4.9 4.9 Turn right, northeast on I-15.

6.3 11.2 **Exit** at Baker; turn right at the stop sign onto Kelbaker Road.

22.2 33.4 Pass by Cima basalt flows. This is also the location where the Mojave Road snaked through the basalt field on its route between Soda Spring and the Colorado River (King and Casebier, 1976).

20.4 53.8 **Stop** sign. Turn left on Cima Road.

0.1 53.9 Arrive at Stop 1.

Stop 1. Kelso Depot and nearby homes and schools. UTM 622938 | 3875281

Kelso was founded in 1905 as a water stop for locomotives on the San Pedro, Los Angeles, and Salt Lake Railroad. It became "Kelso" when two warehousemen put their names into a hat along with that of a third worker, John Kelso, who had previously left the area. A small depot, post office, and eating house were built. The railroad served local mines, and drew water from springs in the Providence Mountains on the east and later from deep wells. The steep northeast grade leading to Cima required helper engines that were stationed at Kelso. Roads were built along the railroad and connected mines and nearby towns.

Figure 28. Kelso Depot, 1981. D.M. Miller photo.

The “Kelso Clubhouse & Restaurant” was built in 1924. It included a conductor’s room, telegraph office, baggage room, dormitory rooms for staff, boarding rooms for railroad crewmen, a billiard room, library, and locker room. The depot restricted use in 1962 to just a restaurant and boarding rooms, and then closed in 1985. The National Park Service is offering tours of the depot as well as other buildings in the town.

Return to Cima Road and continue northeast, with the rail bed on your right.

13.9 67.8 **Turn right** on Cedar Canyon Road. UTM 596755 | 3829173.

This is the start of our route along the Mojave Road, a mid-nineteenth century transportation corridor linking a series of historically significant springs. Note the historical marker across Cima Road. The Mojave Road follows the approximate route of a centuries old Native American trail system. It was developed as a wagon road by the U.S. military in the late 1850s, also known as the Government Road. This first 4 miles of Cedar Canyon Road parallels the Mojave Road, which is not drivable and lies to the north of the road we are on.

The first documented European exploration of Native American trails in the Mojave came from the Francisco Garcés expedition in 1776, who traveled west south of here but returned east along this route (Haenszel, 2024). Jedediah Smith’s 1826 passage was followed by that of Antonio Armijo in 1837 and John C. Fremont in 1844. The Treaty of Guadalupe Hidalgo, which ended the Mexican War in 1848, brought the region under control of the United States and increased traffic followed with the gold rush bringing miners south of the snow-covered Sierra Nevada. Military surveys by Lt. A.W. Whipple in 1853 were followed by road construction by Lt. E.F. Beale during 1857 to 1860. After the Civil War, Mojave Road was the main mail link between southern California and Arizona. Conflict between travelers and Native Americans resulted in an increased military presence and the construction of small forts and redoubts along the road. The U.S. military used the road extensively to move men and supplies from Los Angeles to and from Fort Mohave on the Colorado River. Use of the road by miners, homesteaders, and ranchers continued in the 1870s, though cessation of Native American hostilities meant the Army no longer had reason to occupy the forts. Portions of the road were used through the twentieth century by ranchers, farmers, and the military while the majority of the historic road decayed.

3.8 71.7 After the pavement ends, enter Cedar Canyon. Drive carefully on this road; despite significant improvements over the last few years, it is still prone to floods and washouts.

2.1 73.8 Continue straight at intersection with Black Canyon Road.

2.0 75.8 **Drive-by** of Pinto Mountain on your left.

Near the base of Pinto Mountain is the cliff-forming 18.8 Ma Peach Spring Tuff (Tps) that was overlain by conglomerate (Tg). Most of the exposures at the mountain (Figure 30) are of ignimbrites and fallout tephra of the 17.8 Ma Wild Horse Mesa Tuff (Twh) with a thin cap of mafic lava flows (Tb) (McCurry, 1988, 1995; Miller, 2012; Reioux and others, 2022). The Peach Spring Tuff and Wild Horse Mesa Tuff provide interesting contrasts for how the pyroclastic density currents traveled across topography.

The Peach Spring Tuff resulted from a super-eruption near Oatman, Arizona ~95 km west of here (Ferguson and others, 2013). The Peach Spring Tuff is also exposed in the Woods Mountain volcanic center (the source of the Wild Horse Mesa Tuff) about 10 km south of Pinto Mountain. At both locations the ignimbrite thins dramatically where onlapping topographic highlands along the sides

Figure 29. Cedar Canyon Road, 1970. Jennifer Reynolds photo.

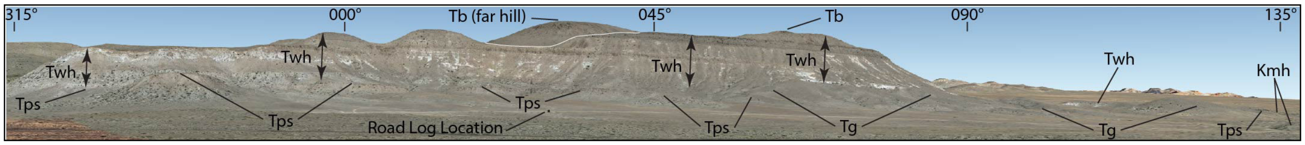


Figure 30. Panorama image of the south side of Pinto Mountain displaying the Miocene section from Peach Spring Tuff to Wild Horse Mesa Tuff and capping mafic lava flows. See text for symbols. Google Earth image.

of valleys (Buesch, 1991). Modeling of the transportation of large lithic clasts in the PST indicates that the density current had a high particle concentration and moved at modest speeds of ~5–20 ms^{-1}, even to distances of ~180 km from the caldera (Roche and others., 2016). These characteristics enabled the current to flow along paleovalleys and onlap topographic obstacles, but not overtop those that were too high.

In contrast, Pinto Mountain is ~10 km away from Wild Horse Mesa Tuff caldera and the relief is mostly gradually increasing northward, with a few significant hill obstacles. One such hill is the ridge-top mesa "Table Top" visible~7.5 km distant on the skyline to the south-southeast where only the upper of three eruptive pulses of Wild Horse Mesa Tuff was deposited. Miller (1995) advanced arguments that the pediment underlying all of the Mid Hills area has been tilted southward after these tuffs were deposited, based partly on the observation of more rapid thinning southward than northward of the Wild Horse Mesa Tuff. It appears that early eruptive phases were not able to surmount nearby hills.

Continue past outcrops of granite, the Cretaceous Mid Hills Adamellite of Beckerman and others (1982), which is about 90 Ma (Wells and others, 2005). The expansive pediment was described by Miller (1995). Out of sight beyond Table Top (to our south) lie more mesas, including Wild Horse Mesa, the source for wood used by nearby mines (Reynolds, 2024, reprinted in this volume). Similar trails between mines and wood sources in the New York Mountains to our north were documented by Reynolds and Reynolds (2024, reprinted in this volume).

At this location, we are crossing a drainage divide between streams leading to Kelso Wash and Soda Lake, and streams leading to Fenner Valley and Bristol Lake.

3.2 79.0 Turn right to Rock Spring parking.

0.2 79.2 Arrive at Stop 2.

Stop 2. Rock Spring

UTM 652305 | 3891310.

Rock Spring is a critical water source along the Mojave Road and also the most prominent. The location was called Camp Rock Spring during the 1866 to 1868 military era. Resources documented here are the spring, an artifact scatter, ruins of two buildings and three habitations, three rock walls that were possibly parts of corrals, and a former parade ground. Figure 31 shows the layout of building ruins.

Historic records indicate that Rock Spring was periodically dry, forcing travelers to stop at the Government Holes location to the west for water. The water source at Government Holes was improved around 1860 with a well by California merchant Phineas Banning and briefly known as Banning's Well. U.S. troops stationed in the area enlarged the well and the location became known as Government Holes, likely deriving its name from Government Road, as Mojave Road was often called.

The spring is a wet place in the sand below a stretch where streams flow on rock, with a large desert olive tree growing over it. A small concrete dam was constructed there. Numerous prehistoric petroglyphs and historic inscriptions by military troops and travelers who camped or were stationed at the springs can be found. Notable among these is an inscription by Charles Stuart of the 4th Infantry who camped at the springs on May 16, 1863. Farther up canyon, the Rock House is situated on the north rim of the canyon.

The rock exposed in the canyon was named the Rock Spring monzodiorite by Beckerman and others (1982). It is a distinctive dark-colored, compositionally variable rock with abundant biotite and hornblende. Reaction rims and other features indicate magma mixing. It is about 90 Ma, as is the rest of the Teutonia batholith.

0.2 79.4 Return to the main road and continue east, crossing deeply cut Watson Wash and then more pediment with thin alluvial cover. We depart from the Mojave Road along here, taking a road about one mile south of the original Mojave Road. This broad flat area, Lanfair Valley, is a continuation of the Mid Hills pediment. Low hills are underlain by bedrock that is more resistant than the granite, commonly marble of Paleozoic age. Much of Lanfair Valley was homesteaded early in the 20th century (Roe, 2024, this volume). Accounts of farming, growing fruit orchards, and work in nearby mines have been archived in several books. Access was by the Nevada Southern railroad, which was built in 1893 to supply mines in the New York Mountains.

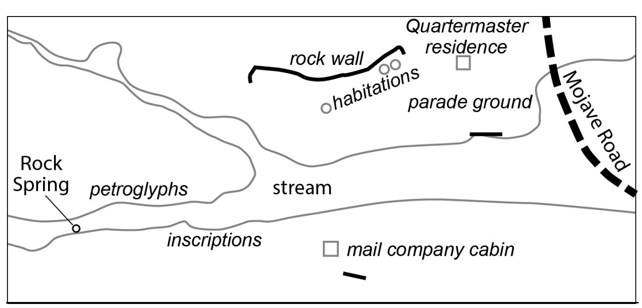


Figure 31. Map of the Rock Spring area, after Livingston and others (2020).

Figure 32. Rock Spring: Dion Dyer and Jenny and Eater Reynolds, 1969. R.E. Reynolds photo.

6.7 86.1 From this hill underlain by resistant marble is a view of the granitic southern New York Mountains beyond the expanse of Lanfair Valley.

0.8 86.9 The El Dorado Road departs from the Mojave Road north of here, trending northeast to south of the Grotto Hills, east of which the road turns north to El Dorado Canyon in the Castle Mountains. It is a wagon road that dates to the same decade as the Mojave Road but is less known. Native American rock art near the trail may indicate that its use predated wagons (McDonald and Gilbert, 2021). To reach this wagon road, drive north on the crossroad at this location for 0.8 miles, reaching the east-west Mojave Road. Drive east 0.2 miles to the junction with El Dorado Road [662373 | 3889982].

2.1 89.0 **Turn right** on Lanfair Valley Road.
UTM 665508 | 3888609

Relicts of the Nevada Southern railroad (Figure 34) can be seen on the west side of the road. The railroad was built from Goffs to service mines and farms to the north (Wilkerson and Vredenburgh, 2024). Ranches were profitable in a wet period of the early 1920s and 1930s (Roe, 2024). The Mojave Road east of here is part of the East Mojave Heritage trail (Vredenburgh, 2024).

2.1 91.1 Pass by the Bobcat Hills on the left (east), location of a significant shonkinite dike swarm that is the same age as similar rocks at Mountain Pass, the world's largest reserve of rare earth elements (Watts and others, 2023). Other rocks of the Mountain Pass area, significantly carbonatite, are not present in the Bobcat Hills and the area is not likely to be economically important.

3.0 94.1 Hackberry Hills where nearby Miocene volcanic rocks related to the Woods Mountains extrusive complex are on both sides of the road. The community of Hackberry lies to the south near here. Follow Lanfair Road and the railroad to Goffs, a siding and village where the Southern Pacific railroad crossed Route 66.

10.7 104.7 Arrive at Stop 3.

Stop 3. Goffs Museum
UTM 676609 | 3865985

Our host, the Mojave Desert Heritage and Cultural Association, will provide a tour of their historic buildings and artifacts of ranching and mining life.

Goffs was created along the railroad in 1883 near the high point between Needles and Amboy. It was a turning point for helper engines. Ten years later the shortline Nevada Southern Railway was built north from Goffs to Lanfair Valley and beyond. Goffs became an entry to agricultural, ranching, and mining pursuits in the eastern Mojave Desert. As employees with families increased at Goffs a school was built in 1911; it has been restored and is managed by the Mojave Desert Heritage and Cultural Association. Square dances were a weekly occurrence at the building in the 1980s.

0.2 104.9 Continue south to connect to Route 66 and turn east. **Stop** at Route 66.

Figure 33. Road grader in Lanfair Valley, 1974. R.E. Reynolds photo.

Figure 34. Nevada Southern (1893) railbed near Hackberry, 1993. R.E. Reynolds photo.

5.8 110.7 **Turn north** on the powerline road NN9101 to Piute Spring.
UTM 686115 | 3865642

12.1 122.8 Cross Piute Pass road (a late route of the Mojave Road) NN101. Continue north.

1.5 124.3 **Turn left** to Piute Spring and Fort Piute. This is a 4WD road, with high clearance essential. It is very bouldery and rough. Double up in suitable vehicles; only 12 vehicles will fit in the parking lot at the fort.

1.4 125.7 Foundations of ranch buildings and remains of turkey pens are visible on the terrace below on the south side of the road. See Haenszel (2024) and Roe (2024) for descriptions of life at this ranch one century ago.

0.4 126.1 Arrive at Stop 4.

Stop 4. Piute Spring and Piute Creek

UTM 683689 | 3887640

This canyon with its reliable stream sourced from a spring farther east was a site for Native American farming and buildings as well as a fort along the Mojave Road. Historic accounts by Haenszel (2024) document the area.

Fort Piute includes a partially restored stone ruin, a horse corral, and associated features (Figure 36). It was very important to the Mojave Road, being the one permanent Army post along the road in this part of the eastern Mojave Desert, and also was a critical water source. Petroglyphs are present up canyon to the west.

Volcanic rocks of the Piute Range rim the canyon to the east and south of Fort Piute (Nielson and others, 1987). Rocks range from basalt to dacite in composition and are early Miocene in age.

Figure 35. Foundations from farm buildings at Piute Springs, 2023. D.M. Miller photo.

Return to Route 66.

15.4 141.5 **Stop**. Cross Route 66, continue south on Piute Valley Road. We are in upper Ward Valley, which drains to Danby Lake far to the south.

5.5 147.0 Camino Camp and Power Station at Hightower Road. Follow complex turns to cross I-40. After crossing the freeway, swing east again toward the axis of Ward Valley. Follow Hightower Road.

This segment of I-40 was constructed in 1960 and subsumed the early 1930s realignment of Route 66 that bypassed Goffs and Fenner. The early 1920s was also the time when Arrowhead Highway abandoned the segment between Searchlight and Arrowhead Junction (aka Searchlight Junction) in favor of what would become I-15. These two events at the beginning of the Great Depression ushered in the ghost town phase of the railroad towns Goffs, Fenner, and Klinefelter.

9.4 156.4 **Turn left** onto BLM Route NS085.

3.7 160.1 **Stay right** onto NS099 Eagle Pass Road. The name of the road appears to have been derived from the Mojave Indians, as this travel corridor from here to the Colorado River is identified as the place from which eagle and hawk feathers were collected (Avi Matpha). Ethnographic accounts of various tribes within the desert and coastland of southern California indicate hawk and eagle feathers were major Mojave trade goods. Eagle Pass Road is included in the 1925 GLO Plat map.

7.3 167.4 Arrive at Stop 5.

Stop 5. Eagle Pass.

UTM 710458 | 3851568

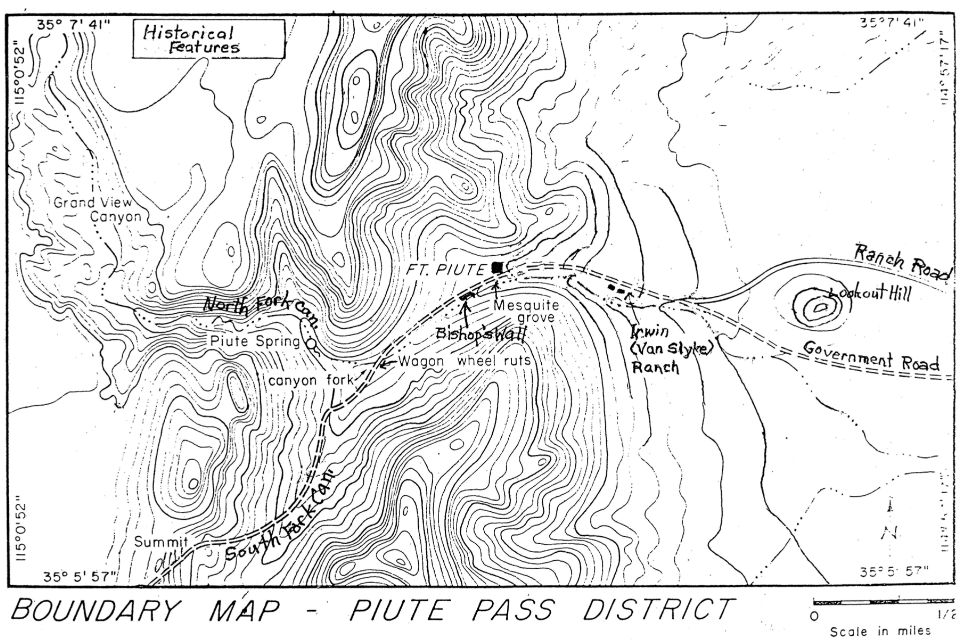
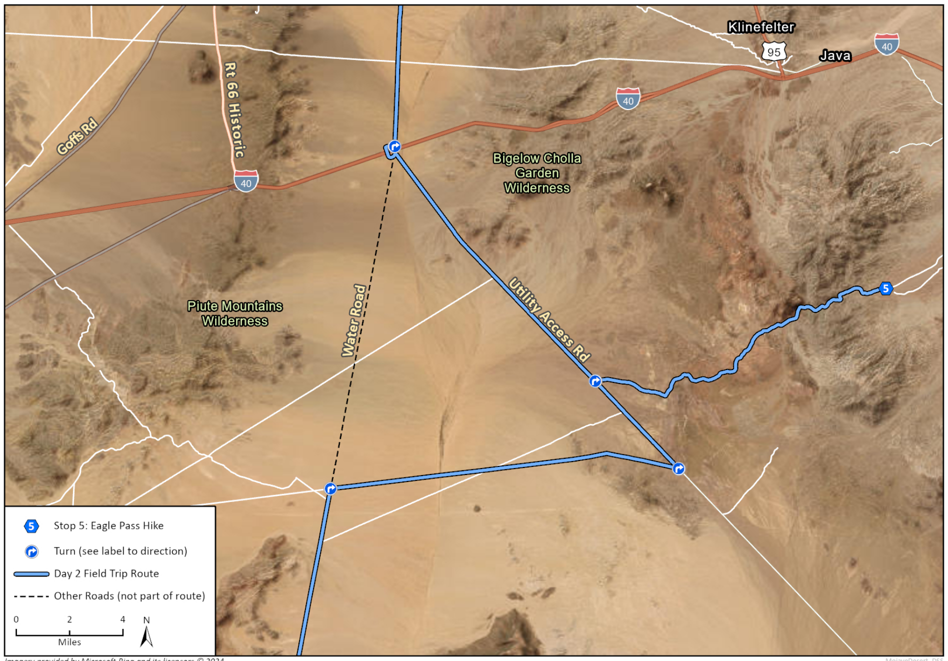


Figure 36. Map of the Fort Piute area (National Register of Historic Places application, 1973, on file at San Bernardino County Museum).



Imagery provided by Microsoft Bing and its licensors © 2024.

Prepare for a short hike to see historic trails and enjoy desert cactus gardens. Please be respectful by keeping the location confidential. Hike up the road and then north to a prehistoric trail. From here, the trail dips west into the wash and follows the route we just drove. Follow the trail east and consider the contrast between walking in the steep walled wash to this open-air trail overlooking Mojave traditional lands for a sense of what past travel was like. When recorded in 1920, the site was considered extraordinary due to the petroglyphs on boulders, but also for various stone tools. The Mojave were known to travel great distances regularly, not just for trade, but for interaction with others.

11.0 178.4 Return to Hightower Road. **Turn left**.

3.7 182.1 **Hard right turn** onto Needles to Ludlow truck trail. The Needles to Ludlow truck trail was established as a primary corridor in the 1950s to serve as access for the various natural gas lines that run through the area. At least half of those lines originally transported oil from oil fields in Orange and Los Angeles counties to delivery points to the east. This trail is a primary route across the mountain ranges west of here.

10.9 193.0 **Turn left** onto NS054, Water Road. We have a lengthy drive down Ward Valley ahead. The Little Piute Mountains are on the west, the Stepladder Mountains on the east. Both have Mesozoic granites structurally overlain by a detachment fault, above which rocks include Miocene volcanic and sedimentary rocks.

29.8 222.8 Cross railroad tracks. This is a spur line that once connected Cadiz and Rice, but now is in disrepair.

0.6 223.4 Cross Cadiz Road.

0.4 223.8 North margin of Danby Lake, a terminal playa that has captured more than a few cars (Figure 37).

2.6 226.4 South margin of Danby Lake.

3.3 229.7 Cross the eastern part of the Iron Mountains, a Cretaceous intrusive complex with a thick mylonitic zone also of Cretaceous age (Miller and others, 1981; Wells and others, 2002).

1.5 231.2 Enter Metropolitan Water District facility. Everything you see within the village of Iron Mountain—the pumping plant, the aqueduct system, and all related transmission lines and facilities—were constructed in the early and mid-1930s.

0.7 231.9 Arrive at Stop 6.

Stop 6. Iron Mountain Pumping plant

UTM 673336 | 3779607

Metropolitan Water District tour.

Leave the facility by driving to the gate.

0.5 232.4 Turn right onto Route NS715 Powerline Road.

3.4 235.8 Turn left into Iron Mountain Divisional Camp. The 215kV powerlines and aqueduct were the primary reasons that Major General George Patton Jr. selected this region of the desert for military training in 1942. The desert was preferred because U.S. entry into WWII would be in North Africa to prevent the Axis

Figure 37. Partially buried car near Danby Lake, 1978. Jennifer Reynolds photo.

powers from taking control of the Suez Canal. Patton selected camps Young, Iron Mountain, and Needles for the first three divisional camps. In 1942, more than one million soldiers were trained in desert warfare at 12 camps and over 18,000 square miles of California and Arizona that made up the Desert Training Center.

A husband and wife lived at Iron Mountain; they were the grandparents of our host Scott McBride. In those days, the town of Rice was quite developed and included a schoolhouse that provided primarily for the many children that lived in the village.

0.2 236.0 Arrive at Stop 7.

Stop 7. Camp Iron Mountain

UTM 671030 | 3776997

Park at the sandbox map. The sandbox map was built by the U.S. Army Corp of Engineers as a scale version of the entire Desert Training Center (DTC) within California. As shown in the handout guide, the map includes a raised viewing platform/bridge from which training exercises could be planned. The map included all communication lines that ran throughout the DTC, as well as mountain ranges, towns, and other geographic features.

Proceed southwest along NS815 bordering fence.

0.9 236.9 **Turn left**, prepare to park.

0.1 237.0 Arrive at Stop 8.

Stop 8. Camp Iron Mountain chapel

UTM 668816 | 3773309.

One of two altars built within Camp Iron Mountain, this is the Catholic altar; the other is the Protestant altar located southeast of the officer's circle. Both altars were constructed in 1943 by the 183rd and 951st Field Artillery Battalions. See the handout for how things here were arranged in 1943. Services were performed by local priests. As a member of the public once commented, of the various elements and remains of the DTC, this is among the most intense to reflect upon if we place ourselves into the mind frame of the thousands of young soldiers who were drafted and trained here. Consider that this may have been the last peaceful place of worship and contemplation for those that did not return.

0.5 237.5 Return to a road along the fence. **Turn left** (southeast).

1.0 238.5 **Turn Right** onto Route NS812

1.4 239.9 State Highway 62. 671156 | 3772203. Turn west to Twentynine Palms; east to Parker and the Colorado River.

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Service station at the Colorado River, 1930. SBd 58-P, California Highway Department.

Destinations through time

David M. Miller and Jennifer Reynolds

The Mojave Desert has been a challenge for travel since prehistoric times, whether by trail, rail, or road. The reasons for travel as well as the mothods employed for travel have changed through time and the routes themselves have changed as a result.

Many routes and many destinations — springs, mines, cabins, depots, towns — have succumbed to abandonment, damage, or destruction, whether by neglect, vandalism, natural disasters such as fire and flood, or just generalized attrition. These images recall some of these places and byways.

Prehistoric

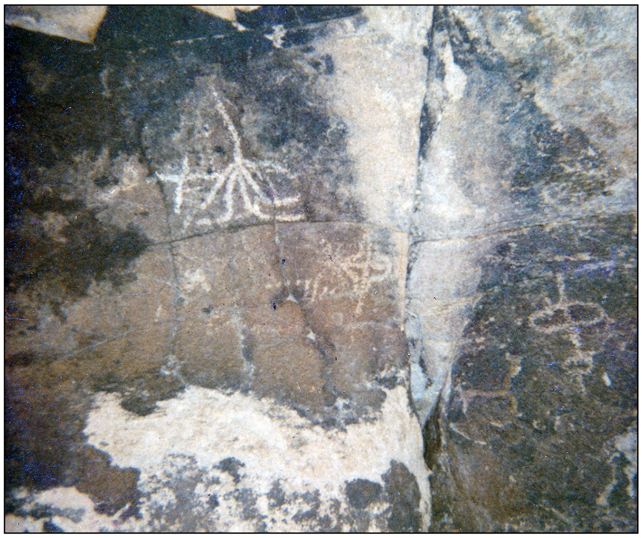
pre-1600.

Direct routes were used by fast, unencumered travelers wise to desert ways. Destinations were resource-rich locations and trade centers.

In today's Mescal Range, dinosaurs traveled to the Jurassic seashore and left their tracks in the sand. R.E. Reynolds photo.

Petroglyphs near the prehistoric turquoise mines in the Halloran Hills. R.E. Reynolds photo.

Petroglyphs near Pipkin Cone. D.M. Miller photo.




Petroglphs and pictographs in Painted Rock cave, eastern Old Woman Mountains, 1966. R.E. Reynolds photos.

Trails in the Travertine Point area above Lake Cahuilla. D.M. Miller photo, 2023.

Shelter cave in southern Wild Horse Mesa contained artifacts including basketry fragments and a "spirit stick." R.E. Reynolds photo, June 1973.

Fish traps along the shoreline of Lake Cahuilla. R.E. Reynolds photo.

Historic explorers

1600–1850s.

Routes favored daily resources such as water and pasture for horses and cattle. Goods were carried by pack animals and draft animals pulling wagons.

Garcés route reenacted during the 2000 Desert Symposium field trip. R.E. Reynolds photo..

Salt Spring, where Jefferson Hunt's party stopped along the Old Spanish Trail in 1849. R.E. Reynolds photo..

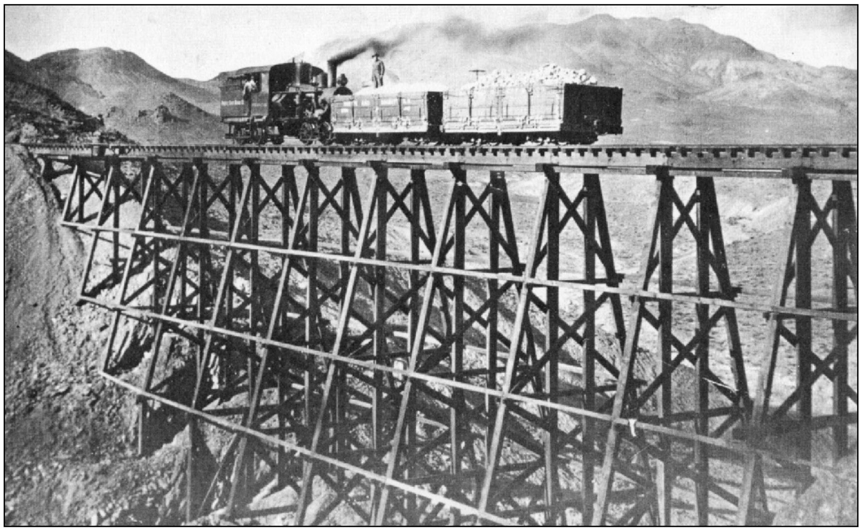
Spanish Canyon cairn at the Crest of Alvord Mountain. D.M. Miller photo, 2023.

Route down into Spanish Canyon. D.M. Miller photo,.

Railroads, mines, and homesteads

1860s–1930s.

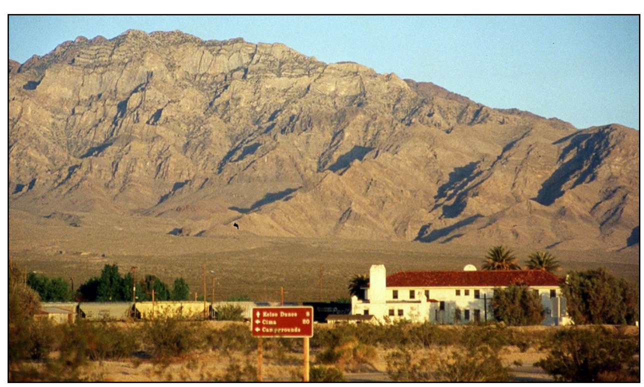
Entirely new and more direct routes, but often devoid of resources. Engineering the landscape resulted in fragmentation of wildlife, plants, and streams.



Borate and Daggett railroad trestle, 1898. Smitheram collection.

Mule team at Silver Lake T&T siding, circa 1906. Reynolds collection.

Railroad foundations at an old crossing at Ash Hill. D.M. Miller photo, 2023.



Kelso Depot and the Providence Mountains, May 1999. D.M. Miller photo.

Kelso depot. Bob Reynolds, Huell Howser, Jim Foote, Jenny Reynolds, 1993. Luis Fuerte photo.

Sagamore mine railroad grade, New York Mountains, 1971. R.E. Reynolds photo.

Tonopah & Tidewater railroad bed, Mesquite Spring. Jenny Reynolds photo, 2017.

Railroad cars buried in Afton Canyon, said to have been abandoned and buried after a derailment in the 1970s. R.E. Reynolds photo, 1999.

Road grader, Colton Hills, view toward Wild Horse Mesa. R.E. Reynolds photo, circa 1976.

Abandoned tractor in Lanfair Valley with Jed and Kate Reynolds. R.E. Reynolds photo, 1977.

Road to the Giant Ledge mine, Caruthers Canyon, 1969. Jenny Flesher photo.

Road to the Black Metal mine, Old Woman Mountains, 1970. Jenny Reynolds photo.

Dozer, Live Oak Canyon, New York Mountains, 1978. R.E. Reynolds photo.

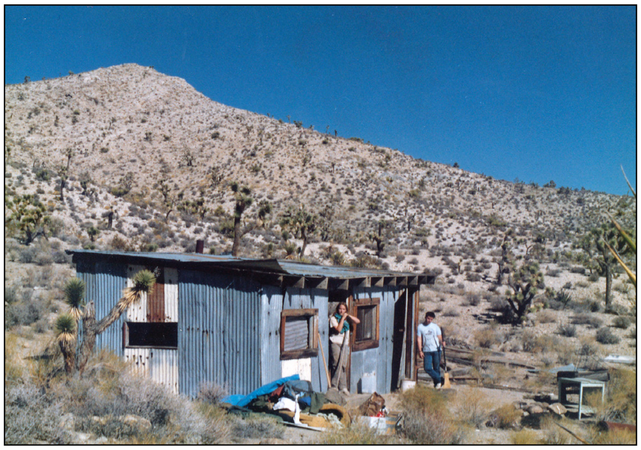
Hay truck stuck in Woods Wash, 1970. Jenny Reynolds photo.

Ungraded road in Lanfair Valley. R.E. Reynolds photo, ca 1990.

Along the Colorado River near Norton's Landing, 1967: Kent Cartwright, Jenny Flesher, Jerry Brem. R.E. Reynolds photo.

Adobe house ruin near El Mirage Lake, 1997. D.M. Miller photo.

Miner's shack, Crescent Peak, Nevada. D.M. Miller photo, May 1991.



Archie Heber cabin, Shadow Valley. R.E. Reynolds photo ca. 1990.

Miner's cabin near Goodsprings, Nevada. R.E. Reynolds photo, 1971.

Miners' cabins, Vontrigger Wash. R.E. Reynolds photo, 1967.

On the road to Pachalka Spring, Clark Mountain, 1969. Jenny Flesher photo.

Short-lived settlement at Pachalka Spring. R.E. Reynolds photo, 1969.

Dugout cabins, Shoshone. R.E. Reynolds photo, 2005.

Jim Winkler cabin, Mid Hills, 1994. R.E. Reynolds photo.

Homestead near Hinkley, 2023. D.M. Miller photo.

Homestead near Saddleback Butte. D.M. Miller photo.

Cree Camp, Halloran Hills. R.E. Reynolds photo, 1999.

Ludlow home along Route 66. D.M. Miller photo, 2023.

May Barnes cabin, New York Mountains, 1980 (left) and 1996 (right, with Jed and Katura Reynolds.). R.E. Reynolds photos.

Ruins of ranch house near Old Woman Springs. D.M. Miller photo.

OX Cattle Company ranch, Lanfair Valley, 1973. R.E. Reynolds photo.

Cima Store (established 1900) and post office (established 1905). R.E. Reynolds photos, 1973.

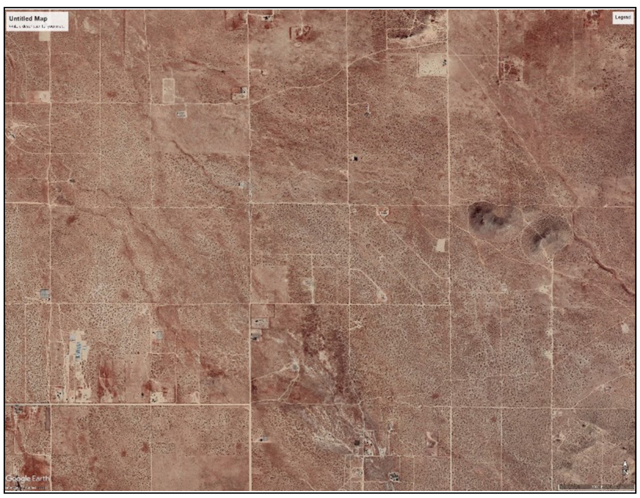
Highways and commerce along them

1930s–1960.

Routes, largely along railroads, led to the growth of towns that served travelers. Supply routes proliferated to deliver water, power, communications, and hydrocarbons to the resource-poor coast.

Early Route 66 at Ash Hill. D.M. Miller photo, 2023.

Traveling toys, Ludlow. D.M. Miller photo, 2024.

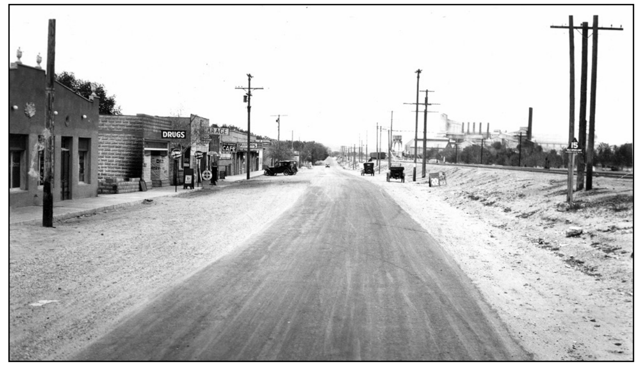


Saddleback Butte area "swindle roads". Google Earth image.

One very wide road on Fort Irwin. D.M. Miller photo, 1998.

Aftermath of an automobile accident, June 12, 1933. SBd 31-E, California Highway Department.

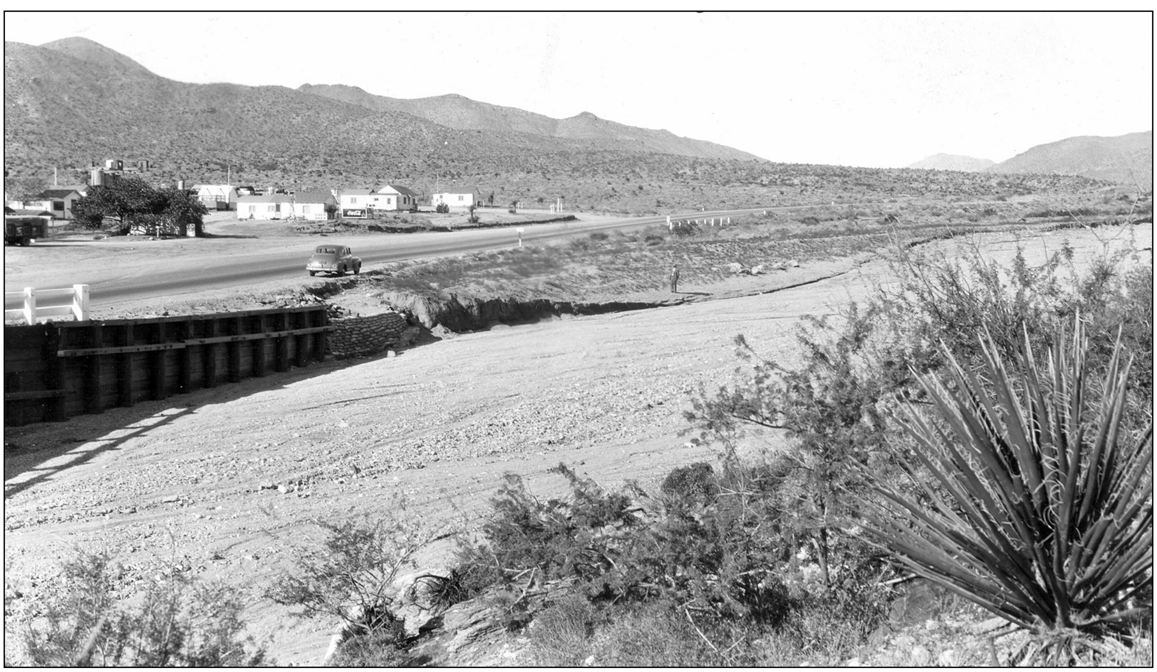
Damage at the quarantine station at Yermo after a wind storm, January 10, 1933. SBd 31-H, California Highway Department.



National Trails Highway through downtown Oro Grande, March 26, 1928. SBd 31-O, California Highway Department.

Victorville Narrows bridge, 1936. W.A. Vale photo, San Bernardino County Museum collection..

Oro Grande bridge over the Mojave River. SBd 31-O, California Highway Department.



Bridge at Wheaton Wash, November 14, 1941. SBd 31-P, California Highway Department.

Road crews on the highway near Harvard, June 26, 1930. SBd 31-L, California Highway Department.

Road crew in Victorville, 1929. SBd 31-C, California Highway Department.

Freeways and the decay of highway towns.

1960–2020.

Yet more direct routes led to increasing fragmentation of desert communities and ecosystems.

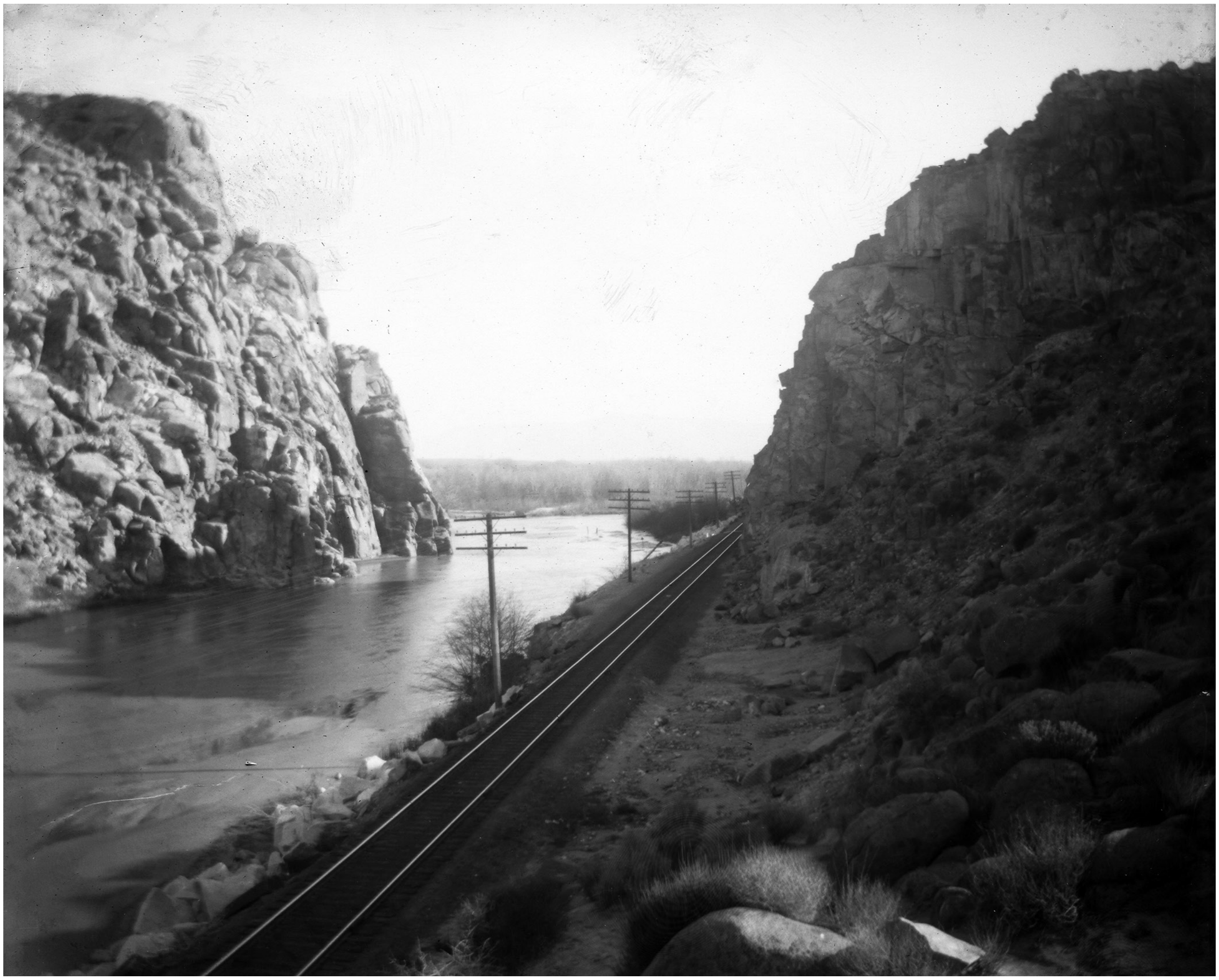
Interstate 15 in the Cave Mountain area. D.M. Miller photo.

Freeway cut at Toomey Hill. D.M. Miller photo.

Disturbance associated with I-40 crossing south of the Granite Mountains. D.M. Miller photo, Oct. 1980.

View north of Interstate 15 from the powerline road east of Manix Lake; Tiefort Mountains on skyline. Jenny Reynolds photo, 2017.

Stopping for a dip in 1967 at Basin Road before freeway drainage systems constrained Cronese Lake. Jenny Flesher; Jerry, Carol, and Pickle Brem. R.E. Reynolds photo.



Railroad tracks through the Mojave River Narrows, Victorville, ca. 1900. Scanned from W.A. Vale glass plate negative, San Bernardino County Museum.

Railroads and mining in the Mojave Desert and southwestern Great Basin, California and Nevada

Gregg Wilkerson[1] and Larry M. Vredenburgh[2]
[1] California State University, Bakersfield; [2] Mojave Desert History and Cultural Association

ABSTRACT— Between 1876 and 2017 thirty-seven railroads were constructed in the Mojave Desert and southwestern Great Basin. This paper addresses the growth of railroads and their links to mining districts over time.

Early transcontinental routes that were built through our study area, the Mojave Desert and southwestern Great Basin, were the Southern Pacific–San Joaquin line (1876) and the Southern Pacific (SP) line that linked Mojave to Needles (1883). The SP connected with the Atlantic and Pacific (A&P) at Needles (Topock), which had been built from east to west from Albuquerque. These two lines both reached Needles at nearly the same time. The Southern Pacific sold their line to the A&P in 1884. In 1885 the California Southern railroad (a subsidiary of the Santa Fe) connected at Barstow with A&P, creating a new line to the port in San Diego through the Cajon Pass. In 1905 the San Pedro-Los Angeles and Salt Lake (which was purchased in 1921 by the Union Pacific) was completed from Salt Lake City to the port of Los Angeles using some track agreements with the Santa Fe for their line between Colton and Barstow. The Carson and Colorado (C&C) was originally planned to connect Carson City with Fort Mojave on the Colorado River. That destination changed to Tonopah, then Candelaria and finally to Keeler in the Cerro Gordo mining district.

The transcontinental railroads provided a transportation framework from which a network of railroads was later connected. These later railroads primarily served individual mines and mining districts. Following the 1848 discovery of gold in Coloma, California on the American River, gold was discovered all along the western slope of the Sierra Nevada—as far to the northwest as the Klamath Mountains. By the late 1850s other mineral deposits were discovered east of the Sierra Nevada, eventually eastward into Nevada, the Mojave Desert, and Arizona.

Construction of the main lines through our study area immediately provided transportation that was less expensive than the mule teams that predated them. Several short lines were built to mineral deposits that were close to the main lines, however distance and demand required the construction of several significantly longer rail lines. There were two long-line railroads dedicated to reaching the Bullfrog (Rhyolite) mining district: Las Vegas and Tonopah (1905) and Tonopah and Tidewater (T&T, 1907). The T&T's primary destination was the Lila C. Mine in the Greenwater Range east of Death Valley.

Changes in United States monetary policy in 1893 and the exhaustion of high-grade deposits led to booms and busts that affected the railroads. Competition from trucks and automobiles also contributed to a reduction in demand for railroad services. Many went bankrupt or were assimilated or merged to survive. During WWII almost all the mining-dedicated railroads in the Mojave Desert and Great Basin were scrapped for much-needed iron to support the war effort. With a few exceptions, today only the original transcontinental lines remain in operation. The Golden Age of the mine railroads that linked remote parts of this area is but a distant memory.

Study area and data summaries

This report describes railroads and their relationships to mines in the California and Nevada portions of the Mojave Desert as well as the southwestern part of the Great Basin along the Carson and Colorado railroad (Figure 1). Maps and detailed descriptions of the railroad routes,are provided at greggwilkerson.com/railroads.

1849: The California Gold Rush

January 24, 1848, was the day James W. Marshall found a gold nugget in the mill race of Sutter's lumber mill at Coloma on the American River. This triggered a huge migration to California that included federal funding (Pacific Railroad Act of 1862) for railroad construction to connect the Midwest (Kansas City, Saint Louis) with the California gold fields (Sacramento). These contracts were issued to the Central Pacific and Union Pacific railroad

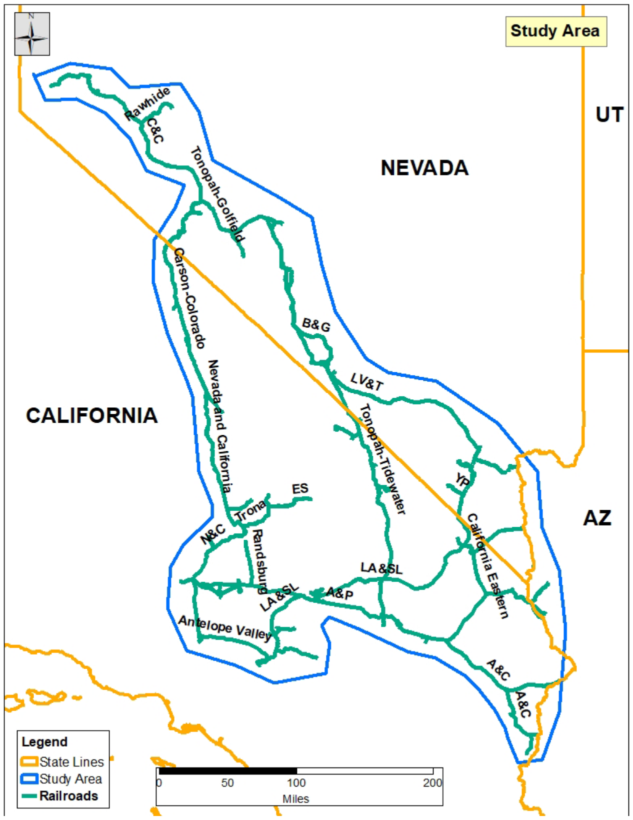


Figure 1. Study Area (blue boundary) with railroads shown. See text for abbreviations of railroad names.

companies. The resulting railroad connected Omaha, Nebraska with Sacramento, California and was completed in 1869.

Discoveries 1856-1876

By the time the SJVL had reached Palmdale, mining districts shown in Table 1 in our study area had been discovered (Figure 2):

Table 1. Mining district discoveries 1856–1876

Mining District (MD)	**Discovery**	**Abandonment**
Goodsprings (Yellow Pine) MD	1856	1964
Santa Fe MD	1856	1964
Comstock MD	1858	1882
Blind Springs MD	1859	1882
Jumbo MD	1859	1930
Silver City MD	1859	1945
Como MD	1860	1936
New York (Vanderbilt) MD early	1861	1941
Buena Vista MD early	1862	1943
Ivanpah MD early	1862	1943
Red Ridge MD	1862	1862
White Mnt MD early	1862	1890
Buckeye (Stedman) MD	1863	1960
Churchill MD	1863	1930
Lone Mountain (Tonopah)	1863	1947
Silver Peak MD early	1863	1948
Candelaria MD early	1864	1890
Randsburg MD early	1864	1935
Cerro Gordo MD	1865	1938
Garfield MD	1865	1945
Nopah MD	1865	1957
Pilot MD	1865	1941
Yerington MD	1865	1930
Silver Star MD	1866	1945
Tokop MD	1866	1930
Columbus Marsh MD	1866	1885
Eagleville MD	1869	1950
Gold Point MD	1870	1870
Searles Lake MD	1870	2024
Charleston MD	1873	1873
Rock Hill MD	1873	2024
Stedman-Bagdad MD	1874	1874
Bristol Lake MD	1875	2024
Fitting MD	1876	1876
Wabuska Wash MD (gold)	1876	1945

1876: San Joaquin Valley Line, Southern Pacific

The first railroad in our study area was a segment of the present Antelope Valley railroad (AVR) which connects Cajon Pass to Palmdale and Mojave. The Tehachapi to Mojave to Palmdale section of this route was originally part of Southern Pacific's (SP) San Joaquin Valley Line (SJVL) which connected Sacramento to the San Fernando Valley at Lang station. That railroad was built 1875 to 1876 and connected Bakersfield (Summit) to Los Angeles via Tehachapi, Mojave, Lancaster, Palmdale, Soledad Canyon, and the San Fernando Valley (Serpico, 2000: 1-2). This segment of the SJVL was not made for any particular mining destination. But it did provide easy access to the mines of the Mojave District including the Golden Queen (1876) and Portland Cement (1955) mines. The SJVL reached Los Angeles via a tunnel from the San Fernando Valley. The line was completed at Lang on September 5, 1876 (Serpico, 2000:12-15). The Mojave to Los Angeles segment of the SJVL is still operated by the SP.

Discoveries: 1877-1895

Mining districts discovwered between 1877 and 1885 in our study area are shown in Table 2.

1882: Atlantic and Pacific

The Mojave Desert portion of the Southern Pacific and Santa Fe railroad was the Atchison, Topeka and Santa Fe (AT&SF). It did not have a particular mining district destination when constructed but many railroads with mine destinations were connected to it after it was built. This included the Ludlow and Southern, Calico and Odessa, Borate and Dagget, Saltus, Pacific Gypsum, Randsburg, and Boron railroads (all too short to show

Table 2. Mining district discoveries 1887–1895

Mining District (MD)	**Discovery**	**Abandonment**
Red Rock MD	1878	1882
Bagdad-Chase MD early	1880	1910
Barstow MD early (gold)	1880	1945
Bishop MD early	1880	1903
Calico MD	1880	1880
Orogrande MD	1880	2024
Providence MD	1880	2024
Slate Range MD	1880	1960
Borate MD	1881	1907
Calico Silver MD early	1881	1915
Divide MD	1881	1915
Greenwater MD	1881	1881
Coso MD	1882	1882
Owens Lake MD	1882	1882
Sacramento Mnts MD	1882	1932
Soda Mnts MD	1882	1882
Cason River MD	1883	1883
Gilbert MD	1883	1883

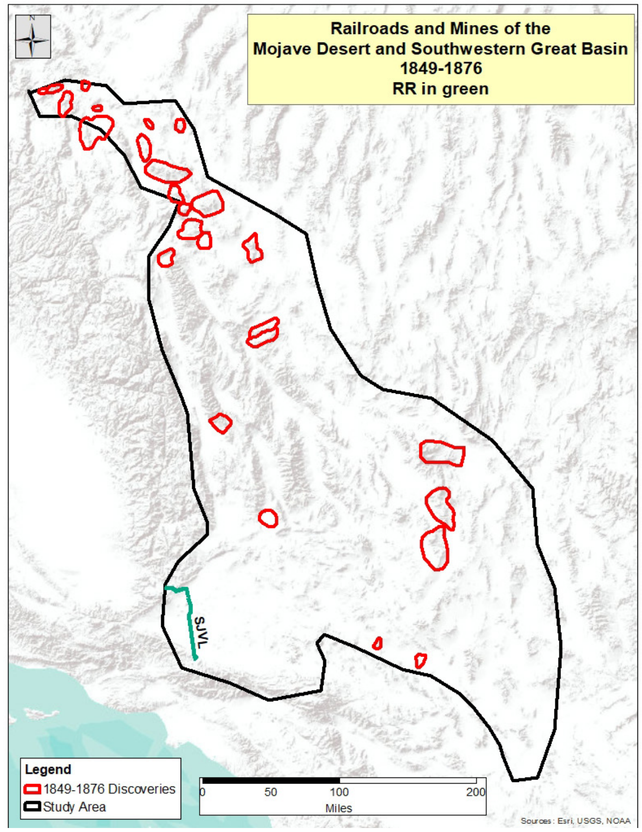


Figure 2. Map of railroads and mining districts 1849 to 1876

on Fig. 3). Mining districts near the A&P were the Sacramento, Piute, Clipper, Marble, Bristol Mountains, Bristol Lake, Southern Cady, Hector, Kramer. and Mojave.

Railroad owners P. Huntington, Mark Hopkins, Governor Leland Stanford, and Charles Crocker built the Southern Pacific railroad. They started in Sacramento and built to Bakersfield, thence over the Tehachapi Mountains to Mojave, which was reached in 1878. Proceeding eastward they reached Waterman (now Barstow) and the Calico mining district and finally Needles at the Colorado River in 1882 (Chappell, 2005: 41-42, Myrick, 1963).

The Southern Pacific (SP) was building another line from Los Angeles to Yuma, while its competitor the Atlantic and Pacific railroad (APR, a subsidiary of the Atchison, Topeka, and Santa Fe railway) was building track from Winslow, Arizona to Topock (southeast of Needles), which was reached in 1882 (Chappell, 2005, p. 42).

With one railroad coming from the east to Needles and another from the west, a negotiation between APR and SP resulted in the sale of the Mojave-to-Needles segment to Santa Fe. After a series of mergers and bankruptcies the old Atchison, Topeka and Santa Fe railway (AT&S) became the Burlington Northern and Santa Fe (BN&SF) railway in 1996 (Chappell, 2005, p. 42).

1882: Candelaria

The Candelaria mining district was discovered in 1864 and the Carson and Colorado (C&C) railroad was built through the area in February 1882. The Candelaria Railroad connected the town to the C&C. Candelaria was the reason the C&C changed its plans to build a railroad to Fort Mojave on the Colorado River. Service to Candelaria was closed in 1931 (Myrick, 1962: 209; Western Mining History, 2023d).

1883: Carson and Colorado

Mining activity in the 1850s and 1860s in northern Nevada (Comstock in 1859; Candelaria in 1864) and east-central California (Aurora in 1860; Bodie in 1859) resulted in incorporation of the Carson and Colorado Company (C&C) on May 10, 1880. The original plan was to build the railroad from the Mound House on the Carson River (10 miles east of Carson City) to Fort Mojave on the Colorado River near present-day Needles. The line reached Keeler on the east shore of Owens Lake in 1883. The C&C became part of the Southern Pacific railroad and operated through 1960 and never made it to the Colorado River (Myrick, 1962, p. 169). The Nevada and California (N&C; Mojave to Owenyo) and the C&C (Carson City to Owenyo) were absorbed by the Southern Pacific railroad in 1912. The narrow-gauge line from Mina to Benton on the old C&C was abandoned in 1938, and the line from Benton to Laws in 1942. The last revenue run on the S.P. narrow-gauge from Carson City to Keeler happened in 1959. The rails were pulled up in 1960 (Nordell, 2024).

The C&C connected to several short-line mine railroads. These were the Rawhide (never completed),

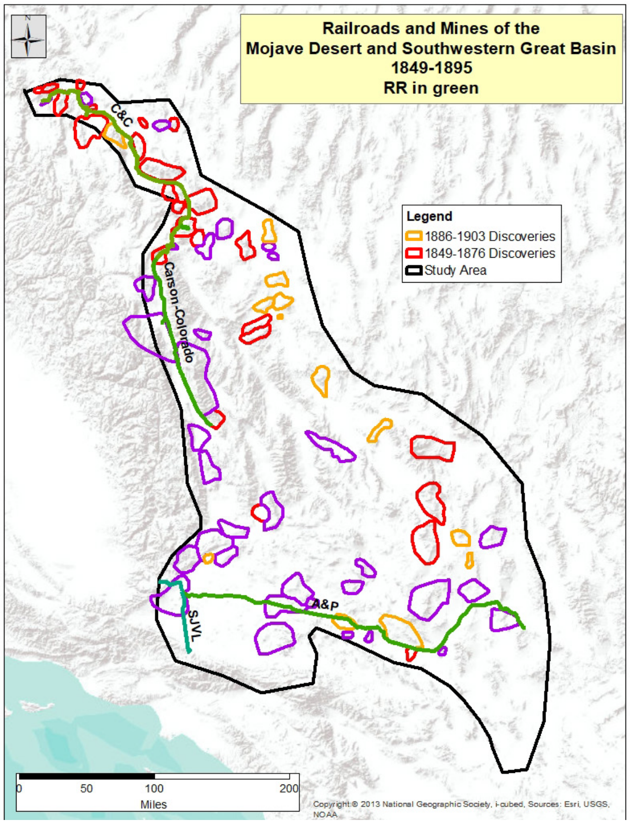


Figure 3. Map of railroads and mining districts 1849 to 1895

Table 3. Mining district discoveries 1896–1903

Mining District (MD)	Discovery	Abandonment
Goldfield MD	1897	1949
Copper World Smelter	1898	1920
Hector MD	1898	1920
Wagner MD	1898	1898
Cuprite MD	1900	1924
Stonewall MD	1900	1900
Tohopah MD	1900	1947
Mountain View MD	1901	1907
Johnnie MD	1902	1902
Kohen (Saltdale) MD early	1902	1949
Bare Mts MD	1903	1903
Bristol Mts MD	1903	1935
Castle MD	1903	1923
Sunset-Crecent MD	1903	1927

Rhode's Marsh, Belleville, Candelaria, Bishop (never completed), Dolomite, Swansea, and Keeler (Cerro Gordo Smelter). The mining districts near the C&C included the Como, Wabuska Marsh, Churchill, Desert Mountains, Yerington, Mountain View, Buckey, Fitting, Pamico, Garfield, Santa Fe, Pilot, Rhode's Marsh, Candelaria, Eastside, Basalt, Buena Vista, Blind Springs, Volcanic Tablelands, White Mountains, Bishop Tungsten, Southern Inyo, Alabama Hills, and Cerro Gordo.

1885: California Southern

The California Southern (CS) railroad connected San Diego to San Bernardino, then Cajon Pass and Barstow. It was completed in 1885 under a partnership with the Santa Fe railroad (Myrick, 1963:774). This line became part of the Los Angeles and Salt Lake railroad through track agreements in 1905 (Serpico, 1988; Signor, 1988). The CS and LA&SL connected to the Mojave Northern and Cushenberry Mine railroads. The CS line went through the Oro Grande and Barstow mining districts.

1893: Denver depression

A nationwide economic depression from 1893 to 1896 resulted in bankruptcies of many mines and railroads, especially those that produced mainly silver. This collapse was exacerbated by the repeal of the Sherman Silver Purchase Act of 1893 which precipitated a dramatic fall in silver prices. The oversupply of silver was also caused by the discovery of the Leadville District in the San Juan Mountains of Colorado (Steeples and Whitten, 1998).

Discoveries: 1896-1903

Mining districts discovered between 1896 and 1903 in our study area are shown in Table 3.:

1896: Borate and Daggett railroad

The Pacific Coast Borax Company was owned and operated by Francis Marion Smith. His first large mining venture was at Borate in the eastern Calico Mountains. The district was discovered in 1883 and developed in 1890.

Figure 4. Train on trestle at Borate, Calico District. Death Valley National Park collection.

Figure 5. Copper World Smelter. From Larry Vredenburgh collection.

The Borate and Daggett (B&D) railroad was finished in 1896. Main mines of the Calico District were the Union, Centennial, Pacific, Union Borax, and Palm Borate (MRDS, 2011; Southern Pacific, 1964, p. 170, 187, 189; Wright and others, 1953: 244; Myrick, 1963: 823-827). In 2022, lithium enrichments in the clays around Borate were reported (Benson, 2023). The B&D shared some tracks with the Calico and Odessa (C&O) railroad.

West of these borate mines were the rich silver mines of Calico. The Borate and Daggett railroad (B&D) was built by Smith from Borate, past Calico and down to the Mojave River at Daggett. This work began and was completed in 1898. At Daggett a borate shipping facility and silver ore processing mill (Waterman mill) were built. By 1905 the reserves at Borate were nearly all developed and in 1907 the much richer Lila C. Mine was discovered. In that year the tracks of the B&D were taken up and the line abandoned (Wilkerson, 2022; Chappell, 2004, p. 43; Myrick, 1963: 823-827).

1896: Copper World smelter

The Copper World mine and smelter in the Clark Mountains never had a railroad, but it became a possible destination that affected other railroad developments. The original smelter was built in 1896 (Hewett, 1956, p.135; Wilkerson, 2020h; Vredenburgh, 1996).

1898: Randsburg (early)

The Randsburg railroad serviced the mines of Atolia, Red Mountain, and Rand Mountain by connecting to the Atchison, Topeka and Santa Fe railroad at Kramer Junction. The first gold discovery in the El Paso Mountains was at Goler (between Red Rock Canyon and Randsburg) in 1893. This discovery drew many miners to the area and the surrounding hills were heavily prospected. In 1895 a party of prospectors found placer gold at the foot of the Rand Mountains and soon traced the source of the gold to an outcropping near the top of the mountain. This discovery would become the fabulous Yellow Aster mine, and a minor rush to the new Rand district was initiated. Some of the important mines of the district were the Big Norse, King Solomon, Monkey Wrench, Minnehaha, Bully Boy, Napoleon, Gold Coin, and of course the famous Yellow Aster (Western Mining History, 2023a; Myrick, 1963: 793-808).

The Randsburg railway was a 28.5-mile branch of the Atchison, Topeka, and Santa Fe railroad (AT&SF). The line started at Kramer Junction, California, and terminated at Johannesburg, California, with a stop at Atolia. The line was completed on January 5, 1898, and began operation on January 17, 1898. The railway was acquired by the AT&SF in 1903. During its 35-year history, the Randsburg railway served a number of local mining operations; it also provided passenger service (Wikipedia, 2023c; Myrick, 1963: 793-798). The Randsburg line did not connect northward to the Nevada and California railroad.

Gold mining in the Randsburg mining district continued through the early 1930s. There was a hiatus in gold mining from WWII until the Yellow Aster reopened as an open pit operation from 1986 to 1994. Tungsten mining in the Atolia area continued through the Korean War (circa 1953) (Western Mining History, 1923a). The Randsburg railway served as a supply link to the Rand Mine, which produced more silver than any mine in California. The Rand mine closed in 1929, as it was no longer profitable (Myrick, 1963: 793-798). The Randsburg railway ceased operations on December 30, 1933, a victim of the Great Depression and a decline in the mining industry. The rails were removed the following year. Portions of the grade are still visible along U.S. Route 395 between Kramer and Johannesburg (Wikipedia, 2023c; Myrick, 1963: 793-798).

1902: Nevada Southern and California Eastern

The Nevada Southern-California Eastern railroad (NS&CE) was originally built by a consortium headed by Isaac C. Blake of the Needles Reduction Company to service the New York and other mines in the New York Mountains. The NS began at Goffs on the Atlantic and Pacific railroad. The Nevada Southern railroad (NS) was incorporated December 15, 1892 (Myrick, 1963: 842; Chappel, 2005). The original destination for the NS&CE were the mines of the Vontrigger Hills (Exchecker District) and New York Mountains.

Beginning at Goffs in January 1893 the Nevada Southern railroad proceeded north to Manvel, arriving there in July of that year. Manvel was the headquarters of the Rock Springs Land and Cattle Company (Chappel, 2005, p. 43; Myrick, 1963: 841-848). The mines of the

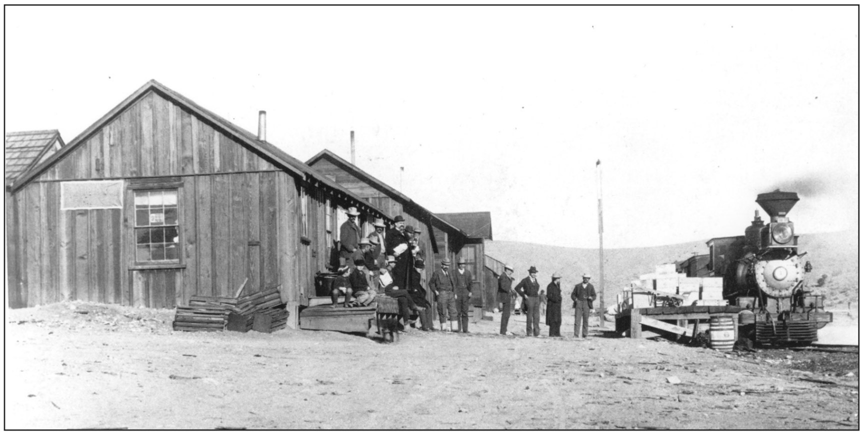


Figure 6. Manvel (now Barnwell). Myrick (1963:846) and Larry Vredenburgh collection

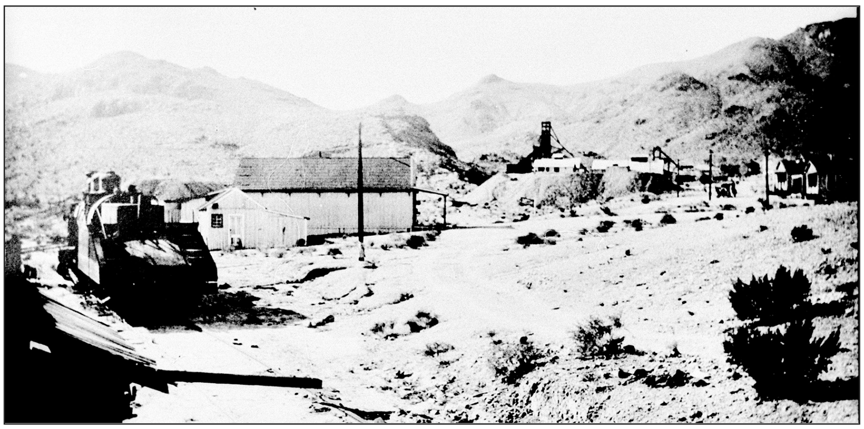


Figure 7. Ludlow in the early 1930s. Los Angeles Metropolitan Water District collection

Exchequer District in the Vontrigger Hills were near this first phase of NS construction (Wilkerson, 2020a).

Because of the silver crash of 1893 and resulting depression in the mining industry, plans to extend the line to Pioche from Manvel ended with the company's bankruptcy in 1894. At that time the NS had built the line to the mesa overlooking the mining camp of Vanderbilt. (Chappel, 2005, p. 43; Myrick, 1963: 841-848). In 1898 a smelter was built at the Copper World Mine in the Clark Mountains by the Ivanpah Copper Company (Wilkerson, 2022b). This resulted in a rejuvenation of the NS as California Eastern railway (CE; Chappel, 2005, p. 43; Aubery, 1902; Aubery, 1908; Hewett, 1956: 135; Myrick, 1963: 841-848).

Construction resumed in April 1901. The rejuvenation started at Manvel (renamed Barnwell) in the New York Mountains and proceeded to the mining camp of Vanderbilt (Wilkerson, 2020c). From there it was built northward along the Ivanpah Valley to the railroad's terminus at a point near the Ivanpah mining camp at the Los Angeles and Las Vegas (LA&LV) railroad, arriving there in 1902. An extension of the railroad to the mining district of Goodwell was surveyed but never constructed. The California Eastern railway became a branch of the Santa Fe in July 1902 (Chappel, 2005, p. 43; Myrick, 1963: 841-848).

Competition in 1905 from Senator Clark's San Pedro, Los Angeles & Salt Lake railroad (LA&SL) (which crossed the California Eastern north of Vanderbilt) and construction of the Tonopah & Tidewater reaching north from Ludlow reduced revenues for the California Eastern and the line was abandoned March 10, 1921 (Chappel, 2005, p. 53; Myrick, 1963: 841-848; Menchaca, 2023).

1903: Ludlow and Southern railroad

The Ludlow and Southern (L&S) railroad was built to serve copper mines in northern Bullion Mountains. It connected to the Atlantic and Pacific (A&P) at Ludlow and was within the Stedman-Bagdad mining district.

Copper and gold mineralization in the area of the current Bagdad-Chase and Roosevelt mines was discovered most likely around the early to late 1880s by John Suter, roadmaster for the Atlantic and Pacific subsidiary of the Santa Fe railway. Discovery dates, which have been reported or which

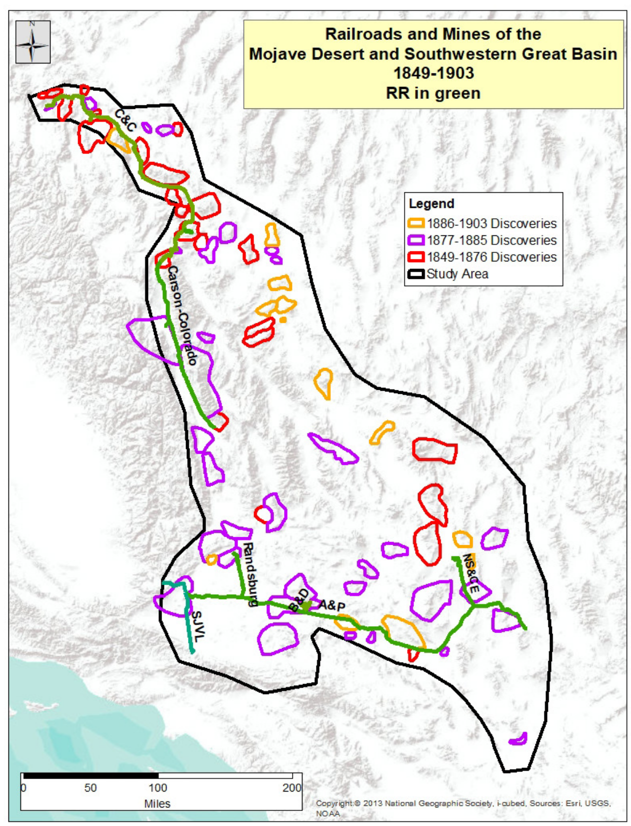


Figure 8. Map of railroads and mining districts 1849 to 1903

can be inferred from various sources, range from 1880 to 1903 (Mansfield, 2005). Construction began in 1902 and 1903 on the 7.8-mile-long railroad, which was built with spurs going to Stedman and Bagdad-Chase mills (Myrick, 1963: 827-835; Ross, 2009). The Bagdad-Chase served the mines of the northern Bullion Mountains. These included the Ragtown, Old Pete, Bagdad, Ambush, Buckey-Stedman, Dull Pick, Gold Standard, Markerson, and Bullion Range mines and the mills at Stedman and Bagdad (Wilkerson, 2020d; 2020e; Ross, 2009; Bonas and Anderson, 2023).

The Bagdad Chase was one of only four gold mines in California to be authorized to remain in production during World War II; the ore's silica content made it useful as a flux in smelting. Although not very profitable after WWII, the mine operated continuously from 1940 to 1954. The railroad fell into disuse in 1916 with the arrival of diesel-powered trucks for ore haulage. The railroad was dismantled in 1935 (Mindat, 2020c; Myrick, 1963: 827-835; Ross, 2009).

Discoveries: 1904-1909

Mining districts discovered between 1904 and 1909 in our study area are shown in Table 4:

Table 4. Mining district discoveries: 1904–1909

Mining District (MD)	**Discovery**	**Abandonment**
Bullfrog-Rhyolite MD	1904	1916
Pacific Plaster MD	1904	2024
Piute MD	1904	1916
Bullfrog MD	1904	1914
Big Maria MD	1905	1933
Ardan (Blue Diamond) MD early	1905	2024
Carrera mine (Bare Mnts)	1905	1916
Danby MD	1905	1905
Nopal-Tecopa MD	1905	1914
Arden MD	1906	1906
Atolia MD	1906	1955
Alunite MD	1907	1907
Castle Mnt (Hart) MD old	1907	1955
Chubuck mine (Kilbeck Hills)	1907	1930
Exchecker MD	1907	1907
Silurian Hills MD	1907	1907
Sutor MD	1907	2024
Tecopa MD	1907	1940
Kramer-Boron MD	1908	1908
Calico Silver MD late	1909	1938

1904: Tractor Road

Pacific Coast Borax had purchased the Lila C Mine from Willim Tell Coleman in 1890. This mine was in the Greenwater Mountains east of Death Valley. Smith proposed and built a wagon road from the upper end of the California Eastern railroad at Second Ivanpah over the State Line Pass in the Spring Mountains thence to Mesquite Valley, California Valley, Tecopa, Shoshone, Eagle Mountain and then northwest to the Lila C. Mine. This road was completed in 1904. An experimental diesel-electric tractor ("Gibbs Engine") was designed, ordered, and built but never put into service on Smith's Tractor Road. This contraption had a gasoline engine that generated electrical power to motors geared to the rear wheels of the borax wagons. Instead of using "Gibbs", an older steam tractor, "Old Dinah" (that had been in use at the Calico Mountains borate mines prior to building the Borate and Daggett railway and is now on display at the Death Valley Visitor's Center) was brought to Ivanpah II at the junction of the NS&CE railroad with the LA&SL railroad in the south-central Ivanpah Valley near the Vanderbilt Mine But it broke down on State Line Pass at the eastern end of the Clark Mountains and had to be towed by mules back to Ivanpah (Hildebrand, 1982).

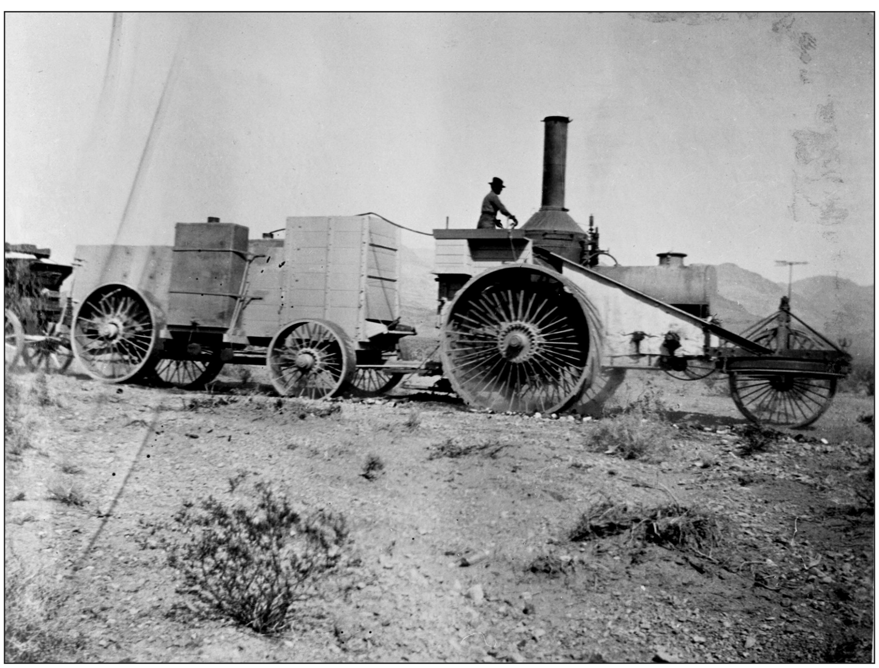


Figure 9. Tractor and wagons for the tractor road. Photo by Richard Bayley. Mojave Desert Historical and Cultural Association collection

1904: Tonopah and Goldfield railroad

The Tonopah and Goldfield (T&G) railroad was built to service both the Tonopah and Goldfield mining districts. It connected to the C&C, LV&T railroads and T&T railroads.

The Tonopah mining district was discovered May 17, 1900, by

Jim Butler following a hunt for his lost mule. The district operated during the period 1900 to 1947. The Goldfield District, located in Esmeralda and Nye Counties, was discovered in 1902. It is one of Nevada's most famous historic gold districts. Extremely rich ore discoveries resulted in the rapid development of the Goldfield camp into the state's largest city, only to be nearly abandoned in the 1920s as the gold ran out. From 1903 through 1959 the district produced over 4,000,000 ounces of gold. Currently, a large project is underway to resume mining at Goldfield (Western Mining History, 2023g).

The route from Tonopah Junction (Mile Post 143) on the Carson and Colorado railroad) to Tonopah was surveyed in 1903. On July 25, 1903, the Tonopah railroad Company was formed and tracks reached Tonopah on July 23, 1904. Flooding destroyed parts of the railroad in 1904 soon after it was built. Grading began February 11, 1905, and service was established Sept. 25, 1905. The line was abandoned after several cycles of near bankruptcy in 1927 (Myrick, 1962: 236-267).

The mines and geology of the Tonopah District are described by Albers and Stewart (1972), and Ashley (1974), Kral (1951), Lock (1912), Balliet (1914), Bastin and Laney (1917), and Spur (1905). Tonopah's history is described by Latschar (1981).

Principal mines included the Mizpah, West End Consolidated, Halifax Tonopah, Jim Butler Tonopah, MacNamara, Mizpah Extension, Montana - Tonopah, North Star, Rescue Eula, Tonopah Belmont, Tonopah Extension, and Tonopah Midway Mines. The most productive of the Tonopah mines were centered between Mount Oddie and Mt. Brougher, near the south end of the San Antonio Mountain Range. Some of the more productive mines were on the southwest flanks of Mount Oddie (Mindat, 2023b).

1904: Pacific Cement Plaster

The Pacific Cement Plaster Company was situated between Amboy Crater and Bristol Lake. It was connected to the Atlantic and Pacific (A&P) railroad. The company built a mill at Amboy as early as 1905 and commenced operations the following year. To feed the mill, a narrow-gauge track about 1.5 miles long was strung south to the gypsum beds in Bristol Lake. The cars were pulled by mules (Myrick, 1963: 835-837). The California Salt Company had its own railroad to process salt from evaporation ditches in Bristol Lake. They were producing salt in 1904. The mill and railroad, refurbished during WWII, are still in operation (Myrick, 1963: 840).

1905: Ivanpah

The Ivanpah railroad was a spur line that connected to the LA&SL railroad. It was in the Ivanpah Valley adjacent to the Ivanpah mining district. Ivanpah (sometimes referred to as Ivanpah I) was a short-lived silver mining town. In 1862, gold was discovered in the northeast side of the Clark Mountains, 7.3 miles southeast of the present Mountain Pass mine. In 1869 the town of Ivanpah was established there and existed at least until the mid-1880s. Mining continued through 1915 with some activity in the 1930s and up to WWII. The main mines of the Old Ivanpah district were the Kewanee, Mollusk, Morning Star, New Era, and Teutonia (Hewett, 1956; Tucker and Sampson, 1943: 438-465; Wright and others, 1953. The Morning Star mine was developed between 1927 and 1933. It became an open pit operation from 1974 to 1990. Concentrates were made at the refurbished Vanderbilt mill in the New York Mountains (Wilkerson, 2022g; Western Mining History, 1923i).

The town moved south within Ivanpah Valley in 1905 as "Ivanpah II" with the arrival of LA&SL railroad which joined the Nevada Southern-California Eastern railway (NS&CE) at the Ivanpah Junction. A spur line was built from the LA&SL/NS&CE junction north to the mines. The Ivanpah was a northward continuation of the California Eastern railroad. In addition, there was a spur line built to the Vandenberg mine. The Ivanpah railroad and its associated lines (Searchlight and Barnwell) were decommissioned after several washouts in 1923 (Myrick, 1963: 842-845).

1905 (San Pedro) Los Angeles and Salt Lake

The Los Angeles and Salt Lake (LA&SL) railroad, as its name indicates, connected Los Angeles and Salt Lake. It did not have any specific mining district in mind as a destination when construction started, but many mine railroads later connected to it. These included the Cushenberry, Mojave Northern, Calico and Odessa, Ivanpah, Yellow Pine (Goodsprings), Blue Diamond, and Six Companies railroads. Mining districts near or serviced by the LA&SL were the Lucerne-Big Bear, Oro Grande, Barstow, Calico, Borate, Cronese, Providence, New York, Ivanpah, Sunset-Crescent, Goodsprings, and Ardan.

The Los Angeles and Salt Lake (LA&SL) railroad involved competition, mergers, and cooperation between several companies. The LA&SL began surveying and constructing a subsidiary Utah Southern railroad southwest from Salt Lake to Milford, Utah. In 1888 a reorganized LA&SL built railroad grade 145 miles but only 8 miles of track from Milford to Pioche, Nevada. The crash of 1893 led to a reorganization and rejuvenation of the LA&SL by Edward Henry Harriman until 1898. At this time a competitor and owner of the rich copper mines at Butte, Montana, Senator William Andrews Clark, purchased the Los Angeles Terminal railway. Clark also created the Utah and California railroad and obtained the rights to survey a route across Utah to the Nevada state line. A compromise between Harriman and Clark on July 9. 1902 resulted in a merger. Track was laid east from Los Angeles and west from Utah. The efforts joined at an empty area of Nevada desert about 27 miles west of Las Vegas on January 30, 1905. The LA&SL later became part of the Union Pacific railroad (Chappel, 2005, p. 43;

Myrick, 1963: 623-683). The old LA&SL route is still in operation.

1906: Silver Peak

The Silver Peak railroad (Blair) line was a spur line from the Tonopah and Goldfield railroad that serviced the Silver Peak mining district. Blair Junction was about halfway between Tonopah and Tonopah Junction in Big Smokey Valley on the southern flank of the Monte Cristo Range. The Silver Peak railroad Company was organized in 1906 and the line was completed to the Tonopah and Goldfields railroad at Blair Junction that same year. The district ceased activity in 1948 following a fire (Myrick, 1963: 202-293).

The mines in the Blair-Silver Peak area included the 16 to 1, April, Black Warrior Mine, Blair, Columbus Mine, Coyote Mine, Crescent Mine, Crowning Glory Mine, Dewar Perlite, Drinkwater Mine, Esmeralda Prospect, Foote Minerals Gravel Pit, Gold Hill, Golden Eagle Mine, Great Gulch Mine, Homestake, Last Chance, Mary, Mineral Ridge Mine, Modern Milling, Oremonte, Pocatello Mine, Red Light Mine, Silver Peak, Silver Peak Marsh, Solberry Mine, Vanderbilt, Vega Mine, Virginia Group 17 Claims, and Western Soldier Mine. These mines are described in Spurr (1906), Minobras (1973) Keith (1977); Hewett (1956), Koschmann and Bergendahl (1968), Albert and Stewart (1972), Shamberger (1976), Quade and Tingley (1984), and Lowe and others (1985). Some of the major mines were at elevations of over 7,000 feet while the towns were at 4,300 feet. A tramway 1.5 miles long connected the mines to the ore bins at the foot of the mountains and huge wagons were used to haul ore to the mills (Myrick, 1963: 292).

1907: Quartette (Searchlight to Cottonwood)

The Quartette railroad (Q, Fig 14) connected Searchlight to Cottonwood Cove on the Colorado River. It connected to the Barnwell and Searchlight (B&S) railroad at Searchlight and from the B&S to the NS&CE railroad at Barnwell.

Gold was discovered in 1897 at Searchlight and a mill was built at Cottonwood Cove. The 16-mile-long Quartette connected them in 1902. In 1906 a new mill was built in Searchlight. In the 1930's an amalgamation and cyaniding plant was built at Cottonwood Island and the railroad rebuilt. Operations ceased in 1953 when the Davis Dam was constructed (Canyon Country, 2023).

The Quartette later expanded its lines to Barnwell to the west and Nipton to the northwest. These lines were abandoned in 1924 (Myrick, 1962: 848-854).

1907: Western Minerals (Calico)

The Western Minerals railroad connected to the Calico and Odessa (C&0) railroad and through it to the Atlantic and Pacific (A&P) railroad. Borates in Lead Mountain west of Calico and southwest of Daggett at the Columbia Mine were discovered before 1894. These deposits were purchased by the American Borate Company for the manufacture of boric acid. They built the "Western Mineral railroad" to the mines in 1901. This route shared part of the C&O that connected the Waterloo Mill at Daggett with the ore bins for the Waterloo mine on the southern slope of the Calico Mountains. The Western Mineral railroad along with its mine and mill were dismantled in November 1907 when better ore (colemanite) was discovered in Tick Canyon thirty miles north of Los Angeles (Myrick, 1963: 826).

1907: Barnwell and Searchlight

The Barnwell and Searchlight (B&S) was a subsidiary of the Quartette railroad. It connected Barnwell and the NS&CE railroad to Searchlight, Nevada. The Searchlight mining district was discovered in 1897 and was most productive from 1903 to 1907. The main producing mines were the Bay City, Continental Heap, Coyote, Cyrus, Duplex, Good Hope, Padden, Quartette, Searchlight and Southern Nevada (Callahan, 1939; Lincoln, 1923; Ferguson, 1929; Longwell and others, 1965: 201, NDM, 1983, 1984; USBOM, 1937: 15; Ransome, 1907).

The Barnwell and Searchlight railroad was incorporated shortly after the mines started production and was completed on March 31, 1907 (Myrick, 1963: 851). The Barnwell and Searchlight with its parent company the Quartette railroad ended operations in 1924 (Canyon Country, 2023).

1907: Tonopah and Tidewater

The Tonopah and Tidewater was built to connect Ludlow on the A&P line to the Lila C mine near Death Valley Junction. After reaching Death Valley Junction, the T&T was extended to Rhyolite in the Bullfrog mining district (Chappell, 2005, p. 46; Myrick, 1963, p. 545-597).

The T&T was a main line connection for several spurs, including the China Ranch, Tecopa, Gerstley, Lila C., Ryan (Death Valley), Ash Meadows, Carrera, and Bullfrog and Goldfield railroads.

Mining districts near the T&T were the Bullfrog, Bare Mountains, Ash Meadows, Greenwater, Resting Springs, Nopah-Tecopa, Silurian Hills, Soda Mountains, and Southern Cady Mountains.

After the failure of his tractor road, Smith proposed building a railroad north from Senator Clark's San Pedro, Los Angeles & Salt Lake railroad which was then under construction. Clark initially agreed to this situation, but after Smith had built a number of miles of standard gauge grade north of Las Vegas, Clark refused to let Smith connect the T&T to his Salt Lake and Las Vegas railroad. Instead, Clark began building his own railroad from Las Vegas to Beatty and Rhyolite. He would name this the Las Vegas and Tonopah railroad (LV&T). This set up a competition to see who would first reach the new mining town of Rhyolite. Clark planned for his new railroad to service the mines at Rhyolite, Bullfrog, Tonopah, and Goldfield in Nevada. In response to this double cross,

Figure 10. Ore bins and town of Ryan, looking northwestward down Furnace Creek. DM photo 7295, Waring (1916) Report 15. Photo No. 33

Smith abandoned railroad making at the Lila C (Death Valley Junction) and built his Tonopah and Tidewater (T&T) railroad all the way from Ludlow on the Santa Fe railroad. The T&T would go to the Lila C via Crucero and the future town of Baker, thence northward to Gold Station south of Beatty and then west to Rhyolite. The T&T was incorporated July 19, 1904. Construction commenced at Ludlow November 19, 1905, and the line was completed to Gold Center in the Bullfrog mining district in October 1907. The T&T never made its own track to Tonopah. The T&T absorbed the failing B&G railroad in September 1918 when its parent company the LV&T was closed by the United Railroad Administration. The Death Valley (Ryan) railroad (part of T&T) was abandoned in 1931. The Ludlow T&T station was closed October 8, 1933 (Chappell, 2005, p. 46; Myrick, 1963, 545-597).

1907: Soda Lake

The Tonopah and Tidewater railway passed along the western edge of Soda Lake and the eastern slope of the Soda Mountains. Here two salt railroads were built. The almost always dry Soda Lake had a veneer of evaporite minerals that formed and reformed annually. Two groups of entrepreneurs attempted to collect and beneficiate these salts in the vicinity of Soda Springs (later to become Zzyzzx, Vredenburgh, 2022). This enterprise was attempted by the Pacific Coast Soda Company which purchased 22 mining claims from Russ Avery in October 1907. A mile and a half long 30-inch gauge spur line was built out into Soda Lake from a plant near Soda Springs. Around 1911 another company, the Pacific Salt and Soda Company, built a plant north of Soda Springs to process the chemical salts. The track for this company's short railroad was 36-inch gauge. These operations did not last very long, and little is known about them. (Chappell, 2005, p. 47-48; American Mining Review, 1908).

1907: Las Vegas and Tonopah

The history of the Las Vegas and Tonopah railroad is associated with three gold districts: Tonopah, Goldfield, and Bullfrog-Rhyolite. Four railroads competed for these markets: Tonopah and Goldfield (T&G), Bullfrog and Goldfield (B&G), Las Vegas and Tonopah (LV&T) and the Tonopah and Tidewater (T&T). The Los Angeles and Salt Lake (LA&SL), by a compromise with Union Pacific, had been completed January 30, 1905, under the direction of Senator Clark. Clark had a tentative agreement with Francis Marion "Borax" Smith in July 1904 to build a line from the LA&SL at Las Vegas over to Smith's Lila C mine and Death Valley Junction. Clark reneged on that agreement and initiated a "race" with Smith to build railroads to what is now Beatty and Rhyolite (Myrick, 1963: 455-554; Legends of America, 2023). The LV&T connected to the Carrera, B&G, T&G and T&T railroads. Mining districts near the LV&T were the Bullfrog, Bare Mountains, and Charleston.

Ed Cross and Frank "Shorty" Harris discovered the Bullfrog mine on August 9, 1904, and the town of Rhyolite was booming in 1905. Clark's engineers surveyed the LA&T route February 25, 1905. Smith commenced his T&T railroad from Ludlow, and at the same time the B&G was building track south from Goldfields. Meanwhile additional discoveries were being made at Goldfields, Bullfrog, and Tonopah. The LV&T was completed to Gold Center, south of Beatty, October 12, 1906, and made it to eastern Rhyolite via Beatty on December 18, 1906. The next phase in the LV&T was to build a railroad north to Bullfrog. This section of the LV&T sometimes was laid down parallel to the B&G line. The LV&T arrived at Goldfield in October 1907 (Myrick, 1963: 455-554).

The LV&T also played a key role in the development of Las Vegas as a tourist destination. The railroad brought visitors to the city from other parts of the country, and many of these visitors were attracted by the city's casinos and nightlife. This helped to establish Las Vegas as a center for gambling and entertainment, a reputation that it still holds today. The LV&T ceased operations in the 1930s due to declining mining activity in the region and the increasing popularity of automobiles and trucks for transportation.

1907: Crystal Salt (Saltus)

The Saltus railroad was a spur line off the Atlantic and Pacific (A&P) railroad. Salt was discovered in the 1880s at Bristol (Dry) Lake between the southern tip of the Bristol

Figure 11. Saltus train. California Division of Mines and Geology collection.

construction of a 3-foot gauge railroad. It operated through 1930 (Myrick, 1963: 760).

1908: Bullfrog and Goldfield railroad

The Bullfrog and Goldfield (B&G) was a competitor of the Tonopah and Goldfield (T&G) railroad. It was organized in March 1906 to build a railroad south of Goldfield to the Bullfrog (Rhyolite) mining district (Myrick, 1962, p. 262). The two companies sometimes had parallel tracks. Some sections of the B&G were shared with the Las Vegas and Tonopah railroad (LV&T). Various mergers, expansions and contractions occurred on the LV&T, T&G, T&T and B&G between 1908 and after WWI. In 1914 the B&G was absorbed into the Las Vegas and Tonopah (LV&T) railroad. The B&G and associated railroads were abandoned in September 1948 (Myrick, 1962, p. 288).

Goldfield was serviced by the T&G railroad which connected north from Goldfield to Tonopah. The LV&T went south from Goldfield through the eastern Chispa Hills and then south to the Esmeralda/Nye County line. Here the LV&T and the B&G tracks ran parallel or on similar routes to Stonewall Pass and Bonnie Clair. Southeast of Bonnie Claire the LV&T and B&G diverged with the LV&T going around the north side of the Bullfrog Hills and the B&G going around the south side. The Goldfield had spur lines in the Goldfield Hills that had several mines as far north as the northwest end of Montana Ridge.

Mountains and the eastern flank of the Bullion Mountains (Wilkerson 2021d; 2021e; Myrick, 1963 :840).

On the north side of Bristol Dry Lake is the company town of Saltus. Salt is harvested in a series of trenches. The salt is conveyed to the plant by a network of small gauge railways originally built in 1910 (Myrick, 1963: 840). The geology and chemistry of these salts are described by Rosen and others (2020). Saltus is 3.9 miles east of the Pacific Coast Plaster (PCP) mine, plant, and railroad. The mine and railroad are still active.

1907: Ardan Plaster railroad

The Ardan Mine railroad was a spur line off the Los Angeles and Salt Lake (LA&SL) Railroad. A sister railroad, the Blue Diamond, was built in 1925. Gypsum for plaster was first mined in the Diamond Mountains in 1907 by the Ardan Plaster Company. Part of this operation involved

Figure 12. Saltus train circa 1985. Larry Vredenburgh collection

1909: Red Rock Canyon railroad

The Red Rock Canyon (RR) railroad was a spur line from the Nevada and California railroad that was built to access the Los Angeles Aqueduct northwest of Red Rock Canyon and the southwest end of Indian Wells Valley. It was built by Southern Pacific from September 1908 to January 1909. The 23-mile-long line was dismantled in December 1910 after 22 months of operation (Myrick, 1962, p. 205).

Discoveries: 1910-1915

Mining districts discovered between 1910 and 1915 in our study area are shown in Table 5.

1910: Tecopa

The Tecopa railroad connected the T&T railroad at the Amargosa River and northeastern flank of the Sperry Hills with mines of the southern Nopah Range. The mines included the Gunsight, Noonday, War Eagle, Apex, Blue Dick, Columbia, Oro Fino, Shoshone, and Donna Loy Talc mines (Armstrong and others, 1987; Goodwin, 1957:

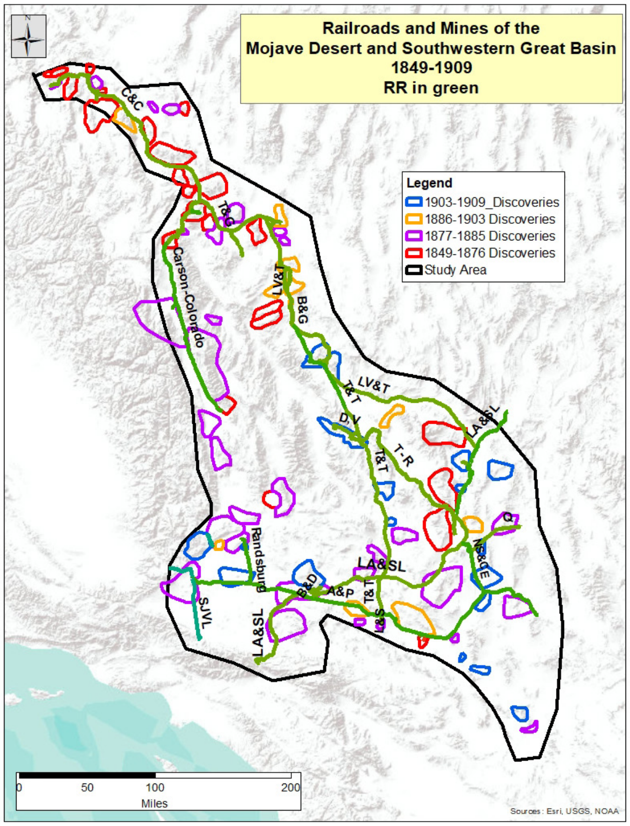


Figure 14. Map of railroads and mining districts 1849 to 1909

353-724, Norman and Stewart, 1951; Sabine and Mayerle, 1985). The settlement of Tecopa developed near the Amargosa River at an area of hot springs.

The Gunsight mine was discovered and worked in 1865. J.B. Osborn erected a 10-stamp mill and three water-jacket furnaces a few years prior to 1882. The T&T railroad reached Tecopa in 1907. At this time both the Gunsight and Noonday lead-silver mines were being developed. The Tecopa railroad Company was incorporated in California in May 1909. Work on the railroad to the mines began in October 1909 and service to the mines was established in early 1910. Unfortunately, the mines closed soon afterwards but reopened from 1913 to 1918. By 1922

Table 5. Mining district discoveries 1910–1915.

Mining District (MD)	**Discovery**	**Abandonment**
China Gardens MD	1910	1950
Cronese MD	1910	1934
Rhodes Marsh MD	1912	1916
Barstow MD late (limestone)	1913	1960
Bishop MD late	1913	2002
Clipper MD	1913	1913
Little Rock MD	1913	2024
Oro Grande MD	1914	1975
Volcanic Tablelands MD	1914	1925
Kilbeck Hills (Chubbuck) MD	1914	1950
Stedman-Bagdad-Chase MD late	1915	1960
Carrera mine	1915	1916, 1927
Eastside MD	1915	1915
Midland MD	1915	1925
Nine Mile Canyon MD	1915	1966
Southern Cady MD	1915	1915
Whipple MD	1915	1915

production had declined and the rail lines were taken up for scrap in 1938. Some sporadic mining continued through 1957 (Myrick, 1963, 593-597; Lengner and Ross, 2006, 2009, Tucker and Sampson, 1938: 440-450; Eric, 1948: 238; Goodwin, 1957).

1910: Lone Pine

This narrow-gauge railroad connected the Carson and Colorado (C&C) railroad and the Nevada and California (N&C) railroad to the town of Lone Pine. This spur was created as part of the C&C line to Owenyo in 1910 (Myrick, 1963: 208). The line was abandoned with the demise of the old Carson and Colorado and old Nevada and California by Southern Pacific in 1960.

1910: Baxter-Ballardi

The Baxter-Ballardi mine railroad was a short spur line off the Basin siding on the Los Angeles and Salt Lake (LA&SL) railroad to limestone quarries. It is at the eastern end of Afton Canyon between eastern Cady and Cave mountains. Here the LA&SL followed the Old Mojave Road (Wilkerson, 2018c; Casebier, 2010). Limestone has been mined here starting in 1907 (Logan, 1947). The railroad was built around 1910 and was expanded in 1914 and 1917. The property was acquired in 1930 by the Portland Cement Company. They changed operations to supply iron to its plant in Mojave and the line was dismantled in 1930 (Myrick, 1963:760). The Cave Mountain iron deposits are mined from the Baxter open pit mine

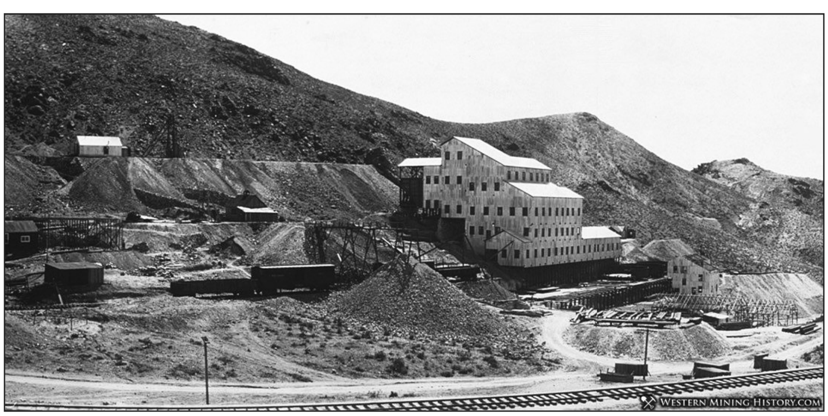


Figure 13. Montgomery-Shoshone Mines and Mill with railroad. Western Mining History, mindat.org/photo-125495.html accessed Jan. 1, 2024.

Figure 15. Tecopa Railway with Tonopah and Tidewater engine at Tecopa ore loading bin. Death Valley National Park Collection Photo No. TTR 28A by Green; also Larry Vredenburgh collection.

which has been intermittently active from the 1930s to the present (Bishop, 2012).

1910: Arizona and California

The Arizona and California (A&C) railroad was a subdivision of the Atchison, Topeka, and Santa Fe (AT&SF). In the Mojave Desert, this route began at Cadiz, California where it met the main line of the AT&SF, formerly the Atlantic and Pacific railroad (APR). The A&C line ended in Parker, Arizona. A few mine railroads connected to the A&C including the Midland and Chubbuck railroads.

The A&C went through or near the Kilbeck Hills, Danby, Riverside. and Whipple mining districts. A southern branch of the A&C went south through Blythe to Ripley. This branch was near the Little Maria, Big Maria. and Southern Big Maria mining districts.

The main line of the A&C was originally constructed between 1903 and 1910 by the Arizona and California railway. The line between A&C Junction and Parker opened by June 1907. The Colorado River bridge near Parker was completed in June 1908 and the track connection in Cadiz, California was completed June 10, 1910. Service to Cadiz commenced on July 1, 1910 (Myrick, 2001). Passenger service was suspended in October 1955 (Kauke, 1955). The A&C is now part of the Genesee and Wyoming Company (2023).

1910: Nevada and California

The Nevada and California railroad connected Mojave to Owenyo and completed the secondary goals of the Carson and Colorado (C&C) railroad. On May 11, 1905, the C&C and its affiliated lines were purchased by the Southern Pacific railway (SP). The C&C lines were renamed the Nevada and California railroad (N&C). The SP expanded the C&C system north from Hazen to Fallon and south from Owenyo to Mojave. In doing so, rail travel was possible from Los Angeles to Carson City.

SP also took out the old C&C narrow gauge rails and replaced them with standard gauge as far as Tonopah Junction. Passenger service commenced in October 1910 (Myrick, 1962, p. 202-208). The Nevada and California was decommissioned in 1912 after seven years of service. The N&C with the C&C were absorbed by the Southern Pacific railroad in 1912 (Nordell, 2024). Note: another Nevada and California railroad connected San Francisco with Reno (Hanson, 1994).

1911: Yellow Pine (Goodsprings)

The Yellow Pine (Goodsprings mining district) railroad connected to the Los Angeles and Salt Lake (LA&SL) railroad at Jean siding and was near the mines of the southern Spring Mountains (Myrick, 1963: 753-759.)

Minerals in the Spring Mountains were known to Native Americans and Spanish explorers. A systematic reconnaissance of the area was led by Nathaniel V. Jones in 1856 and the Potosi mine was developed in 1861. Lead development was attempted from 1861 to 1891 and gold from 1893 to 1898 when the Yellow Pine mill began processing copper ores. In 1905 the LA&SL railroad came to Jean. The district's proximity to the railroad facilitated mine developments as did the re-evaluation of zinc resources. A narrow-gauge railroad from Jean to Goodsprings and the Yellow Pine mine was built in 1910–1911.

More lead, zinc and copper zinc mines were opened during WWI. Between 1902 and 1930, cyanidation extracted more gold and silver from the ores.

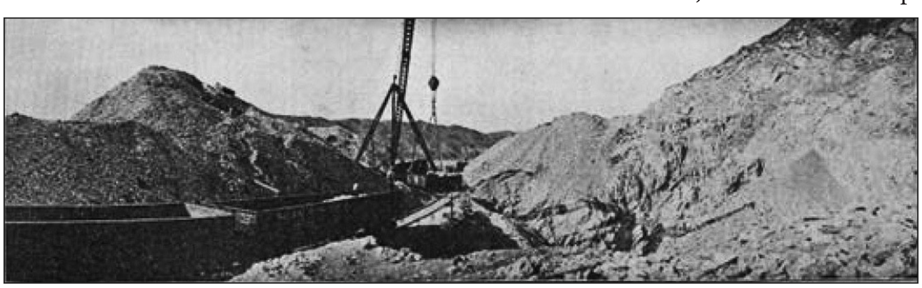


Figure 16. Baxter (White Marble) Mine. California Division of Mines and Geology, 1915. Larry Vredenburgh collection.

Figure 17. Yellow Pine railroad engine on trestle. https://www.pinterest.com/pin/619667229954407697/ accessed Nov. 14, 2023.

There was some renewal of activity during WWII, but by 1964 most of the mines were dormant and the railroad was dismantled (Hewett, 1931; Longwell and others, 1965; Wilkerson, 2018a, 2019; Myrick, 1963: 753-759). The rails were torn up in 1934 (Queho Posse Chapter 1919 E Clampus Vitus, 2023).

1913: Mojave Northern

The Mojave Northern railroad (MN) connected to the Los Angeles and Las Vegas railroad (LA&LV). Its destinations were the limestone and silica mines of the Sidewinder, Black, and Quartzite mountains. The Sidewinder Mountains and Black Mountain east of Victorville host several limestone mines including the Three Colored Marble, White Mountain, Alvic, Black Mountain, and Devil's Gorge quarries (MRDS, 2011; Wright and others, 1953: 142; Southern Pacific, 1964: 76). The Quartzite Mountains, north of Victorville, host silica deposits that were produced at the Superior Silica, Oro Grande, Atlas Silica, Quartzite and Riverside Cement Silica quarries. The Quartzite Mountains also had limestone (Southwest Portland, Riverside, Mack's Peak, Original Canyon, Sparkhule, Shay-Klondike), copper (Amazon, Liberty), and gold (Gold Bullion, Embody, Liberty, Ozark, Dents Grandview) mines. These are described in Wright and others (1953), Bowen (1954) and Cloudman (1916). Cement producers need both lime and silica. The limestone and silica deposits were known in 1880 and first developed in 1916. They are now consolidated under the CEMEX company (CEMEX, 2023; Vredenburgh, 1992).

Construction of the Southwestern Portland cement plant and associated railroads began in 1913 and was completed in 1917 with a one kiln stack. Owner-manager Carl Leonardt was confident in his company's product and technological advances. He considered building ships of concrete during World War I. The line operated as a common carrier early in the railroad's history. In the 1920s, advanced sales spurred expansion. With a large new kiln, additional milling equipment, and slurry tanks, it was expected that the factory would produce 2,200 barrels of cement a day. In 1926 the plant expanded to four kilns. With more technological improvements the factory produced 5,000 barrels a day. In 1942 additional quarries were opened nine miles east at Black Mountain with a railroad expansion to the new mine in 1947 and 1951 (Geocaching, 2023; Myrick, 1963:860-864). The mine and plant are still in operation.

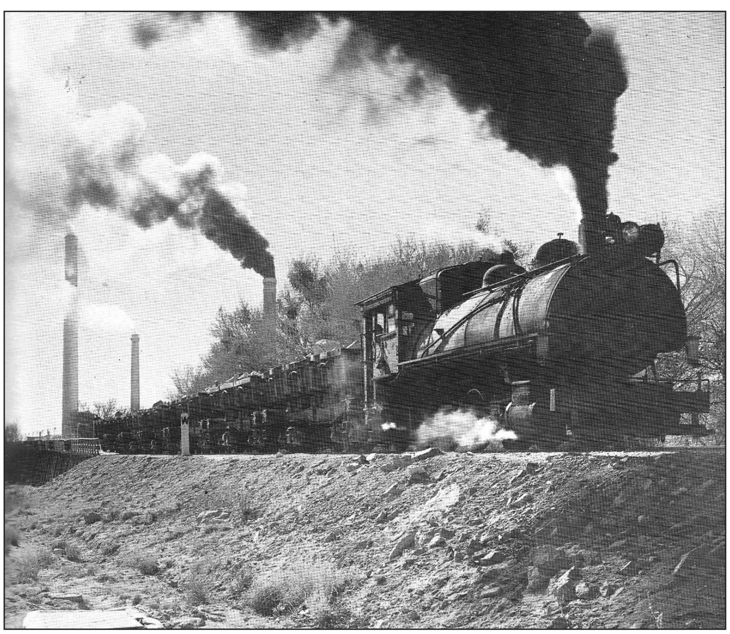


Figure 18. Mojave and Northern backing into Leon Plant. Myrick (1963:865); Southwestern Portland Cement Company collection.

1913: Calico and Odessa

The Calico and Odessa (C&O) railroad connected to the Atlantic and Pacific (A&P) railroad and serviced silver and borate mines in the Calico and other mountains east of Barstow, California. The Calico silver district was discovered in 1881. The Calico district figured prominently in Shumway, Vredenburgh and Lane's classic book Desert Fever (Vredenburgh and others, 1980). There were no less than 46 mines of note near Calico with the most important being the Waterloo, Bismarck, Oriental, Garfield, Silver King, and Burning Moscow. The Calico and Odessa railroad was built in 1912–1913. The mines were all closed by 1915 (Vredenburgh, 1985; Vredenburgh and others, 1980, Vredenburgh, 2013; Myrick, 1963: 823-827; Wilkerson, 2017). Exploration programs for gold and silver are currently being implemented at Calico (Wilkerson, 2022a).

1914: Carrera

The Carrera railroad was a spur line off of the Las Vegas and Tonopah (LV&T) railroad. It was located on the southwest flank of the Bare Mountains in the Bare Mountain mining district. Gold and silver had been discovered in this district in 1905. A limestone formation in Carrara Canyon was named after the famous Carrera limestone of the Carrara Mountains in Italy. The American Carrara Marble Company was formed in 1912. The town of Carrara at a site near the LV&T was officially dedicated on May 8, 1913, and the mine railroad was completed in 1914. The mine operated with what was then huge equipment capable of moving 15-ton blocks of marble. The mine operated from 1915 to 1916. There was a short rejuvenation of Carrera RR in 1927 by the T&T but it did not last (Myrick, 1963:605-607). Descriptions of the marble mines are found in Kral (1951:6), Minobras (1973: 34) and CDMG (1981: 48).

1914: Owens River Valley (grade only)

The Owens Valley railroad (OVR) was incorporated November 17, 1910, to create a connection for the town of Bishop (Myrick, 1962: 314), which the Carson and Colorado railroad had bypassed. This short line started at the Laws siding and was designed to end at Bishop 5.3 miles to the southwest. This was called the "Red Apple Route." It was to be an electric-powered railroad.

The railroad connected to Laws siding is at the southwest edge of the volcanic tablelands at the north end of Owens Valley and then on to Bishop southwest of Laws. Bishop was named for one of the first European settlers in the area, Samuel A. Bishop. The city of Bishop came into being in 1860 due to the need for beef in Aurora, Nevada, a booming mining camp some eighty miles to the north (Wikipedia, 2023c; Western Mining History, 2023e).

The short line to Bishop from the C&C was intended to be built in as part of the expanding construction programs for the Los Angeles Aqueduct. The OVR grade plan was near several tungsten and antimony mines on the northeast flank of Coyote Ridge: the Rosi, Yaney, Pickup, and Bishop Antimony, all part of the Bishop Tungsten District. The mines were discovered in 1913. The Pine Creek tungsten mine operated through 2001 (Norman and Stewart, 1951; Lemmon and Tweto, 1962; Bateman, 1956). The last phase of construction (laying down the rails) for the OVR railroad was never completed (Myrick, 1962: 314-315).

1914: China Ranch

China Ranch railroad is in the north-central part of the Sperry Hills about halfway between Tecopa and the Western Talc mine. It was a spur line off the Tonopah and Tidewater (T&T) railroad. In the 1890s a Chinese man named Ah Foo came to this canyon from the borax works in Death Valley. He developed a successful ranch, raising livestock, hay, fruits, and vegetables to help feed the local silver miners and their draft animals. The "China Man's Ranch" became a favorite resting spot, with its cool running stream and beautiful trees (HMdb, 2023).

In 1900 Ah Foo disappeared somewhat mysteriously, though the ranch name has stuck. After many changes of owners and financially unsuccessful ranching attempts over the next 90 years, the current owners began planting young date palms in 1990 and opened China Ranch to the public in 1996.

The China Ranch line was a spur to the Tonopah and Tidewater railroad built in 1914 (Myrick, 1963, p. 586). It accessed the China Ranch from the Acme siding. It also was near Upper Canyon nitrate mine, owned by the Pacific Nitrate Company. The Ratcliff mine was another nitrate occurrence in the Shoshone area (Waring and Huguenin, 1917; Nobel, 1925; Norman and Stewart, 1951).

1915: Trona

The Trona railroad (TR) connected the mines of Searles Lake to the Nevada and California railroad. The TR also connected to the Epson Salt monorail railroad. When John Wemple Searles arrived in the area in the 1860s, he was looking for gold and silver to mine. Instead, he found a white crystalline powder, borax, in the dry lakebed that would bear his name. In 1873, he went into production as the San Bernardino Borax Mining Company. Long mule teams were used to haul borax in wagons to San Pedro, until the much closer settlement of Mojave was

Figure 19. Trona Railroad Engine No. 1. at borate processing facility. Larry Vredenburgh collection.

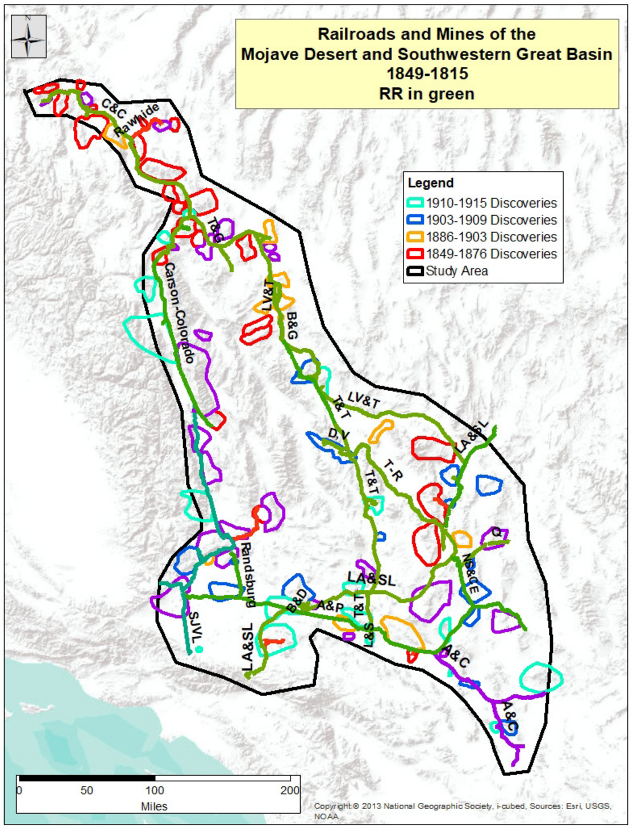


Figure 20 Map of railroads and mining districts 1849-1915.

used after the Southern Pacific railroad reached it in 1876 (Wikipedia, 2023c; Myrick, 1963: 798-808).

In 1895 the San Bernardino Borax Mining Company was sold by Searles to the Pacific Coast Borax Company, owned by Francis "Borax King" Smith. He shut down production at the company's section of Searles Lake the next year (Wikipedia, 2023c; Myrick, 1963: 798-808).

In 1917, construction was completed on the American Trona Corporation building in San Pedro to process and store salt potash. In 1926, after becoming the American Potash & Chemical Corporation, it began producing borax, soda ash, and sodium sulfate. Production of these chemicals continued to expand until the 1980s as more and more wells were drilled to develop a variety of products from the Searles Lake brines. (Wikipedia, 2023c; Myrick, 1963: 798-808). The Trona facility extracts and ships 1.75 million tons of chemicals each year (Hughes, 2005).

1915: Rawhide Western (grade only)

The Rawhide Western (RW) railroad was never completed. It was planned, surveyed, and graded to connect Rawhide to the Carson and Colorado (C&C) railroad.

The Rawhide district of Mineral County, Nevada was discovered in 1906. The original Regent district was situated about two miles northwest of the town of Rawhide. The district became known as Rawhide when it was expanded to include discoveries made at Rawhide in 1906. Placers in the Rawhide district are found in Rawhide Wash and tributaries extending about 4 miles southeastward from the townsite of Rawhide to the alluvial fan at the base of the hills (Western Mining History, 2023e).

The Rawhide Western railroad was formed in March 1908. A fire devastated the town of Rawhide on December 4, 1908, and a flood destroyed part of it in August 1909. The district recorded production from 1913 to 1916 and again in 1928. Mining at Rawhide stopped in 1941. The RW railroad was never completed. (Myrick, 1963: 235).

Discoveries: 1916-2017

Mining districts discovwered between 1910 and 2017 in our study area are shown in Table 6.

1916: Midland

The Midland railroad served the U.S. Gypsum Brown mine from the Arizona and California (A&C) Midland siding (Sampson and Tucker, 1940: 128). The mine is in the southeast part of the Little Maria Mountains. A railroad was built from Blythe Junction to the Palo Verde

Table 6. Mining district discoveries/rediscoveries 1916–2017

Mining District (MD)	**Discovery**	**Abandonment**
Ash Meadows MD	1916	Still operating
Las Vegas MD	1916	1916
Little Maria MD	1916	1916
White Mts MD late	1916	1945
Gerstley mine	1917	1926
Marble (Chubbuck) MD	1917	1917
Ash Meadows RR and MD	1918	1919
Old Woman MD	1920	1920
Candelaria MD late	1922	1935
Clarkdale MD	1931	1940
Comestock MD middle	1933	1942
Cushenbury Mine	1947	2024
Wabuska Wash MD late (limestone)	1947	1960
Silver Peak MD late lithium	1966	2024
Pamilco MD	1967	1967
Black Horse MD	1969	1969
New York (Vanderbilt, Morning Star) MD late	1969	1993
Ivanpah MD late	1974	1990
Arica MD	1989	1994
Randsburg MD late	1989	1994
Rawhide MD late	2000	2024
Buena Vista MD late	2006	2024

Valley in 1915–1916. A narrow-gauge line was built to the mine site in 1925. The A&C supplied water to the town and mine. The Midland plant was expanded and another underground gypsum mining venture was added in 1936 at the Victor Mine. Originally discovered as a gold-silver and base metal mine, it was later developed as a gypsum mine. Open pit mining commenced in 1946. The Midland plant closed in 1966 (Vredenburgh, 2024; Myrick, 1963: 840).

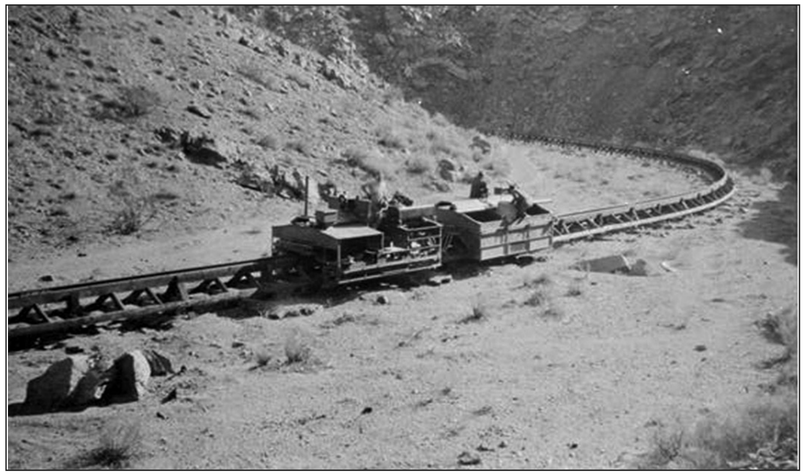


Figure 21. Epsom Salts Monorail. From the Brush Collection Photo No. 14. Courtesy Mojave Desert Heritage and Cultural Association.

1918: Ash Meadows

The Ash Meadows railroad was a spur line off the Tonopah & Tidewater railroad. It was part of the T&T subsidiary Death Valley railroad (Myrick, 1963: 608-622). The line connected to the T&T at Bradford siding in California and went northwest, across Ash Meadows in the Amargosa Valley to the Nevada-California state line, to the clay mines in Nevada. Ash Meadows had a ranch operated by Dad Fairbanks who provided food services to the T&T (Myrick, 1963: 602). This line serviced the Clay Camp, Nevada Clay, Ash Meadows, and Tenneco mines. Production started about 1918 and continues today (Cornwall, 1972; Denney and Drews, 1965; Kral, 1951; Castor and others, 2006; Papke, 1970: 23-34).

1922: Chubbuck

The Chubbuck railroad was a spur line that connected to the Arizona and California railroad (A&C) at the north end of the Kilbeck Hills and the western flank of Ward Valley between Cadiz Junction and Rice Junction. The spur led to the Chubbuck Station Dolomite and the West of Chubbuck Limestone mines (Wright and others, 1953: 174; Southern Pacific, 1964: 174). The limestone mine is near the Desert Butte copper-lead-zine mine (Goodwin, 1957: 628; Wright and others, 1953: 8).

The Chubbuck mine, railroad, and town were constructed from 1922 to 1925. A post office was opened in 1938 and a school in 1932. The mine and plant supplied additives to the cement used in building the Colorado River Aqueduct in the late 1930s. The operations ceased in the 1940s (Vredenburg and others, 1981).

1923: Randsburg (late)

The Randsburg railroad was revitalized in the 1920s when it serviced the tungsten mines of Atolia. The original Randsburg line was built in 1898 and connected to the A&P (later the Atchison, Topeka and Santa Fe) railroad at Kramer Junction.

Gold mining in the Randsburg mining district continued from 1923 through the early 1930s. There was a hiatus in gold mining from WWII until the Yellow Aster reopened as an open pit operation from 1986 to 1994. Tungsten mining in the Atolia area continued from 1906 through the Korean War (circa 1953). The Randsburg railway served as a supply link to the Rand mine until it closed in 1929, as it was no longer profitable (Myrick, 1963, p. 793-798).

1924: Epson Salt monorail

The Epson Salt monorail (ESM) railroad connected to the Trona railway at the southwestern end of Searles Lake. The monorail was part of a mining venture promoted by Thomas Wright, a Los Angeles florist. The unique railroad was built from 1923 to 1924. It was 28 miles long and made from Douglas fir. It operated through 1926, providing saltpeter for gunpowder, and was sold for scrap in 1930 (Myrick, 1963: 808-814; Rapp and Vredenburgh, 1992).

The Epson salt mine excavated magnesite in Tertiary clays and processed it in a plant six miles south of Trona. The project was abandoned in 1927 (U.S. Geological Survey, 1984; Wright and others, 1953: Magnesium Table,

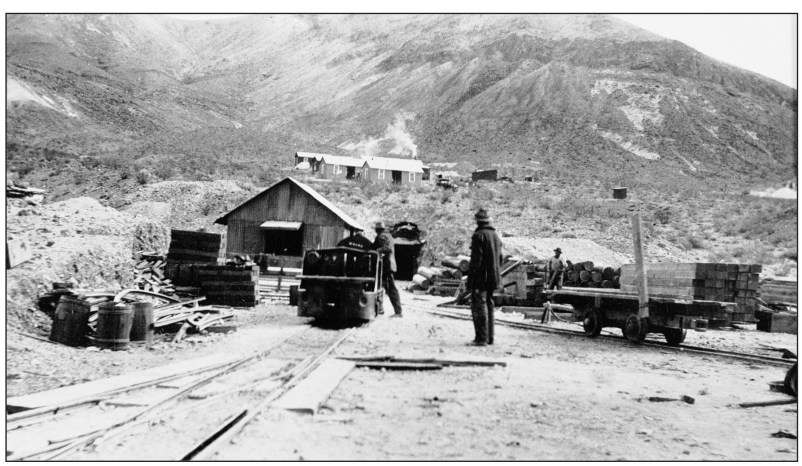


Figure 22. Gerstley Baby Gauge Railroad. Gerstley or State Lease Mine, Pacific Coast Borax. Shoshone. California Division of Mines and Geology Collection DM photo A7301. See. Inyo County 1926 rept.

p. 183; Jahns, 1951; Hewett and others, 1936: 96; Newman, 1924: 742).

1925: Blue Diamond (late)

The Blue Diamond was a revitalization of the Ardan railroad. The Blue Diamond mine and mill were initially owned by a Los Angeles company known as Blue Diamond. This company commenced mining in 1925 after an 11-mile-long rail line to Arden on the LA&SL railroad was re-constructed to standard gauge. An on-site processing plant was added in 1941, followed a year later by the construction of a nearby company town, known as Blue Diamond, Nevada. The mine was eventually sold to James Hardie Gypsum, which expanded operations in 1998. British Plaster Board (BPB) took over the gypsum factory a few years later, and developer Jim Rhodes purchased 2,400 acres in 2003 (Wikipedia, 2023; Myrick, 1963, p. 761).

1926: Gerstley Baby Gauge

The Gerstley railroad was a spur line off the Tonopah and Tidewater (T&T) railroad north of Shoshone in the Resting Springs Range. The Gerstley railroad was built by Pacific Coast Borax (PCB, owner and operator of the T&T) to service its borate mines northeast of Shoshone about 1921. This was a baby gauge (2-foot) line and connected the T&T to ore bins at Gerstley. The railroad hauled ore from the mine and water back to it. The line ran for five years until 1926 when PCB moved all its operations to the Kramer deposit at Boron (Myrich, 1963: 587, Hees, 2023). Information about the Gerstley mines is found in Evans and others (1976), Noble (1931: 63-75), Norman and Stewart (1951) and Papke and others (1975).

1927: Saltdale

Saltdale was on the north side of Koehn Lake playa in Fremont Valley between the El Paso and Rand mountains. It was adjacent to the Nevada and California railroad. It was mined illegally for several decades. Mining claims were staked in 1909 by Thomas Thorkildsen and Thomas Rosenburger. The Consolidated Salt Company constructed a crushing and screening plant and laid a baby-gauge railroad track onto the playa, from where a gasoline-powered locomotive hauled the salt to the crusher. Consolidated began shipping in 1914 and was processing 240 tons or more a week by October of that year. The output in 1914 totaled 20,000 tons. In January 1915 the company was shipping about twelve cars of salt weekly. After several court challenges to the legitimacy of the mining operations involving interpretations of the 1901 Saline Placer Act, the mine shut down in 1975 (Hensher and others, 1998; Wilkerson, 2023).

1928: Boron

The Boron railroad connected to the Atlantic and Pacific railroad. In 1913 John K. Suckrow accidentally discovered the Kramer borate deposit when he drilled a water well. Suckrow's farm was immediately purchased by John Ryan of the Pacific Borax Company (PCB) and underground mining soon began. The discovery was only three miles from the Santa Fe (formerly Atlantic and Pacific) railroad. The PCB company closed its mines in Death Valley and concentrated its efforts for open pit mining at Boron in 1928, constructing the Boron railroad. It connected the town to the mine and was extended in 1957 to connect to new and bigger borate recovery plants. The railroad is still in operation (Myrick, 1963: 610; Troxel and Morton, 1961: 60-66; Siefke, 1979, 1980, 1984, 1991; Wilkerson, 2022b).

1931: Six Companies (Boulder branch line)

The Six Companies railroad connected operations at the Hoover Dam to the Los Angeles and Salt Lake railroad south of Las Vegas. It took more than a heroic effort to build Hoover Dam in the 1930s: it also took a railroad. The Boulder branch line was set up by Union Pacific (formerly the LA&SL) in 1931 to haul all the project's building materials. The Six Companies railroad was built to a point near the dam and operated through December 1, 1961. Over three decades it transported 35,000 carloads of construction materials weighing about 2,000,000 tons (Myrick, 1963: 734-752).

1955: Portland Cement (Mojave)

The Portland limestone mine and cement plant were built west of Mojave along the southeast margin of the Tehachapi Mountains in 1954-1955. The original name was the Creal mine and plant. To service this mine and plant, the Portland Cement (PC) railroad was built to connect to Mojave where it joined the Atchison, Topeka and Santa Fe railroad. This was formerly part of the San Joaquin Valley line. In 1962, 95% of the plant output was exported by rail (Troxel and Morton, 1962: 221-222).

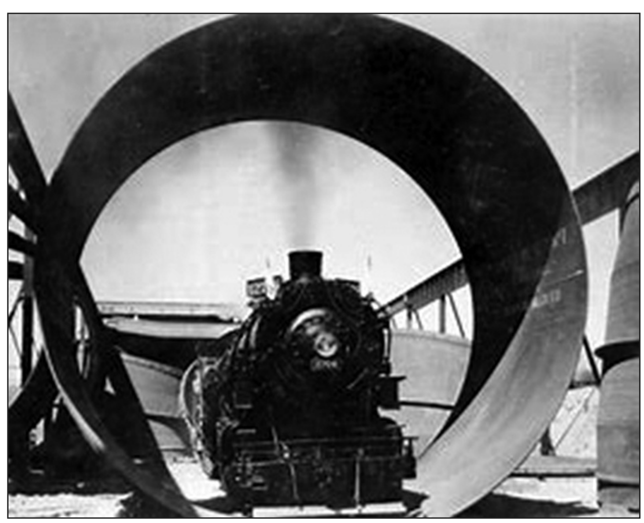


Figure 23. Six Companies locomotive and Hoover Dam giant pipe. thelasvegastourist.com Broken link in www.bing.com accessed Jan. 16, 2024.

Figure 24. Cal Portland Cement plant with railroad lines, Mojave in 1972. https://www.pinterest.com/pin/357754764129999754/ accessed Jan. 1, 2024.

1957: Cushenbury

The Cushenbury railroad connected to the Los Angeles and Salt Lake (LA&SL) railroad at Hesperia. That railroad is now part of the Union Pacific railroad company. The Cushenbury limestone quarry was opened in 1947 by the Permanente Cement Company, and operated intermittently and on a small scale until it was shut down in 1950. During this period the deposit yielded several thousand tons. The limestone was trucked to Thorn; from Thorn it was shipped by rail to the Los Angeles mill of the Kennedy Minerals Company where it was ground for use as whiting (Wright and others,1953, P. 174; Rapp and others, 1990; Myrick, 1963:864).

Renowned industrialist Henry J. Kaiser originally developed the Cushenbury limestone quarry to supply his steel making operations in Fontana, California during World War II. He built the cement plant and 35-mile-long railroad in 1957. The facility was modernized in 1982 and Mitsubishi Cement Corp. purchased the plant in 1988. Today the Mitsubishi Cement Corporation Cushenbury Plant is one the leading industries in the Victor Valley (Mitsubishi Cement Corporation, 2023).

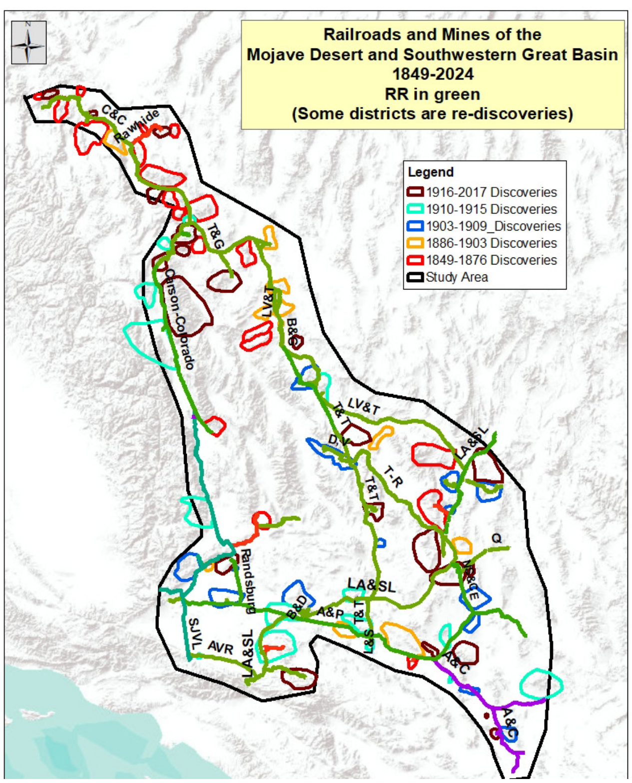


Figure 25. Map of mining district discoveries or rediscoveries, 1849 to 2006

1967: Antelope Valley Palmdale-Colton cutoff

The Cajon Pass to Palmdale section of the Antelope Valley railroad (AVR) was called the Palmdale-Colton Cutoff. Proposals for the building of this line were first considered in 1881 while the San Joaquin Valley line (1875–1886) was being built. The cutoff was not built until 1967 by the Southern Pacific railroad. Service was discontinued in 1971 and resumed in 1994 as part of the Los Angeles Metrolink system. Union Pacific purchased the Southern Pacific lines on the AVR in September 1996 (Serpico, 2000).

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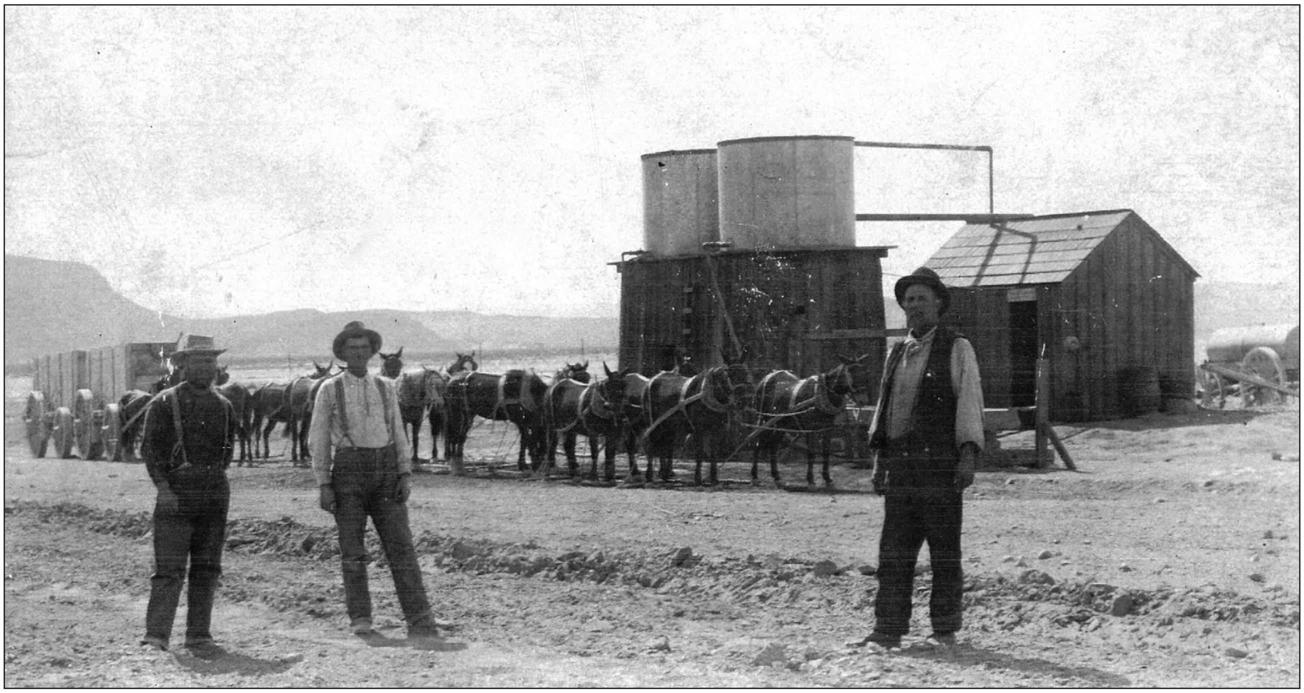

Borax wagons from Borate at Marion with Elephant Mountain in left distance. Teamster Charles White may be at far left; Joshua R. Ridge of Daggett at far right. Jacki Ridge collection.

Wild Horse Mesa mule trails

Robert E. Reynolds[1]

Introduction

Wild Horse Mesa is the largest volcanic mesa in Southern California. Its table land can be seen east of the Providence Mountains from which it is separated by Barber and Beecher canyons (Figure 1). It lies south of Macedonia Canyon and Columbia Mountain and west of Wild Horse Canyon, Hole in the Wall, and Black Canyon Road. Deep canyons cut the volcanic rocks of the mesa, which covers about 14 square miles. McCurry and others (1995) describe the Peach Spring Tuff and the Wild Horse Mesa Tuff that form the flat surface and resistant cliffs of the mesa.

Figure 1. Wild Horse Mesa and Beecher Canyon (left), 1993. R.E. Reynolds photograph.

Wild Horse Mesa ranges in elevation from 4800’ on the south to 5510’ at its north end. The south end holds a playa surrounded by creosote and Mojave yucca. The middle of the mesa supports Joshua trees and cat’s claw. The north half of the mesa is covered by piñon, juniper, and agave. It was this woodland that was harvested before the turn of the century to fuel mining operations in the Providence Mountains.

Mining north of the mesa started with the formation of the Rock Springs mining district in April 1863. Work progressed slowly, in part because of a lack of workers, but shafts and tunnels were dug at several mines. By November, three separate districts were recognized: Rock Spring, Macedonia and Silver Hill. The district was abandoned when a miner was killed by an Indian at Rock Spring in June 1866. The district remained idle until 1871, after army redoubts had been established along the Government Road and calm was restored (Casebier, 1987; Vredenburgh and others, 1981). In 1872 a smelting works was established in the Macedonia district and supplies were hauled by wagon from San Bernardino. Fifteen tons of ore were shipped in September of that year. About the turn of the century, the Macedonia mine was renamed the Columbia mine. The Columbia, with a five stamp mill, operated in 1910–1911 and again in 1935–1936. Nearby, the Francis Copper mine was open in 1917–1918 and in the 1930s (Vredenburgh and others, 1981).

The Columbia mine is just one mile north-northwest of the north end of Wild Horse Mesa; Macedonia Canyon and Columbia Mountain are 1.5 miles and two miles north, respectively. The Globe and Providence mines are 1.5 miles west of Wild Horse Mesa and approximately one mile north of Summit Spring (Wright and others, 1953). The most productive mine in the area, the Bonanza King is 15 miles south of the old Macedonia district and only about three miles west of the south end of Wild Horse Mesa.

The silver lodes that were to become the Bonanza King were located in 1880. There was a flurry of claims, mining, recapitalization, and partnerships through 1881 and into 1882. In July, a ten-stamp mill was freighted to the Bonanza King from Mojave and between 100 and 150 men were actively employed (Vredenburgh and others, 1981). Called in 1884 the “richest silver mine in California” (Myrick, 1953), the mill shipped bullion during a total of 28 months that was valued at about $1,700,000.00 (Vredenburgh and others, 1981). The mill burned to the ground in July 1885, but the nearby Kerr mine operated a five-stamp mill from 1885 to at least 1890. The Bonanza King was reactivated in 1905 and 1907 with a gasoline-powered ten-stamp mill. The mine and its dumps continued to yield silver in 1915–20 and 1923–24 (Vredenburgh and others, 1981).

<?> *This article was originally published in “Ancient Surfaces of the East Mojave Desert” (San Bernardino County Museum Association Quarterly, Vol. 42 No. 3, 1995) and is included in this volume with permission. It is modified by minor editing for clarity, and the trails are redrawn, in places modified using aerial imagery in which the paths are visible. The area under discussion is now encompassed within the Mojave National Preserve.*

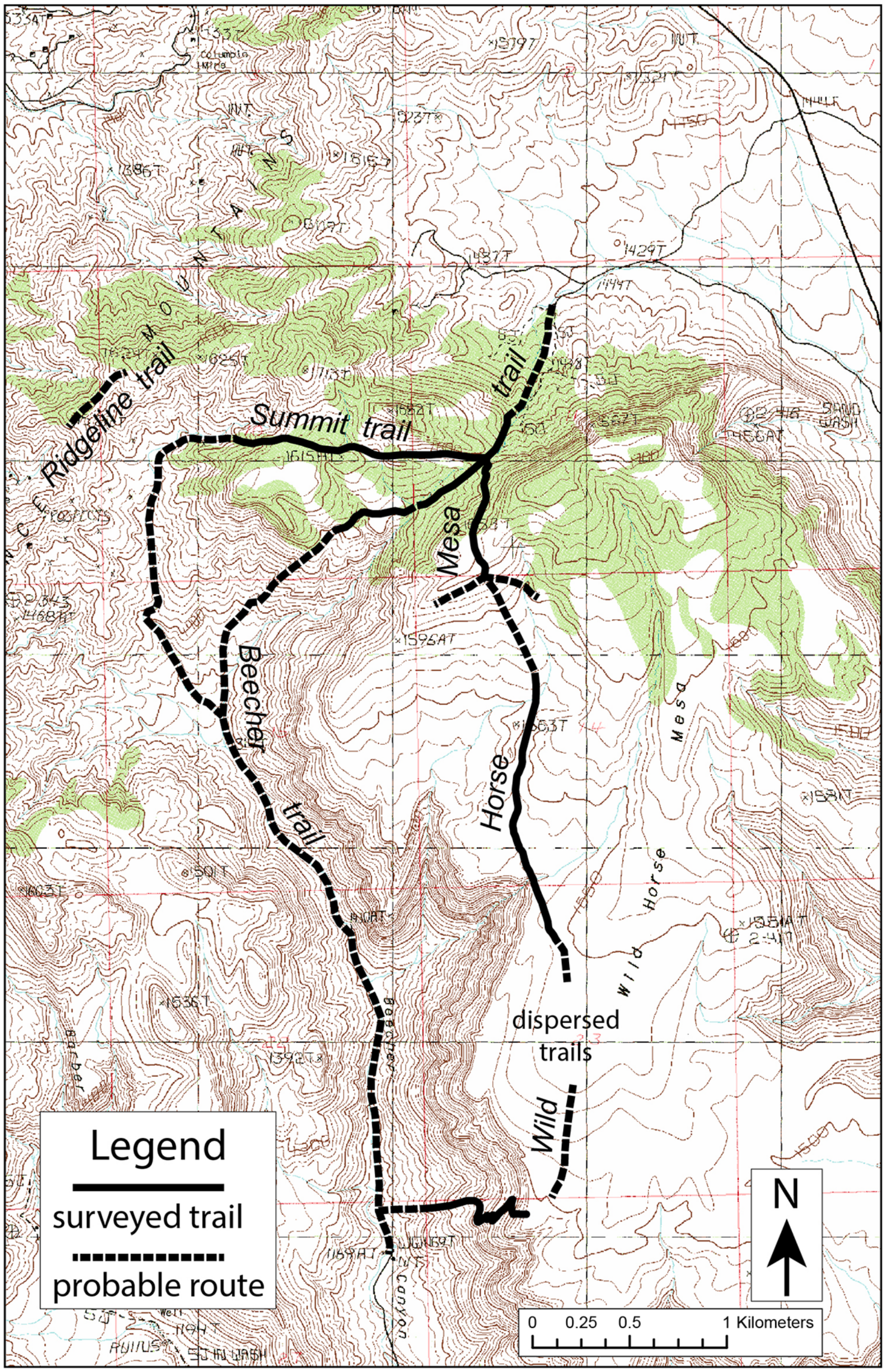

Figure 2. Routes of mule trails on Wild Horse Mesa.

The productivity of the Macedonia district and the Bonanza King mines in the 1870s and 1880s demanded wood for mining timbers and charcoal for ore reduction. These materials could readily be obtained by mule trains from the flat surface of Wild Horse Mesa reached by trails through Beecher Canyon. A network of trails for wood and charcoal hauling was developed across the northern and western portions of Wild Horse Mesa (Figure 2). A supply cabin or overnight waystation was built near the north end of the mesa.

The mule trains could find water at Rouse Well, one-half mile north of the mesa. Beecher Well, two miles up Beecher Canyon, is of uncertain date, but was probably an historic source of water. Rouse Well, actually a pair of wells, is 1.25 miles southwest of the Wild Horse Canyon Road which leads to the Macedonia Canyon Road. A road runs west-northwest from Fenner to Bonanza Well. What is now the Black Canyon Road is shown in 1908 (Mendenhall, 1909) as a branch road running north from the Fenner Road through Wild Horse Canyon, continuing a short distance down Macedonia Canyon, then to the Government Road west of Cedar Canyon. Mendenhall's description, however, indicates that this route is not accurately drawn. A more straightforward road was in use by 1917 (Thompson, 1921) which allowed passage through Wild Horse Canyon, Macedonia Canyon, and then to the railroad sidings of Ames or Elora on the Los Angeles and Salt Lake railroad.

There were also undeveloped water sources for the mules. Geologic mapping (McCurry, 1985) shows major landslide structures in the canyon wall west of Beecher Well and these structures may have caused a spring to flow near the canyon bottom. Personal observations in the 1970s and 1980 indicate that Wild Horse Mesa itself is very wet in the spring of most years and after monsoonal summer rains. After spring snows and rains, the creeks flow, ponds fill, and soil is hard to walk on because it is so muddy. Summer rains fill natural tanks and eroded volcanic basins to provide water for deer, big horn sheep, porcupine, coyote, and mountain lion.

The trails

The Wild Horse Mesa mule trails are described using informal geographic names used by campers, hunters, and from discussion with local residents including T. More and the late James Winkler of Needles.

Wild Horse Mesa trail

The Wild Horse Mesa trail probably started at Rouse Well at the northern foot of Wild Horse Mesa. It is partially obscured by bladed roads up the north slope of the mesa. The trail runs to the mesa saddle where it branches. It switchbacks steeply upslope (Figure 3) to the crest of the mesa and then runs 1/3 mile southwest to reach its maximum elevation at 5420'. Mule traffic has cut down a path about an inch deep through the desert varnish and white tuffs. From this high point, you can look over the flat terrain of the mesa and west where the Bonanza King mine and Mitchell Caverns are visible at the southeast base of the Providence Mountains. After this high ridge, the trail becomes difficult to follow, probably because timber was everywhere and mule trains chose various routes to stands of trees. Panniers (J-shaped hooks forged from one inch steel rod and mounted on a mule's pack frame to support a balanced load) were found in this area (SBCM collections). There are very few piles of charcoal from here south on the mesa. However, there are numerous stumps and stacks of juniper cordwood which generally run along the west edge of the mesa. Although the trail cannot be followed, it must have reached a point on the west edge of the mesa that is approximately east of Beecher Well. Remains of a rock-buttressed trail run down a slope so steep that the route was probably only used to descend from the mesa. In Beecher Canyon, existing roads obscure the trail, but the route was probably down canyon, past Domingo Spring and then past the 7lL Ranch to Bonanza King Well and north to the Bonanza King mine. This trail gains 600 feet in its first mile and drops 1800 feet by the time the 7lL Ranch is reached; it is about 7.5 miles long.

Beecher trail

At Wild Horse Mesa saddle, Beecher trail runs southwest, then crosses the wash to a low plateau of tuff on the north wall of the canyon. It drops down cactus-covered slopes of metamorphic rock to the main channel of Beecher Canyon. There is evidence of wood cutting and charcoal making at the saddle and along the upper portions of the trail. Although the trail cannot be followed to the canyon bottom, it probably connected with the Wild Horse Mesa trail at Beecher Well. It drops 1400 feet in four miles.

Figure 3. Switchbacks on the Wild Horse Mesa trail leading up to the mesa top, 1993. R.E. Reynolds photograph.

Figure 4. Summit trail, view toward Providence Mountains, 1993. R.E. Reynolds photograph.

Figure 5. Juniper woodpile along the Summit trail, 1993. R.E. Reynolds photograph.

Figure 6. The charcoal burning area on Summit trail, showing four rock piles, 1993. R. E. Reynolds photograph.

Summit trail

The Summit trail (Figure 4) runs west-northwest from the mesa saddle in gullies cut in soft sediments of the Summit Spring Formation that underlies the Peach Spring Tuff (McCurry and others, 1995). The 3/4 mile long trail runs past numerous piles of juniper logs three to four feet long and up to 18 inches in diameter (Figure 5). Associated with these piles are concentrations of charcoal. In these charcoal areas there are often four large but moveable blocks of rock or rock piles (Figure 6). Perhaps a “floor” of logs was laid out on the rocks to increase ventilation and assure good initial draft when a stack of wood on the “floor” was ignited. The charcoal, once the coals were cool, would then have been loaded onto mules and hauled to the reducing furnaces of the mines. A shovel blade found near the saddle may reflect efforts to control the spread of flames from the charcoal operations. The Summit trail runs westerly, then south through Beecher Canyon to connect with Beecher trail. This trail drops 900 feet along its three mile length.

Ridgeline trail

A trail has been noticed west of Hill 5593 on the ridge that runs westerly to the Globe mine. My inspection has not yet located a trail connecting the Summit trail with this ridgeline trail or with the Columbia mine to the north.

Summary

Wood is a precious commodity in the Mojave Desert. Before the turn of the century, when mining operations depended upon wood for timber and shoring and charcoal for ore reduction and when supplies were difficult and expensive to obtain, the piñon-juniper woodlands of Wild Horse Mesa were as much a bonanza to miners as was the ore they sought to extract from the nearby mines.

Acknowledgements

Larry Vredenburgh kindly reviewed a draft of the original manuscript, and his insights are appreciated. I would also like to recognize the generosity and kindness of the late Jim Winkler, who not only shared his knowledge about the Mid Hills area but his cabin near the foot of the mesa. Thanks to David Miller for preparation of the updated map.

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Pack mule trails in the New York mining district

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Introduction

When an unexpected, late-night storm near the Nevada border blanketed our sleeping bags with drifts of snow in the 1960s, a hasty, flashlight search of a topographic map for shelter led us to discover the abandoned but weatherproof cabins of the Sagamore mine. The morning light introduced us to the glory of the New York Mountains (and our beagle to the excitement of tracking rabbits through the snow). We have explored the mines and canyons with friends and colleagues, and we have met many people who have lived in and visited the region long before our "discovery." This paper is a result of research, observation, and exploration since that 1960s. snowstorm.[1]

The New York Mountains contain many of the highest peaks in the Mojave National Preserve. Steep-walled canyons, spectacular rock formations, piñon–juniper vegetation, and historic mines make the range an inviting area to explore on foot. Recreational hiking and climbing can be challenging. But it is surprisingly easy to travel on foot between historic mines on routes laid out and improved more than a century ago.

Background

The coming of the railroad to Lanfair Valley in 1893 changed the social dynamics in the New York mining district. Miners in three different canyons had formed a self-reliant but interdependent community that communicated and traded by a series of foot and pack mule trails. In 1893 the focus changed toward the new Nevada Southern Railroad and the food, supplies, and technology that it carried.

Although the New York mining district was established in 1870 (Vredenburgh and others, 1981; Vredenburgh1995), the mining press (Crossman 1890-91) reported mining activity as early as 1861. The district was worked in 1873 and again in 1880. Eight silver mines, including the Keystone mine, were active, as were four copper mines. The mining methods and milling techniques were constantly being upgraded. Smelted bullion was shipped to San Bernardino and raw ore was taken by freight wagon 25 miles to Goffs on the A&P (later A.T. & S.F.) railroad.

In the 1890s, Isaac Blake bought up existing silver mines in Sagamore Canyon and named them the New York mine. In 1893 Blake built the Nevada Southern Railroad north from Goffs to Manvel (now Barnwell), named by Blake for the president of the Santa Fe. Manvel in turn renamed Goffs "Blake." Blake intended to extend the line as far north as Utah, serving mines along the route and hauling ore to his reduction company in Needles (Myrick, 1953). Unfortunately for the Blake empire, silver prices fell and the New York mining district became idle (Vredenburgh and others, 1981), although it has been suggested that Blake's purchase of the New York mine was less for its ore than to increase tonnage for his railroad (Myrick, 1953). Manvel remained the end of the line for the railroad as funding schemes failed and nearby bonanzas, such as Vanderbilt, floundered. Receivers took over the Nevada Southern in December 1894, and much of Blake's property collapsed in debt immediately thereafter. A new company, the California Eastern Railway, took over the line in 1895 and at the turn of the century extended it to Leastalk (now lvanpah). The Santa Fe loaned the funds for the expansion, and by 1901 owned the line outright—renaming Manvel "Barnwell," and changing "Blake" back to Goffs.

The New York mine was revived in 1907 when N.P. Sloan purchased it and formed the Sagamore Mining Company. In 1914, fifteen men were working at Sagamore, one of whom was Bert Sharp (Sharp, 1984). Bert and his wife, Maude, could walk four miles to their homestead north of the railroad siding of Maruba (Ledge) in about an hour. By 1917, the Sagamore mine was idle again (Vredenburgh and others, 1981). Mendenhall (1909) notes that there was no water along the Santa Fe between Vontrigger Springs and Barnwell. His 1908 map shows no roads to water sources in the New York Mountains. This probably reflects a time when mines were idle but before the enactment of the 1910 Homestead Act (Sharp, 1984).

Mines in the New York Mountains with names recognizable today appear in inventories by the California Division of Mines and the U.S. Geological Survey (Aubury, 1908; Bateman and Irwin, 1954; Cloudman and others, 1919; Eric, 1948; Hewett, 1955; Jenkins, 1942; Tucker and Sampson, 1930; Wright and others, 1953). They include the Bronze (Live Oak) mine in Live Oak Canyon, the Copper Queen mine in Keystone Canyon, the Sagamore (New York) mine in Sagamore Canyon, and in Caruthers Canyon the Hard Cash and Giant Ledge mines[2]. The Gold Chief (Golden Quail) mine is at the mouth of Caruthers Canyon, south of New York Mountain Road.

[1] *This article was originally published in "Ancient Surfaces of the East Mojave Desert" (San Bernardino County Museum Association Quarterly, Vol. 42 No. 3, 1995) and is included in this volume with permission. It is modified by minor editing for clarity, and the trails are redrawn, in places modified using aerial imagery in which the paths are visible.*

[2] *U.S. Geological Survey 7.5 minute and 15 minute topographic maps label the Hard Cash mine as the Giant Ledge.*

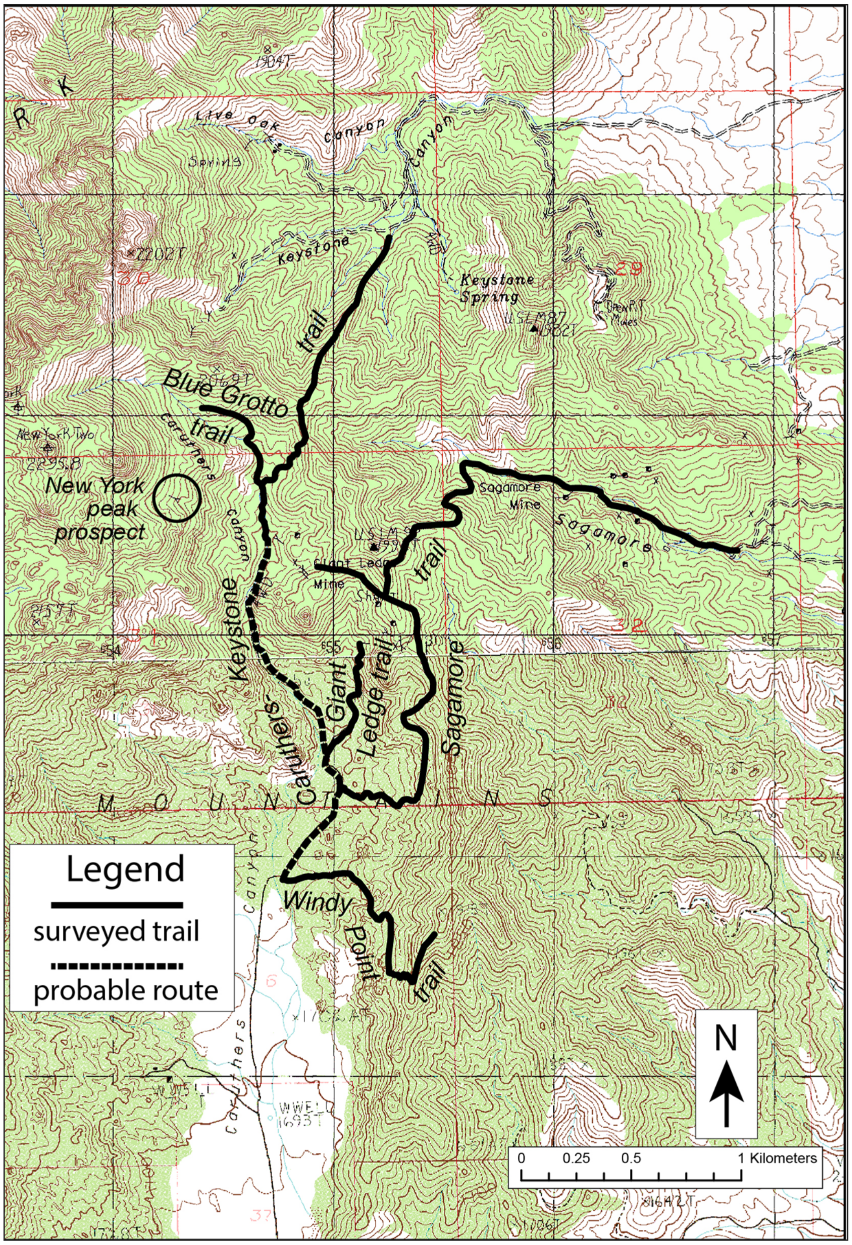

Figure 1. Routes of pack mule trails in the New York Mountains..

Before the coming of the railroad in 1893, news and supplies came to the New York mining district with freight wagons carrying 9000 pounds of supplies and equipment (Vredenburgh and others, 1981). Between these occasions, miners probably visited and traded or borrowed supplies locally. When other mining camps were occupied and active, miners could socialize and trade. When camps were abandoned, they could recycle and reuse materials from them. The mines in Keystone, Sagamore, and Caruthers canyons are only about two miles apart, an easy two-hour hike.

The trails that were developed between mine camps of the New York mining district crossed the rugged topography with gentle ascents and descents (Figure 1). Trails were often improved by cuts in ridges and through dikes and outcrops. Rock lagging and buttressing can still be seen where trails cross slopes with rivulets, streams, and gullies. Switchbacks were built to assist a gentle ascent to mines, saddles, and ridge tops. Trails start and end near water sources. A holding corral was built east of the Giant Ledge mine. These features indicate that the trails were specifically designed and constructed for pack mules hauling heavy supplies, lumber, and charcoal between mines. Whether the trails were developed by independent mule skinners or as part of the community of mines in the New York mining district, they played an important part in the early activity of the district.

The Ivanpah quadrangle of 1912 (Marshall, 1912) shows roads in Fourth of July Canyon and Caruthers Canyon. They connected to the New York Mountain Road and ran to Ledge (later Maruba, and later the OX Ranch headquarters, probably a shipping siding for the Giant Ledge mine. A road connected Sagamore Canyon and Keystone Canyon to Barnwell via Mail Spring and Lycre Well (Marshall, 1972). In 1912, no road was shown from Sagamore to the railroad siding of Purdy, a stop on the old Nevada Southern named after a railroad man and Blake's partner in the Nevada Reduction Company (Myrick, 1953). But this road was apparently available in 1914 when the Sharps walked to their homestead south of Purdy. A Sagamore–Purdy road is shown in the 1917 Thompson survey (Thompson, 1921).

The trails

In this paper, trails are described with informal place names used by campers, miners, and residents. Mules were used in the mining district to haul sacks of ore from the mines (Frizzell, 1985) and to haul wood for mine timbers and charcoal to fuel coking operations which reduced lead ores. That the trails were used by pack mules is evidenced by panniers, a pair of J-shaped hooks formed from one inch steel rod and mounted on the left and right side of a pack frame to support a balanced load of wood or charcoal. Panniers, some broken, have been found along the trails.

Caruthers–Keystone trail

This trail starts at The Oaks in Caruthers Canyon. The Oaks, a former cabin site (structures in shambles still

Figure 2. Wheelbarrow at the New York Peak prospect, 1994. R.E. Reynolds photograph.

stood here in the late 1960s), is on the east side of the wash at the road crossing. This is approximately the contact of bedrock with alluvial valley fill, and water often flows to this point. Historic wells are located here, and a dam was built in the middle 1900s. Forage is available on the flats. The Caruthers–Keystone trail is partially obscured by the road which, prior to 1950, was pushed by bulldozer to the Hard Cash mine. The trail runs north, past the junction with the road to the May Barnes cabin. It clings to the west canyon wall until it crosses the wash to the east wall. A great deal of work went into buttressing the trail and subsequent roadway. The trail passes the Hard Cash mine and continues up canyon to the Upper Camp, where there was a cabin site and a forge for smithing. Near the line between section 30 and 31, the trail branches northeast from the Blue Grotto trail The Caruthers-Keystone trail switchbacks northeast to a saddle on Monument Ridge and proceeds north to the junction of ridges at the west end of Sagamore Canyon. It then follows a north-northeast trending ridge with gentle slope, crosses the 29/30 section line, and reaches the Keystone Road one canyon west of Keystone Spring. This trail is about 1.9 miles long and gains 860 feet in elevation.

Blue Grotto trail

This short trail leaves the Caruthers–Keystone trail near the 30/31 section line and proceeds west-northwest along the north slope of Caruthers Canyon. There is buttressing to cross rivulets, and switchbacks help gain 250 feet in altitude. The trail disappears after 1/4 mile at copper prospects and a spring.

New York Peak prospect

The New York Peak prospect is on the west slope of Caruthers Canyon below a pinnacle that is 1/4 mile east of the highest point in the New York Mountains (VABM 7532, New York 2) and marked on the map with an adit symbol (circled). We tried to locate a supply trail to the prospect but found none. We were at first very impressed that the prospectors had hauled a 150-pound, hand-forged steel wheelbarrow (Figure 2) to the prospect 1800 feet higher in elevation than The Oaks. We then realized that it had been assembled on site from three pieces. Some giant of a person had hauled a thirty inch long section of Nevada Southern railroad track to this site to use as an anvil (Figure 3)! This piece of track suggests the prospect dates later than 1893.

Giant Ledge trail

The Giant Ledge trail (Figure 4) leaves the Caruthers–Keystone trail at the junction to May Barnes cabin. After 1/4 mile, it passes the cabin site, crosses the wash, and switchbacks to the Consolidated tunnel, a gain of 300 feet in one-half mile. The Consolidated tunnel was an exploratory effort to reach the riches of the Giant Ledge vein. It was pushed at least 1/4 mile through granite and ended when only low-grade ore was found (Frizzell, 1985).

Figure 3. Anvil made of railroad track, wired to forked log and braced by tree and rock, at the New York Peak prospect, 1994. R.E. Reynolds photograph.

Figure 4. Rock foundations near the Giant Ledge mine, 1994. R.E. Reynolds photograph.

Windy Point trail

This trail leaves The Oaks and runs east-northeast up a low ridge. In ¼ mile, the topography steepens and the trail turns south for 2,000 feet. It then switchbacks to the ridge top and turns north to the Windy Point mines on Monument Ridge. Approximately one mile long, this trail gains 500 feet in elevation.

Sagamore trail

The pack mule trail from The Oaks serviced the original Giant Ledge tunnels and connected areas of wood cutting and charcoal making. The Sagamore trail (Figure 5) leaves the Caruthers–Keystone trail ¼ mile north of The Oaks, where an intermittent stream runs west to the upper dam in Caruthers Canyon. On the low slopes along the first quarter mile, the trail passes through a juniper cutting area (Figure 6). Stumps, stacked wood, and charcoal indicate that cord wood and charcoal were hauled away for fuel and reduction ovens. The trail passes adits and prospects of the Athens, Morningstar, and Miama claims on the west slope of Monument Ridge. It passes rock foundations and turns northeast, then runs north through a saddle. A short branch runs northwest to the Giant Ledge mine. The main trail continues north along the east crest of Monument Ridge. One quarter mile east of the Giant Ledge and about one quarter mile south of USLM 92, the trail comes to a corral: two fenced pens, 8x10' and 10x10', are anchored to piñon trees (Figure 7). Milled lumber and wire nails suggest that the corral was repaired and still in use after the turn of the 20^{th} century. Two tent cabin foundations are nearby. This site is located at elevation 6340', the maximum elevation of the trail, 720 feet above The Oaks and 800 feet above the main Sagamore mine. The Sagamore Trail proceeds northeast on the east side of Monument Ridge and east of USLM 92, reaching the ridge on the south side of Sagamore Canyon. It switchbacks northeast down a ridge to the canyon bottom. This broad portion of the west end of Sagamore Canyon is a wood lot with stacked logs to 18" diameter and 3 to 3.5 feet long. Piles of charcoal remain in flat areas. The trail then runs east down the well-watered canyon for 2 /3 mile to the main Sagamore workings. The Sagamore trail is about 2.1 miles long.

Summary

The years between 1860 and 1893 were years of discovery and development in the New York mining district. Trails were developed for pack mules to haul food, equipment, and wood to the mines. The mules hauled sacks of concentrated ore and charcoal to the smelters. In fact,

Figure 5. Snow defines the Sagamore trail, 1994. R.E. Reynolds photograph.

Figure 6. Stumps left in the wood cutting area along the Sagamore trail, 1994. R. E. Reynolds photograph.

if distance mattered, communication via two-mile-long mule trails would have been easier between Caruthers, Keystone, and Sagamore canyons than it would have been to Manvel or Ledge after the coming of the Nevada Southern railroad.

The Nevada Southern Railroad, constructed in 1893, changed the focus of communication and trade. Supplies could be obtained at the rail sidings of Ledge and Purdy. Homesteaders entered Lanfair Valley and social gatherings became frequent after 1910. The Lanfair "boom" was short-lived (Casebier, 1987) and the Santa Fe abandoned its California Eastern branch to Goffs in 1923 (Myrick, 1963). But the mines remained, and interest in their riches never really died. May Barnes, who lived in the cabin at the foot of the Giant Ledge trail, described their mining venture for us.

> *We were living at Colton. 1n 1951, Bob Engels came along and got Sam Barnes all excited about some patented mining interests in the New York Mountains about 25 miles northwest of Goffs, California. Sam was always interested in mining so he bought an interest in the property. They got Jerry Anderson, who ran a grocery store in Colton. We moved to the Mountains and a mining company was formed. The Whites, Andersons and several others joined in with Bob Engels and Sam.*
>
> *The first thing they did was to repair the road that led up to what was called the Hard Cash mine and the property was patented. We were about 25 miles from Goffs where we got our mail. The Bozarth Ranch covered all the territory for miles for grazing. A cabin was built for us to live in. We lived in a very nice campground 'til our cabin was finished. The men all continued to work on the road, and gather samples. Seemed like it was a very complex ore and a lot of lime. The mine had been worked years before. There was a track coming out of a long tunnel and an ore car still there. We gathered up some real good samples.*
>
> *A Mr. Miller, who had worked for mininq companies, came by and they hired him to dig out the spring which was a short distance from our cabin. They ran a long pipe from a spring to the road where they could get our water tank filled and moved near the cabin for household*

Figure 7. Corral on the Sagamore trail, 1994. R.E. Reynolds photograph.

uses. We raised rabbits and had tomato vines. There was another mine across the mountains called Copper Queen which had some action. Finally the Giant Ledge Lead and Copper Company ran out of money. We were left up there and we ran lines and staked claims over that mountainside. Jerry Anderson bought up some of the mining interest and we moved into Needles in October 1952. As of my knowledge Gerry Anderson purchased all the shares.

There was another ranch in a canyon beyond ours called Caruthers.

At one time the Santa Fe sent several men out there for several days to take samples. They said they had come up with some good samples but we didn't hear any more that I know of.

Acknowledgements

The authors thank May Barnes for sharing her adventures in the New York Mountains for this paper, and for the personal insights that she and her daughter, Helen Lozano, provided about Caruthers Canyon. Larry Vredenburgh kindly reviewed a draft of the 1995 paper and we appreciate his comments and suggestions. Thanks also to David Miller for preparing an updated map.

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Homesteading in the eastern Mojave Desert

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Introduction

Signed by President Abraham Lincoln into law on May 20, 1862, the Homestead Act encouraged western migration, changing life forever in the wild untamed valleys and mountains of the west including the area addressed herein, the eastern Mojave desert. Though the Mojave Desert[1] was not nearly as suitable for homesteading as more temperate locations, a series of wet years beginning after the turn of the twentieth century convinced hundreds of homesteader families, immigrants, and veterans of World War I to move to the area. Under the Homestead Act, any American (including women, former slaves, and recent immigrants) could claim a portion of federal domain that could be theirs in return for several years of hard work plus a small filing fee. The homesteading experience in the Mojave Desert failed largely because of environmental and economic factors, as more than half of all homesteaders failed to gain title to the lands they claimed, while many others met at least a degree of short-term success. However, their hard work and formidable determination left a legacy of land in private ownership inside Mojave National Preserve boundaries. Evidence of failed homesteading activity along the eastern Mojave Trail can still be seen today in the form of vacant plots of land cleared for farming, stone foundations, and crumbled, abandoned dwellings.

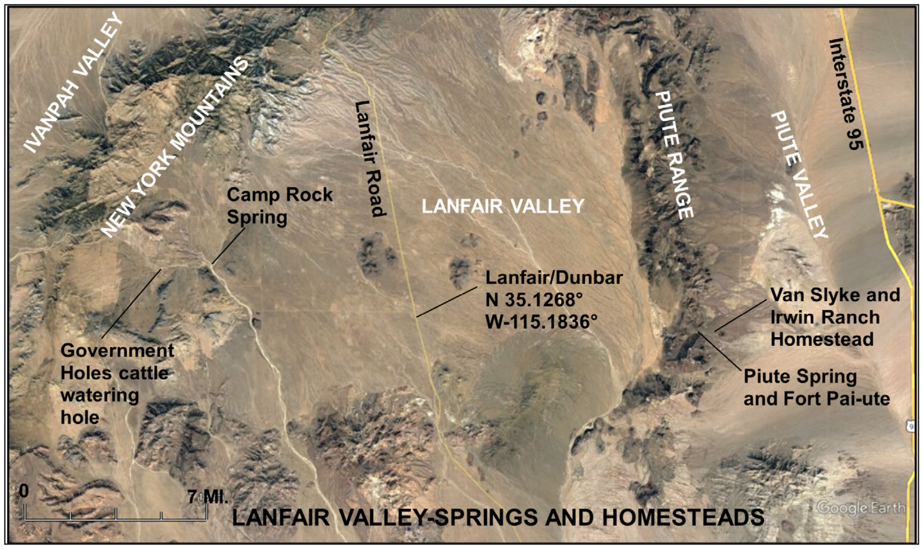

Figure 1. Map of the Lanfair Valley area, showing place names, springs, and sites referred to in the text.

Early explorations

The Mojave [Mohave] Trail begins at the Colorado River and for thousands of years was a Native American ancient trade route across the eastern Mojave Desert spanning approximately 270 miles between Needles and Mission San Gabriel (Casebier, 2014) before becoming a well-known and watered path taken by early settlers and pioneers travelling to the Sierra Nevada and Los Angeles basin. The word Mohave is reported to have been derived from the Mohave Indians who lived along the lower Colorado River (Sherer, L.M., 1967), and more directly from the Mojave[2] River named by Joseph C. Fremont in 1844. In 1848 the United States acquired what is now California, Arizona, New Mexico, and Texas with parts of Utah, Nevada, and Colorado as a result of war with Mexico. In 1853–1854 a series of government expeditions led by the War Department sent parties of explorers out along northern parallels in search of a preferred and practical rail route in support of a “Pacific Railroad” for purposes of connecting the United States from sea to shining sea. The Army Corp of Topographical Engineers led by Lieutenant Ameil Weeks Whipple (Whipple Mountains namesake) travelled west along the 35th parallel arriving in 1854 at the Rio Colorado of the West. With Mohave Indians as guides Whipple’s expedition travelled across the eastern Mojave Trail, naming many of the features and notable springs along the way. These springs, Piute, Rock, Marl and Soda, were seasonably reliable water sources forming along the lower reaches of southwest–northeast trending mountain ranges that include the Granite, Providence, Ivanpah, New York, and Castle mountains.

Several valleys of the eastern Mojave Desert, including Lanfair, Piute, and Ivanpah, were connected by the Mojave

1. The Mojave Desert is an approximate 25,000 square mile arid region bound by the Garlock Fault on the north to the San Andreas Fault on the southwest, on the east by the Colorado River and south by the Sonoran Desert. Mining in this region has played an important role in the development of California.

2. Mojave [Mohave] is composed of two Indian words, aha, water, and macave, along or beside. Aha denotes either singular or plural number. Mojave translates as “along or beside the water,” or freely as “people who live along the water (river).”

Figure 2. School children and their teacher in a Lanfair Valley settlement. Source: (WEBINAR| Unearthing Black History in the Desert - Civil Rights (U.S. National Park Service; nps.gov)

Trail and later by rail lines of the Santa Fe. During the years 1900 to 1919, prior to and during the highpoint of the homesteading period, rail transportation was fully developed and the Santa Fe railroad allowed full exploitation of the Mojave Desert. The rail could haul in food and water and haul ore out faster and cheaper than the large wooden wagons of yesteryear. During that period, in 1910, inspired by dryfarming techniques and mining booms in the New York and Ivanpah mountains, Ernest Lanfair, a merchant from Searchlight, Nevada, claimed a portion of the valley that bears his name. His homestead and several others became the heart of Lanfair, an immigrant farming community established north of the rail lines that played a crucial role in accessing the Mojave Desert. At Lanfair siding along the Santa Fe Railway, some 15 miles south of the homestead, Ernest Lanfair hosted a July 4, 1914 Immigrant Party, reportedly helping newly arriving immigrants to stake and record their claims, and to work, clear, and plant their land to meet government requirements. When the Mojave National Preserve was created in late 1994, more than 85,000 acres (exclusive of the Catellus[3] railroad grant lands) within the Preserve remained in private hands (Nystrom, 2003). Most of that, some 70,000 acres, was in Lanfair Valley. It was largely a relic of less than two decades of homesteading activity. In Lanfair Valley, homesteaders' inability to reconcile agricultural traditions with environmental realities is imprinted on the land, demarcated by straight lines of tamarisk and square areas without brush.

Homesteaders in Lanfair Valley

Schoenkopf (2020) described the following families in Lanfair Valley: *Estella (Stella) Baker and Anna Jones—only black women homesteading claims, William Bronson, Frank Carter, William H. Carter—Civil War Veteran, Nanie Mary Craig, Robert Edwards, Mathew Hodnett, Richard W. Hodnet, Ulyssess Hodnet, William Hodnet who incorporated the Dunbar Water Company, Stonewall Jackson from Georgia, Nathan Lowe, Henry Morton, John Richard Multon, Eliza Louise (Hawthorne), Millie C. Shepard, Lila A. Smith, Alfred Summers—former Buffalo Soldier who served in the U.S. 10th Calvary regiment, Annie Taylor, widow of Thomas Taylor, and William C. Williams.*

Homesteading in a land of little forgiveness, the Mojave Desert, where dreams developed and faded, was challenging as impressive flash flooding, blowing sand, creosote bush and cactus, inaccessibility to markets, and lack of water made desert living a true hardship. To sustain life, homesteaders naturally settled close to water sources. These watering holes were positioned at convenient distances and higher elevations, making summer heat slightly less miserable than area settlements to the south. With the coming of the railroads in 1883, mining and cattle ranching flourished in the eastern Mojave at places like Ivanpah, Providence, Vanderbilt, Hart, and localities in the once prosperous yet short lived dry farming communities (Lanfair, Dunbar and Ledge [later named Maruba]) in Lanfair Valley. Piute, Marl, and Rock springs were vital to the existence of early homesteaders while serving the mines of New York and Providence mountains.

As the years went by, the population of Lanfair Valley slowly dwindled. In the election of 1916, 64 voters cast their ballots in Lanfair (U.S. National Park Service, 2021). By 1924, only 27 voters existed and the United States Postal Service decided there was not enough business to keep its Lanfair office open. There were no permanent Lanfair residents after 1946 (Westec Services, 1978).

Overall, between 150 and 175 homesteads received land titles in Lanfair Valley, including 24 run by African-Americans who settled the communities of Dunbar and Maruba (Gothard, 2022). After receiving the patent to their land, some chose to sell to cattle ranchers immediately and use the money to pursue other dreams elsewhere. They determined "success" not by whether their children continued farming, but by how well the homesteading generation equipped their children with the life skills, money, and education needed to succeed in an ever changing world.

Piute Creek

Thomas Wilson Van Slyke, prospector by trade, originally homesteaded the site just below Piute Gorge along the banks of Piute Creek on May 12, 1930 and a patent was

Figure 3. Map of the Van Slyke and Irwin ranch near Fort Piute.

issued for a little less than 140 acres on September 27, 1937 (Casebier, 2014). With abundant year-round water (100 to 630 acre feet per year, *Freiwald,* 1984) supplied from fault bound Lanfair Valley to the west, Thomas and his brother William cleared land and experimented with alfalfa, fruit trees, and grapes in compliance with Homestead Act requirements. In 1944, at 73 years of age Van Slyke sold his ranch to George and Virgina Irwin who raised turkeys and also experimented with agriculture. The Irwins' ranch lifestyle was short lived. Plagued by bobcats and coyotes, they threw in the towel in less than two years (Casebier, 2014). Can you imagine what the bobcat and coyotes thought when they first laid eyes on these very large birds? *"What a big quail, how does that taste?"*

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Ruins at Fort Piute in 1925. Dr. Allen Haenszel photograph in the Arda Haenszel collection, San Bernardino County Museum.

A History of Piute Pass

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The earliest recorded reference to Piute Pass was made by Father Francisco Garcés in 1775. On his outward trek across the Mojave Desert he had traveled the Mojave Trail almost directly westward from the Mojave Villages at present Needles. Then, returning to the Colorado River, he branched northeast from his outgoing route at the Devil's Playground when the Indians begged him to visit their rancherias, crossed the Providence Range possibly through Macedonia and Wild Horse Canyons, and, passing Rock Spring, made a curve around the north end of Lanfair Valley. Then, after following an Indian trail south along the west foot of the Piute Range, he turned eastward through the mountains to a place where there was abundant water.[1] The Mojaves called it Ahakuvilya, and the Chemehuevis Pa'ash,[2] but Garcés did not refer to it by name. He did say that it was Chemehuevi territory. Piute Pass is the only place in the whole area where there is a lot of water, however, and the direction and distance are correct for reaching Sacramento Springs, where he rejoined his outward route.

Perhaps we can say that Garcés was not the first to record the pass, though, for Malcolm Rogers of the San Diego Museum of Man, examining the site in the 1920s, found evidence in the petroglyph styles there (Figure 1) of temporary camping by San Diegito I people from 9000 B.C. Then there was temporary camping by Amargosa II people, whose petroglyphs are most numerous, around 3000 B.C. Prehistoric Yumans also did a lot of rock writing there about 1000 A.D. The Chemehuevis, he found, didn't make many petroglyphs, but evidence of their settled occupation is suggested by Garcés and confirmed by the reports of Whipple and Mollhausen in 1854.[3]

At the edge of the settled Mojaves' agricultural territory in the Colorado River Valley, the Chemehuevis, with a migratory culture on the desert, still were known to cultivate a few areas in the eastern Mojave where there was enough water. And Piute Springs was one of them. Noted in 1854 were the presence of many tortoise shells and signs that the Chemehuevis raised corn and melons. The latter were typical of Chemehuevi settlements as late as the 1880s.[4]

Figure l. Petroglyph near Piute Springs, 1925. Dr. Allen L Haenszel photograph from the Haenszel collection.

Father Garcés was the first white visitor to Piute Pass. Fifty years later he was followed by the first American, Jedediah Smith.

On their way west in 1825, having struck the Colorado, trapper Jedediah Smith and his party traveled down it to the Indian settlements near the site of later Fort Mojave, about 15 miles north of Needles. After some trading, he tried to follow a trail the Mojaves told him about, starting from Beaver Lake on the western bank and heading directly west, probably through Pictograph Canyon at the north end of the Dead Mountains, to what must have been Piute Springs, where he camped. But his horse was stolen, and the next day he lost the trail in Lanfair Valley.

Returning to the river after another night at Piute, he was able, in a second attempt, to enlist the aid of some run-away Mission Indians as guides, and they took him for the third time to Piute Springs, the regular first stop on the proper route, and then on through the pass.

The next year, 1827, Smith found himself again on the Colorado River and short of provisions. This time the Mojaves were unfriendly, and it is thought that a recent visit by another group of white men had turned them against whites. Smith's suspicions were realized when the Mojaves attacked his party as it was divided while crossing the river. All but Smith and eight of his men were killed. The survivors on the west bank held off the attackers until nightfall, and then fled westward in the darkness to Piute Springs, where they rested all the next day before going on.[5]

** This article was originally published in "Ancient Surfaces of the East Mojave Desert" (San Bernardino County Museum Association Quarterly, Vol. 42 No. 3, 1995) and is included in this volume with permission. Most of the area under discussion is now encompassed within the Mojave National Preserve. Equivalent figures have been substituted when original images were not available.*

In his brief accounts of the two trips Smith gave only enough details to indicate his routes, and there is no description of Piute Pass.

In the 1830s and 40s white travel slowly increased on the early Spanish Trail down the Muddy and Colorado Rivers to the Mojave Villages.[6] This trail followed much the same route that Smith had taken from the vicinity of the later Fort Mohave westward, making the first stop at Piute Springs.

> *The Mojaves themselves, and other desert Indians, accustomed to traveling long distances on foot without carrying water and perhaps with only a handful of chia seeds for food, took the more direct version of the Mojave Trail running parallel a few miles south.[7] But most of the white travelers, New Mexicans, and a few American traders and trappers used the more roundabout Piute Springs, Rock Spring, Marl Springs route because of their riding and pack animals that needed a water supply more abundant and regularly spaced. True, in 1829–1830 Antonio Armijo, directed by the governor of New Mexico, and his scout, Rafael Rivera, had worked out a shorter, diagonal route from the vicinity of Las Vegas to a junction with the Mojave River trail at a point east of the present Daggett. This diverted some of the increasing traffic, though the old route down the Colorado and west to the Mojave River via Piute Pass was still used.[8]*

But the gold rush to California caused a sudden expansion in the need for overland routes, especially those in the south which avoided Sierra snow. The ultimate solution would be the railroad, it was believed. So in 1853–54 Lt. A. W. Whipple led a survey party across the far west along the 35th parallel, one of several such expeditions seeking a practical route for a railroad.

Coming from the Needles area, the Whipple expedition followed Piute Wash around the south end of the Dead Mountains to Sacramento Springs, then angled northwest to Piute Pass. Whipple had engaged Mojave chiefs Iretaba and Cairook as guides, and they steered him to the "white man's" route because he had a large party, many animals, and even a light instrument wagon.[9]

The railroad surveys were not just charged with seeking a route suitable for a railroad. They were also directed to report in detail the kind of country they passed through—the geography, geology, natural history, and inhabitants. The command and escort were military, but the party included civilian scientists as well. And since there were no cameras to record the details, an artist, Baldwin Mollhausen, was engaged. Of special value for historians were Lt. Whipple's personal interest in anthropology and his careful observation and notes.

The official government report of the expedition is divided into sections, four of which deal with Piute Pass. Whipple was the first to refer to the site by that name. In his "Preliminary Report" he wrote,

> *We encamped upon a pretty rivlet, which watered a small valley that had been converted by the mountain Pai-utes into a luxuriant garden. Passing the crest of a hill, and … by a gradual ascent over wide prairies of rich grama grass, we reached a rocky glen [Rock Spring]."[10]*

In the "Itinerary" section we find evidence of recent Indian occupation.

> *Mar. 3, Camp 137*
>
> *Continuing the survey northwest about 9 miles [from Sacramento Springs] over the smooth gravelly slope, we reached, at the point of a mountain, Paiute creek, a finely flowing stream of water. Finding good grass also. we encamped. A little basin of rich soil still contains stubble of wheat and corn, raised by the Paiutes of the mountains. Rude huts, with rinds of melons and squashes scattered around, show the place to have been but recently deserted. Upon the rocks, blackened by volcanic heat, there are many Indian hieroglyphics. Some of the more simple have been copied. Others are too complicated or too much defaced by time to be deciphered…*
>
> *Mar. 4, Camp 138*
>
> *At 8:00 A.M. we filled our canteens and started. For the sake of the instrument wagon, the guide led us up the creek to a deep ravine, from which he ascended and passed over the crest of a sharp dividing ridge to a plain of great extent. He afterwards told us that the pack-train should have kept the ravine. and saved the hill.11*

From the section "Topographic Features" comes a description of the route through the pass.

> *We approach the base of a cluster of sharp crested hills from 800 to 900 feet in height, at the rock base of which flows a rivulet called Paiute creek. Upon its borders, near Camp 137, are patches of fertile soil, which have been cultivated by Indians producing corn and melons. There are cedar trees and grass upon the hill sides. The stream flows southeast… The ascent … has been gradual, except near the entrance to the creek, where several rough ravines were crossed…*
>
> *From Camp 137 the trail ascended a tortuous ravine to the head of one of the branches of Paiute creek, and then mounted to the crest of the ridge, about 830 feet above the cultivated fields in the valley. From this point sketches were taken, showing a wide gap between the hills upon the left, and upon the right a low valley, 1/4 mile wide, appearing to drain the*

waters of the plain, which lay extended towards the west, into the same great valley that receives Paiute creek… The course of the trail is nearly magnetic west across a vast plain extending about 20 miles to Camp 139 at Rock Spring.[12]

There were two routes to Lanfair Valley through the upper pass. One was the main gorge on the north, in which rise the springs, which is too narrow for wagons. The other was the south fork canyon trail over the summit, to which the chiefs directed the party.

The "Report Upon the Indian Tribes" describes the Chemehuevis.

West of the Rio Colorado we enter the range of the widely extended Utah nation. Those that roam over the region traversed by us, call themselves Paiutes, and are closely allied to those that massacred the party of the lamented Capt. Gunnison. This band probably does not number above 300 persons. Though supposed to maintain a scanty and precarious subsistence, principally upon roots, they are probably distinct from the Diggers of California. We passed through one little valley of theirs, at Paiute creek, where wheat and melons had been cultivated.

Plates in this section of the Report contain sketches of Chemehuevi Indians, and of their implements, while the text gives an extended description of their appearance and customs. Plate 38 (Figure 2) contains a group of petroglyph designs sketched from the rocks in Piute Pass.[13]

Mollhausen was a bit more literary in his book about the trip.

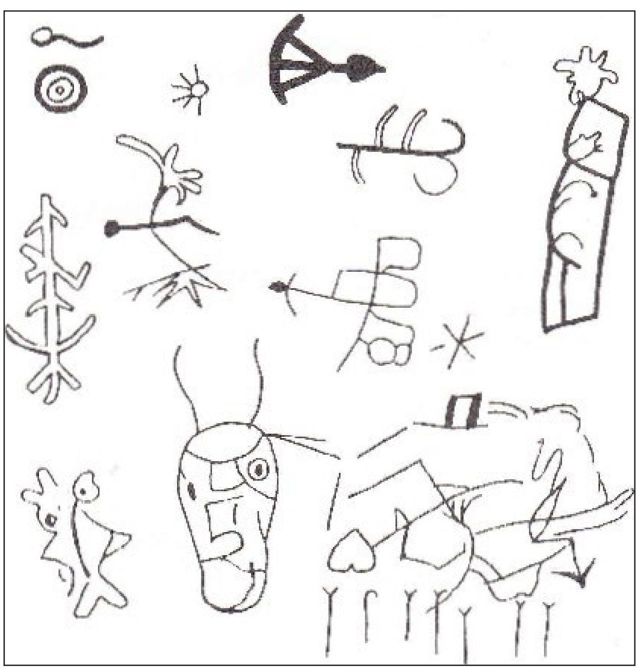

Figure 2. Petroglyphs at Piute Springs in 1853–54 as illustrated in Whipple's Report.

Where the mountains began to tower up high above us, we discovered the first traces of water, as a small brook trickled over a few acres of land, and then vanished again in the sand at the end of the valley. Reeds and rushes must at one time have grown luxuriantly at this spot, for on the top of the banks we saw many heaps of them, which had apparently served the Indians as couches. In the valley itself the reeds had been burnt away, but green sprouts bursting here and there from the ground through the black ashes, announced the approach of spring. We thought we had now reached the spot where it would be best to encamp, but the Indians led us still deeper into the mountains, until we came to a small valley, which at that time of year, when it showed only a withered vegetation of grass and shrubs, had no particular attraction; but lying as it did, hidden among lofty rocks, and surrounded by a dreary inhospitable desert, might, later in the spring, or in the hot summer, appear to a traveler coming upon it accidentally as a marvel of fertility. It seems that the Indians cultivate there fields of maize and wheat; everything indicated that at certain seasons it must present an animated appearance, and the number of turtle shells lying about showed this to be a favorite food of the natives of the country…

We found ourselves very agreeably situated on the banks of this full-flowing brook, where there was grass for our cattle in the valley, and even on the declivities of the nearest rocks; the sun shone warmly and pleasantly; the dry wind that had troubled us so much on the preceding day could not find us out here, and the soft sand on which we spread o:r blankets, was a very agreeable change from the sharp stones on which we had to rest our wearied limbs the preceding night, a couch that had left them still sore and stiff.

On the 2nd of March we left the valley with its pleasant spring, and following it when it became a ravine deeper into the mountains, came to its end at a steep ridge. Slowly the Expedition climbed this, until at the summit of the height a wide prospect to the west unexpectedly opened to us. A dreary and inanimate plain lay before us, the monotony of which was not much relieved by the yuccas that stood pretty thickly towards the west; but what did essentially improve the prospect, was the rocky range of hills that rose behind them. and beyond these again, white glittering peaks, which we took for the southern points *of the Sierra Nevada. Descending from the mountain ridge into the plain, we followed our guides in a southwesterly direction, over a tolerably good road.*[14]

The account in the manuscript diary of Lt. David Stanley, Whipple's Quartermaster, is mainly concerned with the road.

Mar. 3, [1854]

… up a canon in the mountains on the left of the valley…we found a good spring of running water and encamped. Little grass—old Indian camp—bad cañon.…

Mar. 4

We moved up the little canon in which we encamped one mile and ascending about four hundred feet, we saw directly to the west a wide plain stretching out, over which our day's march lay.[15]

Figure 3. Government Road from the summit of Piute Pass looking toward Lanfair Valley, 1969. Arda Haenszel collection..

This, then, was Piute Pass in 1854 (Figure 3).

Though actual construction of a railroad would come later, there was an immediate need for a wagon road along the 35th parallel. In 1858 Lt. Edward F. Beale made inspection trips westward and eastward along the route and was awarded a contract for construction of such a road. It was to meet the Colorado River at a point about 15 miles above present Needles that came to be called Beale's Crossing.[16]

As the road building party worked its way across Arizona in 1859, Beale arranged to have Samuel Bishop bring supplies by wagon from Los Angeles. As Bishop and his band of hardy frontiersmen reached the Colorado, however, they were attacked by the Mojaves, and withdrew to Piute Springs to reconnoiter. United, the members of Bishop's party were a match for the Mojaves, but they could not defend themselves while divided in ferrying the supplies across the river.

Meanwhile, because of repeated and disastrous attacks by Indians on immigrant parties and other travelers along the Mojave River and in the vicinity of the Colorado, Col. William Hoffman had assembled a huge force at Ft. Yuma, and was even then marching up river to subdue the Indians in Mojave Valley and establish a fort there for protection of travelers.

Bishop sent a message to Hoffman asking for military protection when crossing his supplies.

While waiting for the answer, Bishop set his men to work building the road through Piute Fass (Figure 4), making that stretch the first part of the Mojave Road to be built in California. It must have been at this time that Bishop carved his name in fancy letters on a boulder forming part of a wall in the canyon.

Hoffman refused to send any troops ahead to help Bishop. Beale badly needed the supplies, so Bishop could not wait for Hoffman to arrive. He decided to send his wagons back to Los Angeles, load what he could on pack animals, and cache the rest at Piute Springs for later recovery by Beale. The pack train was then able to use a trail recently reported by Aubry and cross the river at a point above the Mojave territory.

Hoffman and the troops finally arrived, overpowered the Indians, and established Ft. Mojave. Leaving some soldiers to man the fort, he took a few back with him to Yuma by steamboat and sent the rest across the Mojave Desert by the Whipple route.

The overland party, by this time short of rations, discovered the Bishop cache when they got to Piute Springs, and proceeded to steal it. The road builders, coming along later, even more in need of the supplies by the time they reached Piute, found the cupboard bare and had considerable hardship in making their way on to the settlements. Beale was never able to get financial restitution from the army.[17]

Figure 4. The Government Road in Piute Pass. Wagon wheel ruts are visible at canyon forks. Arda Haenszel photograph, 1963, now archived at San Bernardino County Museum, AE84-303.105..

It is interesting to note that camels were prominent in the Beale party of 1859 as part of a government experiment in the use of them on the American desert. Almost 100 years later, George Irwin found the remains of a camel pack saddle in the pass.

The first forts, really mere redoubts, were built along the Government Road to Fort Mojave in 1860 under the direction of Maj. James Carleton. They were Camp Cady west of Afton Canyon, and Hancock Redoubt at Soda Springs on the west edge of Soda Lake. Camps Marl Springs and Rock Spring were added later, as Indian attacks along the road were fairly frequent at this time. These rather rude outposts were built as stations for small groups of soldiers who served as escorts for travelers on the road. They included mail and express riders, stage drivers and passengers, wagon freighters, miners, and immigrants.

In the winter of 1867–68, Lt. J. B. Hardenburgh was sent with a detail to build the last of these outposts on Piute Creek. Having not the faintest idea how to go about it, he and the troops were marking time when a military inspection party arrived led by Maj. Gen. Irvin McDowell, commander of the Department of California, and Maj. Henry Martyn Robert, chief engineer of the Division of the Pacific. They immediately sized up the bewildered lieutenant's predicament and stopped over a day to remedy the situation. They located a site, designed the building, and instructed the men how to begin. Taking the unfortunate Hardenburgh along with them to Ft. Mojave, they sent back a knowledgeable sergeant to direct the work.[18]

Organized by the commander, designed by the top engineer in the West, and built by efficient and highly motivated troops, Ft. Piute was the best-planned and best-built of all the outposts on the Mojave Road. Constructed of rock on a site overlooking the road, it commanded the east mouth of the pass (Figure 5). In the plan there were three connected rooms, the one in the center intended for a corral, and those on either side for living quarters for the men. The east room, of which merely the foundation remains, was the smallest. Somewhat larger, the west room contained a fireplace. The entrance seems to have been to the middle room on the north side through a doorway which was protected by an L-shaped rock wall.

This fine building was occupied by troops mostly during the period of its construction, however. In January 1868 the San Bernardino Guardian reported that a lieutenant and 18 men were stationed at Piute Springs, with a relay of horses for mail escort.[19] But later that year the official mail route was shifted from the Mojave Road to the Bradshaw Road farther south, and Ft. Mojave was then supplied by river steamers.

From 1868, Ft. Piute served basically as a relay station for remaining traffic, which changed somewhat in character as mines were opened all over the desert in the 1870s and 1880s. It was probably at this time that the outer corrals were built.

Figure 5. Fort Piute in February 1963. Haenszel collection.

In 1883 the Southern Pacific Railroad completed a line from Mojave to Needles to meet the Santa Fe, which was building westward to the Colorado River. It followed a more direct route from the Mojave Sink[§] to the river, somewhat south of the Mojave Road, as Whipple had tentatively suggested. Unlike the wagon road, and like the Indians, the rails did not need to wander from water hole to water hole. Local roads, and ruts broken out along the route by railroad construction gangs, eventually were augmented and joined into a cross-country route paralleling the tracks. Water and help could be obtained at the little railroad stations at more frequent intervals, and the Mojave Road fell into disuse, except by occasional travelers or in certain sections. The new route evolved, in the second decade of the twentieth century, into the National Old Trails Highway. Piute Springs was bypassed.[20]

Not entirely abandoned, however, Piute Springs in the 1890s was on occasion the camp of Indians, miners, and some travelers. Needles pioneer, Charles Battye, told of an intended meeting of friends Frank Howard, Johnny Madden, and himself "at Howard's mining claims in the Piute Springs country." This was a tale with a sad ending, for they found Johnny's body on the trail from Vanderbilt.[21] Likewise in the 1890s, Piute Spring was the home of Johnny Moss, known for the discovery of several important mines in the east Mojave.[22]

In the early 1900s the road over the hill was said to be impassable to vehicles. But access to the canyon over the Mojave Road from the east was still open. I know that to be a fact because around 1920 my parents and I were driven over it in a Hupmobile by friends from

§ *Note added by editors: The railroad did not go through the Mojave Sink, but rather Daggett and Amboy.*

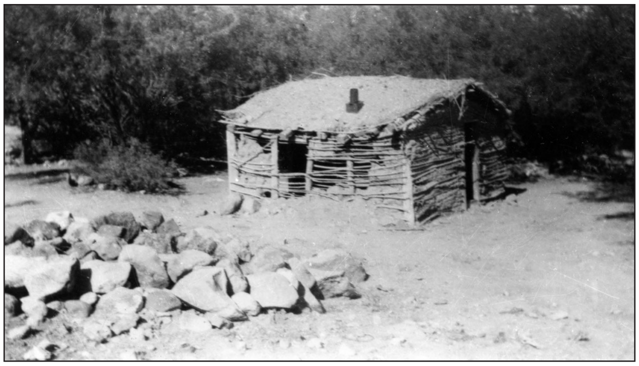

Figure 6. Mud and wattle hut at Piute Springs, 1925. Dr. Allen L. Haenszel photograph in Haenszel collection, now archived at San Bernardino County Museum, AE84-279a.

Searchlight, where my father served as the doctor for the Santa Fe Railroad and the town. At that time my father photographed a mud and wattle house built near the mesquite grove in Chemehuevi fashion (Figure 6), as well as the remains of the fort and the corrals. ln 1924 the Chief Engineer of the California Highway Department Section VIII, E. Q. Sullivan, camped at Piute Springs while resurveying parts of the old road.[23]

In the 1920s the park-like wooded area beside the stream in lower Piute Canyon was a recreation spot for desert residents. The Gus Swearingens and their friends from Needles visited the fort in 1922 and took pictures of it (Figure 7). And in 1925 I remember an outing on which my girl friend and I were treated by friends from Searchlight to a picnic of chicken barbequed there in the canyon beside the stream.[24]

The area at the mouth of the canyon below the fort was homesteaded in 1928 by Thomas Van Slyke, a miner. During World War II, when Patton's trigger-happy trainees in their armored vehicles ranged up into the Piute area practicing for the African campaign, legend has it that Van Slyke stood off a crew that wanted to use the old stone fort building as a military target.[25]

The George Irwin family bought the ranch from Van Slyke in 1944, and for two years tried raising turkeys. It was an ill- fated venture, for the local coyotes grew fat, and the Irwins, though they loved the place, were forced to leave the remote spot for health reasons.[26]

A number of exceptional photographs of the Piute Pass area taken by Walter Fiss (Figure 8) are included in a WPA study of the Mojave Road directed by Josephine Rumble which appeared in 1939.[27]

Informed of the outstanding value of the scenic site in the fields of geology, natural history, prehistory, and history, in 1958 the Bureau of Land Management made a preliminary survey of the pass but had difficulty trying to furnish protection for the area.

Through the efforts of the San Bernardino County Museum in 1973 the entire pass was accepted for the National Register of Historic Places as a historical district.[28]

Figure 7. The Swearingen family and friends beside the fireplace at Fort Piute in 1922. Haenszel collection. now archived at San Bernardino County Museum, AE84-303.

In 1974 vandals toppled the stone containing Bishop's inscription down the cliff and into the stream bed, breaking it into three pieces. When this was discovered by Dennis Casebier, the Bureau promptly raised the fragments by helicopter, fastened them together, and eventually put them on display at the Mojave River Valley Museum in Barstow until such time as the inscription would be returned to its original place at Piute under proper protection.

The earliest known photograph of the fort and corrals was taken by a Needles man, possibly around 1919. This picture shows the walls of the middle and west rooms virtually intact, though the east room had begun to disintegrate. The fireplace wall of the west room, still complete, indicated that the structure had had a peaked roof. By 1922, photographs show that the wall had crumbled down about half way to the top of the fireplace, but all the walls were high enough to preserve the loopholes . Disintegration had proceeded slowly for about 40 years (Figure 9). However, increased visitation by large and small parties, including both deliberate and unintentional vandals, in a steady stream since the 1950s, has done more extensive damage to the structure than in the 100 years preceding.

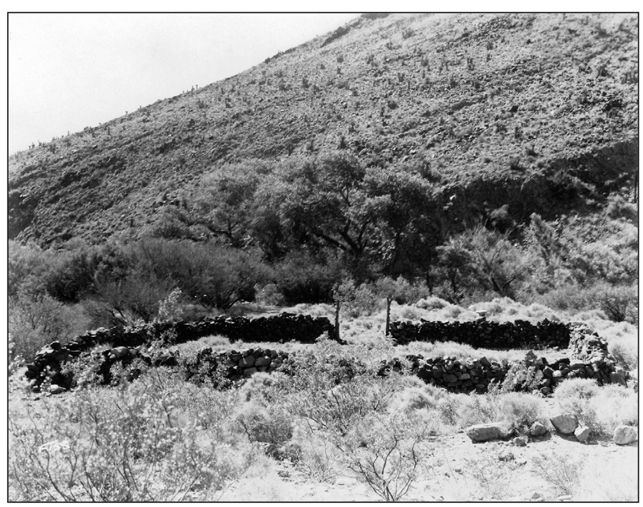

Figure 8. The corral at Fort Piute in the 1930s. Walter Fiss photograph.

Figure 9. Although the walls were crumbling, the loopholes remained at Fort Piute in 1922 when photographed by Dr. Allen L. Haenszel. Arda Haenszel collection, now archived at San Bernardino County Museum, AE84-279b.

In the 1960s, a number of historic remains were still to be seen in Piute Pass (Figure 10). The old road was still visible for much of the route through the pass and across adjoining Piute and Lanfair Valleys. Save where it passes the fort, it ran in or beside the stream through the lower canyon. But still apparent were the wagon wheel ruts worn six feet apart in the soft red formation where the road came up out of the stream bed into the south fork canyon. Approaching the summit, there were even three separate alignments, indicating efforts to improve the grade at the steepest part. Piute Hill was notorious as the worst hill on the road in California.[29] The steep parts have been so eroded by storms that, though their course was still clear, here and there it is impossible to travel on them even on foot (Figure 11).

Beside the fort itself there were remains of other possibly historic structures still visible in the lower canyon. No trace of the Chemehuevi hut remains, but there were remnants of at least three Indian "house rings" below the fort. These may date from the 1850s when Whipple mentioned the presence of brush huts.

Just below the fort was a rectangular masonry wall of patinated native rocks two or three feet high which might have served as an outlying breastwork supporting the fort, or as a small corral. Halfway up the hillside from it, overlooking the fort and the road approaching from the east, was another low wall which may well have been a breastwork.

Across from the mesquite grove there was a stone corral with a gateway facing the road. But the walls of the corral leading-down the hill from the fort had crumbled, and the lower part had been washed away by floods in the tributary draw.

"Bishop's Wall," an L-shaped rock structure whose long side parallels the trail and short side makes a right

Figure 10. Fort Piute in 1962, view from mesquite grove. Haenszel collection.

Figure 11. The Government Road leading from Fort Piute to Piute Pass. Maggie McShan photograph, 1963, in Arda Haenszel collection now archived at San Bernardino County Museum, AE84-303.106.

angle toward the edge of the creek bed, is the deepest mystery. Artifacts indicating a possible aboriginal camp or work site have been found within the L, under the trees and beside the creek. Obviously the spot was known to the natives. Did they build the wall for protection against either weather or possible enemies? A number of petroglyphs occupy prominent exposed faces of boulders forming the wall, and there is at least one metate slick on the top surface of one of the rocks. Did Bishop's men or other white visitors build the wall for some purpose, carefully arranging the decorated boulders to display the petroglyphs? In the upper canyon there is a precedent for this, as there are instances in which rocks used to shore up the road have been placed so as to show the petroglyphs on them to advantage.

This much is known about the history of Piute Pass. The place was unique enough with its flowing-stream and terrible hill to attract attention of visitors through the years and cause them to remember and comment on the place. But the outlying rock structures are not the only mysteries. A rock-covered grave with a nameless headstone indicating burial by white men was discovered near the summit in 1962. The overlying rocks were removed and a much-disintegrated skull was partially uncovered. It had been broken-by a blow on the head. The skull and the rest of the skeleton were not excavated, and the grave was returned to its original appearance. There were accidents on the road down this terrible hill. Did some traveler suffer a fatal fall or become the victim of an unsolved murder? No historical record of this death has been found. [30]

It was a hard land, and life in this remote part of it was precarious. The strong survived, and some of them told us about their experiences at Piute. To this extent can be reconstructed a history of Piute Pass.

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Mapping Padre Francisco Garcés expedition across the Mojave Desert as guided by Indigenous people, late winter of 1776

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The Mojave River and the central Mojave Desert region were loci of Indigenous settlement, travel, and exchange for millennia. This region was a major ancient travel corridor extending eastward from coastal California to the Colorado River and to the Pueblo settlements of northeast Arizona (Earle, 2005). In 1776, Francisco Garcés was guided westward along an existing Indigenous trail from the Colorado River to the San Gabriel Mission of coastal southern California.

His diary is a daily account of the desert crossing, which was translated from original Spanish sources by Coues (1900) and Galvin (1965). The present study reconstructed his entrada from the daily entries. These provide directions and travel distances, a description of vegetation, the presence of water, and the habits of the Indigenous people he encountered. To my knowledge, his route from the Colorado River to the terminus at the San Gabriel Mission has not been traced nor plotted on modern maps. Furthermore, the path into San Bernardino Valley, whether over the San Bernardino or San Gabriel mountains, is uncertain, casting doubt on the course of his entire expedition (Weaver, 1982).

A literature review and an online search of Garcés expedition reveal an abundance of misinformation. The most common misconception is the location of the starting area on the Colorado River. This led to the conflation of his course with several later recorded entries into the Mojave Desert. The route is incorrectly associated with the 19th-century Old Mojave Road, Government Road, and the Old Spanish Trail (Brooks, 1977; Walker, 1986). Nevada State Historical Marker No. 140 near Laughlin, Nevada, is the physical manifestation of this misconception. The marker is 12 miles north of Garcés's actual starting location. Arguably, the marker belongs in California on the west bank of the Colorado River in Piute Wash, where his journey began.

Garcés departed from the river at the mouth of Piute Wash on March 4, 1776 (Figure 1). That day, he traveled 2½ leagues (ca. 2.6 miles) southwest up the wash to a camp at or near Sacramento Springs. The southwest direction of March 4 is unambiguous in his diary. Nonetheless, the Nevada Stateline–historical Fort Mojave area is incorrectly considered Garcés starting area by several authors who claim he departed there to the west-northwest or southwest. The west-northwest departure was used by subsequent parties, including modern recreational traffic (Casebier, 1999). A southwest departure, however, leads directly into the rugged Dead Mountains, which are surely impassable on horseback even for experienced 18th-century equestrians. This confusion regarding the starting location began with Coues (1900) accepting Garcés's inaccurate latitude measurement of March 3, which Coues thought placed Garcés in the Fort Mojave–Stateline area.

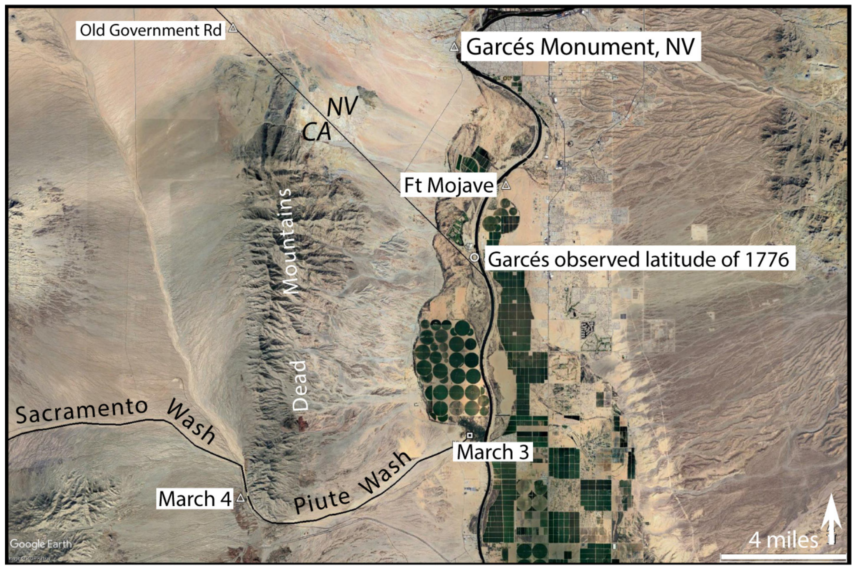

Figure 1. Satellite image showing Garces's starting location on the Colorado River between Laughlin, Nevada and Needles, California.

Garcés expedition was south of all subsequent roads and trails as far west as Afton Canyon. The later roads intersected his trail at the mouth of the canyon. Here, on March 9, he was shown the Mojave River and encamped at or near the canyon's mouth. Thus, he was the first European to see and name the river and the Cady Mountains, although his Spanish designations are not used on modern maps. Traveling up the Mojave River, he encountered and described several rancherias of the

Serrano People (Sutton and Earle, 2017). By March 21 he reached the headwaters of the river in the San Bernardino Mountains, which were hastily crossed using Van Dyke's (1927) Summit Valley–Saw Pit Canyon-Monument Peak–Cable Canyon trail. Traversing west at the foot of the San Gabriel Mountains, Garcés passed through the largely pristine San Bernardino Valley until he reached San Gabriel Mission on March 24.

Garcés's exact path is needed to understand how the desert's environment has changed in a given area. Therefore, we need to know where he was day by day. His observations are important as he saw springs, pasturage, and other environmentally sensitive features more than 100 years before widespread cattle ranching began in the 1880s. Each day, he required many gallons of water for three or four people, three horses, and a mule; pasturage was also necessary. Adequate water was available at every camp except March 7 in the eastern Kelso Dunes area, and pasturage was plentiful at each camp. This is despite the mid-1770s possibly having below-average water-year precipitation (https://www.treeflow.info/california). Presently, the desert seems drier than experienced by Garcés. The springs he used are dry or cannot be found. And pasturage seems diminished if not mostly absent. Whether the current aridity is due to climate change, the development of springs for ranching and cattle production, or both is uncertain.

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Two trails in the East Mojave Desert:
the Mojave Road and the East Mojave Heritage Trail

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ABSTRACT—An ancient trade route across the East Mojave Desert connected the Mojave people, who lived along the Colorado River near the present location of Needles, with coastal California. The first non-native visitors to the Mojave villages were Francisco Garcés in 1776 and Jedediah Smith in 1826. These men were led across the East Mojave by Mojave guides. Over time this trade route became known as the Mojave Road. It became the primary route linking California with New Mexico and other points to the east. During the 1860s and 1870s there was considerable traffic on the Mojave Road. In 1883 a transcontinental railroad was built across the East Mojave Desert. Almost immediately the Mojave Road faded from memory.

It wasn't until the 1960s that Dennis Casebier "discovered" the Mojave Road and wrote several books based on his extensive research that the public became aware of this historic route across the East Mojave Desert. The Friends of the Mojave Road, a group of explorers and adventurers founded by Dennis Casebier, helped to write a trail guide, and assisted in making the Mojave Road accessible.

A second trail, the East Mojave Heritage Trail (EMHT), was developed by the Friends of the Mojave Road beginning in 1984. Unlike the Mojave Road that linked the Colorado River with the coast of California, the EMHT was laid out as a "sightseeing" route that was pieced together by joining historic mining and ranching roads, abandoned railroad berms, roads left from World War II training, utility corridors, and abandoned highway alignments. The Desert Protection Act of 1994 established Wilderness Areas that broke up the EMHT because about 90 miles of the EMHT were closed to vehicle travel. In 2019 by exploring alternative routes that bypassed routes closed by wilderness designations, Billy Creech, currently president of the Mojave Desert Heritage and Cultural Association (MDHCA), resurrected the EMHT. The MDHCA is a non-profit organization that has followed in the footsteps of the Friends of the Mojave Road.

Introduction

Mojave Indians are Pipa Aha Macav — "The People by the River." From their villages on the Colorado River near the present town of Needles, an ancient path led west, eventually reaching the California coast. They flourished because of the agricultural abundance which was watered by the Colorado River. In 1776 Fr. Francisco Garcés (a Spaniard) traveled up the Colorado River from Yuma and became the first non-native to reach the Mojave villages. Mojave guides led Garcés westward across the desert and across the Tehachapi Mountains to the southern end of the Central Valley and back to the Colorado River. Fifty years later in October 1826, Jedediah Smith, the first American to reach California overland, arrived at the Mojave villages from north-central Utah. Mojave guides led him to the California coast on their network of trails.

In 1853 Congress directed the War Department to explore whether there were potential routes along which railroads could be laid to the west coast. Lieutenant Amiel Weeks Whipple led an expedition that arrived at the Colorado River in March 1854. The expedition was escorted to Los Angeles by Mojave guides. Whipple is responsible for many East Mojave Desert place names that are still in use. Beginning on August 31, 1857, Edward Fitzgerald Beale and his crews labored on a wagon road west from Zuni, New Mexico. They arrived at the Mojave villages on October 17, 1857. By this time a well-established route connected Los Angeles with the Colorado River.

Beginning in 1846, for the next 13 years many on both sides lost lives as strife and bloodshed dominated the relationship between the Mojave people and travelers passing through their ancestral lands. Finally in the spring of 1859 more than 500 soldiers under the command of Major William Hoffman marched against the Mojave. Faced against this superior force the Mojave capitulated. A short time later Fort Mojave was constructed to keep the peace. With the establishment of Fort Mojave, the ancient trail became a wagon road. A large amount of commerce and communication with Arizona took place over the Mojave Road. In the 1860s the Chemehuevi and other Indians in the central part of the East Mojave retaliated because of incursions by white men on their ancestral lands. As a result, the Army established small redoubts or forts at springs along the Mojave Road to protect U. S. Mail carriers and government wagon trains.

The Mojave Road's busiest years were during the 1860s and 1870s. Because of reliable water sources it was the preferred route. Also, it was higher in elevation and therefore cooler than roads that crossed the southern deserts of California and Arizona.

By May 1883 the Atlantic and Pacific Railroad building from the east and the Southern Pacific Railroad building from the west laid rails across the desert which joined at the Colorado River just south of Needles. This transcontinental railroad marked the beginning of the end of traffic on the Mojave Road. Soon a road that paralleled the railroad was developed which eventually became a part of Route 66.

Rediscovery of the Mojave Road

In 1953 Dennis Casebier joined the Marine Corps to do his part in the Korean War, but soon after he enlisted, the armistice ending the war was signed. Upon completion at the communications and electronics school, he was sent to the new Marine Base at Twentynine Palms for the remaining two and a half years of his enlistment. While there he spent much of his free time exploring Joshua Tree National Monument and the eastern Mojave Desert. Afterward he returned home to Kansas where he went to college and obtained a degree in mathematics and physics. In 1960 as an employee of the U. S. Navy he moved to Corona, California. Back in California, he rediscovered the desert and began to research the eastern Mojave's history. He bought a set of U.S. Geological Survey topographical maps and noticed a route labeled "Old Government Road." Intrigued to learn more, he discovered not much had been written about it.

Figure 1. Dennis Casebier on the Mojave Road May 1982. MDHCA Photo

His work with the Navy often took him to Washington D. C. While there he began to research at the National Archives and Library of Congress. Old Army records, records of the Bureau of Indian Affairs, and many others contributed to tell the history of the route which was known in those early days as the Mojave Road.

For ten years he studied the history of the Mojave Road and by 1970 became convinced that he needed to document his findings. His first book, *Camp El Dorado Arizona Territory,* was published by the Arizona Historical Foundation at Arizona State University. Through this experience he realized that he wanted to start his own publishing company. In 1971 he formed the "Tales of the Mojave Road Publishing Company [TOTMR]," and in 1975 *The Mojave Road* was published.

At first, Dennis (Figure 1) felt that the Mojave Road would best be experienced as a hiking trail. However, after walking the 138-mile-long trail from Fort Mojave to Camp Cady in October 1975, he realized hiking the Mojave Road would never catch on. The distances are great, few hardy souls would attempt it, and it would never become popular.

Consequently, he began assisting the Bureau of Land Management (BLM) to guide the future of the Mojave Road as a four-wheel drive recreation trail. In 1980, the Associated Blazers of California asked Dennis to lead a small group of four-wheel drive vehicles over the Mojave Road, the first of many trips he would lead.

In May 1981, at a meeting of scientists, desert explorers, and BLM employees held at Zzyzx, the organization Friends of the Mojave Road was formed with Dennis named chairman. The "Friends" entered into a volunteer agreement with BLM to develop the Mojave Road into a recreational trail. They agreed to make minor road repairs, erect rock cairns at intersections to point the way, and prepare and publish a Mojave Road guide. These tasks were accomplished in November 1983 with the publication of the *Guide to the Mojave Road*. On October 4, 1984, an agreement was signed by Dennis Casebier and representatives of the BLM and the California Association of Four Wheel Drive Clubs (CA4WDC) that CA4WDC would adopt the Mojave Road.

The *Guide to the Mojave Road* was published in 1983, and later revised and reprinted as *Mojave Road Guide* in 1986, 1999, and 2010. The 2010 edition is still in print. The original 1975 book *The Mojave Road* is long out of print but can be found online at used book sites. It is the most comprehensive history of the Mojave Road. The *Mojave Road Guide* is more than simply a turn-by-turn road guide; it will immerse you in the Mojave Desert's history, events, and captivating sights.

The sections of the *Mojave Road Guide* include the following: Colorado River to Piute Creek, Piute Creek to Rock Spring, Camp Rock Spring, Rock Spring to Marl Springs, Government Holes, Marl Springs to Travelers Monument Soda Springs, Travelers Monument to Afton Canyon, Afton Canyon to Camp Cady, History of the

Tonopah and Tidewater Railroad (Casebier and Ervin, 2010).

East Mojave Heritage Trail

In early 1984 the Friends of the Mojave Road decided to establish a new route in the East Mojave Desert. After looking at other historic trails, such as the Old Spanish Trail and the Borax Traction Road, that might be managed like the Mojave Road, it was determined that no single trail was suitable. Field reconnaissance began in December 1984 and continued non-stop for the next two years. The trail that was laid out that made use of many historic routes: old mining roads, ranching roads, abandoned railroad berms, roads left from World War II training, utility corridors, and abandoned highway alignments. The 600+ mile route that was laid out started and ended in Needles. However, it was so long that it was decided to split it into 4 segments. Every effort was made to avoid BLM proposed Wilderness Areas. This route at first was named the Ivanpah Trail or the Ivanpah Loop.

According to Billy Creech (2023, p. 1):

> *On an evening in 1986, after several days on the trail camped along what is now EMHT Segment 4, Dennis Casebier sat with National Geographic writer Barry Lopez and photographer Craig Aurness discussing their experience on his work in process trail names, "The Ivanpah Loop." Aurness said to Dennis, "Man this trail is spectacular, it is truly special – it's rugged, remote, historic, and picturesque. But, Dennis, the name really sucks. This trail contains so much heritage of the East Mojave Desert, it is far more than just Ivanpah. You really need to change the name to reflect that." Fortunately, Dennis listened to Craig, and thus, the Ivanpah Loop was rebranded as "The East Mojave Heritage Trail" and a legend was born.*

Following this trip, beginning in September 1986 the route was known as the East Mojave Heritage trail or EMHT.

Like the *Mojave Road Guide*, it was envisioned that guidebooks for the trail would explain the history of the route segments as well as the flora, fauna, geology, geography, and other features of the desert.

Early in 1985 the BLM was notified of the plan to develop the first segment of the EMHT. During the Friends of the Mojave Road Rendezvous in October 1985, the nearly completed route was traveled by several groups, and in the October 10, 1985, *Mojave Road Report* Dennis put out the request for volunteers for numerous tasks: creating narrative logs of the route, darkroom work, making maps, organizing data, photography, artists, researchers, Ivanpah Loop slide show presenters, sponsors, interviewing old-timers, and help with printing.

Work on the guidebook for the first segment of the EMHT began in earnest late in 1986 and it was sent to the print shop on July 1, 1987. The guidebook for the second segment was published in October 1988, the third in October 1989 and the fourth a year later. Each of these books cost about $30,000 to print (Casebier, et. al., 1987, 1988, 1989, 1990). The EMHT guides and the Mojave Road Guide are comprehensive, foundational documents for a number of fields of research.

Federal Management of the East Mojave Desert

On October 21, 1976, long before the 1981 agreement with BLM to develop the Mojave Road as a recreation trail, the Federal Land Policy and Management Act, was signed into law. This Federal law directed BLM to develop a balanced multiple use plan, with the public's input, to guide management of the area. Special emphasis was to be given to protection, recreation use, and wise development of the California Desert Conservation Area's (CDCA) public resources. This law required the BLM to complete the Land Use Management Plan of the CDCA by September 30, 1979. This was a seemingly impossible task, but it was actually accomplished on time. The plan was approved by Cecil Andrus, Secretary of the Interior on December 17, 1980. The central part of the East Mojave was designated as a National Scenic Area, and throughout the CDCA two million acres were recommended to be designated as wilderness, 73 Areas of Critical Environmental Concern were designated, and 11 special areas were also set aside

The BLM Desert Plan was completed after spending $8 million and evaluating some 40,000 public comments. It was a compromise among all competing interests and balanced uses fairly. It divided the desert into zones for protection, use, and development and established several special management areas to ensure preservation of sensitive resources.

However, no sooner was the ink dry on the Secretary of the Interior's signature, than the Sierra Club decided to do an end-run around the BLM's plan. In 1987 they persuaded U.S. Senator Alan Cranston to introduce the California Desert Protection Act before the U.S. Senate. Alan Cranston did not seek re-election in 1992, and Dianne Feinstein was elected Senator replacing Pete Wilson who had been elected Governor of California. At the last minute the House changed the proposed bill from creating a Mojave National Park to a Preserve. Hunting, fishing, and trapping were permitted as allowed by federal and state laws, with certain exceptions. Mining was to be governed by the National Park Service regulations, and grazing was permitted to continue at no more than the then-current level. Feinstein pushed the bill over the finish line. On October 8, 1994, it was passed by both houses of Congress and was signed into law by President Clinton on October 31, 1994. Approximately 2.5 million acres of the East Mojave became wilderness, compared with the 833,000 acres of BLM proposed Wilderness. (For this exercise I defined the East Mojave as the California boundary on the east, the Riverside County line on the south, the Inyo County line on the north and on the west a line primarily following the Tonopah and Tidewater

Railroad to Ludlow, and from there a straight line south to the Riverside County line.) Also, management of the East Mojave National Scenic Area was transferred to the National Park Service and the area was renamed the Mojave National Preserve. Basically, the work done by the BLM with the thousands of public comments was discarded. This new plan was a *Conservation Plan*, compared with the Desert Plan which was considered a multiple use plan. There was little input from either the public or the BLM during the time the California Desert Protection Act worked its way through Congress. But administration of the CDCA under the California Desert Protection Act was BLM's new marching order.

Regarding the newly created East Mojave Heritage Trail, it was sliced into pieces by the newly created Wilderness Areas. A total of 91.5 miles of the route were now off limits. The guidebooks that were created at the cost of over $100,000 needed significant updates. Segments 2, 3 and 4 were the portions of the route most significantly impacted (see Map 1).

On August 3, 1993, a year prior to the passage of the Desert Protection Act, the "Friends of the Mojave Road" was incorporated as the "Mojave Desert Heritage and Cultural Association" (MDHCA). Eventually the MDHCA ceased selling the EMHT guidebooks for segments 2, 3, and 4 because they worried that someone would drive through a wilderness area with one of their guidebooks and they would be held liable.

The EMHT revived from the dead

Although there had been some attempts over the years to work out routes to bypass the wilderness closures, those efforts didn't go anywhere. In part this is probably due to the enormous investment of time and money in publishing the guidebooks. The thought of creating new guidebooks was overwhelming. In time the 660-mile long EMHT passed from the memory of overlanders.

Billy Creech (Figure 2) in 2016 first stumbled onto the EMHT while researching a different route. In 2018 he began researching, planning, and coordinating with the BLM and Park Service authorities to remap a route that bypassed portions that were closed. During the process he forged a relationship with Dennis Casebier as well as the BLM Field Office Manager Mike Ahrens. On Saturday October 12, 2019, at the MDHCA Rendezvous at Goffs, California he recounted the labor that he had poured into updating and modernizing the East Mojave Heritage Trail. I was at that presentation and can tell you that the assembled crowd was electrified by his presentation. Billy presented a well-developed plan to resurrect the EMHT which was long thought dead (Creech, 2020).

Figure 2. Billy Creech checking the East Mojave Heritage Trail April 2019.

The key to this proposal was to publish supplemental route guides (Creech et. al., 2023). Billy had GPS-ed the route and had taken meticulous notes along the way. The new route is 733 miles. Early in 2020 Billy, with the assistance of John Marnell and myself, began working on the supplemental route guides which were completed by August 2020.

In September 2023 a revised Supplemental Guide was printed thanks to a grant from the State of California Off-Highway Motor Vehicle Recreation (OHMVR) Division. The Supplemental Guide is free of charge—you just pay for shipping (https://www.themojaveroad.org/product-page/emht-suppliment-guide).

The MDHCA website describes the EMHT Supplemental Guide:

> *THE COMPLETE SUPPLEMENTAL GUIDE REQUIRED ALONG WITH THE FOUR ORIGINAL EMHT GUIDEBOOKS*
>
> *The East Mojave Heritage Trail, EMHT, is a daunting and spectacular 733-mile remote desert exploration route through one of the most hostile environments on Earth. Planning and preparation are essential to success and this complete guide will provide you not only with critical information, tips, and insights – it is also your required source for updated compliant route guidance and MUST be used in conjunction with the original set of four guidebooks. If you intend to tackle one of the most challenging and rewarding backcountry exploration routes in North America, this supplemental guide is a must have.*

The Supplemental Guide doesn't pull any punches. The trail is remote and rugged (Figure 3). Before attempting it, you MUST have a high clearance 4WD vehicle and have read all the recommendations in the first 4 pages of the supplemental guide.

Subjects described in the guidebooks.

Segment 1: The Mojave Indians; The historic El Garces; Railroad Station; Goffs, the Desert Training Center; The Signal Mining District; Searchlight; The Mojave Road; East Mojave Cattle Industry; Nevada Southern Railway; Lanfair Valley; Last Wolf of the East Mojave; Hart Mining District; El Dorado Canyon Road; Joe Kennedy Well; Barnwell & Searchlight Railway;

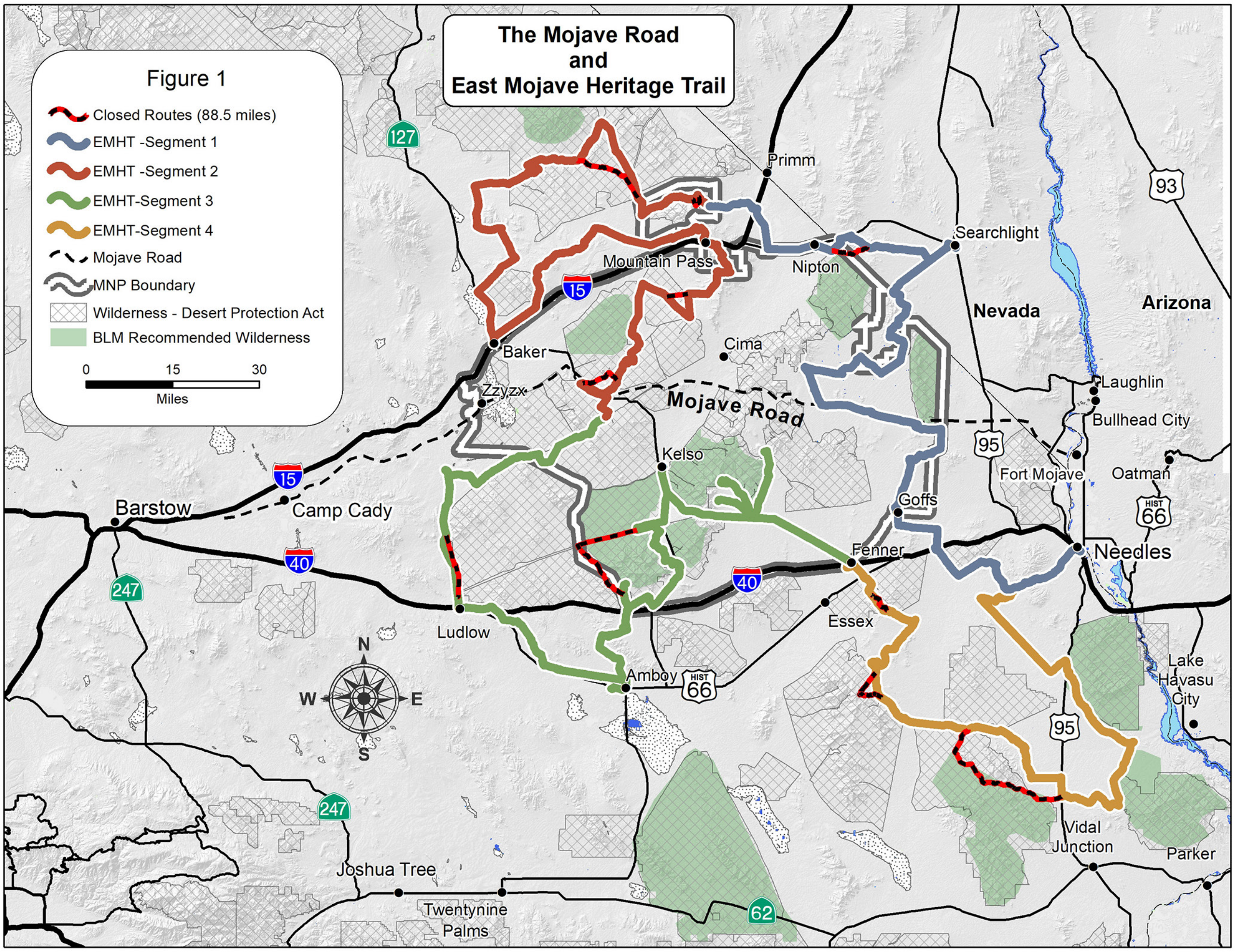

Figure 3. Map of the East Mojave Heritage Trail segments showing BLM proposed wilderness, wilderness areas as enacted, and historical places near the trail.

Walking Box and YKL Ranches; Crescent, Nevada; Nipton, California; Traction Road; Ivanpah.

Segment 2: Ivanpah; Clark Mountain Mining District; Bighorn Sheep; Barstow-Vegas Motorcycle Race; Kelly Field; Salt Lake Trail; Trip to Kingston Springs; Valjean; Borax Smith and the Tonopah & Tidewater Railroad; Riggs; Silver Lake Talc Mine; Boulder Corridor; Silver Lake; Sink of the Mojave River; Baker; Prehistoric Turquoise Mines; Signs of the Desert; Yates Ranch; Rosalie / The Copper World Mine; Molycorp Rare Earth Mine; CALNEV Pipe Line Company; Mescal / Nantan; The Legend of the Kokoweef; J. Riley Bembry's Photos; Standard Camp; Sextette Mining Camp; Toegel City; Riley's Camp; Cima's Gibson Years; Valley View Ranch; Rock Art; The Cima Cinder Cones; Rocky Ridge History.

Segment 3: Rocky Ridge; Edison Co. Power Line; Proctor Canyon; The Devil's Playground; The Union Pacific Railroad; Drifting Sand; Crucero; Tonopah & Tidewater Railroad; Natural Arch; "Ma" Preston-Queen of the Desert; The Bagdad-Chase Mines; Route 66; Transportation Historian; Twentynine Palms Marine Base; Bagdad, California; Orange Blossom Mine; Budweiser Spring; Nuclear Option; Carleton's Piute Campaign; Onyx Mine; Granite Mountains Reserve; Kelso Station; The Vulcan Mine; Father Garces at Foshay Pass; Providence; Mitchell's Caverns; Fenner Valley.

Segment 4: Fenner; Desert Tortoise; Fenner Spring; Willow Spring; Jim Craig & Sunflower Springs; Old Woman Meteorite; Lucky Jim Mine; Lost Arch Inn; Havasu Lake; 7 IL Ranch; Camp Clipper; Santa Fe Railroad; Geology; Wildlife; Hard Rock Mining; Desert Literature.

Items in the supplemental guide not in the original books: Mojave Phone Booth; The Mojave Megaphone

Awards

September 29, 1987. "A Tribute to Friends of the Mojave Road" was read into the Congressional Record by Congressman Jerry Lewis (Rep. CA) as recognition for the work that Dennis Casebier and the Friends of the Mojave Road had done for BLM in the California Desert.

June 15, 1988. A "Certificate of Appreciation" signed and presented by Secretary of the Interior Donald Paul Hodel and presented to Dennis "in recognition of your efforts to educate the public in desert etiquette through your interpretive guidebooks for the East Mojave National Scenic Area."

October 7, 1989. The Director of the Bureau of Land Management approved two awards (one for Dennis individually and one for the Friends of the Mojave Road) "For Exemplary Volunteer Service" on public lands. These awards, which are the highest such awards that BLM grants, were presented at the Tenth Mojave Road Rendezvous in Nipton, CA.

November 9, 1990. A proclamation by Roy A. Mills & the City of Needles, California, for the Friends of the Mojave Road's work with the Mojave Road and East Mojave Heritage Trail projects.

November 10,1990. Special recognition awards from the BLM to the Friends of the Mojave Road, Dennis G. Casebier, Ted Jensen, Neal Johns, Bob Martin, Pete Panattoni, and Jo Ann Smith, on the occasion of completion of the East Mojave Heritage Trail.

November 10, 1990. A letter of appreciation from Ed Hastey, California State Director for BLM, to Dennis G. Casebier and the Friends of the Mojave Road for the Mojave Road and East Mojave Heritage Trail projects

Acknowledgements

I would like to thank both Billy Creech and John Marnell for reviewing this document.

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The De Anza Trail: crossing the Sonoran Desert from Yuma to Ocotillo

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The Unforgiving Sonoran Desert. © W. J. Elliott 1-26-2024. Saguaro cactus—*Carnegiea gigantea*.

Introduction

The de Anza Trail extends from Tubac, Arizona, northwest to the San Gabriel Mission, Monterey, and finally on to San Francisco, California. Since this essay is being submitted to the April 2024 Desert Symposium meeting in Zzyzx, California, this discussion will focus on desert regions in southeastern California and southwestern Arizona. The purpose of this essay is to provide historical background for the current Interstate Highway 8, that carries vehicular traffic from Yuma, Arizona to Ocotillo, California. This approximately 75-mile route runs subparallel to the present-day United States–Mexico border.

Early use of this overland route was by pedestrians, equestrians, wagons, and stagecoaches. One of the biggest problems for these early travelers was the lack of potable water in the Sonoran Desert between the Colorado River and the Yuha Well (as well as fresh-water springs at the base of the Peninsular Ranges near present-day Ocotillo). With the advent of mass-produced motorized vehicles in the early 20th century, unimproved dirt wagon roads needed to be replaced with hard-surfaced roads. U.S. 80 was the first paved road constructed between Yuma and Ocotillo, followed a few years later by four-lane Interstate Highway 8. Along the way, the San Diego Arizona and Eastern railroad was constructed roughly parallel to U.S. 80.

Ever since humans migrated to the western hemisphere, this multi-use corridor has provided a connection between the Atlantic and Pacific oceans. It passes through the Yuma Crossing of the Colorado River.

Climate

The Sonoran Desert, also known as the Colorado Desert (Figure 1; Wikipedia, 2024b), is one of the hottest, most inhospitable places in western North America (Figure 2). Summertime temperatures regularly reach and/or exceed one hundred degrees Fahrenheit during the months of June through September. Daytime winter temperatures hover in the high sixties and low seventies, while nighttime temperatures can fall into the high 30s Fahrenheit. Average annual precipitation is about five and one-half inches (Wikipedia, 2024i).

The point of this blistering introduction is to set the scene for living in, or crossing this desert without adequate preparation, directions, or water. Such was the case when the de Anza party crossed this desolate landscape. Today, however, with modern air-conditioned

Figure 1. Map showing the Colorado Desert as a subset of the Sonoran Desert, which extends further south into Baja California and mainland Mexico. (Wikipedia, 2024i)

Figure 2. Mureto Saguaro cactus. (© W. J. Elliott, 1-2024)

Figure 3. Wild game trail. (© W. J. Elliott, 1-2024)

vehicles on Interstate 8, it is a walk-in-the-park and a short 1-1/2-hour drive.

Game trails and Native American trade routes

Prior to the arrival of humans from the eastern hemisphere, wild game (rabbits, foxes, deer, and the like) created ready-made paths (Figure 3). Many of these lead to safety, food, and/or water.

When humans arrived, it is likely that they followed these same paths for similar purposes. Likely, they set up markers and cairns to provide "road signs," if you will. With time, trade routes were established and became well-worn and easy for early inhabitants to follow.

The Yuma Crossing: 1500s to 2024

In the mid-1500s Spaniards exploring north of Sonora, Mexico, for the seven cities of gold, Cibola, discovered the Colorado River and the Yuma Crossing. Early explorers included Francisco de Ulloa, who in 1539 reached the north end of the Gulf of California but did not venture north of the vast braided delta to the Colorado River sensu stricto. In 1540 Vasquez de Coronado, also seeking seven cities of gold, explored what is now Arizona and viewed the Colorado River from the south rim of Grand Canyon, but returned to Mexico empty handed.

Captain Hernando de Alarcon led three ships north through the Gulf of California from Acapulco to the mouth of the Colorado River where he navigated the shallow delta water and sailed into the Colorado River sensu stricto. He and his sailors sailed north, past the Yuma Crossing, and near the mouth of the Gila River he planted a cross and told of a note buried at its foot. From there he sailed back down the Colorado River to the Gulf of California and returned to New Spain (Mexico).

Also in 1540, Melchior Diaz traveled north, overland from San Geronimo, Sonora, to southwestern Arizona. He and his explorers crossed the Colorado River at the Yuma Crossing, from Arizona to California. Diaz and his 25 soldiers were the first Europeans to cross the Colorado River at the Yuma Crossing (Trafzer, 1998; Wikipedia, 2024d). While in California, Diaz threw his lance at his dog. The lance landed business ended up. His horse bolted and threw him off, whereupon he was impaled on his lance. He died on the way back to the Colorado River.

While drifting down the Colorado River in 1604, having given up trying to find the seven cities of gold (Cibola), Juan de Onate passed the Yuma Crossing on his way to the Gulf of California. He determined that California was not an island, as previously thought (Trafzer, 1998). Later in 1687, Father Eusebio Francisco Kino produced a map that definitively showed that California was not an island, and that an overland route through the Yuma Crossing, from Mexico to the west coast, was possible (Trafzer, 1998).

The magic of the Yuma Crossing

The magic of the Yuma Crossing is that it is the one place along the Colorado River during the early days of Spanish exploration, where draft animals, wagons, and pedestrians could cross the Colorado River on foot, without resorting to rafts or swimming. To the north the river was swift, deep, and wide. To the south, it became a soft, shallow, braided, siliciclastic delta with endless obstacles. It was an hourglass pinch point for east-west surface travel and remains so today.

The present-day Yuma Crossing for the "Ocean to Ocean" U.S. 80 truss bridge and the Southern Pacific Railroad truss bridge is where Middle Proterozoic granitic rocks crop out on each side of the Colorado River. These hard and dense basement rocks make good foundation sites for cast-in-place concrete pier bridge supports.

In the early days of Spanish exploration, a short distance south of these bedrock narrows, the river widened to as much as 500 feet and shallowed with a slow current, allowing pedestrians and horses to cross in waist deep water. Today, dams and modern bridges provide Colorado River crossings that were unavailable to early explorers.

Captain Juan Bautista de Anza and Father Francisco Thomas Garcés 1774–1776

On Wednesday, February 9, 1774, Capitan Juan Bautista de Anza, Father Francisco Thomas Garcés, 34 men, over 100 mounts (horses) and 80 cattle crossed the Colorado River at the Yuma Crossing, about two miles downstream from the confluence with the Gila River (USGS, 1903). At that time, the Colorado River was running about 3 to 4 feet deep and 500 feet wide. Most of the men were able to ride across on their mounts without getting wet; Father Garcés, however, chose to be carried across.

De Anza and his expedition travelled about 30 miles southwest from present-day Yuma, along the west side of the Colorado River to Santa Olaya (a village about 10 miles west of the Colorado River). From there they traveled westerly into Sonoran Desert (Figure 4). Exhausted from trudging over soft sand and through the unforgiving landscape, as well as lacking a map, a guide, and adequate water, the expedition turned back to rest and resupply at Santa Olaya.

Refreshed, the expedition set out again, this time on a more southwesterly route, which eventually turned northwest, past the east side of Laguna Salada and finally to the Yuha Well (Figure 5) (about 7 miles east-southeast

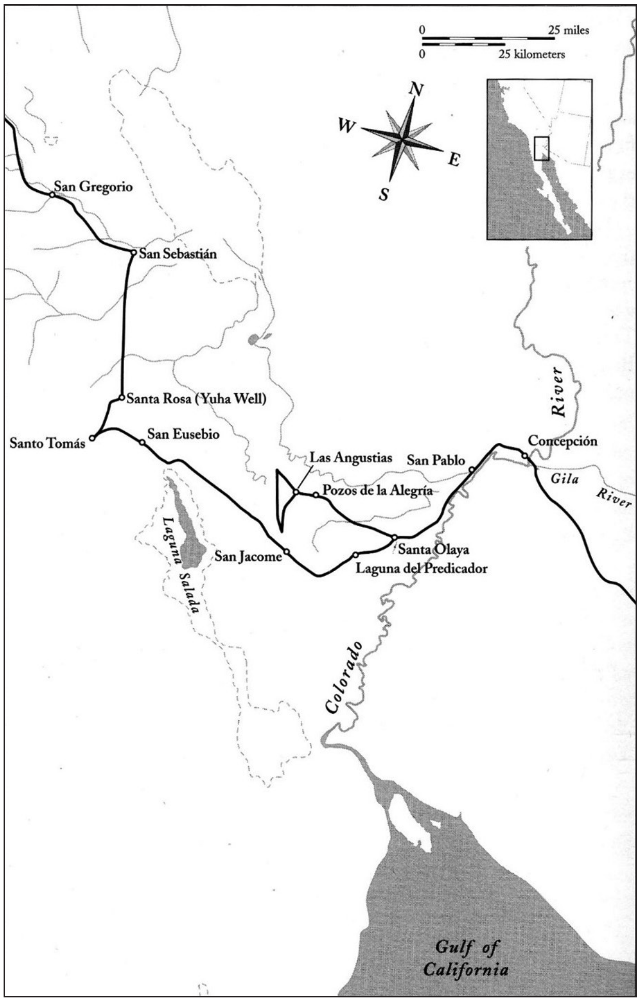

Figure 4. de Anza's first expedition, 1774-75. (Guerrero, 2006, page 34).

of present-day Ocotillo, CA). Kamias Indians led Anza to this well (Santa Rosa de las Lajas), the first good water after leaving the Colorado River (Kindig, 2016). From there it was on to Mission San Gabriel, located about 10 miles east-northeast from present-day downtown Los Angeles. De Anza then led his expedition to Monterey, CA.

Retracing his route to the Yuma Crossing, and back to Tubac, he and his men arrived on May 27, 1774, logging 140 days in the harsh southwestern wilderness.

De Anza made the same journey between September 29, 1775, and June 1, 1776 (logging about 8 months on-the-hoof). This time, with prior knowledge, de Anza was able to cross the Colorado River at the Yuma Crossing and thread his expedition around the south end of the Sand Hills (Algodones Dunes) and west to Yuha Well (Figure 5). From there, he travelled northerly along the eastern side of the Peninsular Ranges to San Gabriel, Monterey, and finally on to San Francisco. This time with 240 colonists, herds of cattle, sheep, and horses, he led the group to Alta California to establish a new Spanish colony (Trafzer, 1998; Guerrero, 2006).

Figure 5. Yuha Well site, southeast of Ocotillo, CA. © W. J. Elliott, 1-28-2024.

Pedestrians, draft animals, and wagons: 1776 through the 1920s

After de Anza's expeditions in the later part of the 18th century, pedestrians, equestrians, and wagons drawn by draft animals crossed the Colorado River at the Yuma Crossing for another 125 years. This waypoint was a familiar stop for travelers heading for the west coast from Missouri and Arkansas via various named and unnamed trails. Presumably, the manifest included explorers, adventurers, prospectors, fur trappers, farmers, ranchers, merchants, scoundrels, and all manner of humanity from the timid to the bold. In those days, there was no such thing as a hard-surfaced road to follow, so of necessity, dirt tracks, trails, and wagon-wheel ruts were followed, as well as just about anything over which they could make westward progress without becoming stuck in mud, soft sand, or quicksand.

Mormon Battalion: 1846 to 1847

The Mormon Battalion marched nearly 1,950 grueling miles from Council Bluffs, Iowa to San Diego, California between July 1846, and July 1847 (Figure 6). Somewhere between 534 and 559 Latter-Day Saints volunteers and their leaders were under the command of regular U.S. Army officers during the Mexican–American war of 1846 to 1848. As with the de Anza expeditions and other early explorers, these recruits suffered from hunger, thirst, and disease.

Their route through Arizona took them from Tubac to Tucson and then west along the Gila River to the Yuma Crossing. From there, they traveled west around the south side of Pilot Knob (Figure 7) and across the Sonoran Desert to present-day Borrego Springs. One of their greatest contributions to the westward movement was the establishment, via the Yuma Crossing, of a good wagon road from the midwest to the west coast. (Wikipedia, 2024f)

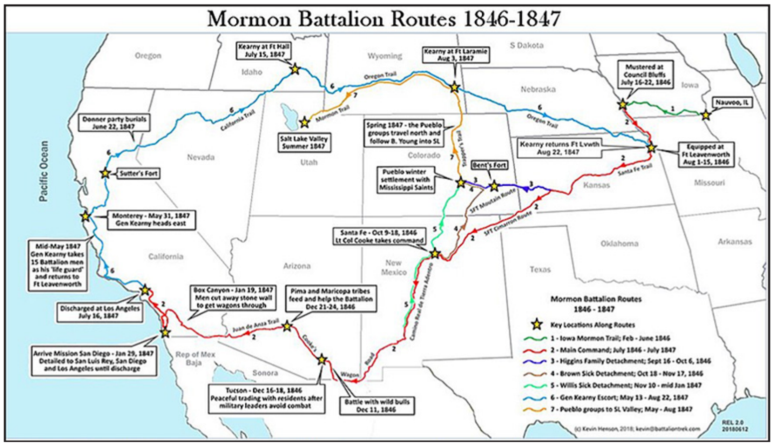

Figure 6. Mormon Battalion Routes 1847-1848. (Wikipedia, 2024f)

Figure 7. Pilot Knob as de Anza would have seen it from the Yuma Crossing. © W. J. Elliott, 1-28-2024.

Butterfield Stage route: 1858 to 1862

The earliest overland stagecoach and mail service between San Antonio, Texas and San Diego, California was known as the Jackass Mail (Figure 8). It carried passengers and mail between July 1857 and June 1861 along the southern route, also known as the southern emergent trail (Wikipedia, 2024h). This route paralleled the Gila River in Arizona and crossed the Colorado River at the Yuma Crossing. From there it skirted the south side of Pilot Knob and then west across the Sonora Desert to Yuha Well (Figure 5), past Carrizo Creek, Agua Caliente, Vallecito, and on to Warner's Ranch on the way to San Diego.

To traverse the soft Sonoran sand, stagecoaches and wagons were oftentimes left behind and the journey was continued on mule back—hence the name Jackass Mail (Ahnert, 2019). Jackass Mail was absorbed by Butterfield Overland Mail in September 1858, and from March 1861 to June 1862 became Overland Mail Corporation.

Watering holes and rest stops can still be found along this route. Three walls of the Araz adobe still stand west of Yuma, and remnants of the Yuha well (Figure 5) can be seen in a dry wash near Ocotillo. Agua Caliente Hot Springs and the historic Vallecito stage station currently function as county parks and campgrounds. Warners Ranch has been partially restored and is open to the public. One of the biggest thorns in the stage line operation was constant attacks by Apache Indians along the eastern Arizona section of the run (Ahnert, 2019).

Now, fast forward about 70 years…..

Figure 8. National Park Service, Butterfield Overland Trail, 2024.

Railroads: 1877 to 2024

Contrary to the hopes of early 20th century San Diegans, there is no railroad across the Algodones Dunes. The rail route from the Yuma Crossing to Ocotillo, CA, skirts the dunes to the north—to go around to the south would place tracks in Mexico. The Southern Pacific Railroad laid tracks from Indian Wells (now Indio) southeasterly to Yuma along the east side of the Salton Sink in the spring of 1877, reaching the west bank of the Colorado River on May 23, 1877. Southern Pacific Railroad built a low "pivot bridge" across the river at the Yuma Crossing in September 1877, thus, completing the coast-to-coast rail line. This turnstile bridge could turn 90° to allow river boats to pass.. It served the railroad until 1923 when a permanent arched steel truss bridge was constructed across the river. The truss bridge is still in use today. (Mariner, 2020; Trimble, 2016).

In 1902 Anthony H. Heber and William F. Holt organized the Imperial and Gulf Railway Company to lay track from the existing Indio-to-Yuma right-of-way, south to El Centro. This work would start at the Imperial Junction (formerly The Old Beach siding), near Niland,

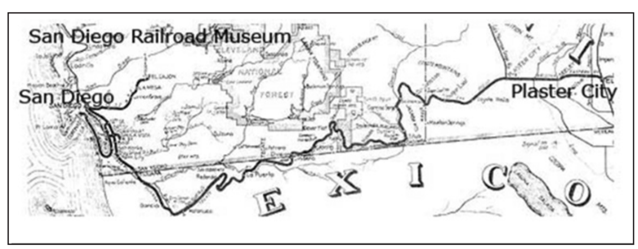

Figure 9. The Impossible Railroad and Carrizo Gorge (DesertUSA, 2024). *From Plaster City, the railroad continues east to El Centro where another railroad's tracks run north to Niland to join up with the Southern Pacific tracks between Los Angeles and the Yuma Crossing. In an obtuse way, this completes the Anza Trail between The Yuma Crossing and Ocotillo. (Railroad tracks were never laid in a straight line, across the Algodones Dunes, between El Centro, CA, and Yuma, AZ.)*

and head south, eventually all the way to Calexico. This work was completed in June 1904. (Signor, n.d.)

Between 1906 and 1919, the San Diego Arizona and Eastern Railroad was completed between San Diego and El Centro (Figures 9, 10). Currently this track is abandoned due to washouts, tunnel cave-ins, landslides, and the tortuosity of the line through the Carrizo Gorge.

To ride the rails from San Diego to Chicago, one rode the San Diego Arizona & Eastern to El Centro, then the Imperial and Gulf Railway Company track north to Niland, and finally the Southern Pacific line southeast to the Yuma Crossing. From there it was a walk-in-the-park to get to New Orleans or Chicago. Passenger service from San Diego to Yuma and points east was sporadic over the years, and was discontinued in the early 1950s, with the final passenger train to El Centro leaving San Diego at 7:05 AM on January 11, 1950. (I was on that train and flew back to San Diego that evening on an old two engine, DC-3 propeller-driven airplane. The ride through the Carrizo Gorge was spectacular!) (Dodge, 1956; Singor, n.d.)

U. S. Highway 80: 1927 to 1964

With the introduction of assembly-line produced, hydrocarbon–powered vehicles in the early 1900s, better roads became a necessity in cities as well as for long distance travel. Up until about the 1920s roads were mostly washboard dirt, dusty in the dry season and muddy in the rainy season.

The alignment for U. S. Highway 80 was preceded by Route 12, from San Diego to El Centro in 1909, and by Route 27, from El Centro to Yuma, Arizona in 1915. These were established dirt wagon roads. Before construction of the plank road across the Algodones Dunes vehicular traffic headed north to Niland to go around these sand traps.

The first wooden plank road across the Algodones Dunes was completed in October 1912; it consisted of 8-ft long boards laid perpendicular to the direction of travel. This must have been an extremely annoying, tire shredding, teeth chattering and kidney punishing ride (Figure 11). A new and improved 6½-mile long plank road was constructed in 1915, with two parallel sets of 25-inch-wide planks laid along the path of travel. This improvement saved tire-wear, as well as teeth and kidneys. That same year, the "Ocean to Ocean" automotive bridge across the Colorado River was completed, thus eliminating the need to wade across the river or pay for a ferry ride.

The old plank road across the Algodones Dunes was replaced in 1926 with a 20-foot-wide asphalt roadway constructed on a built-up sand embankment. Opened in 1927, it was officially designated as U.S. 80—an east-west transcontinental corridor that connected the Pacific Ocean to the Atlantic Ocean (Figures 12 and 13).

On July 1, 1964, U.S. 80 in California was officially removed from the state highway system and replaced by the new Interstate Highway system. Portions of the old U.S. 80 remain in use as frontage and side-roads between Yuma and San Diego. (Legend has it that the California Highway Patrol uses straight stretches of old U.S. 80 in the Imperial Valley to catch speeding vehicles on Interstate Highway 8).

In the Sonoran Desert, old U.S. 80 passed through Yuma, AZ, and over the Colorado River at the Yuma Crossing. In California, the road passed through Winterhaven, El Centro, and Ocotillo before heading up the grade to the Desert View Tower and on to Jacumba

Figure 10. SDA&E railroad crossing near Plaster City. © W. J. Elliott, 1-25-2024.

Figure 11. Remains of the old original plank road at Gray's Well. © W. J. Elliott, 6-29-2011.

Figure 12. U. S. Highway 80 in California. (Wikipedia, 2024j)

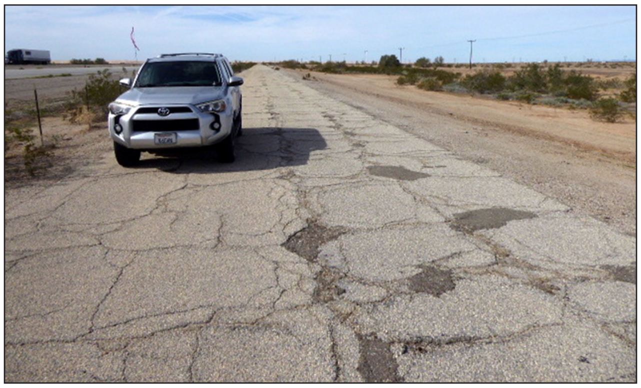

Figure 13. Old U.S. 80, degraded pavement near Pilot Knob. © W. J. Elliott, 1-25-2024.

Figure 14. Interstate Freeway 8, from Casa Grande, Arizona to San Diego, California. (Wikipedia, 2024d)

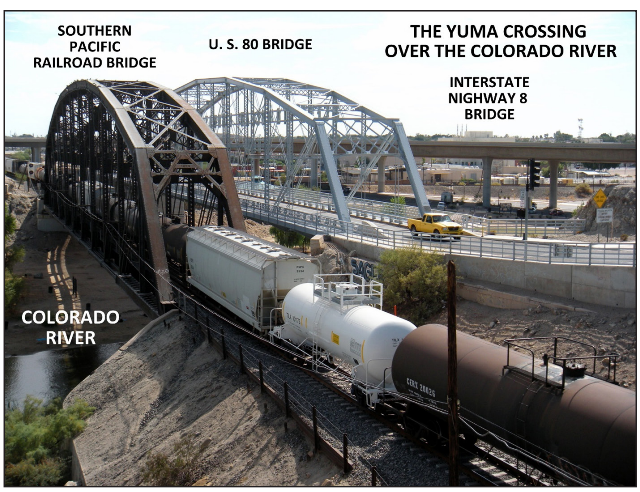

Figure 15. The Yuma Crossing. © 9-21-2011 W. J. Elliott.

Hot Springs near the crest of the Peninsular Ranges (Wikipedia, 2024g; Wikipedia, 2024j).

Interstate Highway 8

In 1956 President Eisenhower signed into law the Federal-Aid Highway Act of 1956. The Dwight David Eisenhower National System of Interstate and Defense Highways is now commonly known as the Interstate Highway System. Lieutenant Colonel Eisenhower had accompanied an army expedition driving from Washington D. C. to the army Presidio in San Francisco in 1919. This 62-day adventure started on July 7, and traveled 3,200 miles through summer heat. Besides mechanical difficulties and poor-quality bridges, Eisenhower noted that the road was a succession of dusty roads, ruts, pits, and holes. Hence his perception of the need for paved roads to carry economic civilian traffic as well as military assets in time of war.

The interstate highway route took 35 years and 597 billion dollars (in equivalent 2022 dollars) to complete between 1956 and 1992 (Figure 14). Some small stretches are still incomplete (Wikipedia, 2024c). Construction of the section of Interstate Highway 8 through the Imperial Valley began in June 1966, with the 12-mile section from Seeley to SR-111. Built in segments, Interstate Highway 8 was completed between San Diego, CA and Casa Grande, AZ, with construction of a new reinforced concrete beam bridge over the Colorado River at the Yuma Crossing on August 18, 1978 (Figure 15). (Wikipedia 2024d).

This route parallels or sub-parallels old U.S. 80, and in some cases was built on top of the old road. De Anza would likely be amazed, and perhaps amused, to see what human accomplishments have come to pass in the approximately 200 years since his journey across the unforgiving sands of the Sonoran Desert.

Modern transportation corridors

Often times, pipelines, electric lines, telephone lines fiberoptic cables, and other non-vehicular means of transporting commodities and communications have followed or closely approximated these old ground-surface routes used for historical and present-day travel.

Underlying geology

Traveling west across the Sonoran (Colorado) Desert from Yuma, AZ to Ocotillo, CA, what one sees from the car window does not look terribly complex or exciting. Don't be fooled. Starting with the railroad and the U.S. 80 bridges over the Colorado River at the Yuma Crossing, both structures are anchored on Middle Proterozoic granitic rocks (western edge of the North American craton). From there Interstate Highway 8 crosses over alluvium along the north side of the Colorado River. After reaching the All-American Canal, surficial geology transitions to older alluvial fan deposits and younger alluvium enroute to Ogilby Road.

The first prominence rising above the desert floor on the left (south), seven miles west from Yuma, is Pilot Knob (Figure 16). It is composed of Middle Proterozoic gneiss and has been mined in recent times for construction aggregate. West from Ogilby Road for 6 miles the highway passes over the Algodones Dunes – a favorite recreation site for sand buggies and off-roaders. Early explorers and travelers, however, traveled southwest along the Colorado River on the east side of Pilot Knob to skirt the southern

Figure 16. Pilot Knob construction aggregate quarry. © W. J. Elliott, 1-28-2024.

end of the Algodones Dunes and then turned west and northwest to get to the West Coast.

From the west side of the Algodones Dunes, at Grays Well and a preserved piece of the old plank road (Figure 11), the highway crosses Quaternary alluvium and scattered patches of recent sand dunes. At the East Highline Canal the geology changes to Quaternary lake deposits formed when Lake Cahuilla and its predecessors filled the Salton Sink.

Continuing west to South Dogwood Road, on the south side of the freeway, a black horizontal line on the side of a large white water tank marks sea level, approximately 32 feet above ground level (Figure 17). Continue west to

Figure 17. Water Tank at El Centro. © W. J. Elliott, 1-28-2024.

Figure 18. Westerly dipping Palm Spring Formation, east of Ocotillo. © W. J. Elliott, 1-28-2024.

the West Side Main Canal. About 4 miles past this canal, one reaches the western edge of mapped Cahuilla lakebed deposits. For geographic reference, this contact is about one mile east of Plaster City on old U.S. 80. From here to Ocotillo, the highway passes through older alluvium and westerly tilted (Figure 18) nonmarine Pliocene Palm Spring Formation (Dibblee, 1954).

Continuing westward from Ocotillo, the road climbs up through Carrizo Gorge, underlain by Cretaceous La Posta granitic rocks (Walawender, 2000). Near the top of the grade, Desert View Tower offers an excellent view back across the Sonoran Desert – where on a clear day the Salton Sea and the Chocolate Mountains can be seen in the distance.

Now for the part that is concealed by all this surficial stuff.

First, the Salton Sink contains a thickness of about 4 miles (Damiata and others, 1986) of Miocene to Recent sedimentary debris (Dibblee, 1954) – mostly contributed by the Colorado River. This plate boundary rhombochasm is home to Quaternary volcanic activity at the southern end of the Salton Sea (Elders, and others, 1986) as well as several geothermal plants that generate electricity (McKibben and others, 1986).

From east to west, Interstate Highway 8 crosses over the following hidden geology:

1. The Algodones fault, conjectured to be a southeastern extension of the San Andreas fault along the east side of the Algodones Dunes. (The southern end of the San Andreas fault sensu stricto ends at Bombay Beach along the east side of the Salton Sea.)

2. The Imperial fault between Holtville and El Centro, which was the source of two M=6.25 earthquakes in 1915, the M=6.9 Imperial Valley earthquake in 1940, and the M=6.5 Imperial earthquake in 1979. This fault is the southeastern extension of the San Jacinto fault, as well as a right-stepover of the San Andreas fault through the Brawley seismic zone (Wikipedia, 2024-k)

3. The Elsinore fault, which bleeds southeastward into the Laguna Salada fault in Baja California, can be found along the west side of the Coyote Mountains. The M=7.2 Easter Earthquake of April 4, 2010, occurred on the Indiviso fault, a sister fault, just east of the Laguna Salada fault (Wikipedia, 2024a)

More named and unnamed faults and locations of historical earthquakes can be found in reports (Strand, 1962; Morton, 1977; Jennings, 1994.

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Remains of stone house at El Mirage, March 1996. D.M. Miller photograph.

Combustion metamorphic paralava and clinker from Hope Ranch, Santa Barbara County, California

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ABSTRACT— In a sea cliff at the community of Hope Ranch in Santa Barbara County, California, there is ongoing underground combustion of bituminous material in the Miocene Monterey Formation. Outcrops in the cliff expose high-temperature combustion metamorphic rocks where calcareous, phosphatic, and siliceous mudstones have been transformed into clinker and vesicular paralava. Paralava represents sedimentary rocks which have become molten whereas clinkers have been sintered and metamorphosed but not become molten. In the clinker, opal-CT has been transformed into cristobalite and calcite and quartz have reacted to form wollastonite. Paralava occurs as three types: silica-rich, phosphate-rich and Ca-rich. The latter (which attained a higher temperature) is the last to form and coats silica-rich paralava and cements clinker fragments. Silica-rich paralava is amorphous or nanocrystalline and may contain globules of phosphate-rich paralava which were immiscible in the silicate melt. The Ca-rich paralava commonly contains crystalline phases: anorthite, Ca-rich clinopyroxene, wollastonite, cordierite, fluorapatite, and hematite. In order to form paralava with these compositions, local temperatures produced by combustion must have been on the order of 1100–1650° C.

Introduction

Combustion metamorphism (CM) is a special case of pyrometamorphism where organic-rich rocks such as coal and oil shale ignite in the presence of atmospheric oxygen and produce very high temperatures (Grapes, 2011). CM sites in southern California primarily exist in Santa Barbara and Ventura counties and are the result of the burning of bituminous or kerogen-containing material in the Miocene Monterey and Sisquoc formations or the Eocene Juncal Formation. Before the phenomena were understood, these sites were often referred to as "volcanoes", solfataras, or "fire wells" because of the flames and sulfurous odors. The only southern California CM sites that have been studied in detail are Grimes Canyon in the Monterey Formation (Bentor and Kastner, 1976; Bentor et al., 1981; Bentor, 1984) and the Eocene Juncal Formation in the Dick Smith Wilderness (Mariner et al. 2008), both in Ventura County, and the Orcutt oil field in the Sisquoc Formation (Eichhubl, et al., 2001; Lore et al., 2002; Eichhubl and Aydin, 2003) in Santa Barbara County. Other documented sites in Santa Barbara County include a ridge 12 km southwest of Santa Maria, Redrock Mountain 6 km south of Los Alamos, Schumann Pass north of Casmalia and 6 km south of Guadalupe (Arnold and Anderson, 1907), and the sea cliffs near Santa Barbara (Whitehead, 1976). Rincon Point is an additional well-known but unstudied site in Ventura County (Arnold and Anderson, 1907; Whitehead, 1976). Another site in the United States that has been studied in detail is the Powder River Basin in Wyoming (Cosca and Essene, 1985; Cosca et al., 1989; Clark and Peacor, 1992). Sokol and Volkova (2007) present a summary of worldwide sites where CM has occurred as a result of natural coal fires.

The Santa Barbara sea cliff CM locations have been known since the late 1700s (Whitehead, 1976) and have produced sulfur and salammoniac crystals (Rogers, 1912). In 2021 a CM site in the sea cliff at the community of Hope Ranch, about 2.2 km west of the Arroyo Burro Beach County Park beach access point, attracted attention when it started a brush fire (Hayden, 2021). Subsequently, steam and or smoke has issued from several small vents 5–25 meters above the beach and temperatures as high as 136C have been measured at the surface (Lynch and Adams, 2024). A white patch of mineralization is associated with some of the vents about 25 m above the beach (Figure 1). The ammonium sulfate minerals boussingaultite and tschermigite have been identified from white material found on the beach near the base of the cliff and are assumed to have come from this area. Other flare ups of combustion occurred in this area in 2020, 2019 and 2017 and near the beach at More Mesa around 2000 (Hayden, 2020). The rocks in the cliffs and talus consist of siliceous, calcareous, and diatomaceous mudstones that have a pink or rosy-red coloration. This site occurs in landslide deposits in the Monterey Formation (Minor, 2007) that had significant movement in 2005 and minor slumps in 2018 and 2022 based on satellite imagery. In 2006, glowing-hot coals were visible and acrid smoke was being produced (Schultz, 2006). In the 1920s the fire and smoke was such a nuisance that property owners constructed a pipeline and levee to create

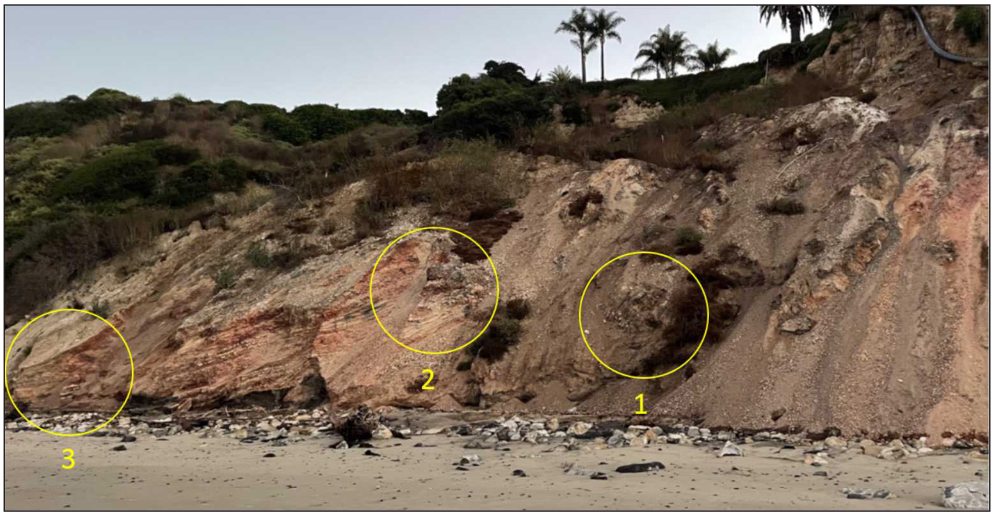

Figure 1. Site of combustion vents and paralava in this study. Active steaming/smoking vents are about 25 meters above the base of the cliff. Notice the pink coloration of many of the rocks and white sulfate deposits around the active vents (upper right). There are additional thermal anomalies to the east (right) of this site.

a pond that eventually extinguished the fire and it was dormant for decades (Whitehead, 1976).

Sedimentary rocks that have been involved in combustion metamorphism have been classified either as clinker, where mineralogical and or microstructural changes (sintering) have taken place without melting, or paralava, where melting has taken place with or without subsequent crystallization (Cosca et al., 1989). The studies of the Grimes Canyon site by Bentor et al. (1981) have focused on the paralavas with no descriptions of the clinker while at Red Canyon only clinker was described though Lore et al. (2002) acknowledged that some intergranular melting probably occurred. The combustion "fumarole" in the Dick Smith wilderness was primarily studied by mass spectroscopy of gas samples and water chemistry; no petrographic observations of rocks were presented (Mariner et al., 2008).

At the CM site at Redrock Canyon in the Orcutt oil field, Eichhubl et al. (2001) divided the transition from unaltered siliceous mudstone in the Sisquoc Formation to clinker into five stages based on color, texture and mineralogy (Table 1). While the lithologies at Hope Ranch are somewhat different from the Orcutt field there are some similarities in that the diatomaceous and siliceous mudstones also have a light red to pink color that is probably equivalent to the oxidized mudstones of Eichhubl et al. (2001).

The Miocene Monterey Formation has a high biogenic component, with silica coming from the tests and frustules of diatoms and radiolarians, carbonate from coccoliths and foraminifera, and organic material, mostly type II kerogen, from marine algae Behl (1999). The hydrocarbons in the Monterey Formation are sulfur-rich with up to 8–14% sulfur (Orr, 1985). Isaacs (1984) and Hornafius (1995) provide detailed stratigraphy in the sea cliffs west of Santa Barbara. The stratigraphy of the Monterey Formation has not been mapped in detail at the Hope Ranch location, probably because of the landslides. East of Arroyo Burro, a 90 m-thick section of the Middle Monterey (Luisian-Mohnian) consisting of porcelanite, organic-rich phosphatic calcareous shale, chert, and tar-filled breccia is exposed (Hornafius, 1994). West of Hope Ranch at Goleta Slough, Upper Mohnian calcareous and noncalcareous diatomaceous rocks and brecciated dolostones are exposed along with the diatomaceous mudstones of the Sisquoc Formation and Pliocene (?) tar seeps (Isaacs, 1984).

Experimental

Since much of the sea cliff was inaccessible, collection of samples otherwise out of reach was facilitated with a 7.3 m-telescoping painter's pole tipped with a metal roller attachment serving as a hook. Photo documentation was aided with a point and shoot camera attached to the pole. Bulk density was determined by cutting blocks, either dry with a diamond band saw (friable samples) or with a wet tile saw. Dimensions were measured with a micrometer to determine the volume and the mass was measured with a balance.

Specimens were analyzed by X-ray diffraction (XRD) copper radiation and a Rigaku SmartLab SE

Table 1. Siliceous mudstone alteration zones at the Orcutt oil field (Eichhubl et al., 2001).

Alteration Zone	Color	Texture/Mineralogy
Unaltered	Light gray	Opal-A, smectite, illite, kaolinite, quartz (detrital)
Coked	Medium to dark gray, black	Opal-A, smectite, illite, kaolinite, quartz (detrital)
Oxidized	Yellow-orange, oxidation fronts along joints	Opal-A, illite, quartz, feldspar, hematite
Sintered Oxidized	Bright orange, uniform oxidation	Cristobalite, hematite, illite, quartz, feldspar
Clinker	Dark red, purple, black	Anorthite, tridymite, cordierite, hematite, cristobalite; coalescence of micropores to macro pores (50-100 μm).

Figure 2. Area 2, upper outcrop sampled with the telescoping pole showing Locations 1-7 that were sampled.

diffractometer equipped with a HyPix-400 detector. Diatomaceous layers in the Monterey Formation have a high opal content which at this site has transformed to opal-CT from burial diagenesis (Keller and Isaacs, 1985). The XRD patterns of some opals are very similar to cristobalite and the parameters, primarily full width at half maximum (FWHM) and location of the (101) reflection located at 0.40 nm, outlined in Elzea et al. (1994) have been used to identify the opaline/cristobalite phases. The FWHM was determined by peak profile fitting. It is noted that the cristobalites measured in Elzea et al. (1994) are from standard materials and FWHMs may not be representative of all cristobalite samples since the FWHM is dependent on crystallite size.

Selected specimens were vacuum impregnated with epoxy, sectioned, and then polished for examination in a JEOL 7600F scanning electron microscope (SEM) equipped with an Oxford X-Max energy dispersive spectrometer (EDS) and hkl Nordlys electron backscatter diffraction (EBSD) system. Samples were prepared for EBSD by giving a final polish with colloidal silica followed by a thin (20 nm) carbon coat in order to prevent charging at 20KV. Raman spectroscopy was performed with a Renishaw inVia microscope equipped with a 514 nm laser (~ 1-2 µm spot size).

Observations

Monterey Formation (coked/oxidized)

Beneath the steaming/smoking vents at the Hope Ranch site, much of the adjacent outcrops have been covered by talus, which combined with the steepness of the sea cliff, makes observation and mapping of some alteration zones difficult. Three areas, in the vicinity of a steaming/smoking vent and associated white sulfate deposits located about 25 m above the beach, were investigated (Figure 1).

Area 1

Area 1 consisted of relatively unmetamorphosed calcareous and siliceous mudstones that were highly fractured and joint surfaces are often coated with shiny black vitreous asphalt. The calcareous mudstone is brown in color, relatively dense (2.01 g/cm^3) with little porosity, and finely laminated (mm scale). Some layers are rich in quartz ± opal-CT, with others being calcite-rich, including foraminifera tests. Framboidal pyrite is rare (< 0.5%).

Area 2

Area 2 consists of a sequence of rocks that dip at a moderate angle (30°–40°) to the southwest (Minor et al, (2007). They range from diatomaceous and siliceous mudstones at the bottom of the cliff to calcareous mudstones, clinker, and paralava at the top of the outcrop (Figure 2). The area is not abnormally warm and the paralavas represent an extinct combustion site that has been exhumed. It has been estimated that the sea cliffs in the area retreat at the rate of about 10–30 cm per year (Alessio and Keller, 2020) and in the space of several months we have observed changes in the area with new talus cones forming. This coupled with the landslide exposed an extinct combustion zone or vent.

At the base of the sea cliff, highly fractured rocks consisting of pink-colored diatomaceous mudstone are exposed along with black organic-rich siliceous mudstone (Figure 3). These have relatively low densities of 0.83g/cm^3 and 1.02g/cm^3, respectively. Gypsum crystals are common on joint surfaces. The pink-colored diatomaceous mudstone consists primarily of an opal phase intermediate between opal-A and opal-CT [(101) reflection = 0.410 nm, FWHM 1.09°], detrital quartz, plagioclase and illite. Opal-CT lepispheres have been observed on fracture surfaces and phosphate- and sulfate-containing nodules are concentrated in certain layers (Figure 4a). The pink color is concentrated on joint surfaces where the phosphorous content ranges from 3–15 atomic % and scattered iron oxide crystals occur (Figure 4b). In contrast, fresh fracture surfaces are light yellow gray in color.

The black siliceous mudstone contains gypsum, quartz, Opal-A and/or Opal-CT, plagioclase, illite, clinoptilolite and from 15–40 atomic % carbon. Raman spectra of the black mudstone display well defined disorder (D) and graphitic (G) bands equivalent to the diagenesis metamorphic zone of Schito et al. (2023) which has an estimated temperature of up to 100°C.

In Figure 2 samples collected in the vicinity of Locations 1 and 5 are relatively low-density (0.92–1.24 g/cm^3) siliceous mudstones that consist primarily of

Figure 3. Samples collected from base of cliff at Area 2. Siliceous mudstone showing rosy exterior and yellow-tan interior (a). Organic-rich siliceous mudstone (b).

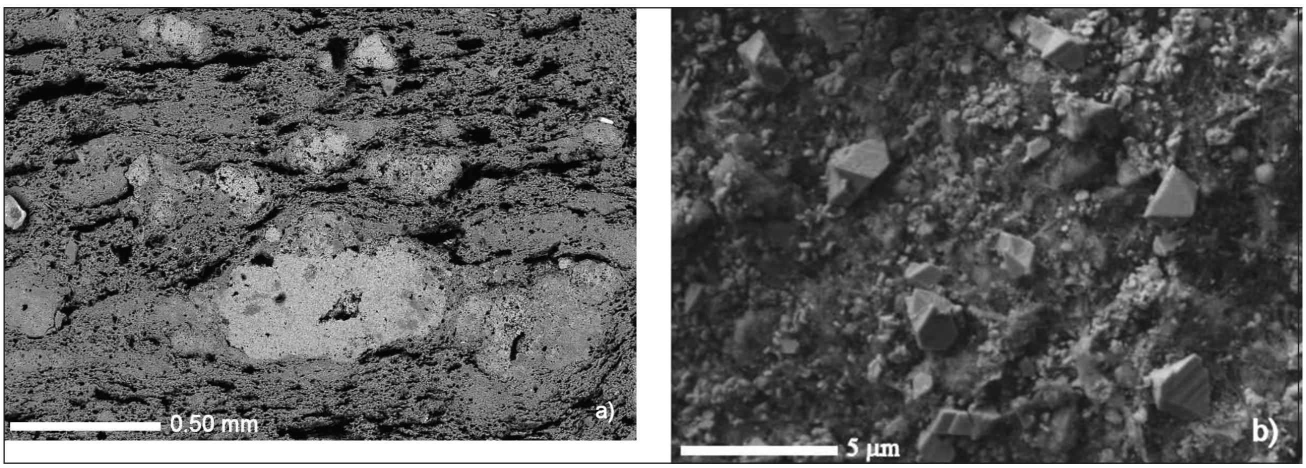

Figure 4. Backscatter electron (BSE) image of cross section of pink siliceous mudstone showing phosphate- and sulfate-containing nodules (light) (a). SEM image of iron oxide crystals on rosy-colored joint surface (b).

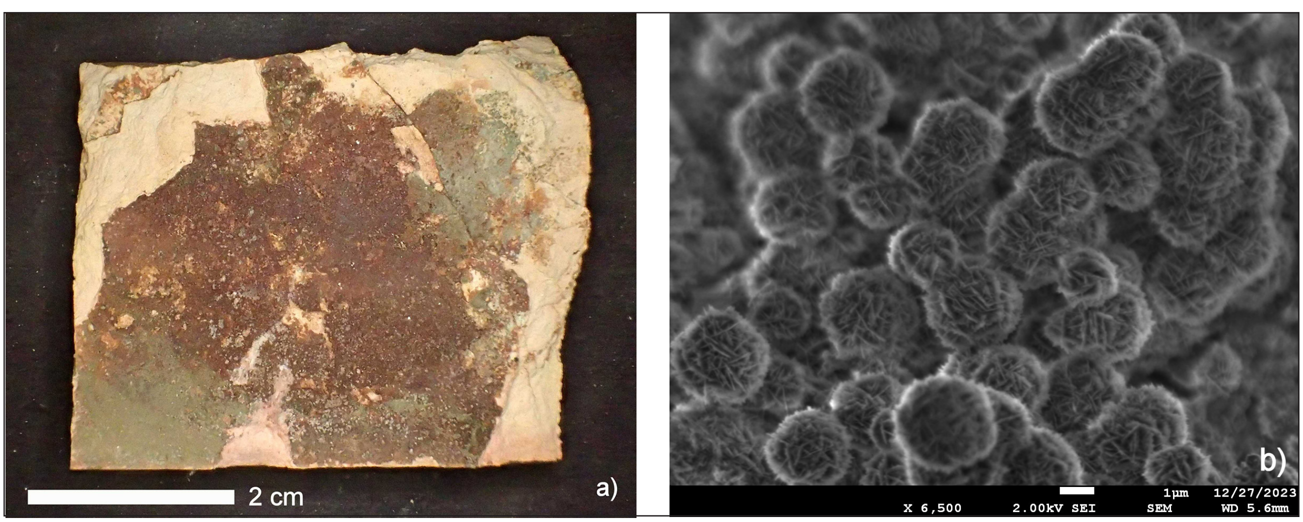

Figure 5. Siliceous mudstone from Location 5 showing light pink-tan interior and brick-red iron oxide coating on joint surface (a). SEM image of opal-CT lepispheres from pink-tan interior surface of 5a (b).

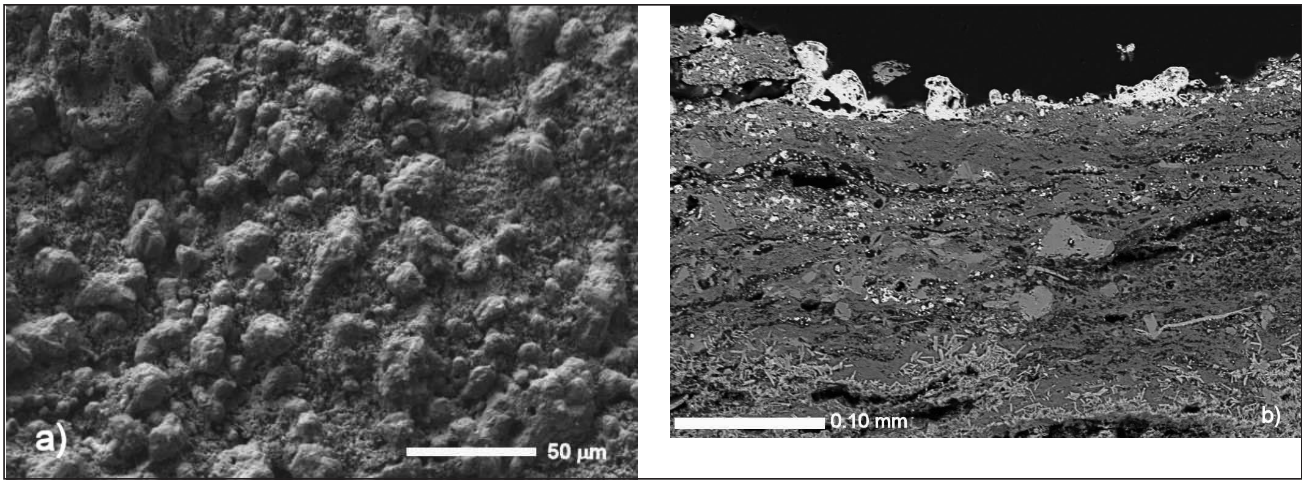

Figure 6. SEM image of brick-red surface of siliceous mudstone in Figure 5a showing iron oxide crystals (a). BSE image of cross section of 6a showing iron oxide crystals (light) on joint surface and within 0.15 mm of the surface (b).

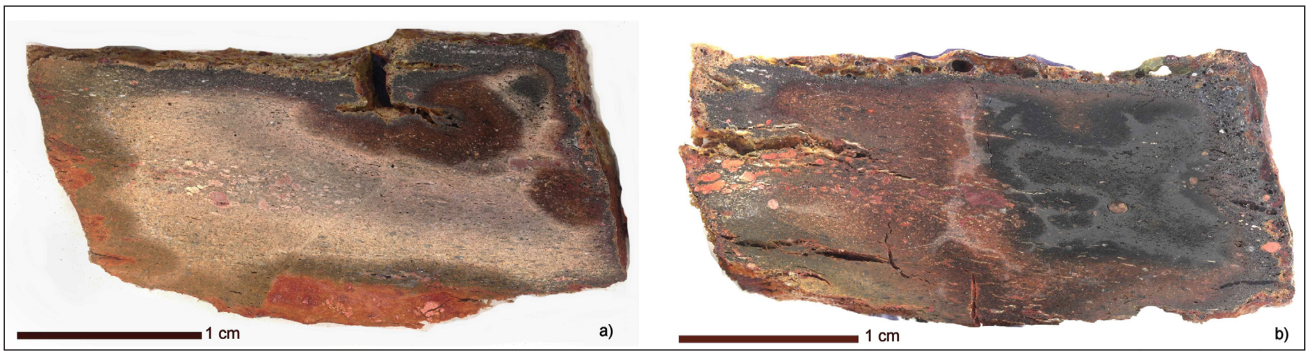

Figure 7. Cross sections of clinkers showing coloration differences ranging from less altered pink, to brick red and brown (a) to brown and black (b). In both samples a thin veneer of paralava is present on the top surfaces.

detrital quartz and opal-CT. Samples from Location 1 are light tan in color while samples from Location 7 are pinkish in color internally with a brick-red coating on joint surfaces (Figure 5a). Opal-CT lepispheres are common on fracture surfaces of both samples (Figure 5b). Iron oxide crystals to 20 µm were present on the brick-red joint surfaces (Figure 6a) but minute iron oxide grains were only observed within 100–200 µm of the surface (Figure 6b). Samples from Location 5 and the pink siliceous mudstone at the base of the cliff probably have attained the oxidized alteration zone of Eichhubl et al. (2001) and often have what they refer to as ductile opening-mode fractures. These are often relatively wide with blunt tips. Locations 6 and 7 contain relatively dense (1.43–1.72 g/cm^3) laminated calcareous mudstones containing quartz, calcite, and opal-CT and are similar to those exposed at Area 1.

Clinker and paralava

Area 2

Location 4 (Figure 2) represents dense white and gray banded clinker formed from calcareous mudstone and consists of quartz, opal-C/cristobalite, and wollastonite. The opal-C/cristobalite (101) XRD reflection at 0.407 nm shows a significant narrowing (FWHM 0.22°) from the opal-CT in the calcareous mudstone (FWHM 0.98°) and the wollastonite formed from calcite reacting with detrital quartz and opal-CT.

Locations 2 and 3 in Figure 2 contain siliceous clinker that often occurs as breccia fragments (to 6 cm) (Figures 7, 8a) that are cemented with paralava. As combustion progresses, material is consumed leaving overlying rock unsupported which can fall into the void, creating piles of breccia fragments. The color of the siliceous clinker can vary from pink to brown to black depending on the degree of alteration and original composition (Figure 7). Some clinker consists of quartz, plagioclase, and opal-C with a 0.409 nm (101) XRD reflection and FWHM significantly smaller (0.38°) than the opal-CT in the siliceous mudstone. Others have been completely transformed to opal-C/cristobalite (0.407 nm; FWHM 0.21°). Clinker commonly shows small flattened vesicles (10–100 µm) which formed from coalescence of nanoporosity in the original siliceous mudstones as a result of the sintering process (Figure 8b).

We have used the presence of significant vesicles as evidence of melting and the presence of paralava. Eichhubl and Aydin (2003), however, have shown that as CM progresses, nanoporosity in siliceous and diatomaceous mudstones may coalesce to form micro porosity on the

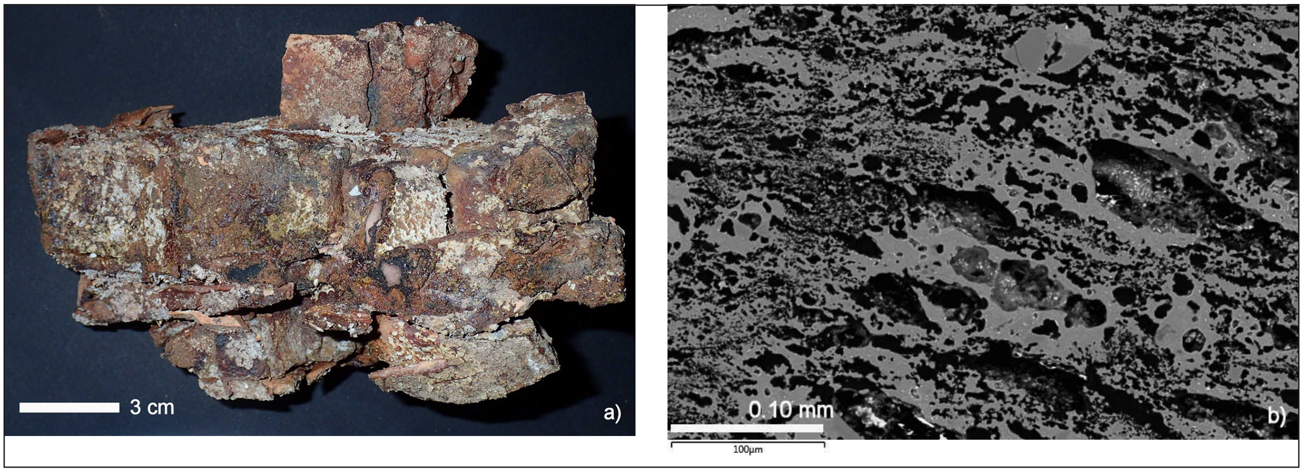

Figure 8. Clinker fragments cemented with paralava (a). BSE mage of cross section of sintered clinker converted to opal-C/cristobalite with coalescence of nanopores to form micropores (b).

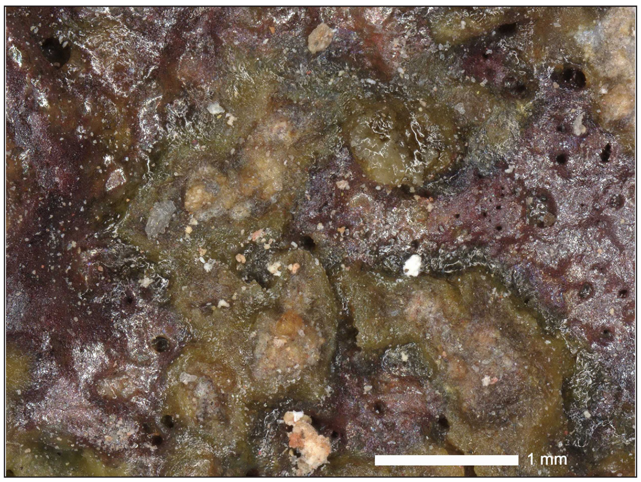

Figure 9. Surface of yellow paralava coating on clinker.

Table 2. Bulk compositions of paralavas (weight %).

	Ca-rich*	**Ca-rich***	**Si-rich**	**Si-rich**
SiO_2	41.84	48.71	61.83	68.34
TiO_2	0.75	0.86	0	0.94
Al_2O_3	10.95	11.06	17.27	15.24
Fe_2O_3	5.87	5.45	1.64	2.87
MnO	0	0.04	0	0
MgO	1.36	1.75	1.54	1.81
CaO	26.58	24.15	1.53	1.29
Na_2O	0.79	1.33	2.15	2.27
K_2O	0.36	0.77	3.45	3.76
P_2O_5	4.41	1.40	0	0
Total	92.92	95.55	89.01	96.52

*crystallized or partially crystallized

scale of tenths of mm. The color of paralava that cements clinker can range from yellow to olive to black (Figures 9, 11). Minute crystals of hematite have been found on some paralava surfaces and internal to black paralava which may account for the black color (Figure 10). Paralavas are vesicular and consist of two major types (Table 2); high-silica content (60–68 wt % SiO_2), which is usually black in color and calcium-rich (21-24 wt % CaO), which is yellow- to olive-colored (Figure 9). They appear to have developed in two separate episodes and may have had different parent materials.

The composition of the silica-rich paralava is similar to the siliceous mudstones whereas the Ca-rich paralava probably formed from a calcareous mudstone. The

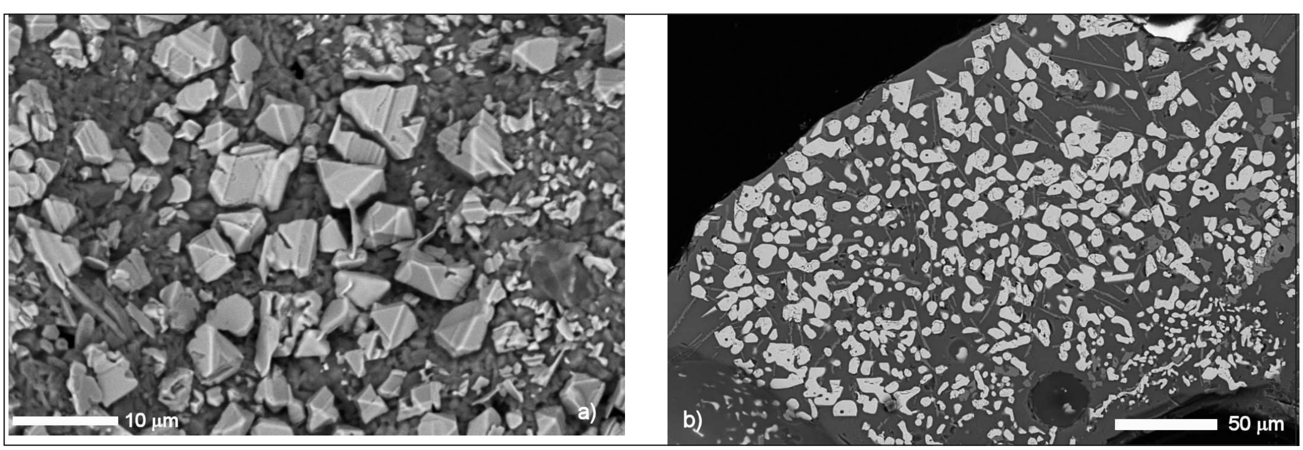

Figure 10. BSE image of surface of paralava on clinker showing iron oxide crystals (a). BSE image of cross section through black paralava showing included iron oxide crystals (b).

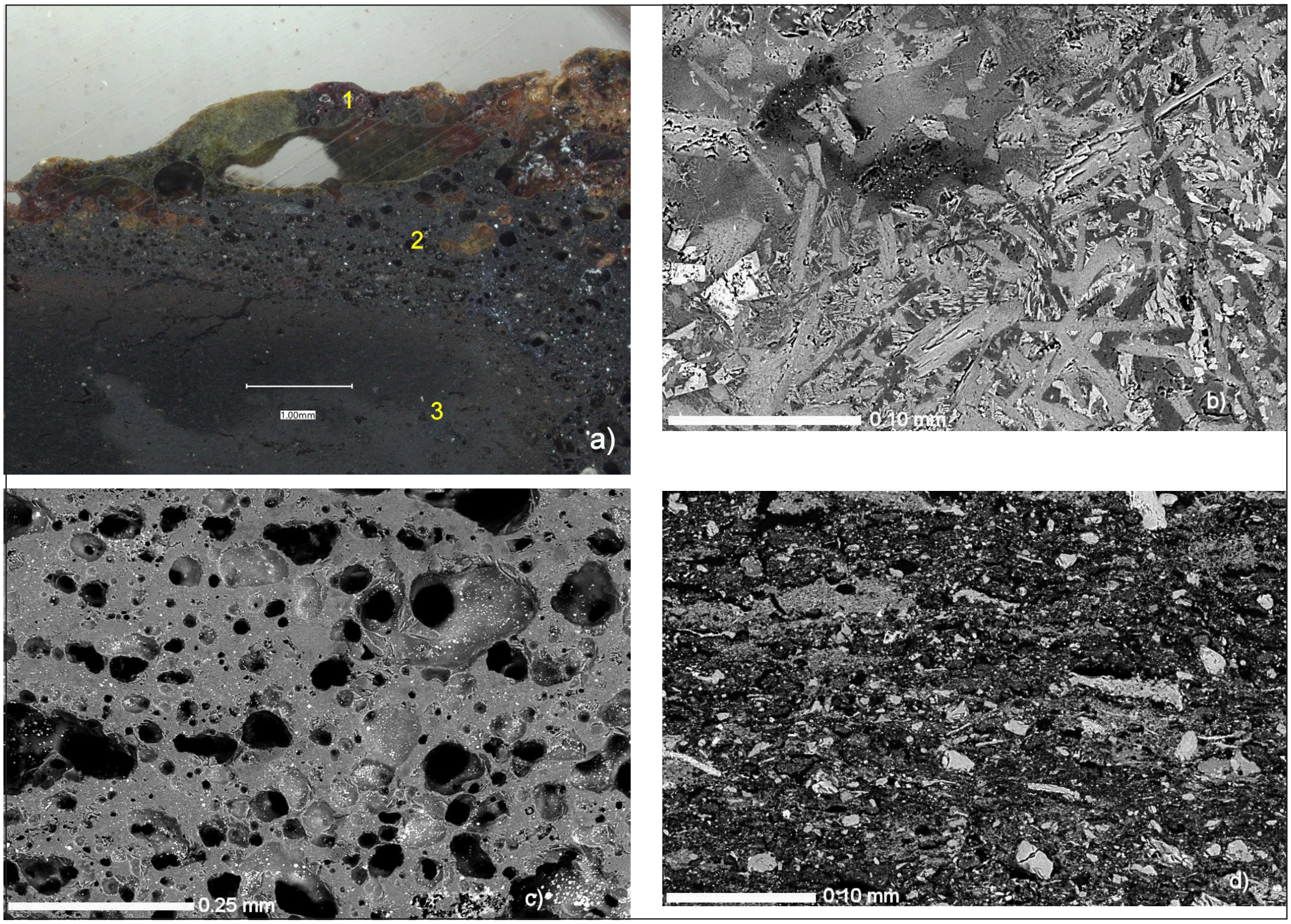

Figure 11. (a) Detail of cross section of clinker in Figure 7b showing yellow-green Ca-rich paralava (top) coating black silica-rich paralava on clinker (bottom). (b-d) BSE images of Area 1-3. (b) Area 1: Ca-rich paralava consisting of anorthite, wollastonite and clinopyroxene, (c) Area 2: silica-rich vesicular paralava, and (d) Area 3: siliceous clinker.

calcium-rich paralava is only 0.10–0.40 mm thick. It formed later in time than silica-rich paralava, which it coats, and it also cements clinker fragments (Figures 11a, 12, 13). The Ca-rich paralava tends to be less vesicular than the silica-rich paralava but large voids commonly separate the two (Figures 11, 12).

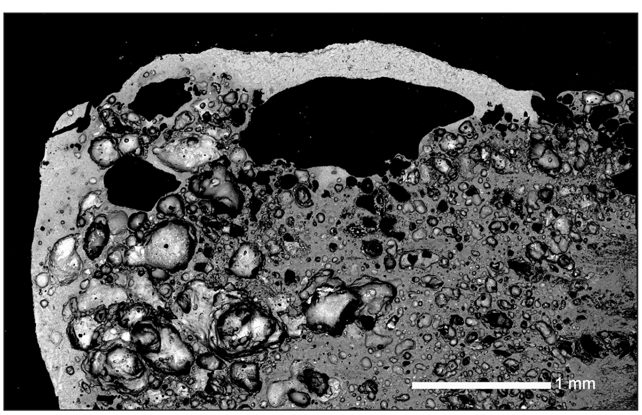

Figure 12. BSE image of cross section through two stages of vesicular paralava. Lower right (darker) has a high-silica content which is coated in places by thin ribbons of a more calcium-rich crystallized (light) layer. See yellow paralava in Figure 9 and detail in Figures 13-14.

The high-silica paralava is very vesicular (voids from 10–200 µm) and primarily amorphous to nanocrystalline based on EBSD and XRD, whereas the Ca-rich paralava may be completely crystalline or have a number of crystalline phases in an amorphous matrix (Figures 13–15). The major crystalline phases vary with location and include anorthite, wollastonite, and a Ca-rich pyroxene (intermediate between diopside and fassaite), fluorapatite, cuspidine, and an ellestadite-like phase. Grain sizes range from 10–40 µm. Minor crystalline phases include hematite, garnet, fluorite, barite, anhydrite, and unidentified Ba-silicates. Figure 13 shows an example where Ca-rich paralava touching silica-rich paralava shows a chilled contact with anorthite and pyroxene crystals in an amorphous groundmass whereas the outermost Ca-rich paralava is completely crystalline with the anorthite and pyroxene crystals in a crystalline wollastonite groundmass. Detrital quartz and plagioclase along with fragments of silica-rich paralava or clinker have been found encased in Ca-rich paralava (Figure 15). These fragments show signs of reaction and dissolution by the Ca-rich paralava. The detrital plagioclase, with a composition of An_{47}, has a reaction rim of An_{75} where it is in contact with the Ca-rich melt (Figure 15a) and the

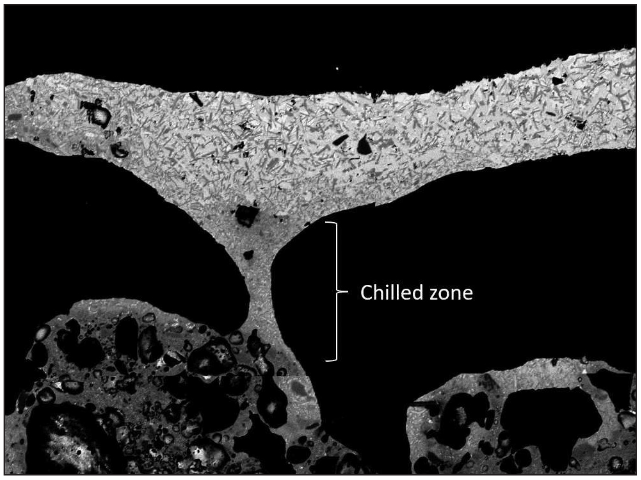

Figure 13. BSE image of cross section showing contact between two stages of vesicular paralava (Ca-rich at top, silica-rich at bottom). The thin neck is a chilled zone containing anorthite and minor clinopyroxene crystals in an amorphous groundmass.

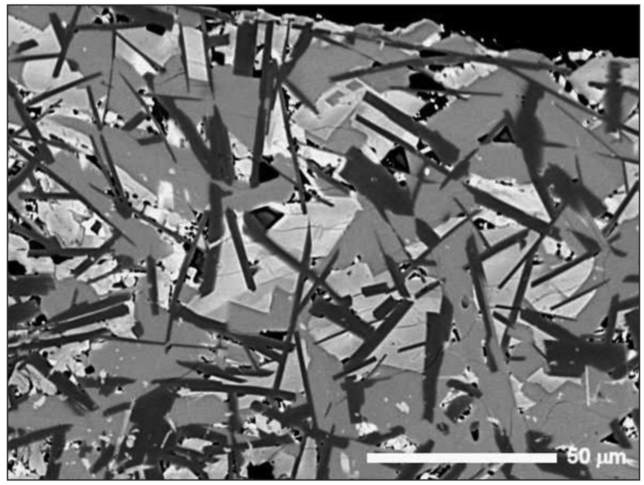

Figure 14. BSE image of cross section through calcium-rich paralava above chilled zone in Figure 13. Euhedral dark-gray laths are anorthite, medium-gray groundmass is wollastonite and light-gray euhedral crystals are Ca-rich clinopyroxene.

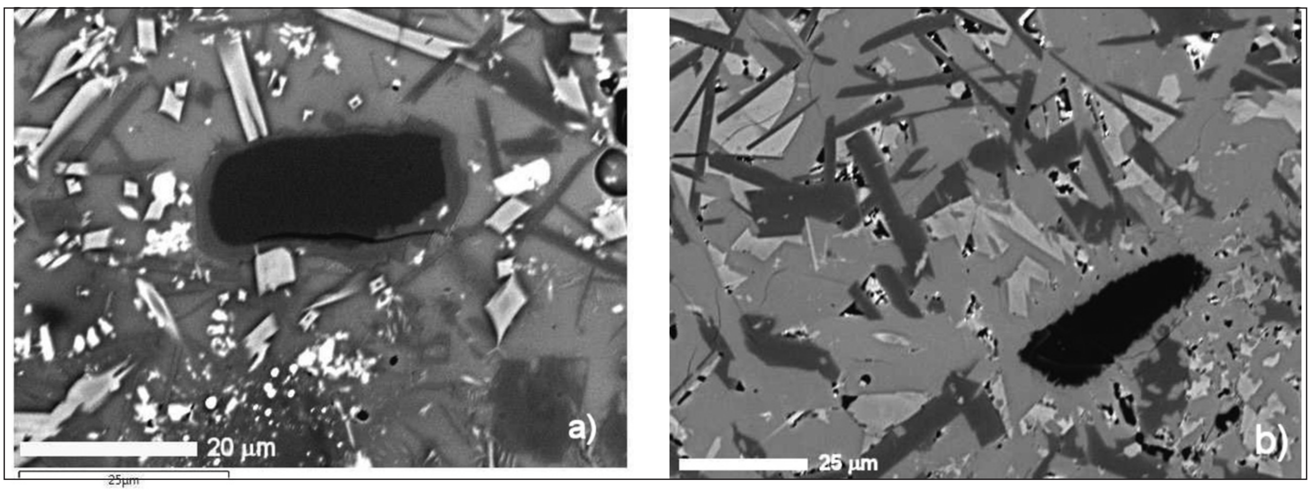

Figure 15. BSE images of cross section of paralava from Figure 13. Dark laths are anorthite and light crystals are Ca-rich clinopyroxene. Detrital plagioclase (black; An_{47}) with Ca-richer reaction rim of (An_{75}) in contact with amorphous groundmass (a). Detrital quartz grain (black) with scalloped edges from melting in contact with amorphous groundmass (b).

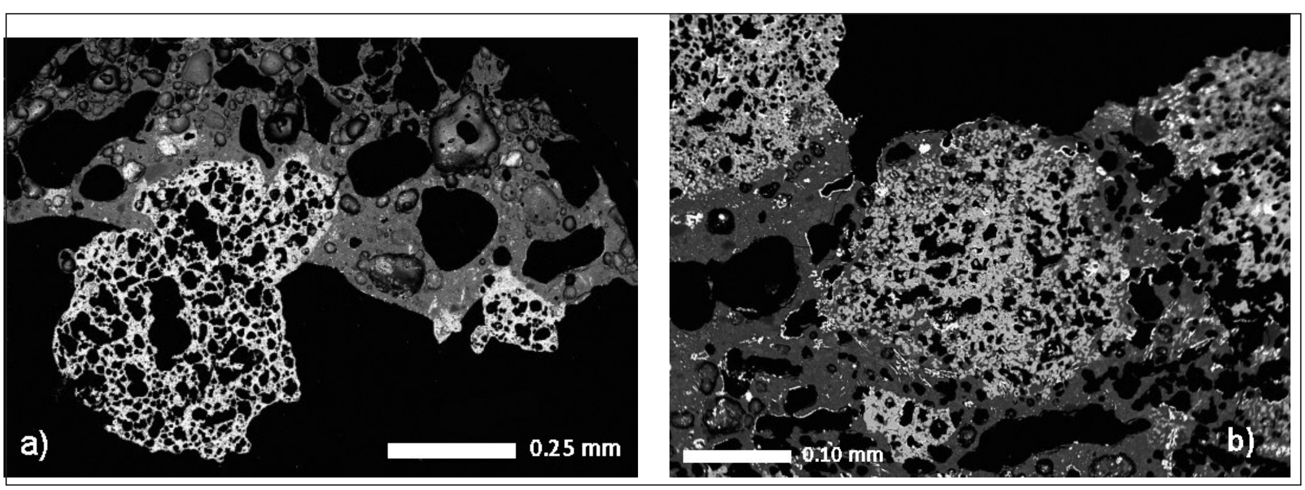

Figure 16. BSE image of cross section through vesicular phosphate nodules consisting of primarily of whitlockite encased in silica-rich paralava (a). Detail of vesicular nodule consisting of an unidentified calcium phosphate (b).

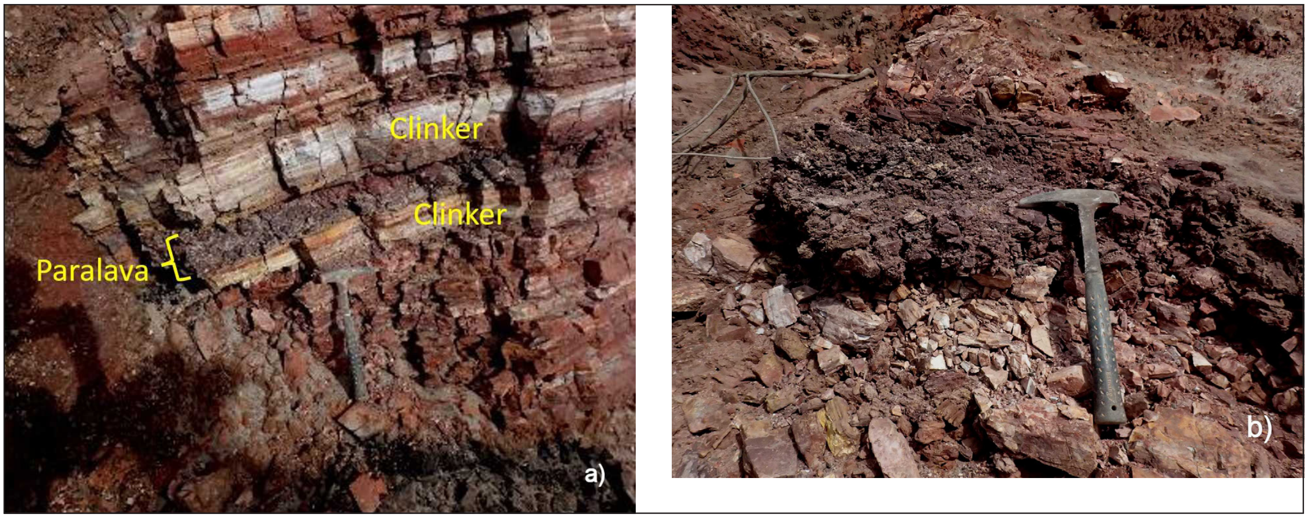

Figure 17. Area 3 consisting of interbedded white cristobalite/wollastonite clinker bracketing a 10 cm-thick layer of brecciated clinker and paralava (a). Clinker-paralava lens 2 m to the right of area in 17a (b).

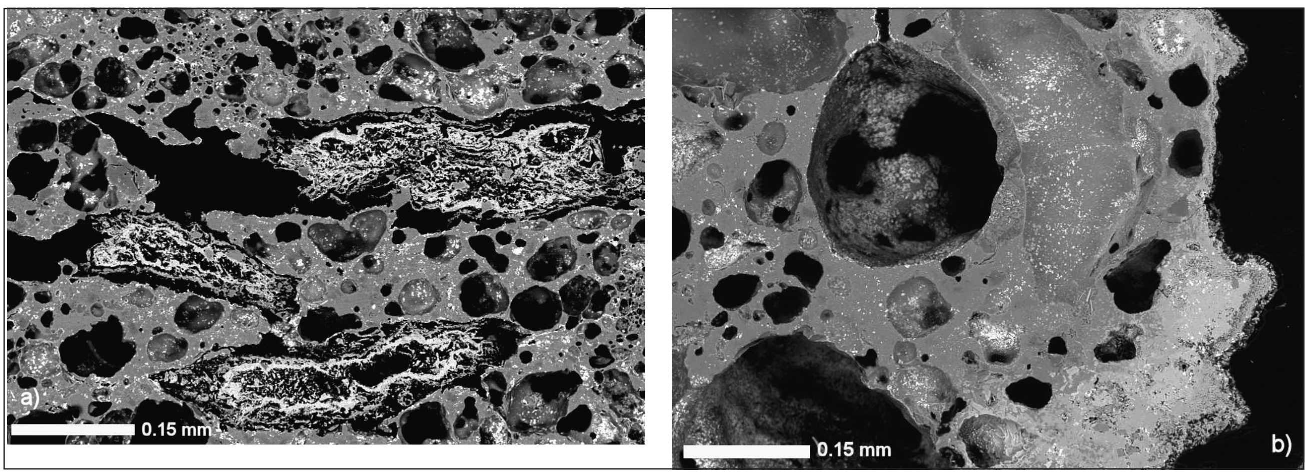

Figure 18. BSE image of cross section through vesicular silica-rich paralava in Figure 17a with spongy elongated inclusions of wollastonite (a). Ca-rich outer rind (light on right) consisting of cuspidine and wollastonite in contact with more silica-rich paralava (dark on left) (b).

detrital quartz has scalloped edges from dissolution in the melt (Figure 15b).

In some silica-rich paralava, globular vesicular masses (to 0.3 mm) of crystalline calcium phosphate have been observed (Figure 16). The presence of vesicles strongly suggests they were at one time molten. Similar globules have been observed at Grimes Canyon and Bentor et al. (1981) attributed them to the immiscibility of silicate and phosphate melts. At Hope Ranch phosphate pellets of similar size have been observed in unmetamorphosed Monterey siliceous mudstones (Figure 4a) and evidently this immiscibility has prevented them from being incorporated into the silicate melt. However, silicate melts of this composition may be highly viscous, which coupled with geologically short times at high temperature may have prevented incorporation. In some vesicular nodules the phosphate phase has been identified as whitlockite by EBSD (Figure 16a). In others, the phase could not be positively identified by EBSD (Figure 16b).

Area 3

Area 3 consists of interbedded red gypsum-containing mudstone and white clinker bracketing a 10 cm-wide band of clinker/paralava (Figure 17a) and a 20 x40 cm lens of brecciated red clinker and reddish-gray paralava (Figure 17b).

The white bands on either side of the 10 cm-wide brecciated paralava layer consist of fractured clinker containing primarily cristobalite/opal-C, wollastonite and lesser tridymite. The breccia consists of vesicular fragments of silica-rich paralava with spongy elongated inclusions of wollastonite (Figure 18a) which may represent foraminifera tests that have been metamorphosed. In the larger lens (Figure 17b) some fragments consist of silica-rich vesicular paralava which locally has a thin layer of Ca-rich paralava containing wollastonite and cuspidine (Figure 18b). The cuspidine probably formed from fluorapatite as a reaction product.

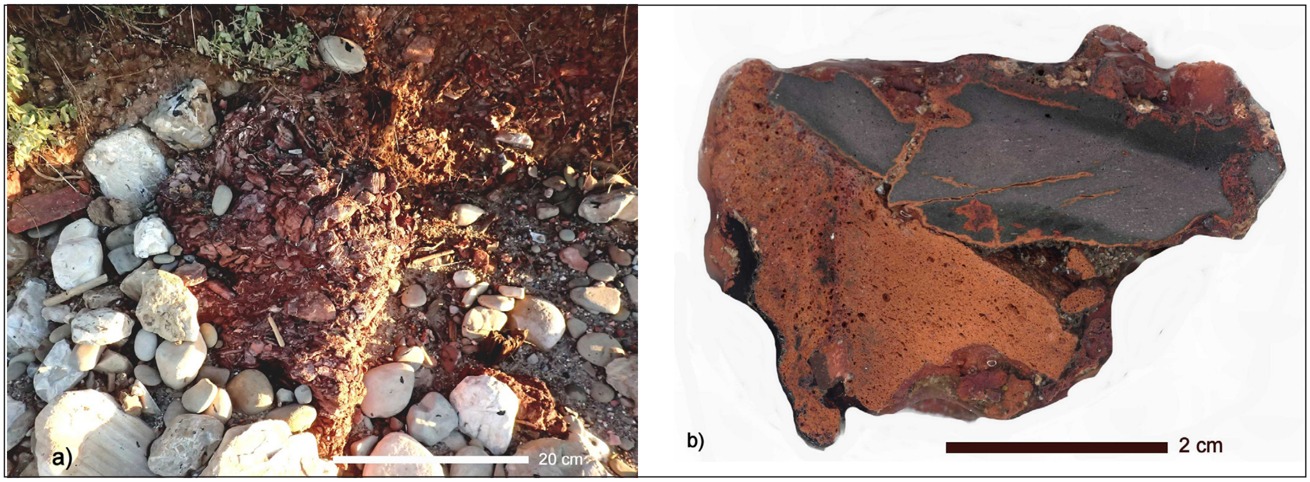

Figure 19. Outcrop of brecciated clinker and paralava at Ellwood Beach (a). Cross section of clinker and paralava breccia fragment (b).

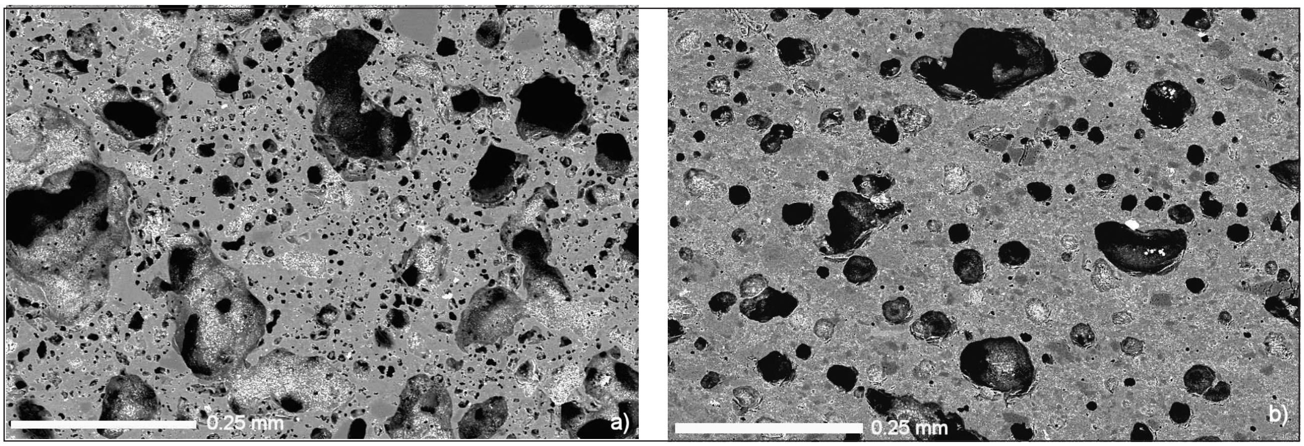

Figure 20. BSE images of cross sections of Ellwood Beach vesicular paralava in Figure 19b; brick-red fragment consisting of cristobalite/opal-C and cordierite (a) and black fragment containing cristobalite, quartz and a spinel phase (b).

Other Areas

At the base of the sea cliff at Ellwood Beach several small exposures of brecciated brick-red and black clinker and vesicular paralava are exposed (Figure 19a). These are all that remain of more extensive active combustion metamorphic sites that were excavated in the 1940s and then extinguished in the 1960s (Bartlett, 1994). In cross section, both the red and black fragments are vesicular with the brick-red fragment having much finer scale porosity (Figures 19b, 20). The brick-red fragment has a bimodal distribution of vesicles with many in the 5-10 µm size range and others much larger (100-300 µm). It consists of primarily of cristobalite/opal-C and moderate amounts of cordierite with iron oxide crystals often lining the walls of larger vesicles while the black fragment consists primarily of opal-C/cristobalite, quartz and a spinel phase.

For about a kilometer along the base of the cliffs, between the previously described Hope Ranch site and the Arroyo Burro Beach access, about eight well-rounded boulders (to 40 cm) of brecciated clinker and paralava have been found. These are typically variegated, with different fragments ranging in color from brown, black, brick-red and yellow-orange (Figure 21) but several of those that were sampled consisted of fragments with various shades of brown, gray, olive or yellow. There are no obvious outcrops of clinker/paralava in the cliffs above the beach but some of the cliffs do have a pink color associated with CM sites. The fact that the boulders are well rounded implies they have been in the surf zone for a long time and their present location may not be close to where they originated.

Most of the fragments in Figure 21b are vesicular. The black fragment was one of the few samples studied that contained noticeable framboidal pyrite, along with cordierite, Ca-rich plagioclase and minor quartz (Figure 22a) while the adjacent yellow fragment consisted of porous, but not vesicular, apatite along with minor plagioclase, implying it had not melted (Figure 22b).

The percentage and size of vesicles in the more common yellow-olive-gray paralava fragments varied dramatically with some olive layers having very few to others with vesicles to mm-size comprising up to 30% of the fragment (Figure 23a). These were typically well

Figure 21. Rounded boulder of clinker/paralava on beach between Arroyo Burro Beach and Hope Ranch (a). Cross section through brecciated clinker/paralava from beach bolder in 21 a (b).

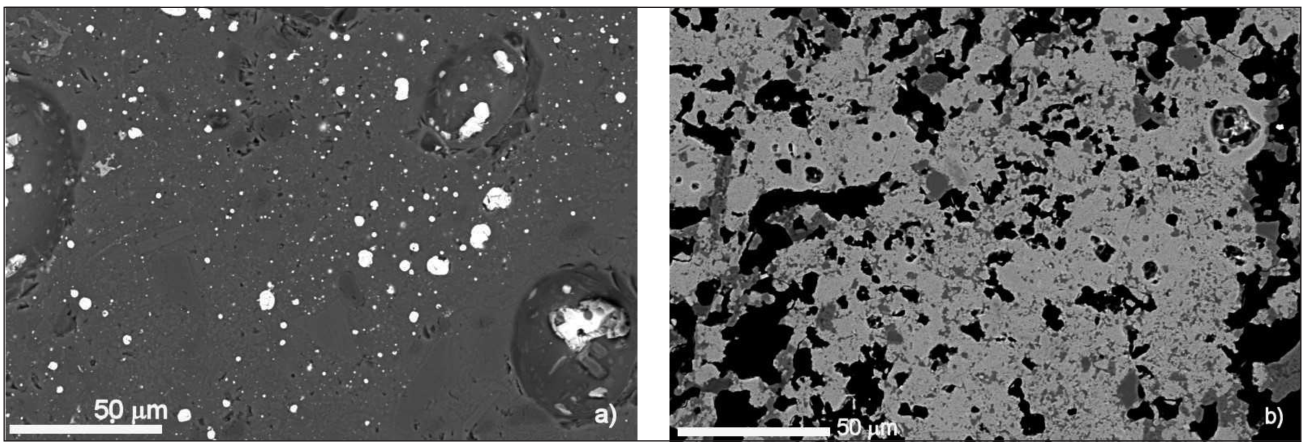

Figure 22. BSE image of cross section of black vesicular fragment in Figure 21b showing framboidal pyrite (light) with cordierite and Ca-rich plagioclase (a). BSE image of cross section of porous yellow band in Figure 21b containing fluorapatite (light) with minor quartz and plagioclase (b).

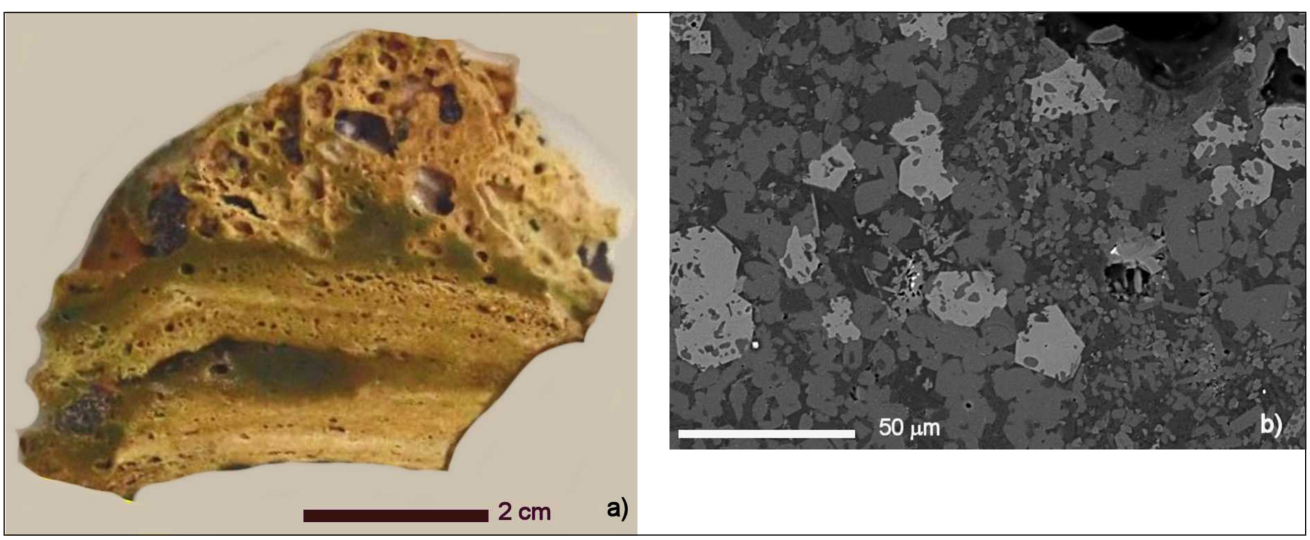

Figure 23. Cross section through yellow-olive-colored vesicular paralava from beach boulder (a). BSE image of yellow-colored layer in 23a containing Ca-Fe pyroxene (light), Ca-rich plagioclase (dark) and wollastonite (medium) (b).

crystallized consisting primarily of various proportions of Ca-rich plagioclase, wollastonite, Ca-rich clinopyroxene and in some cases tridymite (Figure 23b). The olive-colored nonvesicular layers in Figure 23a consist primarily of Ca-rich clinopyroxene and Ca-rich plagioclase with minor wollastonite whereas the vesicular yellow layers contain considerably more wollastonite. At Hope Ranch Ca-rich paralava formed only thin ribbons whereas some of the beach boulders consisted completely of Ca-rich paralava.

Summary and discussion

Located 10–25 m up the sea cliff at Hope Ranch are several sites of active combustion metamorphism in the Monterey Formation with vents, producing steam and or smoke and ammonium sulfate minerals. Similar sites existed at Ellwood Beach but have been excavated and extinguished. Some areas of the Monterey Formation, including the Hope Ranch site, are susceptible to spontaneous combustion (SC). The mechanisms for SC are complex, and Onifade and Genc (2020) and Ünal (1995) review factors that contribute to SC. The Monterey Formation is well known as a source of hydrocarbons. When exposed to oxygen they can oxidize, releasing heat (self-heating). If the surrounding rocks are good insulators the temperature can rise, thereby increasing the rate of oxidation, creating a feedback loop that leads to thermal runaway, which can raise the temperature to the point of ignition. Factors such as the rank of the bitumen (level of chemically active materials) and reduced particle size can also promote oxidation, as can the presence of water. For oxygen to be readily available for combustion, the rocks must be permeable. Some units of the Monterey Formation have very low density and are highly fractured with many joint planes. Bentor et al. (1981) suggested that tectonic activity is required to produce significant fracturing and the Hope Ranch area is part of the Santa Barbara fold and fault belt (SBFFB) (Minor et al., 2007). The most significant contributor to fracturing at Hope Ranch is the landslide which has shown repeated movement at various scales and has fragmented rock on the scale of 5–10 cm in many places and which at the time of movement can create frictional heating. This fracturing serves as a conduit for the introduction of both oxygen and water from the ocean to the oxidizing hydrocarbons. As combustion progresses, material is consumed leaving overlying rock unsupported which can collapse producing more fracturing. The oxidation of pyrite has also been shown contribute to SC, but in general, pyrite was rare in the rocks we examined at the site. Very low levels (< 1%) of framboidal pyrite were observed in some calcareous mudstones and in a few instances reached several percent in black paralava. Increased levels of organic sulfur have also been shown to increase the spontaneous combustion tendency of coal (Gao et al., 2021) and the Monterey Formation does have a relatively high organic sulfur content (Orr, 1985). The exact mechanism for SC at Hope Ranch is not known but the site has many of the attributes that make it susceptible to SC.

In a sea cliff at Hope Ranch there are several small outcrops that expose high-temperature combustion metamorphic rocks that presently are at ambient temperature and represent extinct CM sites. Similar material has been found at Ellwood Beach and as rounded boulders along the beach from Hope Ranch towards Arroyo Burro Beach. At these outcrops, calcareous, phosphatic and siliceous mudstones have been transformed into clinker and vesicular paralava. In the clinker, opal-CT has been transformed into opal-C/cristobalite and calcite and quartz have reacted to form wollastonite. Paralava, which represents sedimentary rocks which have become molten, coats and cements clinker fragments which have been metamorphosed but not become molten. Paralava occurs as three types; silica-rich, phosphate-rich and Ca-rich, the later which is the last to form usually coats the others and appears to have been more fluid. Silica-rich paralava is amorphous or nanocrystalline and may contain globules of phosphate-rich paralava which were immiscible in the silicate melt. The Ca-rich paralava commonly contains crystalline phases; anorthite, Ca-rich pyroxene, wollastonite, fluorapatite and hematite.

Bentor et al. (1981) divided the paralavas in the Monterey Formation at Grimes Canyon into low-temperature melts (LTMs) and high-temperature melts (HTMs) based in part on composition. They considered LTMs to represent partial melting of silica-rich parent rocks and have compositions of granitic minimum melts of S-type and therefore had melting temperatures less than 1000C. They further divided HTMs into high-, intermediate- and low-SiO_2 and phosphatic and did not attempt to estimate the melting temperature of the SiO_2 HTMs. They assumed the melting temperature of the phosphatic paralavas had to have been at least 1650C based on the melting point of apatite. The low-SiO_2 HTM of Bentor et al. (1981) corresponds to what we have been calling Ca-rich paralavas at Hope Ranch.

Cosca et al. (1989), caution that estimating melting temperatures based solely on that of simple phases may be misleading since the presence of solid solutions or fluxing by a liquid may reduce the melting temperature. They estimated minimum melting temperatures of paralavas from 1-atm experimental data in silicate systems of similar compositions (Schairer and Bowen, 1947; Schairer, 1950). This was accomplished by converting compositions from weight % oxides to their CIPW normative equivalents (in weight %). When we plotted the data from Table 2 in the system leucite-anorthite-SiO_2 we obtained minimum melt temperatures from 1500C to 1200C for some of the Ca-rich and Si-rich paralavas, respectively.

Grimes Canyon is the only other site where paralavas formed from the Monterey Formation have been described (Bentor et al., 1981). The crystalline phases in the paralavas at Grimes Canyon are similar to Hope Ranch in that both have cristobalite, wollastonite, calcic plagioclase, and apatite but differ in that cordierite, gehlenite, and andradite are also common at Grimes Canyon. Even in the Hope Ranch area there are local differences in paralava mineralogy, and at Ellwood Beach and in paralava in beach boulders, cordierite and tridymite have been found. Considering the much larger scale of paralava at Grimes Canyon it is not unexpected that additional minerals may have formed as a result of a much wider range of parent rock compositions being available.

Acknowledgements

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Climate change and the California deserts: repeat photography and vanishing keystone species

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ABSTRACT: In this study, repeat photography was used to assess long-term vegetation changes at sixty-five locations in the California deserts. All sites showed discernable physical or vegetational changes. Of these, climate change and its impact on plant numbers and percent vegetation cover was considered the primary factor driving changes at thirty-three sites (50.8%). The impact was considered negative on twenty-six sites with impacts decreasing with increases in latitude and elevation. Severe declines in numbers were noted in five keystone species: Joshua trees (*Yucca brevifolia* and *Y. jaegeriana*), ocotillo (*Fouquieria splendens*), teddy-bear cholla (*Cylindropuntia bigelovii*), and desert fan palm (*Washingtonia filifera*). Other factors contributing to vegetation changes included direct human impact (20.0%), recovery after past human disturbances (10.8%), wildfires (9.2%), invasive species impacts (3.1%), livestock grazing (3.1%), groundwater pumping (1.5%), and spring-flow increase (1.5%). I concluded climate change has had a significant negative impact upon perennial vegetation, including five keystone species, in California's Sonoran and Mojave deserts.

Introduction

The arid regions of California include the hottest and driest places in North America (Dimmitt et al., 2015). To survive in the extreme climate, plants have evolved a wide variety of morphological, physiological, and biochemical adaptations (Evert, 2006; Raven et al., 2005; Taiz and Zeiger, 2002). As a result of these adaptations, some scientists have hypothesized that desert plants may be resistant to the increasingly arid conditions associated with climate change (Gonzalez, et. al., 2010). Modeling studies, however, suggest that some arid-land plants may not be able to adapt to climate change (Notaro et al., 2012). Populations of Joshua trees (*Yucca brevifolia*) for example, are projected to decline in number, or possibly become extinct (Cole at al., 2010). A recent analysis using satellite data confirmed aspects of these modeling studies by documenting a long-term decline in vegetation cover within California's Sonoran Desert (Hantson et al., 2020). This decline was attributed to temperature increases associated with climate change. As a remote-sensing study, however, the researchers were unable to identify species or specific plant assemblages that were declining. The study was also confined to the western one-third of California's Sonoran Desert. A more comprehensive analysis of climate change's impacts on plant life across the entire California desert region would be gained by long-term empirical studies that monitored vegetation changes at numerous sites across the state's desert landscapes. Long-term studies, unfortunately, are challenging because of personnel issues, funding problems, or inconsistent administrative support (Pelton and van Manen, 1996).

The technique of repeat photography overcomes some of the problems associated with long-term studies. It involves two basic steps: acquiring historical images and relocating sites. The technique is a useful tool for evaluating changes in plant density and species composition over time (Hastings and Turner, 1965; Bullock and Turner, 2010; Gilbert et al., 2022). Despite the simplicity of the process, repeat photography

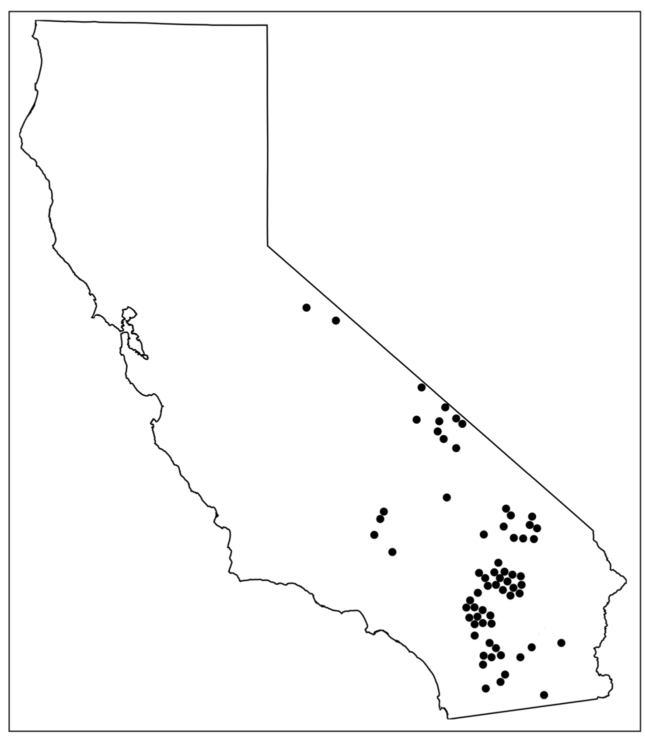

Figure 1. Relative locations of sixty-five repeat photography sites in the California deserts.

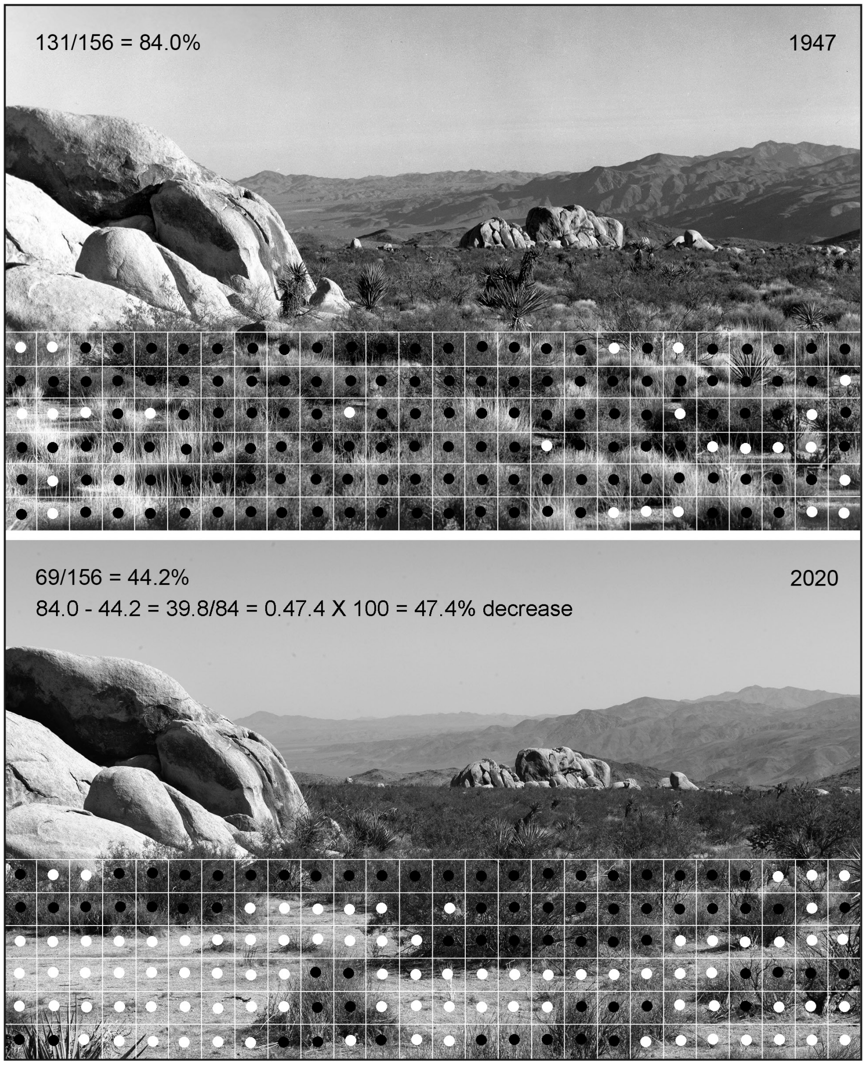

Figure 2 Technique used to compare vegetation changes at selected repeat photograph sites. Shown is the White Tank Campground site. White dots indicate where exposed bare ground can be seen in cells. Black dots indicate where vegetation fills entire cell. Percent decrease calculation is shown. Upper righthand corner shows year in which image was taken.

investigations of landscape and vegetation changes are rare and, to the best of my knowledge, have never focused on the desert regions of California. This study uses repeat photography to assess changes in plant abundance, diversity, and community composition resulting from increasing aridity.

Methods

To test the hypothesis that desert plant populations are resilient in the face of climate change, I located sixty-five sites depicted in photographs taken between the years1886 and 2008. The mean age of the historical images was seventy-four years. Locations were not randomly selected since they were dependent upon the availability of images conforming to the following five criteria. (1) Historical images had to be of landscapes, ideally with limited direct human impacts. (2) Photographs needed to contain topographies that were sufficiently discernable for accurate site identifications. Elements most frequently used to confirm locations were alignments of nearest ridgelines. (3) Photographic archives from national and state parks were given priority because these sites were frequently named, easily found, and supportive historical documentation was often available. (4) Effort was made to select sites that broadly represented the state's three desert regions: the Sonoran, Mojave, and Great Basin. (5) Sites needed to be accessible. Many areas that could once be reached by automobile were inaccessible in the early 21st century. Wilderness designations within parks and broad swaths of land along the U.S.-Mexico border have resulted in the closure of many roads and prevented vehicle access.

Historical and early twenty-first century photographs were acquired from institutional archives, individuals, and from my own personal collection. Images which included vegetation were uncommon in photographs taken prior to 1940. Early photographs typically focused on people, buildings, mining sites, or geological features. The exceptions were the photographs of Stephen Willard (1894–1966) held in the collections of the Palm Springs Art Museum. Willard's images were unusual in that they typically showed plant assemblages, were taken from an earlier era (1920 to 1965) and were of extraordinary resolution. His pictures were used in this study more often than those of any other photographer.

Repeat photography commenced in 2019 and continued into 2024. Digital adjusting of contrast and lighting on faded historical photographs aided in revealing ridgelines and landscape features. I visited each of the historical sites with a copy of the enhanced image and shot a current photograph from the same perspective. (See Table 1 for site and image details and Figure 1 for relative site locations). Notes regarding plant species present were taken during site visits and, if necessary, plant specimens were collected for later identification. Once in the lab, old and new images were positioned side by side on a large computer screen and examined for differences between them (Table 2). Digitally enlarging photographs often allowed confirmation of species identifications and enabled counting of individual plants. When feasible, a grid was laid over identical sections of an image pair for tabulating vegetation coverage and, when possible, the number of individuals of a species (Figure 2). Grid cells were marked with a black dot when vegetation cover was 100% or marked with a white dot when bare ground was clearly visible. The percentage of change in vegetation cover for each image pair was calculated (Table 3). Calculations of percent cover and numbers of individual plants were based only on what could be discerned in old and new images. Five of the image pairs are shown in Figures 2 and 5–12. The remainder have been published separately (Cornett, 2024). In this paper, vegetation cover refers to all plant species in an image without regard to species designations.

Limitations of the repeat photography method

Five limitations and biases were considered when analyzing changes in repeat photography pairs. (1) Each image pair represented two moments in time at a single site. It is possible, particularly when there were long durations between pictures, that intermediate plant communities may have come and gone during the time intervals between photographs. For example, at the Kessler Ranch area of Mojave National Preserve, the 1935 image did not show a Joshua tree woodland in the foreground (Figure 5). However, after 1935, a Joshua tree woodland appeared to have established there only to be later destroyed during the Dome Fire in 2020 (Figure 6). (2) Each frame captured just a fraction of the landscape. If the camera were pointed in another direction, different landscape changes might have been recorded that could lead to different conclusions. At the Hole-In-The-Wall site in Mojave National Preserve, the historical image was directed north at the southern limit of the Hackberry Complex Fires of 2005. The landscape behind the camera, however, had not been burned in the 2005 fire. (3) Photographers generally take their images along established roadways. Roadways of the past often become roadways of the future. Such areas are more likely to show direct human impacts when roads are widened and paved, motorist services appear, and settlements form (sites PR, PW, BS). (4) National and state parks have been established, in part, because they contain popular vistas and destinations. An inordinate percentage of useful historic images were taken at such locations. Because visitor conveniences (such as parking lots, campgrounds, and restrooms) expand to keep pace with increasing visitation, images reflecting direct human impacts were likely overrepresented at such locations (HB, IN, AC). (5) Finally, there was probably a historical bias in the vegetation images because photographers favored iconic desert plant species such as Joshua trees, ocotillos,

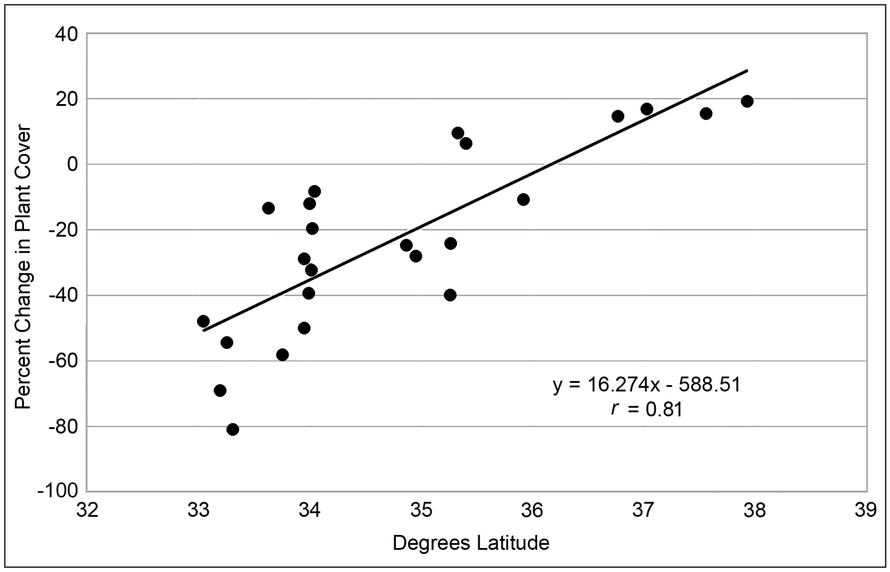

Figure 3. Regression line showing relationship between latitude and percent changes in vegetation cover. Positive changes in plant cover are strongly correlated with increasing latitude. Calculated from the twenty-four repeat photograph sites where differences were presumably a result of climate change.

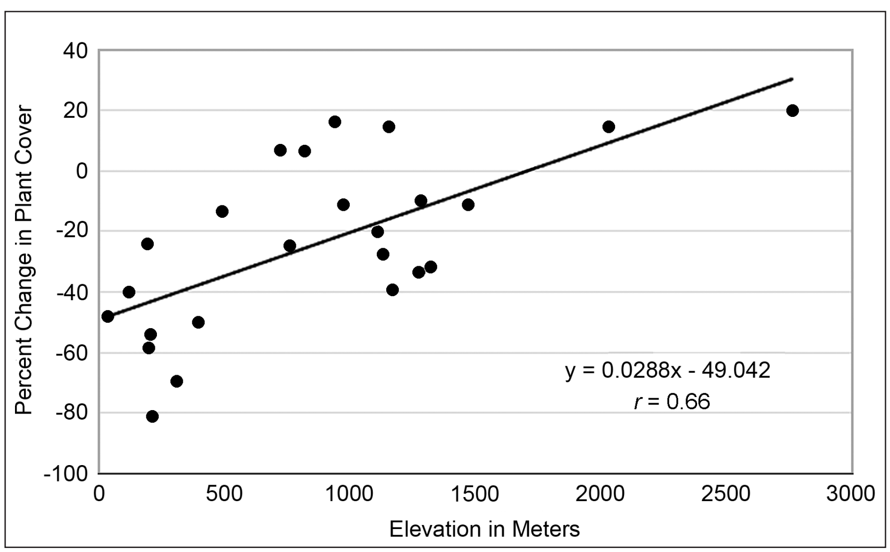

Figure 4. Regression line showing the relationship between elevation and percent changes in vegetation cover. Positive changes in vegetation cover are moderately correlated with increasing elevation. Calculated from the twenty-four repeat photograph sites where differences were presumably a result of climate change.

Table 1. Repeat photography sites, site abbreviations, site coordinates, elevations (in meters), years in which repeat images were taken, and number of years between images.

Sites and Abbreviations	Latitude °N	Longitude °W	Elev. (m)	Years of Images	Years Between Images
Death Valley National Park					
Artists Drive (AD)	36.361056	116.802056	205	1935, 2021	86
Ashford Mill (AM)	35.918528	116.683861	974	1926, 2022	96
Daylight Pass (DP)	36.763611	116.929472	1,154	1930, 2022	92
Harmony Borax Works (HB)	36.480194	116.874139	-75	1886, 2021	135
Inn at Death Valley (IN)	36.450639	116.857139	-15	1928, 2023	95
Lee Flat (LF)	36.474528	117.625028	1,612	1928, 2021	93
Grapevine Canyon (SC)	37.031833	117.336694	937	1986, 2022	36
Telescope Peak (TP)	36.215111	117.081806	2,850	1987, 2021	34
Wildrose Charcoal Kilns (CK)	36.246250	117.075833	2,013	1961, 2021	60
Joshua Tree National Park					
Cottonwood Spring (CT)	33.736250	115.809278	917	1968, 2020	54
Hidden Valley Campground (HV)	34.016556	116.161944	1,283	1938, 2020	82
Intersection Rock (IR)	34.016583	116.164167	1,287	1938, 2019	81
Keys View KV	33.926944	116.187472	1,579	1931, 2020	89
Live Oak Picnic Area (LO)	33.999528	116.053861	1,296	1958, 2022	64
Lost Horse Mine (LH)	33.941167	116.136278	1,583	1967, 2020	53
Lost Horse Ranger Station (LRS)	34.011500	116.182500	1,248	1938, 2020	82
Oasis of Mara (OM)	34.128056	116.039694	603	1936, 2020	84
Pinto Basin Road (PR)	33.820722	115.762472	788	1940, 2020	80
Pinto Wye (PW)	34.022778	116.018639	1,112	1958, 2021	63
Quail Springs Picnic Area (QS)	34.060472	116.225944	1,203	1950, 2020	70
Sheep Pass Group Campground (SP)	33.999000	116.122444	1,390	1930, 2021	91
Split Rock Picnic Area (SR)	34.008944	116.054500	1,308	1947, 2020	73
Upper Covington Flat (UP)	34.008861	116.304778	1,471	1956, 2022	66
White Tank Campground (WT)	33.984333	116.019444	1,173	1947, 2020	73
Mojave National Preserve					
Black Canyon Drive (BC)	34.986000	115.390278	1,097	1938, 2022	84
Cima Dome (CD)	35.317194	115.547194	1,534	1986, 2020	34
Essex Road (ER)	34.920389	115.439472	928	1938, 2023	85
Hole-In-The-Wall (HW)	35.047417	115.397222	1,330	1988, 2023	35
Kelso Dunes (KD)	34.883917	115.721472	765	1987, 2023	36
Kessler Ranch (KR)	35.300611	115.535194	1,494	1935, 2021	86
Mid Hills (MH)	35.134694	115.405806	1,625	1989, 2021	32
Mitchell Caverns (MC)	34.944167	115.513889	1,315	1936, 2021	85
Providence Mountains St. Rec. Area (PM)	34.944472	115.493111	1,132	1989, 2023	34
Zzyzx (ZZ)	35.143861	116.104694	287	1908, 2021	113

Table 1. Repeat photography sites (continued).

Sites and Abbreviations	Latitude °N	Longitude °W	Elev. (m)	Years of Images	Years Between Images
Anza-Borrego Desert State Park					
Citrus Groves (CG)	33.306306	116.367250	210	1929, 2022	93
Borrego Palm Canyon (BP)	33.280000	116.432722	378	2008, 2022	14
Borrego Springs, town center (BS)	33.250583	116.380639	204	1947, 2022	75
Borrego Valley, central (BV)	33.273972	116.361833	177	1932, 2023	91
Borrego Valley, northeast (BR)	33.307222	116.384500	210	1910, 2022	112
Coyote Canyon (CC)	33.359000	116.393056	306	1933, 2021	88
Fish Creek Bajada (FC)	33.048500	116.069194	36	1926, 2022	96
Glorieta Canyon Fan (GC)	33.191111	116.365750	311	1983, 2021	38
Palm Bowl (PB)	32.864278	116.233667	309	1984, 2022	36
Seventeen Palms (SE)	35.254028	116.110556	123	1916, 2020	104
Split Mountain Gorge (SM)	32.990083	116.116583	139	1928, 2022	94
Coachella Valley					
Andreas Canyon (AC)	33.760722	116.549778	255	1927, 2021	94
Desert Hot Springs West (DH)	33.944030	116.593830	401	1940, 2022	82
Escena Golf Development (EG)	33.838778	116.497083	128	1979, 2022	43
Indian Canyons Bajada (IC)	33.750583	116.539611	199	1979, 2021	42
Palm Canyon South (PC)	33.733750	116.536333	251	1924, 2022	98
Palm Canyon North (PN)	33.741639	116.537917	216	2007, 2022	15
Palm Desert (PD)	33.743472	116.360528	56	1939, 2020	81
Salton Sea (SS)	33.520861	115.939611	-84	2003, 2021	18
Tamarisk Country Club (TC)	33.774278	116.435444	81	1941, 2022	81
Whitewater Canyon (WC)	33.927056	116.642472	443	1940, 2022	82
Whitewater Flood Plain (WF)	35.254028	116.546528	194	1938, 2022	84
Red Rock Canyon State Park					
Ricardo Campground (RC)	35.372028	117.995750	722	1930, 2022	92
Red Rock Butte (RR)	35.382556	117.985639	818	1930, 2023	93
Colorado Desert					
Algodones Dunes (AL)	32.708444	114.957194	43	1919, 2023	104
Corn Springs (CS)	33.62525	115.324806	492	1953, 2020	67
Western Mojave Desert					
Pilot Knob (PK)	35.404361	117.254361	1,060	1926, 2021	95
Saddleback Butte State Park (SB)	34.707938	117.863586	761	1935, 2022	87
Walker Pass (WP)	35.728444	118.137333	928	1935, 2022	87
California's Great Basin Desert					
Owens Valley (OV)	37.558889	118.562944	2,031	1933, 2023	90
Mono Lake (ML)	37.925306	119.032722	2,761	1933, 2023	90

Table 2. Description of primary change and change category in repeat photographs.

Image Site Location	Nature of Primary Change	Primary Change Category
Death Valley National Park		
Artists Drive	slight loss of plant cover due to road widening and paving	direct human impact
Ashford Mill	plant cover decrease	climate change
Daylight Pass	plant cover increase, shrub diversity increase	climate change
Harmony Borax Works	installation of paved parking lot and access road	direct human impact
Inn at Death Valley	minimal loss of plant cover due to resort expansion	direct human impact
Lee Flat	plant cover decrease but increase in Joshua tree numbers	livestock grazing
Grapevine Canyon	plant cover increase, desert fan palms removed	climate change
Telescope Peak	pinyon pines increase and expand upslope	climate change
Wildrose Charcoal Kilns	logging ceases at end of 19th century, pinyon pines increase	vegetation recovery
Joshua Tree National Park		
Cottonwood Spring	desert fan palm and cottonwood numbers surge	increase spring flow
Hidden Valley Campground	adult Joshua tree numbers increase, juveniles vanish	climate change
Intersection Rock (IR)	adult Joshua trees decrease in number, juveniles vanish	climate change
Keys View	pinyon pines gone; junipers increase	climate change
Live Oak Picnic Area	camping prohibited, plant cover increases	vegetation recovery
Lost Horse Mine	adult Joshua trees gone, some juveniles present	wildfire
Lost Horse Ranger Station	Joshua trees increase but juveniles gone, plant cover increases	vegetation recovery
Oasis of Mara	desert fan palm numbers decline	groundwater pumping
Pinto Basin Road	loss of some plant cover due to road widening and paving	direct human impact
Pinto Why	numbers of adult and juvenile Joshua trees decline	climate change
Quail Springs Picnic Area	loss of plant cover due to road paving and widening	direct human impact
Sheep Pass Group Camp	plant cover increases, Joshua tree numbers increase	vegetation recovery
Split Rock Picnic Area	plant cover declines, perennial bunch grasses vanish	climate change
Upper Covington Flat	plant cover and Joshua tree numbers decline	climate change
White Tank Campground (WT)	plant cover declines, perennial bunch grasses vanish	climate change
Mojave National Preserve		
Black Canyon Drive	Mojave yuccas increase, creosote bushes become larger	livestock grazing
Cima Dome	most vegetation destroyed by Dome Fire of August, 2020	wildfire
Essex Road	loss of some plant cover due to road widening and paving	direct human impact
Hole-In-The-Wall	loss of most vegetation in Hackberry Complex Fire of 2005	wildfire
Kelso Dunes	plant cover decreases	climate change
Kessler Ranch	loss of most climax vegetation in Dome Fire of August, 2020	wildfire
Mid Hills	loss of most vegetation in Hackberry Complex Fire of 2005	wildfire
Mitchell Caverns	select plant species show shift in elevation and dominance	climate change
Providence Mountains S. R. A.	shift to more xeric vegetation	climate change
Zzyzx	mining ends and vegetation returns	vegetation recovery

Table 2. Primary change categories (continued)

Image Site Location	Nature of Change	Primary Change Category
Anza-Borrego Desert St. Park		
Citrus Groves	conversion of creosote scrub habitat to citrus grove	direct human impact
Borrego Palm Canyon	hikers directed around oasis, juvenile *W. filifera* return	vegetation recovery
Borrego Springs, town center	plant cover and ocotillo numbers decline	climate change
Borrego Valley, central	replacement of native wildflowers by exotic weed species	exotic plant invasion
Borrego Valley, northeast	once abundant *Cylindropuntia bigelovii* is extirpated	climate change
Coyote Canyon (CC)	ocotillo, *Fouquieria splendens,* declines	climate change
Fish Creek Bajada	ocotillo, *F. splendens,* declines	climate change
Glorieta Canyon Fan	plant cover declines, *C. bigelovii* declines	climate change
Palm Bowl	desert fan palm, *W. filifera,* declines	climate change
Seventeen Palms	*W. filifera* juveniles and plant cover decline	climate change
Split Mountain Gorge	Ocotillo, *F. splendens,* declines	climate change
Coachella Valley		
Andreas Canyon	increase in palm numbers due to dam construction	direct human impact
Desert Hot Springs West	plant cover decreases 49.9%, diversity eliminated	climate change
Escena Golf Development	replacement of creosote scrub with golf course	direct human impact
Indian Canyons Bajada	plant cover declines, *C. bigelovii* extirpated	climate change
Palm Canyon South	increase in palm numbers after flood and fire	vegetation recovery
Palm Canyon North	*W. filifera* adults and juveniles decline	climate change
Palm Desert	loss of dune habitat due to development	direct human impact
Salton Sea	water diversions cause Salton Sea to shrink	direct human impact
Tamarisk Country Club	native plant community replaced with golf course	direct human impact
Whitewater Canyon, mouth of	loss of *C. bigelovii* and other native perennials	wildfire
Whitewater Flood Plain	sand hummocks and climax vegetation gone	climate change
Red Rock Canyon State Park		
Ricardo Campground	*Y. brevifolia* and plant cover increase	climate change
Red Rock Butte	plant cover increases	climate change
Colorado Desert		
Algodones Dunes	loss of natural habitats due to freeway construction	direct human impact
Corn Springs	plant cover and *W. filifera* decline	climate change
Western Mojave Desert		
Pilot Knob	bare ground occupied by invasive species	exotic plant invasion
Saddleback Butte St. Park area	*Y. brevifolia* decline in region	climate change
Walker Pass	*Y. brevifolia* declines, more xeric vegetation	climate change
Great Basin Desert		
Owens Valley	increase in plant cover	climate change
Mono Lake	increase in plant cover	climate change

desert fan palms, and fields of spring wildflowers, when compared to less charismatic shrubs (IR, OM, GC).

Repeat photography research questions

Six questions were considered in evaluating changes between old and new images. (1) Were there indications of direct human impact, including construction, road building, or off-road-vehicle use? (2) Was there evidence of competition from non-native species? (3) Was there evidence of livestock grazing in the past or present? (4) Was there evidence of wildfires? (5) Were there indications of severe weather events such as sheet flooding? (6) Were there quantitative differences in vegetation cover or numbers of certain plant species? If the answer was no to the first five questions and yes to the last one, I concluded that increasing aridity associated with climate change was responsible for observed changes in desert vegetation. I used differences in percent cover, numbers of individuals of a species, or plant age classes to determine the quantity of the changes. Because photographs were being compared, rather than analyzing old and new on-the-ground data sets, conclusions about the cause of such changes was subjective in some cases. Final conclusions were based upon my personal experience along with information provided by colleagues who reviewed image pairs and commented on differences.

Table 3. Sites for which climate change was most probable cause of differences in plant cover, and where images enabled calculations.

Image Site Location	% Plant Coverage Change
Ashford Mill	-11.0
Borrego Springs Downtown	-54.4
Borrego Valley, northeast	-81.4
Corn Springs	-13.5
Daylight Pass	14.5
Desert Hot Springs West	-49.9
Fish Creek Bajada	-48.4
Glorieta Canyon Fan	-69.2
Grapevine Canyon	16.4
Hidden Valley Campground	-33.1
Indian Canyons Bajada	-58.1
Intersection Rock	-10.4
Kelso Dunes	-25.2
Mono Lake	19.6
Owens Valley	14.7
Pinto Why	-19.7
Providence Mountains SRA	-27.7
Red Rock Butte	6.8
Ricardo Campground	7.0
Seventeen Palms	-39.9
Split Rock Picnic Area	-32.2
Upper Covington Flat	-11.1
White Tank Campground	-47.4
Whitewater Flood Plain	-24.2

Results

At thirty-three sites (50.8%), changes in plant species numbers and percent cover of vegetation were best attributed to increasing aridity associated with climate change (NOAA, 2024). The impact was considered negative at twenty-six of the thirty-three sites (78.8%) because of a decrease in cover, declines in recognizable species, or declines in juvenile recruits. Four of these sites are shown in Figures 5 through 12.

Despite the increasing aridity associated with climate change, seven of the sites showed an increase in vegetation cover and/or an increase in numbers of identifiable species (Table 2). At two sites, increase in shrub cover on alluvial plains likely reflected increasing precipitation in the area over the past thirty years: a recorded increase in precipitation of 19.6% at Mono Lake (WRCC, 2023) and a projected increase of 3.5% at the Owens Valley site (Prism, 2024). Increase in vegetation in Death Valley's Grapevine Canyon was attributed to enhanced moisture availability resulting from a flash flood in October of 2015. Establishment of single-leaf pinyon pines (*Pinus monophylla*) at increasingly higher elevations in the Panamint Range was attributed to warmer temperatures due to global warming (Tingley, 2015). The Ricardo Campground, Red Rock Butte, and Daylight Pass sites showed increases in plant cover. The Ricardo Campground site also showed an increase in Joshua trees and the Daylight pass site showed an increase in plant species diversity. Considering area declines in precipitation and increases in temperature, these vegetational increases remain unexplained (EPA, 2023).

Direct human impacts were found to be the second leading cause of landscape changes in this study. Thirteen sites (20.0%) showed such impacts. Most frequently, impacts involved creating, paving and/or widening of roadways. Most of these changes occurred in or near national or state parks as they have been forced to deal with explosive rises in visitation (NPS, 2022). Other direct impacts included conversion of native plant communities to agricultural fields (CG), residential and commercial developments (PD), or golf courses (EG, TC).

At seven sites (10.8%), individual plant species, and vegetation in general, had been damaged or removed in the past but appeared to be recovering despite a more hostile climate. The recovery was a result of cessation of disturbance activities at four of the sites: logging of pinyon pines at the Wildrose Charcoal Kilns in Death Valley National Park, informal camping at Live Oak Picnic Area

Figure 5. Kessler Ranch area circa 1935, showing absence of a Joshua tree woodland in the foreground. The absence of the trees may reflect their use as fuel by ranchers.

Figure 6. Kessler Ranch area in 2021, showing establishment of Joshua tree woodland after 1935. Most of the woodland; within the frame boundaries; was destroyed in the Dome Fire of 2021.

in Joshua Tree National Park, surface mining at Zzyzx Desert Studies Center in Mojave National Preserve, and closing of non-sanctioned trails at Borrego Palm Canyon, in Anza-Borrego Desert State Park. A fifth site, Sheep Pass in Joshua Tree National Park, appeared to be recovering from a century-old wildfire and a decades-long period of cattle grazing in the early 19th century. A sixth site, south Palm Canyon in the Indian Canyons Tribal Park, most likely was recovering from a historic flood as well as the Dry Falls Fire of 1980. Except for Borrego Palm Canyon, it is not known if the recoveries are presently continuing or if they have ceased due to aspects of climate change.

Relatively recent wildfires destroyed all or most of the vegetation at six repeat photography sites (9.2%). None of these sites had historical records, photographic documentation, or field evidence of previous fires. Each site demonstrated some level of post-fire rejuvenation, but

Figure 7. West of Desert Hot Springs; view of San Jacinto Peak, Coachella Valley, 1940.

Figure 8. West of Desert Hot Springs. View of San Jacinto Peak in 2024. Perennial vegetation cover has been reduced by 49.9%. Creosote bush and brittlebush are the only shrubs that remain

none yet appeared to be on a trajectory that indicated a return to established pre-fire communities.

Five less frequent reasons for landscape changes were identified. (1) Two sites had been altered by the arrival of exotic weed species (3.1%). In the central Borrego Valley site (BV), these included common Mediterranean grass (*Schismus barbatus*), Russian thistle (*Salsola australis*), and the newest invasive, Egyptian knapweed (*Volutaria tubuliflora*). At the Pilot Knob site in the Mojave Desert (PK) the landscape had been overrun by a species of exotic *Brassica.* (2) Livestock grazing was considered the primary factor in vegetation changes at two sites including decreases in vegetation cover, elimination of perennial grasses, and/or a shift towards less palatable species (LF

Figure 9. Entrance to Coyote Canyon, Anza-Borrego Desert State Park, 1933.

Figure 10. Entrance to Coyote Canyon in 2021. The number of ocotillos, *Fouquieria splendens,* has declined by 76.5% at this location.

and BC). A possible important secondary factor at the grazing-impact sites may be increasing aridity associated with climate change. Unfortunately, no local climate records exist for either site. Groundwater pumping was identified as the primary cause in the decline of desert fan palm (*Washingtonia filifera*) numbers at the Oasis of Mara in Joshua Tree National Park (Moret, et al., 2016). (4) Despite increasing regional aridity, an expansion of vegetation was recorded at Cottonwood Spring in Joshua Tree National Park. The expansion was a result of an increase in the number of desert fan palms and Fremont cottonwoods (*Populus fremontii*). Adult fan palm numbers rose from ten to thirty-one, a 310% increase. Cottonwood numbers increased from one to seven, a 600% increase. Both increases likely reflected enhanced spring flow resulting from shifting along the Cottonwood Spring Fault (R. Hazlett, personal communication).

In addition to vegetation cover, I examined changes in the numbers of iconic and keystone plant species depicted in photograph pairs. Two Sonoran Desert species, teddy-bear cholla (*Cylindropuntia bigelovii*) and ocotillo (*Fouquieria splendens*), showed consistent declines in numbers or even extirpation at sites where they had originally appeared (Table 4). Teddy-bear chollas vanished from three of the four sites in which they were formerly present and had an 81% reduction in numbers at

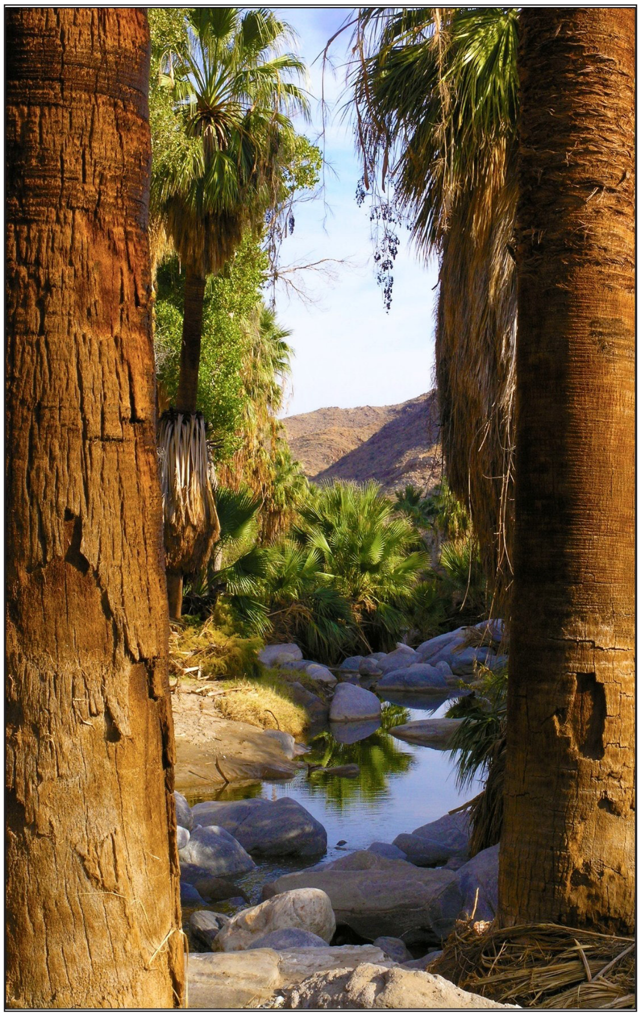

Figure 11. North end of Palm Canyon at Indian Canyons Tribal Park in 2007, showing adult and juvenile desert fan palms (*Washingtonia filifera*).

Figure 12. North end of Palm Canyon in 2022, fifteen years after the image in Figure 11 was captured. Adult desert fan palm numbers have declined by 66.7%, and juveniles have declined by 41.7%.

the fourth site. Ocotillo numbers were identical at one of six sites but declined or were extirpated at the remaining five. The hydrophilic desert fan palm depends on fossil water emanating from desert springs and seeps and was thought to be independent of long-term fluctuations in precipitation (Cornett, 2010). However, at the ten sites where this palm species occurred, five showed declines in numbers, no longer supported juvenile recruits within populations, or both.

In the Mojave Desert, *Y. brevifolia* (western Joshua tree) and *Y. jaegeriana* (eastern Joshua tree) fared poorly at all but one of the twelve historical photograph sites (Table 4). Wildfires eliminated all adult Joshua trees at three sites (LH, CD, KR). Adult numbers were declining, and juvenile recruits were absent (or nearly so) at five sites (IR, PW, SR, UC, WP). Adult numbers increased at three sites, but juveniles were absent or had declined (HV, LR, SP). The importance of juvenile recruits to a viable population cannot be overstated (Harper, 1977). Only at Lee Flat, in Death Valley National Park, were both adult and juvenile trees increasing in number. The Lee Flat site was both the highest latitude and highest elevation site among the twelve sites where Joshua trees appeared in the historical images.

Four sites included single-leaf pinyon pines (*Pinus monophylla*). At the two lowest elevations and most southerly locations, these pines had declined in number (KV, MC), whereas at the two highest elevation sites they had increased (TP, CK). However, I attributed the increase of pinyon pine numbers at the Wildrose Charcoal Kilns site not to climate change but to a natural recovery following late 19th century cessation of logging. The increase on the slopes of Telescope Peak I associate with global warming and the enhanced ability of pinyon pines to establish at higher elevations than in the past (Guida et al., 2014).

I used linear regression to analyze how the percentage change in vegetation cover was associated with latitude (Figure 3). The model indicates that changes in vegetation cover in the California deserts are more likely to be positive at northerly latitudes. There was a significant positive correlation between latitude and increased

Table 4. Percentage increases or decreases in numbers of selected keystone species.

Location	% Change		Site Notes
Cylindropuntia bigelovii			
Borrego Valley, northeast	-100.0		first *Cylindropuntia ganderi* establish
Glorieta Canyon Fan	-81.3		once abundant *Encelia farinosa* extirpated
Indian Canyons Bajada	-100.0		extirpated from area beyond image frame
Whitewater Canyon	-100.0		extirpated by recurring wildfires
Fouquieria splendens			
Borrego Springs, town center	-80.0		growth of town a factor in decline
Coyote Canyon	-76.5		ocotillos still common beyond frame
Fish Creek Bajada	-94.7		ocotillos still occur beyond image frame
Glorieta Canyon Fan	0.0		only site without change in ocotillo status
Seventeen Palms	-100.0		no ocotillos visible beyond frame
Split Mountain Gorge	-19.2		ocotillos appear on surrounding ridges
Washingtonia filifera	Adults	Juveniles	
Andreas Canyon	83.3	0.0	small dam responsible for increase
Borrego Palm Canyon	0.0	100.0	trail realigned away from oasis center
Corn Spring	-68.6	100.0	new well may contribute to decline
Cottonwood Springs	154.5	0.0	realignment of trail a contributing factor
Oasis of Mara	-66.7	200.0	artificial irrigation a contributing factor
Palm Bowl	-29.0	0.0	population peaked around 1984
Palm Canyon North	-66.7	-41.7	decline in area occurred after year 2000
Palm Canyon South	150.0	175.0	canyon scoured in flood of 1922
Grapevine Cyn	-100.0	-69.2	National Park Service removed palms
Seventeen Palms	271.4	-87.5	adult palms no longer produce fruit
*Yucca brevifolia, Yucca jaegerina**	Adults	Juveniles	
Cima Dome *	-100.0	-100.0	Dome Fire of June, 2020
Hidden Valley Campground	72.7	-100.0	most adult trees in decline
Intersection Rock (IR)	-33.3	-100.0	remaining trees are aging adults, no juveniles
Kessler Ranch *	0.0	400.0	survival of some juveniles after Dome Fire
Lee Flat	53.3	31.8	increase in Joshua tree nurse plants
Lost Horse Mine	-100.0	0.0	climax community removed by 2009 wildfire
Lost Horse Ranger Station	116.7	-77.6	recovering from early livestock grazing
Pinto Why	-31.5	-80.8	Mojave yucca, *Yucca schidigera*, also declined
Quail Springs Picnic Area	-50.0	0.0	Joshua trees removed to widen and pave road
Ricardo Campground	100.0	100.0	most Joshua trees are declining
Saddleback Butte area	-100.0	0.0	included largest Joshua tree ever recorded
Sheep Pass Group Campground	52.4	-2.4	plant recovery after wildfire and end of grazing
Split Rock Picnic Area	-50.0	-100.0	elimination of perennial bunch grasses
Upper Covington Flat	-11.3	-100.0	remaining trees aging adults, no juveniles
Walker Pass	-48.9	-55.6	more xeric vegetation replaces Joshua trees

vegetation cover ($r = 0.81$, $p < 0.01$). The same type of analysis was performed using the association between changes in vegetation cover and elevation (Figure 4). This model showed that vegetation cover increases were more likely to be positive at higher elevation sites across the region. The correlation between higher elevation and increase in vegetation cover was significant ($r = 0.66$, $p < 0.01$), but explained less variance compared to the influence of latitude. These analyses were performed using Microsoft Excel 2016.

Discussion

Based upon the repeat photographs, the hypothesis that desert plants are resilient in the face of climate change is rejected. Declines in vegetation cover and keystone species abundances were found to be widespread and often severe, particularly at low elevation and low latitude areas of California's Sonoran Desert. Except for five permanent springs where palm oases occurred, all the Sonoran Desert sites showed declines in vegetation coverage or declines in keystone species (Tables 3 and 4). Half of the palm oases also showed declines in palm numbers, juvenile recruits, or both. Declines in vegetation cover in California's Sonoran Desert agree with Hantson's remote sensing study (Hantson et al., 2020) which also showed plant cover declines.

The Mojave Desert sites, in general, also showed declines in vegetation cover though less severe than in images from the Sonoran Desert. Of the thirteen Mojave Desert sites where vegetation cover could be calculated, nine showed decreases in cover whereas only four showed increases (Table 3). Adult Joshua tree numbers declined at nine of fifteen photograph sites but increased at four sites (Table 4). One site, Kessler Spring, showed no change in these numbers because the 2020 Dome Fire destroyed all adult trees within the image frame. Nine of the sites showed declines in juvenile Joshua tree recruits. Five of the nine sites had no recruits. Only two sites, Lee Flat and Ricardo Campground, showed increases in both adult and juvenile Joshua tree numbers. The adult trees at the lower elevation Ricardo Site, however, were declining as revealed in the dying and shedding of terminal leaf clusters. Lee Flat was the only site which revealed a healthy population of Joshua trees with both increasing numbers of adults as well as juveniles. It is also the highest elevation and highest latitude site of the fifteen Joshua tree photograph sites examined.

The only sites that consistently showed increases in vegetation cover or numbers of single-leaf pinyon pines were those at the highest latitudes and elevations. The four most northerly sites all showed increases in vegetation cover (DP, SC, OV, ML) and the four highest elevation sites either showed increases in vegetation cover or increase in numbers of pinyon pines (TP, CK, OV, ML). These relationships are shown in Figures 3 and 4. In summary, my results suggest that climate change, specifically its increasing temperature component, could be having the greatest negative impacts on the warmer desert regions in California (i.e., at the lower elevation Sonoran and Mojave sites). By comparison, the cooler and more northerly or higher elevation areas do not currently appear to be revealing negative impacts on vegetation. This latter conclusion, however, is tenuous as it is based upon only six repeat photography sites.

These findings suggest that some desert plants at the Sonoran Desert sites are periously close to their adaptive capacities when compared with desert plant populations farther north (Bobich et al., 2014; Buckley and Huey, 2016). Based upon the sharp declines observed in the Sonoran Desert, the images evaluated in this study indicate that plants in the warmer deserts may not be able to maintain their historical abundances and that the prevalence of certain keystone species is threatened (Figures 2, 5–12).

Wildfire

The trends described above are further exacerbated by wildfires that are becoming more frequent and extensive as regional temperatures warm and droughts become severe (Liu et al., 2010; Iglesias et al., 2022; Syphard et al. 2017). In my study, eight of the sites had been impacted by wildfires, although two of the fires had occurred before the widespread acknowledgment of climate change in the late 1980s (Table 2). The remaining six sites were affected by wildfire in the past twenty years. It can be argued that these recent wildfires were associated with climate change phenomena, and that their impacts should be included within the climate change category. When considering this perspective, thirty-nine repeat photography sites (60%) show impacts of climate change. Thirty-two of the thirty-nine sites show negative impacts on vegetation.

Decline of keystone species

Most visually striking was the decline or even extirpation of iconic keystone plant species, particularly those in California's Sonoran Desert. Not only are the ocotillo, teddy-bear cholla, and desert fan palm critically important to a variety of animal species, but they are often used to publicly define California's Sonoran Desert. If present trends continue, we may witness a massive decline in the region's biodiversity and a forced rethinking of how we view our desert landscapes. It is hard to imagine a Mojave Desert without the Joshua tree yet, based on the landscapes shown in the repeat imagery, their declines are real and widespread.

Repeat photography is not a substitute for long-term data gathering on study sites or transects. But, for the moment, it is an available tool for determining actual impacts of climate change across the California desert region.

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Remains of shack at El Mirage, February 1998. D.M. Miller photograph.

Preliminary analysis of spatial relationships between vegetation and nest mounds of ground-dwelling desert ants (Formicidae: *Veromessor* and *Acromyrmex*) across a landscape gradient

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ABSTRACT—Understanding relationships between communities of ants and their respective relationships with surrounding vegetation can inform patterns in the distribution of biodiversity in desert environments. Studies have explored these patterns in the past; however, such projects were generally confined to limited geographic areas. By using a landscape-scale approach, broader variation in the influence of climate upon these relationships within arid environments might be revealed. To assess these relationships, four locations within the Mojave and Sonoran deserts, including one transitional site, were selected for preliminary censusing. Groups of neighboring ant colonies in these locations were surveyed for their respective distances to one another and concomitantly to the surrounding perennial shrubs. Principal components analysis indicated that in the relatively drier Mojave Desert, ant colonies were distributed farther apart from one another and from the nearest vegetation when compared to those that were found in the relatively wetter Sonoran Desert. Among these sites, there was also a positive correlation between the distance of colonies from one another and their distance to the nearest vegetation. Additionally, the farther apart these nests were found to be from one another, the farther away they occurred from the nearest vegetation to them towards the south. These preliminary results suggest that extremely arid plant resource-poor ecoregions such as Death Valley constrain the spatial distribution of ground-dwelling ant communities when compared to the relatively wetter Sonoran Desert environment where vegetation is generally more abundant. Future studies should consider how climate change and urban development will affect these distributions, and if these interactions could be used as indicators of environmental stress.

Introduction

Ground-dwelling ant taxa include some of the most resilient species found in the deserts of North America (Franklin 2012). Their extremely social life history and propensity for collecting plant resources have led to questions concerning the extent to which ant colonies can engineer ecosystems and reshape patterns in the distribution and establishment of vegetation (MacMahon et al. 2000; Wilby and Shachak 2000; DeFalco et al. 2009; Plowes et al. 2013). Understanding how patterns in spatial relationships between ant nests and their surrounding vegetation change along landscape gradients can elucidate patterns in these distributions. Exploring how these colonies are distributed relative to one another as a function of vegetation density might suggest how co-occurring ant colonies respond to variation in plant resource availability and become partitioned spatially (Ryti and Case 1992; Lorinczi 2011).

My project seeks to answer two central research questions regarding the distribution of ground-dwelling ant species and their associated vegetation in desert environments: (i) are their colonies distributed farther from the nearest vegetation in drier environments with less plant biomass compared to those that are relatively wetter with more plant biomass, and (ii) are such colonies also distributed farther from one another in drier environments when compared to relatively wetter environments.

Methods

To test these hypotheses, a pilot study was conducted from 2021 to 2022. Locations where active ground-dwelling ant nest mounds of one or both the genera *Veromessor* and *Acromyrmex* occurred (Figure 1) were surveyed at four sites along a broad landscape gradient from the Gran Desierto in southern Arizona to Death Valley in eastern California (Table 1; Figure 2). This latitudinal gradient extends from the relatively wetter Sonoran Desert to the drier Mojave Desert (Table 2) and represents changes in vegetation composition and density from south to north.

Figure 1. Photos of *Veromessor pergandei* emerging from a nest near the Warm Springs Road in Death Valley (above), and *Acromyrmex versicolor* gathering plant material at the Tinajas Atlas Mountains (below).

Figure 2. Location of surveys: (1) Death Valley, (2) Mission Creek, (3) Indian Pass, and (4) Tinajas Atlas.

The minimum seasonal temperature during winter also generally decreases at the more northern sites along this gradient (Table 2). Nest mounds located in these sites were found using an area search method, a technique normally used to locate landbirds in the field (Ralph et al. 1993). A minimum of 2 and maximum of 9 ant nest mounds in the sites were surveyed and used as subsamples within each of the 4 site replicates. The distance from each nest mound to the nearest perennial shrubs was measured in the four cardinal directions (north, south, east, and west) using meter tape or a laser range finder (Laser Technology TruPulse 360 ′ R), and the location of each nest was recorded in decimal degrees using the mobile app Gaia GPS (https://www.gaiagps.com/).

Average distance from the nearest vegetation to these nests was then calculated from the four cardinal directions using Microsoft Excel. To assess the spatial relationships of nests with each of their nearest neighbors,

Table 1. Site locations where ant nest mounds were surveyed, with pooled summary statistics and genera found. Mean distance of nests to vegetation and their neighbors is reported in meters, and coordinates are in decimal degrees.

Location	Mean distance to vegetation	Mean distance to neighbors	Nest count	Coordinates (lat – long)	Desert ecoregion	Ant genera
Tinaja Atlas	4.75	43.01	7	32.34, -114.10	Sonoran	*Veromessor* and *Acromyrmex*
Indian Pass	5.95	123	2	32.99, -114.79	Sonoran	*Veromessor*
Mission Creek	4.70	24.83	9	34.02, -116.63	Transition zone	*Veromessor*
Death Valley	18.65	314.24	5	35.96, -116.79	Mojave	*Veromessor*

Table 2. Sites where ant nest mounds were surveyed showing relevant climate data. Temperature is reported in degrees Celsius, and precipitation is in millimeters. Data was obtained from WorldClim (https://www.worldclim.org/data/bioclim.html) using the package *raster* in R (R Core Team 2020).

Location	Mean annual temperature	Max. summer temperature	Min. winter temperature	Mean annual precipitation	Mean summer precipitation	Mean winter precipitation
Tinaja Atlas	21.5	38.6	5.9	127	53	39
Indian Pass	22.0	41.2	4.7	83	23	27
Mission Creek	16.5	36.3	1.5	342	42	158
Death Valley	22.9	44.2	2.6	52	10	21

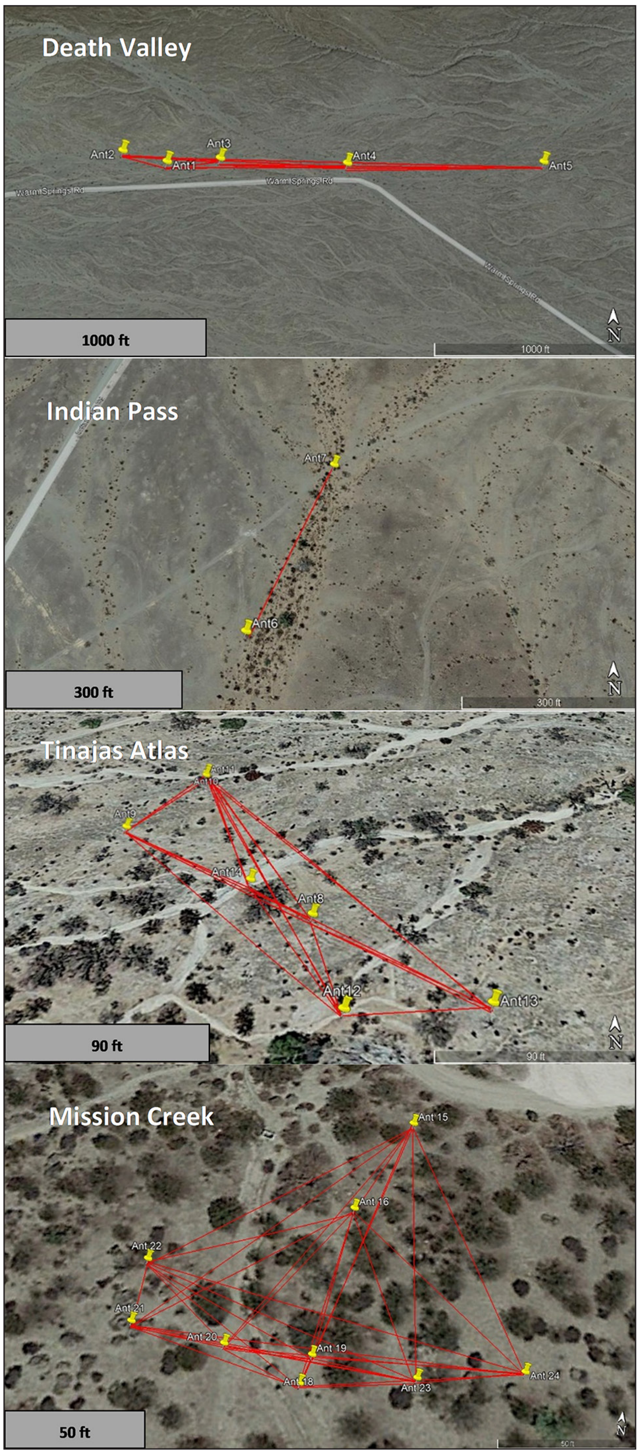

Figure 3. Spatial distributions of ant nest mounds at four desert sites shown in Google Earth. Yellow pins indicate nest mound locations and red lines indicate distances measured between nests. Scale bars are given in feet at the bottom left corner of each image. Images are presented in order of increasing resolution.

the GPS coordinates obtained were plotted in Google Earth Pro (version 7.3.6.9285), and neighbor distances were measured using the ruler tool (Figure 3). These data were arranged into a covariance matrix by site (standardized to account for scale differences), and then used to perform principal component analysis (PCA) for visualizing relationships between variables. The results of the first PCA axis were tested using analysis of variance (ANOVA). Important associations found using PCA were then analyzed separately using Pearson's correlation tests. Statistical analyses were performed in R (R Core Team 2020) using the functions *princomp, anova,* and *cor.test* available in the package *stats* (version 3.6.2).

Results and discussion

The preliminary results of this study were consistent with my hypotheses. The first two axes of principal components analysis (PCA) explained 86.5% of the variance in the model. In the relatively drier area of Death Valley, ant nests were on average found farther from nearby

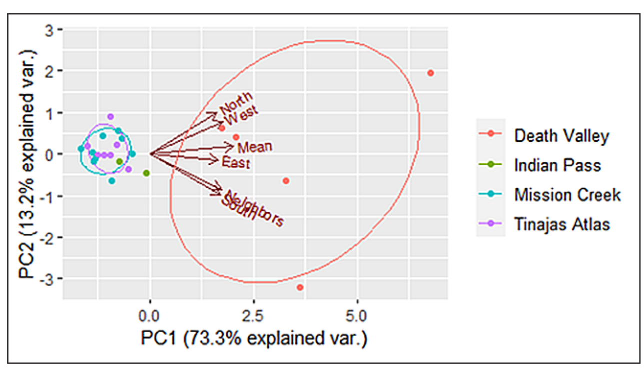

Figure 4. Principal components analysis with eigenvectors showing the association between distance of ant nest mounds to nearest vegetation in the four cardinal directions (north, south, east, and west), average distance of nest mounds to vegetation among cardinal directions (mean), and average distance between neighbor nests (neighbors).

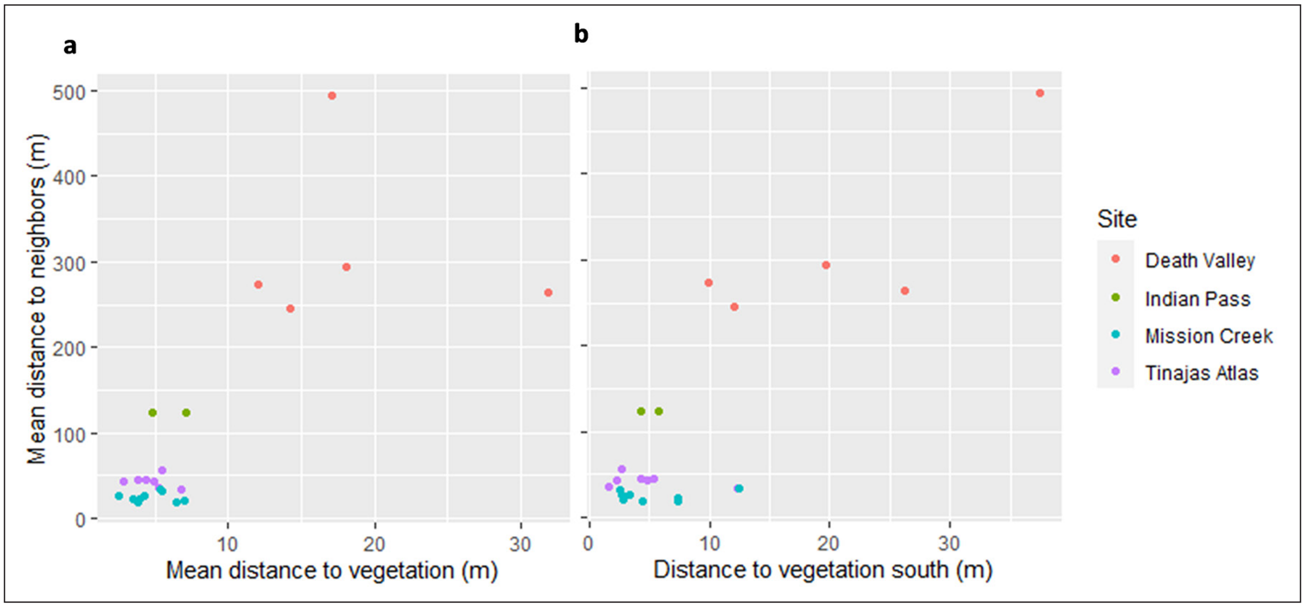

Figure 5. Plots showing correlations between mean distance to neighbor nests and (**a**) mean distance to vegetation (r = 0.77), and (**b**) distance to vegetation to the south (r = 0.86) at 4 sites across the Sonoran and Mojave Deserts.

vegetation compared to those in the relatively wetter Sonoran Desert environment ($F_{1, 21}$, $P << 0.0001$; Table 1; Figure 4). PCA and Pearson's correlation showed that when nests occurred farther from vegetation, they were also farther from their nearest neighbors (t = 5.52, df = 21, P << 0.0001; Figure 5a). These results suggest that plant resources might limit desert ant nest density when vegetation is not abundant, possibly causing the colonies to spread their distributions apart. An unexpected positive correlation was found in the distance between neighbor nests and their distance to vegetation in a southernly direction (t = 7.83, df = 21, P << 0.0001; Figure 5b). This correlation could be related to the movement of foraging ants away from their nests as they learn to track specific geographic orientations. Some ants can use the Earth's magnetic field for navigation (Banks and Srygley 2003; Sandoval et al. 2012), including species found in desert environments (Grob et al. 2018). However, it is unclear why the nests observed in my study were concurrently distributed farther away from each other and vegetation to the south of them in environments where plant resources were relatively limited (i.e., in Death Valley) when compared to areas with more abundant plant resources.

These conclusions are based on a limited data set, so the statistical analyses presented should be interpreted with caution. More research is needed to better illuminate an understanding of the relationships between neighboring ground-dwelling ant nets and their surrounding vegetation with respect to geographic variation in such distributions within desert environments. This research could be improved by including many more site replicates across the Sonoran-Mojavean landscape where these ant communities occur to capture a broader scale of variation in these patterns as climate, substrate, and vegetation change. Including data for the different plant species that co-occur with these ant communities in these analyses (e.g., in the PCA) could reveal additional insight into whether these spatial relationships are related to specific kinds of vegetation. Assessing relevant food resources available from plants (e.g. leaves vs. fruits and seeds) and their phenology (e.g. leaves present or absent, flowering or fruiting) would be useful variables to explore. This information could provide a better picture of the relationships between desert ant colonies and vegetation and indicate if they at all appear to influence each other's distributions. In addition, including meaningful temperature and precipitation data from WorldClim (https://www.worldclim.org/data/bioclim.html) in these analyses could explain variation in how these ants respond to the distribution of major vegetation types as they relate to climate in desert environments. In general, the behavior, life history, and abundance of these desert ant colonies are features of the environment that should be explored further.

Few research agendas currently exist that address questions concerning spatial patterns in the distribution of ground-dwelling ant species and their relationship to vegetation in arid landscapes. As the southwest deserts continue to undergo rapid anthropogenic changes due to renewable energy development and increased urbanization, these kinds of intricate ecosystem processes will likely be threatened (Grodsky and Hernandez 2020). Monitoring ant communities can be a valuable bioindicator as land use change impacts ecological diversity (Andersen 1997; Lobry de Bruyn 1999; Read and Andersen 2000; DeFalco et al. 2009), especially in arid ecosystems. Future changes in climate are likely to alter patterns in the distribution of vegetation with increasing drought in deserts (Munson et al. 2013; Guida et al. 2014). Both increasing temperature (Kaspari

2019) and decreasing precipitation (Gibb et al. 2018) are predicted to have negative effects on the species richness and abundance of ant colonies in deserts as the climate becomes more arid. Examining these spatial patterns will provide a baseline for future studies of such ecological relationships as the environment changes and will contribute to understanding large scale shifts in the distribution of biodiversity across arid landscapes.

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Rock cabin in the east Mojave, May 1995. D.M. Miller photograph.

High temperature rocks from burning oil shale near Santa Barbara, California

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SUMMARY—A small section of Miocene Monterey Formation exposed in sea cliffs near Santa Barbara, CA is actively burning beneath the surface (Figure 1). It is producing clinkers, paralavas, and high temperature minerals by combustion metamorphism. Known since 1784, the heavily fractured bituminous shale is in places too hot to touch. Many features like smoking vents are transient. Ongoing downslope creep and active landslides continually reshape the sea cliffs. Based on mineral samples (Adams and Lynch 2024, this volume), temperatures have reached as high as 1100–1650°C (~2000–3000°F).

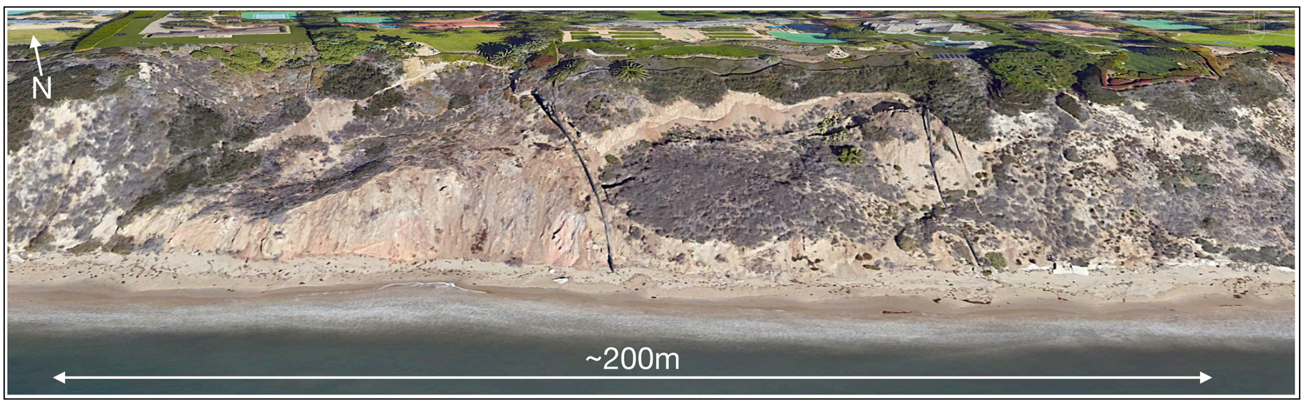

Figure 1. Oblique, annotated Google Earth image. Sea cliffs are about 40m high. Note the characteristic reddish color. The Monterey shale on either side is white or light tan, which is more representative of the formation's typical color. The medium gray areas on the cliff are plants. Other small nearby areas along the beach show clinkers and paralavas.

Introduction

- The site is in the coastal Transverse Ranges. Its physiography is dominated by active faulting with predominantly east–west striking, south dipping reverse faults and anticlines/synclines within the Santa Barbara fold belt.
- Most of the area's rocks are Miocene siliceous and carbonaceous shales. These include the Juncal, Sisquoc, and Monterey Formations.
- The Monterey Formation is a well-stratified bio-siliceous, organic-rich deposit and is the source rock for most of California's natural gas and oil.
- Burning bituminous shale creates high temperatures and occasionally sets fire to brush. Its surface colors and textures are chaotic. The ignition source is unknown.
- There are several similar locations in southern California Miocene shales, e.g., Mariner et al. (2008).

Methods

- Field studies were carried out eight times between May 2023 and Jan 2024, usually during spring tide lows to facilitate beach access. Visits usually started before sunrise to minimize solar heating of the surface which interferes with the interpretation of thermal imagery.
- Tools included iPhone 12 camera, a FLIR ONE 8μ-14μ camera for iPhone, ThermoPro digital non-contact thermometer, and an Elitech WT-1 contact thermometer probe. Each thermometer was calibrated using ice water and boiling water and were found to agree within ± 2°C. In our work, accuracy of a few degrees is acceptable because we were not interested in small temperature differences but rather overall temperature ranges and spatial distribution. A DJI Mavik Pro unmanned aerial vehicle (UAV, or "drone") also obtained photos and videos.

The images that follow (Figures 2–9) illustrate the striking properties of this site.

Results

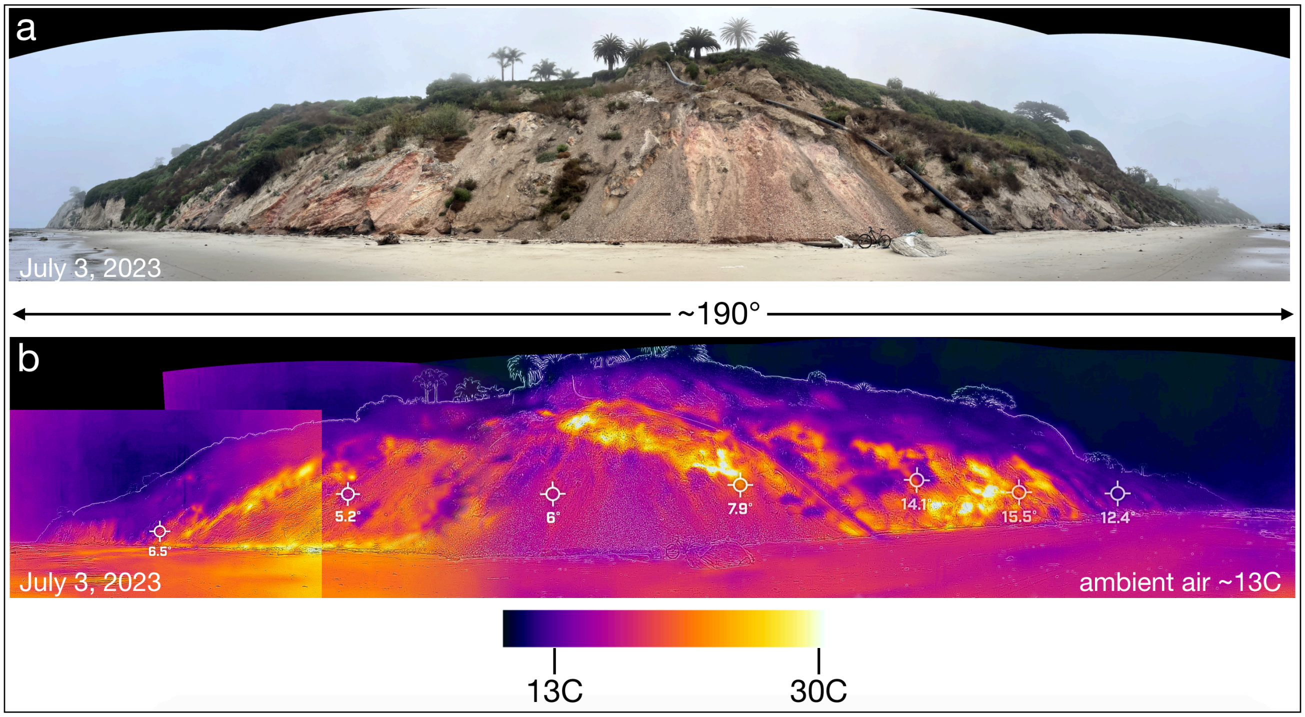

Figure 2. Panoramic composite images of the site taken on 3 July 2023. (a) Upper, visible; (b) lower, thermal infrared. Pictures were taken from slightly different viewing locations. The black diagonal drainage pipe evident in Figure 1 can be identified in both panoramas. Note reddish shale, complex landslides, and nearly absent plants. Many hot spots are small (<1 m) and are not resolved by the low spatial resolution of the camera. Some of the warm areas are at the base of the cliffs at the spring tide high water mark, left side. The abundant vegetation and corresponding absence of hot areas on either side are evident.

Figure 3. Red (hematite) stained shale with moderately dipping stratification and black carbonaceous (charred?) material exposed at the high water line. Note the absence of vegetation due to the unit's constant shedding of surface material by downslope creep.

Figure 4. Smoke from a small vent with surrounding brown areas, possibly deposits from smoke or moist soil from the vents. 3 July 2023

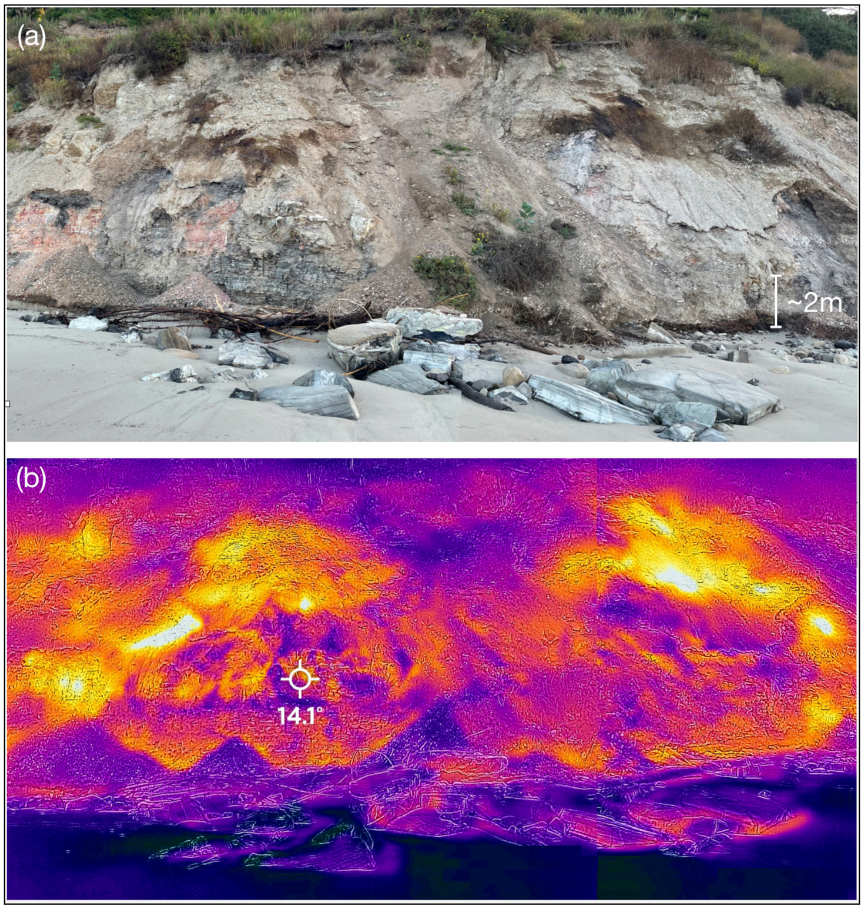

Figure 5. A hot, active area of the pyrolith informally called the "Whale's Tail" because of the black T-shaped feature's resemblance to a whale fluke (far left). (a) visible image and (b) thermal infrared image. The visible colors and structures do not correlate well with infrared temperature distribution. Two red well-stratified areas on the left are actively crumbling as shown by the small triangular colluvial fans below them. The fans are quickly washed away by high tides and currents. Vegetation is rare on the warm regions. Brown areas at the upper right are recent deposits from smoke.

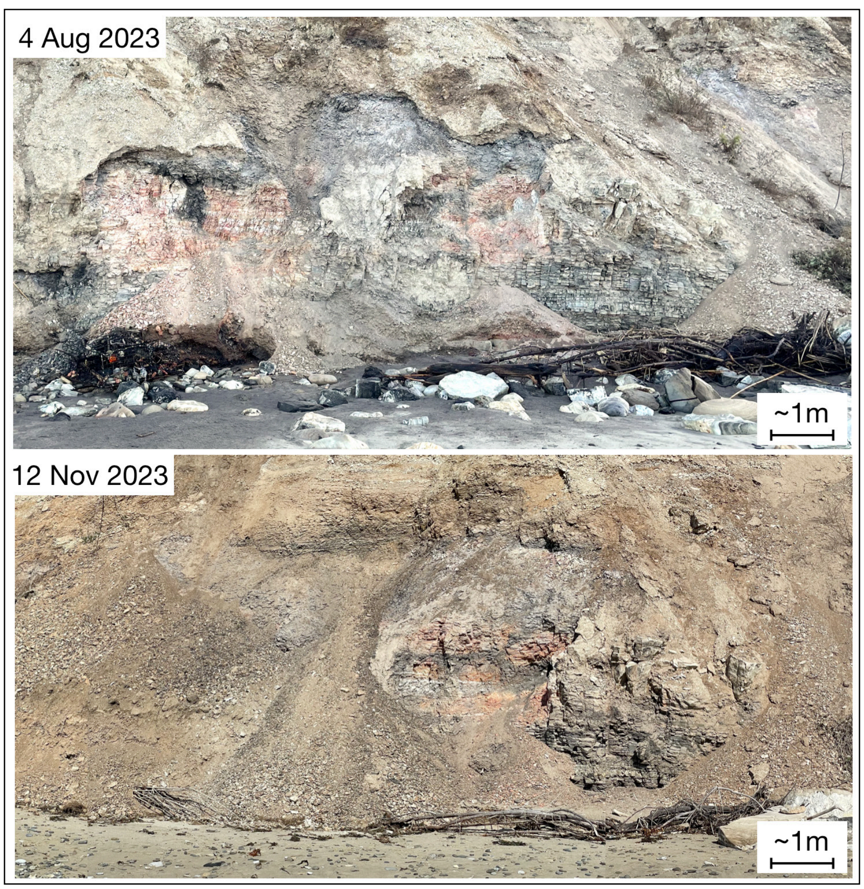

Figure 6. Whale's Tail area showing rapid changes. In less than a hundred days, erosion, landslides, and crumbling have drastically altered the cliff face. Much of it has become unrecognizable except for the dark stratified rocks at the lower right.

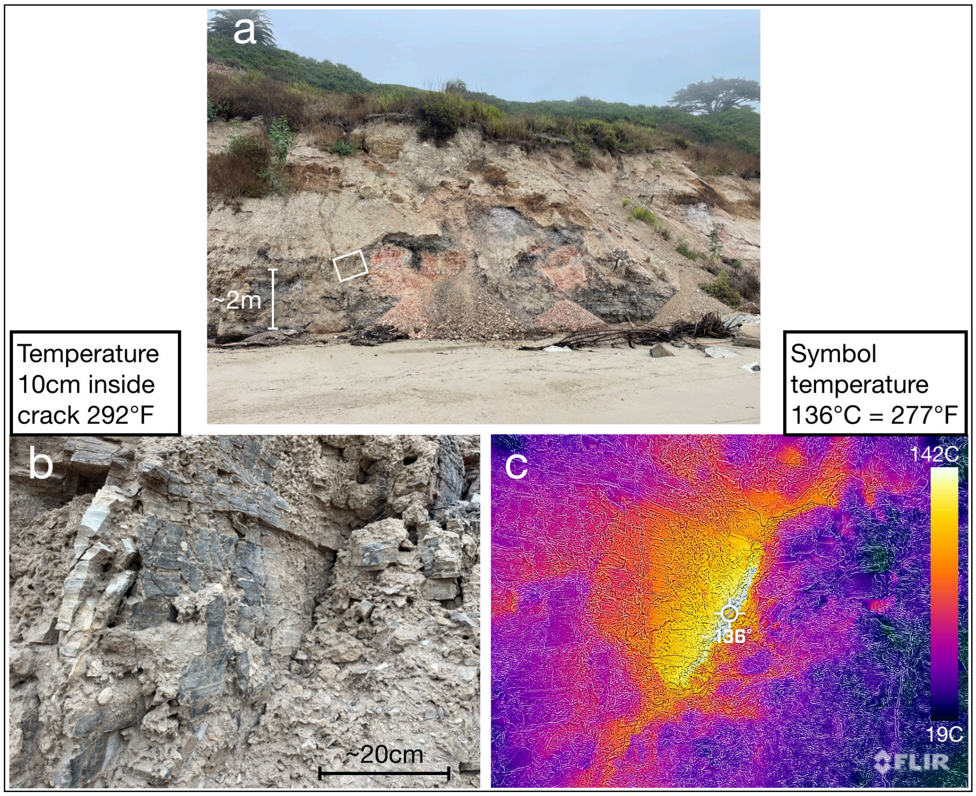

Figure 7. Some surface rocks that are too hot to touch. (a) Whale's Tail area with inset white box of interest. (b) Closeup visible image. (c) Closeup thermal infrared image.

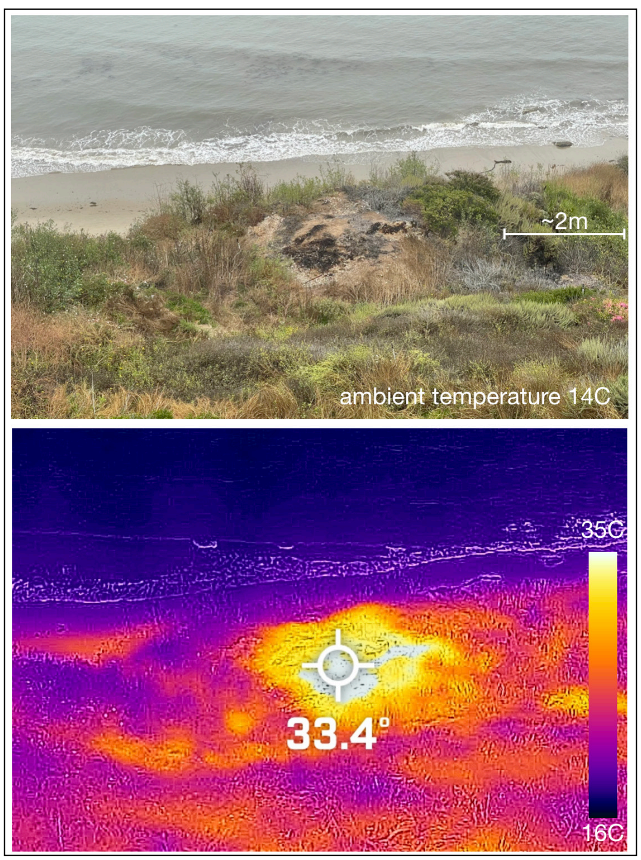

Figure 8. Visible (upper) and infrared (lower) images of an intermittently smoking hot spot (33.4°C = 92°F) taken from the marine terrace ~40m above the beach. The hot spot shows brown deposits and an absence of vegetation. Photo was taken 3 July 2023 on an overcast morning with ambient temperature 14°C (57°F).

Figure 9. Vent showing yellow acicular sulfur crystals. Temperature 10 cm below surface was 440°C (824°F).

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Sulfide Queen gold mineralization at Mountain Pass, California

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ABSTRACT—The Sulfide Queen gold mineralization at Mountain Pass, California is located at the current site of the MP Materials Mountain Pass mine that is producing a suite of rare earth elements. The gold mineralization was originally prospected for lead because of quartz veins in the area that contained visible galena. Gold was discovered during a reexamination of the quartz veins shortly after the price of gold rose to $35 per ounce in the 1930s. Gold mining at the Sulfide Queen ended in 1941 when the U.S. stopped all non-essential gold production prior to the U.S. entering WWII. No work had been done on the gold mineralization at the Sulfide Queen until Molycorp initiated a gold exploration program in the Mountain Pass area in the mid 1980s. Six samples of quartz veins with either visible sulfides or iron oxides from the old underground workings were used to investigate the gold mineralization at the Sulfide Queen. A detailed petrographic and microprobe study in the late 1980s documented that the gold occurs as free gold in quartz veins with accessory pyrite, barite, and galena. The gold mineralization is spatially associated with the carbonatite and the associated minerals in the gold-bearing quartz veins are consistent with the timing of the gold mineralization similar to the emplacement of the Precambrian carbonatite ore body.

Historical review of Sulfide Queen and mining at Mountain Pass

The history of prospecting and mining at Mountain Pass (MP) is best summarized in the introductory section of the first scientific investigation of the MP rare-earth deposits (Olson, 1954). Hewett (1954) described the prospecting for copper, zinc, and lead as starting with the construction of a rail line in 1905 and further stimulated by the rise in prices for commodities needed for WWI including lead, which was the focus of prospecting in the Mountain Pass area where galena was found in veins at "Sulfide Hill". By the early 1930s gold prices had risen to stimulate another phase of exploration. The workings at "Sulfide Hill" were resampled for gold and returned good enough assays that development of a shaft to a depth of 365 feet and numerous levels was used to access the gold-bearing quartz veins in the interval 1939–1941 with approximately $12,000 dollars of gold produced (Hewett, 1954). At the $35/oz price at that time the equivalent amount would be approximately 12,000 ounces. At today's price of about $1850/oz that amount of gold would be worth about $22 million dollars.

The MP deposit was discovered in 1949 by uranium prospectors who noticed anomalously high radioactivity when using their Geiger counter on some gold and lead ore samples from the Sulfide Queen gold mine. Additional work showed that the radioactivity was caused by minor amounts of thorium (not uranium) in the rock. After visiting the Sulfide Queen hill and finding it radioactive along a vein, they located a few claims which they called the Birthday claims. Review of the samples by the U.S. Bureau of Mines identified the mineral as bastnaesite (REE-CO_3-OH/F where REE=rare earth elements). The chairman of Molybdenum Corporation of America (MCA), Marx Hirsch was interested in rare earths as his brother completed his Ph. D thesis on the production of rare earth metals. He was also a director of Ronson, a lighter flint company. Lighter flints, a mixture of REE and iron oxides, were the only use for rare earths at the time. He purchased the claims in the Mountain Pass area in 1951, and MCA signed a contract with the General Services Administration to produce REE concentrates for the government stockpile. Production started in 1952 using the old gold plant to process ore with over 15 % REE.

Introduction

There had been virtually no additional work done on the Sulfide Queen gold mineralization until Molycorp (mining company owned by Unocal) initiated a Mt Pass regional gold exploration program in late 1980s. Although there were several other gold prospects and mines near MP it was unknown whether the gold mineralization at the Sulfide Queen was similar in age or origin to any of these other mineralized areas. As part of this regional gold exploration project, a total of six Sulfide Queen samples were collected from the main vein system on the number 1 and 2 levels of the old underground workings for precious metals analysis using a contracted laboratory that Molycorp used for all their U.S. based gold exploration analysis at that time. Gold grades in these samples ranged up to 0.9 ounces per ton and contained uniformly high amounts of silver, tellurium and lead (Table 1). These

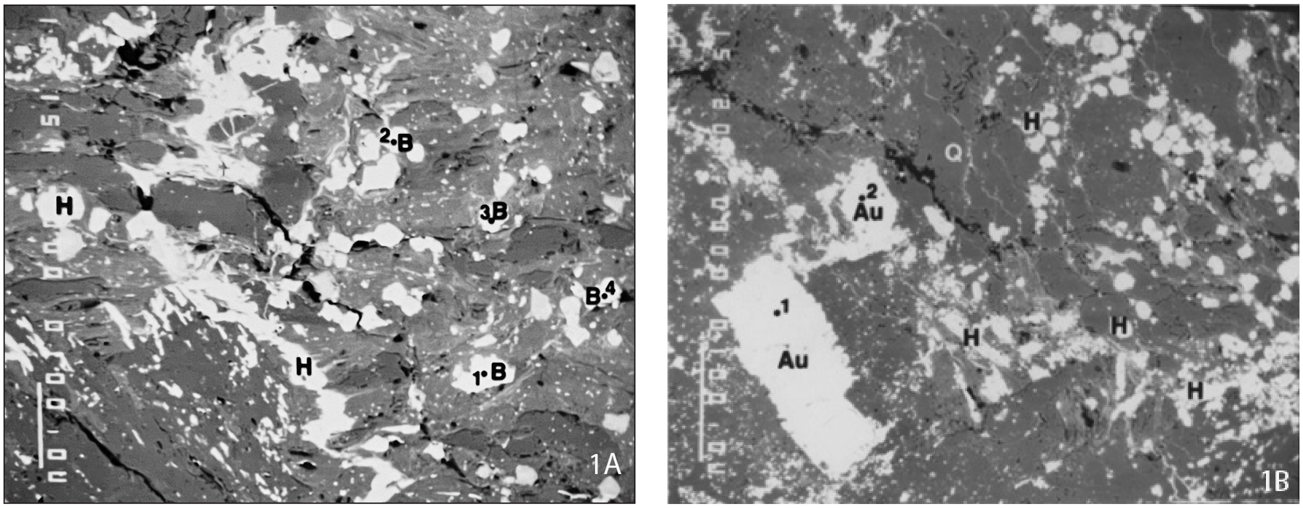


Figure 1. SEM images of Sample SQ3 87-1. 1A: Abundant disseminated barite (B) and hematite or other iron oxides (H). Numbers refer to points of microprobe analysis. 1B: Large native gold grain (~150 microns) in matrix of quartz (Q) and hematite or other iron oxides (H). Note lack of zoning or sulfides in gold grains.

data along with other trace element geochemistry of the samples suggested a possible presence of gold tellurides as well as sulfides or sulfosalts. As a result, a detailed petrographic and geochemical investigation of the nature of the gold mineralization was initiated using SEM and electron microprobe tools. An additional goal was to help in the evaluation of the relationship of the gold mineralization to the emplacement of the Precambrian carbonatite ore body. At that time several other gold prospects and mines in the area were either producing or being explored that were clearly unrelated to the carbonatite spatially or temporally.

Table 1. Geochemical analysis of Sulfide Queen vein samples (ppm except Au oz/ton)

	SQ2 G3	SQ2 87-3	SQ2 87-2A	SQ2-2	SQ2 87-1
Au	0.15	0.36	0.375	0.925	0.665
Ag	15	1.6	1.7	1.6	2.4
Pb	26500	2100	240	1050	2000
Te	9	29	10	27	33

Table 2A. Barite microprobe chemical analysis from Mt Pass carbonatite

Wt%	SQ82-1A	SQ2-1B	SQ2-3A	SQ2-3B	SQ2-4A	SQ2-4B	**Aver (13)**
Ba	52.25	57.42	54.52	54.42	57.63	58.74	55.83
S	13.92	13.56	13.92	13.8	13.64	13.8	13.77
Sr	4.87	0.6	3.7	3.94	1.19	0.67	2.50
Au	NA	NA	NA	NA	NA	NA	
Ag	NA	NA	NA	NA	NA	NA	
Te	NA	NA	NA	NA	NA	NA	
Th	0	0	0	0	0	0	
O	28.91	28.31	27.45	27.79	27.54	26.69	27.78

Table 2A con't. Barite microprobe chemical analysis from Sulfide Queen gold mine

Wt%	87-1A	97-1B	87-1C	87-1D	87-2A1	87-2A2	87-2A3
Ba	57.16	56.23	58.62	58.85	57.87	57.3	53.14
S	13.28	13.38	13.64	12.78	12.98	13.03	13.19
Sr	2.03	1.81	0.57	0.31	0.51	1.02	2.79
Au	0	0.04	0.32	0	0	0.14	0
Ag	0	0.03	0.03	0	0.03	0.03	0.05
Te	0	0.03	0	0	0	0	0
Th	NA	NA	0	0.02	NA	NA	NA
O	27.53	28.41	26.83	28.06	28.61	28.48	30.83

Sulfide Queen sample descriptions

The following is a list of the hand sample descriptions for each of the six samples used in this study. These samples were collected by an exploration geologist in the old underground workings of the Sulfide Queen mine. He collected each sample based on his years of experience in evaluating gold prospects, which is why each sample contained either visible sulfides or iron oxide staining (oxidized sulfides).

1. SQ2 87-2 is a quartz vein with a minor amount of disseminated

Table 2.B. Barite microprobe chemical analysis from Sulfide Queen gold mine

	87-2A4	87-2A5	87-2A6	87-2A	87-2B	87-2C	87-2D	**Aver (14)**
Ba	57.7	59.2	58.43	56.63	58.98	54.38	52.54	56.93
S	12.67	12.93	12.81	13.11	12.7	13.16	13.68	13.10
Sr	1.1	1.01	0.01	0.69	1.1	2.3	3.03	1.31
Au	0	0	0.11	0	0	0	0	0.04
Ag	0	0	0.03	0	0.01	0.01	0	0.02
Te	0	0.03	0	0	0	0.04	0	0.01
Th	NA	0.05	0.14	0	0	0	0.02	0.02
O	28.54	26.78	28.39	29.58	27.2	30.12	30.74	28.58

iron oxide (2-3%). The sample consists predominantly of breccia fragments that contain abundant barite, pyrite, and galena.

2. SQ2 87-2A has no iron oxide present in the sample, which consists of breccia fragments in a quartz matrix. Abundant finely disseminated pyrite appears to post-date brecciation. Moderate amounts of barite and REO-bearing phosphate (monazite?) occur.

3. SQ2 87-1 has abundant disseminated iron oxide and barite present, and the sample appears to be an intensely altered breccia.

4. SQ2 87-3 has a moderate amount of disseminated iron oxide (5-10%) in a quartz vein with several small breccia fragments. Abundant barite and moderate amount of galena and rutile are present.

5. SQ2 87-5 contains a minor amount of iron oxide (1–3%) in a silicified wall rock that contains abundant disseminated pyrite. This sample was not geochemically analyzed.

6. SQ2G 87-3 contains minor iron oxide (1–3%) in altered wall rock with abundant barite and moderate amounts of disseminated pyrite and rutile.

Mineral analysis

Petrographic analysis of the six samples resulted in the identification of abundant pyrite and galena in several of the samples, but no gold was observed. This is attributed to the nearly pervasive coating of iron oxide on most of the samples. At this time, it was also assumed that the gold occurred as a telluride and thus was not as readily identifiable as free gold. SEM and electron microprobe studies were then undertaken to identify the gold-bearing mineral phase or phases.

After considerable scanning using the SEM capabilities of the electron microprobe, several gold grains were found in sample SQ 87 2-1 (Figure 1). Abundant disseminated barite and hematite or other iron oxides are also present in this sample that contains very large (150 micron) gold grains. Several barite grains from this sample, as well as barite grains from several of the other Sulfide Queen mine samples, were analyzed to determine their chemical similarity to barites previously analyzed (in 1982) from the carbonatite at MP (Tables 2A and 2B). The results of this analysis documented the variable nature of barite chemistry in the Sulfide Queen samples. Strontium values of barite grains from both locations tend to range from 1 to 2% in the core and up to 3–4% in the rim. None of the barites analyzed from the Sulfide Queen mine were found to contain anomalous amounts of gold, tellurium, or silver and are chemically like those present in the carbonatite.

Gold grains were found to occur in several different settings in the Sulfide Queen samples. Gold within a matrix of quartz such as in Figure 2A is the most common, and the association of gold and pyrite was

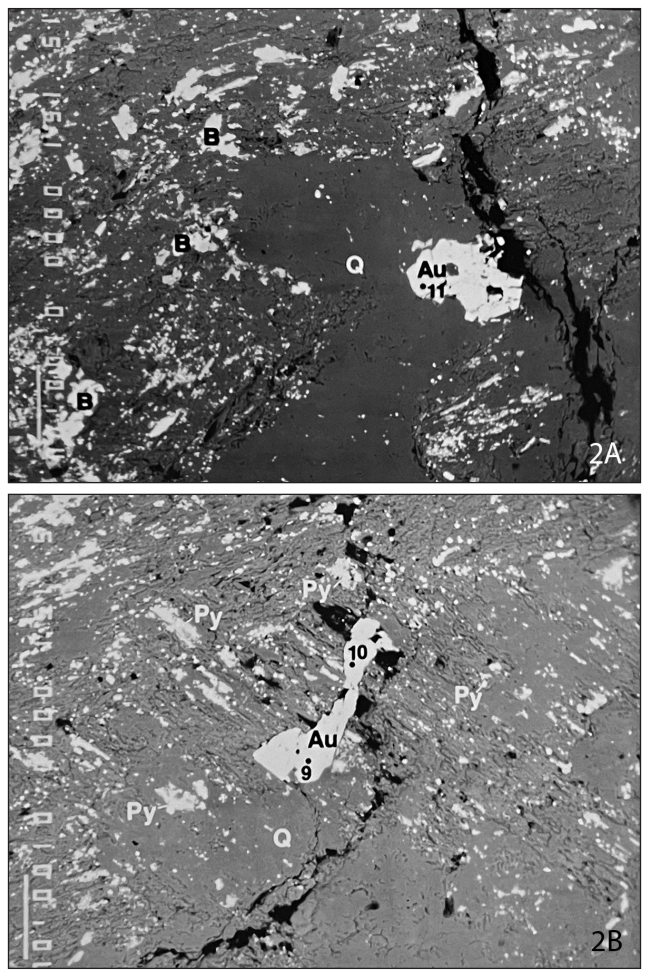


Figure 2. SEM images of Sample SQ2-87-2.
2A: Gold grain in matrix of quartz (Q) in vein that contains abundant barite (B). 2B: Note late cross-cutting nature of gold grain with respect to pyrite (Py).

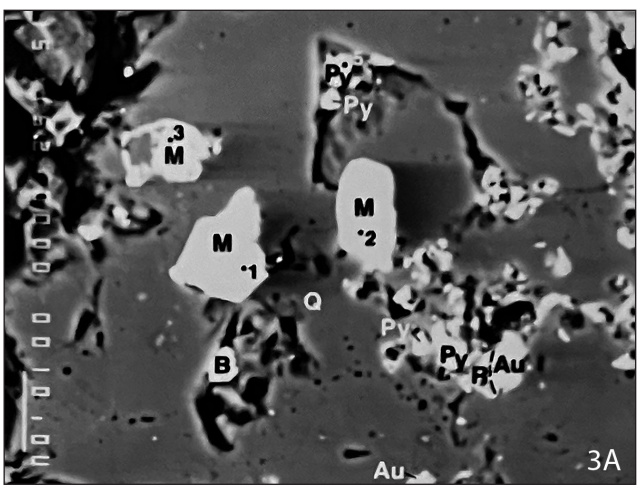
Table 3. Native gold microprobe chemical analysis from Sulfide Queen Mine gold mine

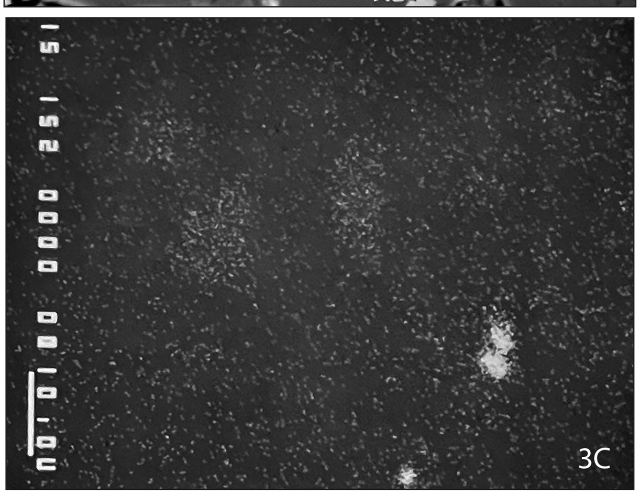
Wt%	87-1A	87-1B	87-2A1	87-2A2	87-2A	87-2B	87-2C	87-3A	97-3B	87-3C	87-3D	Aver
Au	43.65	43.94	31.87	20.46	37.5	43.84	42.39	44.09	41.69	43.16	45.23	39.80
Ag	0	0.08	0.02	0.03	0.03	0	0.01	0.03	0.03	0.03	0	0.02
Te	0.03	0.01	0	0	0.05	0.04	0	0.01	0	0.02	0	0.01
S	0.01	0	0.05	0.23	0	0	0.04	0.06	0.01	0.01	0	0.04
Hg	0.8	0.51	0.51	0.49	0.8	0.48	0.98	0.6	0.93	0.55	0.7	0.67
Si	17.66	17.53	17.26	27.01	20.41	19.56	18.28	17.4	16.77	16.66	16.86	18.67
O	37.72	37.91	50.4	51.79	41.21	36.02	38.31	37.77	40.59	39.55	37.17	40.77

also present in most of the other samples. At least some of the gold appears to be later than pyrite, as shown by the cross-cutting texture of the gold grains where pyrite defines foliation (Figure 2B). Eleven microprobe analyses of gold grains from several of the samples confirmed the fact that the gold is low in silver and tellurium (Table 3). The gold from the Sulfide Queen samples can, therefore,

Table 4. REE-bearing phosphate microprobe chemical analysis from Sulfide Queen gold mine

Wt%	87-2A1	87-2A2	87-2A3	87-2A4	Aver
La	17.54	17.29	17.65	17.3	17.45
Ce	30.01	29.9	28.83	30.36	29.78
P	12.65	12.25	12.07	10.97	11.99
Au	0.36	0.38	0.77	0.38	0.47
Ag	0.08	0	0.01	0	0.02
Te	0	0	0	0	0.00
O	39.42	40.25	40.71	40.93	40.33





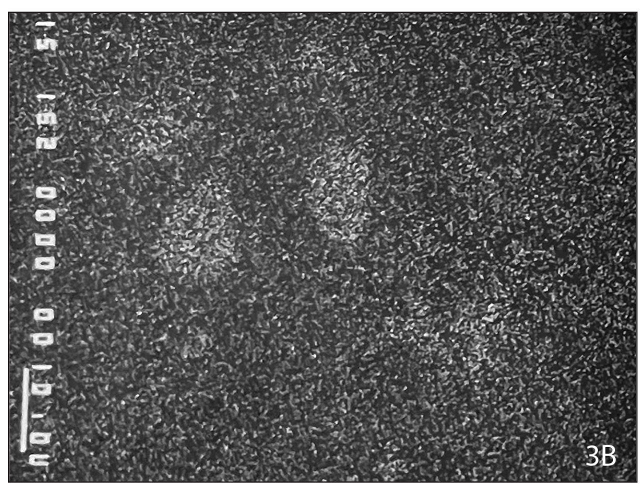


Figure 3. SEM images of Sample SQ2 87-2A.
3A: Abundant REO-bearing phosphates, probably monazite (M), barite (B), pyrite (Py) and rutile ® associated with gold in a matrix of quartz (Q). 3B: Tellurium “ma’” of area shown in (a) at the same scale. Note apparent correlation with REO-bearing phosphate grains. 3C: Gold “map” of area shown in (a) at the same scale. Note lack of correlation of gold and tellurium.

be characterized as very pure free gold. No gold tellurides were found in this investigation. The relatively high silica contents reported in the gold analysis (16–20%) can be explained because of the close spatial association of gold to quartz. Because the electron microprobe analyzes more than the surface of the samples shown on the SEM images, it is very possible that some quartz is encountered by the beam below the surface and thus is incorporated into the analysis. The gold is not encapsulated in silica as shown on any of the SEM images and does not occur within any sulfide. The grain size ranges from several microns up to several hundred microns and it is not uncommon to find numerous grains that are greater than 50 microns.

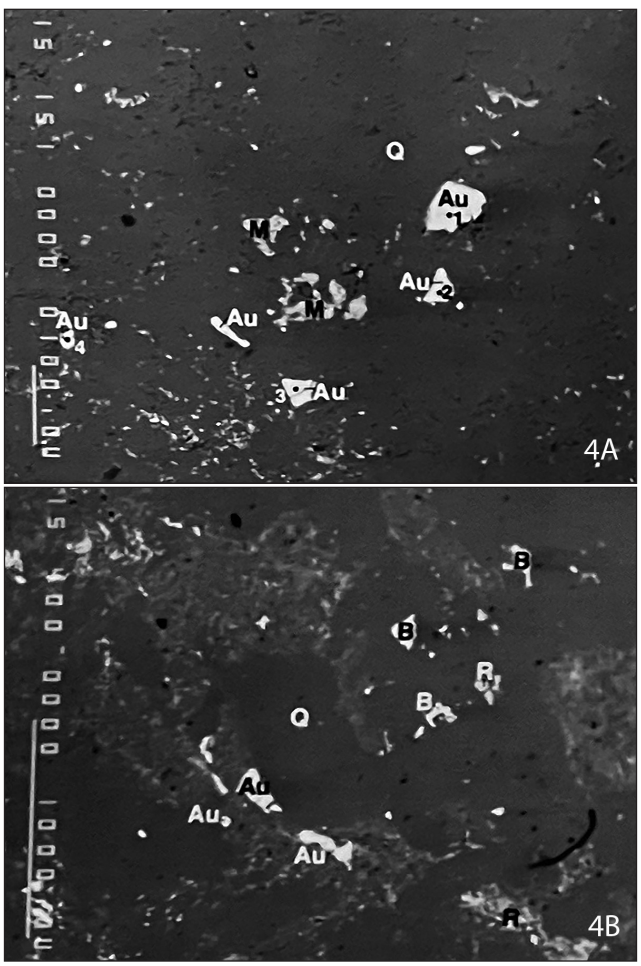
Several of the samples contain abundant disseminated REE-bearing phosphate minerals that are probably monazite. Also, it appears that the monazite in the quartz veins is the host to the anomalous tellurium found in the whole rock geochemical analysis (Figure 3). The most common REE-bearing phosphate found from

Table 5A. Pyrite microprobe chemical analysis from Sulfide Queen Mine gold mine

Wt%	87-2A1	87-2A2	87-2A3	87-2A4	87-2A	87-2B	87-2C	87-2D	87-3A
Fe	44.57	44.21	44.35	44.92	46.13	46.41	46.25	46.23	46.09
S	49.74	49.95	47.85	50.68	52.92	53.28	53.25	53.66	53.76
Pb	0.1	0	0	0	0.94	0.27	0.48	0.09	0.01
Au	0.07	0.19	0	0	0	0.03	0	0	0.09
Ag	0.07	0	0.05	0	0	0	0.02	0.02	0.05
Te	0	0.05	0	0.03	0	0	0	0.01	0
As	3.04	3.37	3.84	1.82	NA	NA	NA	NA	NA
Si	2.4	2.23	3.91	2.55	NA	NA	NA	NA	NA

Table 5A con't. Pyrite microprobe chemical analysis from Sulfide Queen Mine gold mine

	87-3B	87-5A	87-5B	87-5C	G3-A	G3-B	G3-C	G3-D	Aver(17)
Fe	46.21	46.58	46.73	47.37	46.67	46.36	46.77	47	46.05
S	53.68	53.4	53.22	52.53	53.25	53.61	53.2	52.98	52.40
Pb	0	0	0	0	0	0	0	0	0.11
Au	0.03	0.02	0	0.02	0.03	0	0	0	0.02
Ag	0.07	0	0.05	0.04	0.05	0	0.02	0.01	0.02
Te	0	0.01	0	0.04	0	0.03	0	0	0.01
As	NA	NA	NA	NA	NA	NA	NA	NA	
Si	NA	NA	NA	NA	NA	NA	NA	NA	



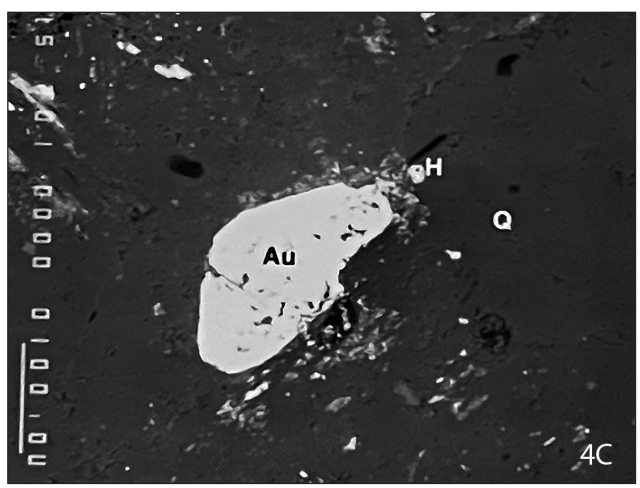


Figure 4. SEM images of Sample SQ2 87-3
4A: Abundant disseminated native gold grains with REO-bearing phosphate (M) in matrix of quartz (Q). 4B: Note lack of association of gold grains with either quartz (Q), barite (B), or rutile ®. No sulfides are present in this field of view. 4C: Large (~200 microns) gold grain in matrix of quartz (Q) with minor hematite or other iron oxides (H).

X-ray analysis of the Sulfide Queen samples is florencite (personal communication Steve Castor, mine geologist at Mountain Pass, Oct 1987). Comparison of the chemistry of the Sulfide Queen phosphates with monazites from the carbonatite, however, suggest they are similar in terms of lanthanum, cerium, and phosphate content (Table 4).

Because of the close spatial association of gold and pyrite in many of the samples (Figures 1, 2 and 3A) several pyrite grains were closely examined to determine the possible presence of gold inclusions. The results of this analysis (Table 5) document the general lack of gold in pyrite that was found to contain anomalous amounts of arsenic (2–4%). It appears there are several generations of pyrite but there does not appear to be any difference in their gold or arsenic contents.

Gold grains appear to be unaffected by any deformational event and generally assume a rather random orientation in most of the samples examined (Figure 4). Rutile, monazite, and barite are three common mineral associations with gold in sample SQ2 87-3 (Figure 4), but the temporal relations of these minerals with respect to gold can not be determined other than to suggest that the gold appears to be somewhat later. This observation is based upon the general cross-cutting relationship of gold to the predominant foliation in the samples (Figure 2B). Gold does appear to be intimately intergrown with quartz such as shown on Figure 4C, helping to explain the silica values reported in the gold analysis.

Discussion

Based upon this investigation, it appears that the Sulfide Queen gold mineralization is significantly different in terms of associated minerals (barite and monazite) and whole rock chemistry to known epithermal gold systems such as those present in the greater MP area such as the Morning Star Mine (Burton 1987), the Golden Quail deposit, Mineral Springs vein system, and the Colosseum mine (Western Mining History). Additionally, the coarse-grained nature of the native gold grains, gangue mineralogy, and spatial relationship to the Precambrian carbonatite distinguish this deposit from the epithermal gold deposits in the Mountain Pass area. These data suggest that the gold bearing quartz vein system at the Sulfide Queen represents a late stage of the carbonatite intrusive event. This interpretation is consistent with textural evidence that shows that the gold mineralization is associated with a suite of minerals not common in epithermal systems, but very similar to those present in the MP carbonatite. The trace element chemistry of the barites that are a major component of the carbonatite is like that present in the barite associated with the gold mineralization. Field relations support this interpretation in that the gold-bearing quartz vein system appears to occupy the same structural position as the carbonatite (personal communication, Dave Osborn, lead of the gold exploration project at MP, 1987).

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Abstracts from proceedings: the 2024 Desert Symposium

The legacy of the Calico Early Man Archaeological Project

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The Calico site, located 16 miles east of Barstow, is a three-component site. Stone tools and flakes of the Lake Manix Lithic Industry are found on the surfaces of a deeply dissected fanglomerate known as the Yermo formation. These artifacts are thought to date to at least 25 ka, given that they are found above the most recent shoreline of Pleistocene pluvial Lake Manix.

Younger tools and flakes of the Rock Wren Lithic Industry, found in a deeply eroded cut in the Yermo formation, have been dated to 14.4 ± 2.2 ka by sediment thermoluminescence. They are essentially Clovis in age.

Excavation of the alluvial fan has yielded a wide diversity of predominantly chert and chalcedony artifacts: scrapers, gravers, drills, reamers, denticulates, burins, choppers, chopping tools, large picks, hammer stones and portable anvils. These tools and flakes were fashioned by hard and soft hammer percussion. The deep excavations have also yielded red and yellow ocher and deliberately shaped limestone balls which have been hypothesized to be bola balls. No hominid fossils have been recovered.

The deep Calico Lithic Industry date is >200 ka by U-Th and Be-10 surface cosmogenic dating. This is the earliest evidence of hominin activity in the United States.

Hand-held GPS device accuracy and precision for detailed mapping and stratigraphy

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Hand-held GPS devices can be used for mapping detailed features and determining stratigraphic thickness of units to within the accuracy of measurements. A Garmin GPSMAP 76CSx has been used while mapping in areas with steep cliffs where traverses and sections can be measured on slopes, but the height of cliffs cannot be easily measured, and elevation differences are important. The Garmin manual states horizontal accuracy of 3–5 m and altimeter accuracy of ±3 m. Horizontal and vertical accuracy determined by GPS and barometric pressure are based on (1) geometry of ray paths of signals from satellites to the device, (2) atmospheric variations along signal paths (including atmospheric density, pressure, temperature, humidity, clouds, and wind), and (3) the accuracy and sensitivity of the device detector. During a workday, changes in geometry of satellites and in atmospheric conditions can influence accuracy. If details of these data are collected, they can be modeled to determine point specific accuracy. Even with no satellite or atmospheric data, field-based metrics can be used, and location-specific data can be calculated to determine the accuracy and precision of the measured data.

To test the resolution and repeatability of measurements with the Garmin device, (1) in the field, the displayed accuracy was recorded at each location and the displayed proximity of recorded locations was monitored, and (2) the accuracy and precision of measured locations were calculated. Accuracy is how close are the points to a known point (such as the center of a target). Precision is how closely or tightly the points cluster, and it has nothing to do with a known location. For field work spanning six years in the Marble Mountains, California, three methods were used to document the locations in the horizontal (Universal Transverse Mercator, east and north; UTMe, UTMn) and vertical (elevation). (1) Spot checks were done by hand-leveling a 1-5 m elevation change along a traverse, and GPS values differed from leveling by 0–2 m. (2) Locations of reference stones were measured at the beginning and end of a traverse (6 stones for 97 time-averaged measurements) for accuracy and precision. (3) Locations of the truck were measured at the beginning and ending of a traverse (46 day-pairs selected for this comparison) for precision. Stone measurements are on reference stones (the known point), so the multiple points represent the accuracy; however, stone measurements can be compared as day-pairs and are included in the Total-pair as precision (Table 1).

The largest ranges were in time-averaged stone data (one stone was measured 30 times over 3.5 years) that had greater differences in weather. For measurements during a day (or over a few days), if displayed horizontal accuracy was constant and points relocated, then measured values (and precision relative to each other) were accurate and consistent. These data confirm that horizontal

Table 1. Statistics for measurements on reference stones (accuracy), and day-pairs and total-pairs (precision). Measurements in meters. SD is standard deviation (s).

		UTMe			UTMn			Elevation		
Data type	#	Range	Mean	1-SD	Range	Mean	1-SD	Range	Mean	1-SD
Stone#	97	5.0	0.0	1.0	7.0	0.0	1.1	20.2	0.0	3.5
Day-pairs	46	6.4	0.3	1.1	5.0	0.2	1.0	12.0	0.5	2.6
Total-pairs	88	8.0	0.4	1.2	9.0	0.2	1.3	20.0	0.8	3.7

accuracy was better than stated by Garmin, and that day-pair vertical precision (as a proxy for accuracy and repeatability, even without calibration) was also typically better than the accuracy stated by Garmin. With care these data can be used for detailed analysis and mapping.

The eruptive and structural history of the Soledad Mountain volcanic complex, western Mojave Desert, California

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Soledad Mountain in the western Mojave Desert hosts the epithermal Au-Ag Golden Queen mine. The mine is situated in a complex of intensely altered rhyolite to dacite lava domes and associated volcaniclastic strata previously assigned to the Miocene Tropico Group (Dibblee, 1967). This study investigates the volcanic, structural, and hydrothermal evolution of the area through detailed geologic mapping within and around the perimeter of the mine complemented by extensive sampling of representative rock units for petrographic and U-Pb zircon geochronologic analysis. This contribution summarizes preliminary results from an ongoing study.

Field and petrographic observations of modal mineralogy, phenocryst abundances, and size distribution indicate that there are at least four textural and compositional varieties of silicic lava domes present at Soledad Mountain, ranging from nearly aphyric intensely flow-banded rhyolite to "crowded" phenocryst-rich porphyritic rhyolite and rhyodacite, as well as discontinuous intervals of volcaniclastic sediments. Alteration is ubiquitous, varying from intense argillic alteration, to quartz-sericite-pyrite alteration, to pervasive silicification. Despite the widespread alteration, the original shape and size distribution of phenocrysts in the rhyolites is generally well-preserved, though relative proportions of feldspars and mafic minerals are more difficult to assess. Rhyolite lava-dome units were differentiated based mainly on the overall abundance and size distribution of phenocrysts, and particularly the abundance of quartz phenocrysts. Future petrographic analysis and point counting will further refine the character and modal compositions of the different silicic units. Poor exposure of contacts between different textural varieties and the pervasive alteration overprint makes field determination of relative ages difficult to determine, especially as these rhyolites seemingly do not represent a simple stack of tabular lavas but rather highly irregular silicic lava domes with both intrusive and extrusive relationships, further complicated by later faulting. Despite these complexities, our preliminary field observations and new geochronological results suggest that the oldest silicic lavas at Soledad Mountain are nearly aphyric, flow-banded rhyolites (Tafr). This unit was evidently followed by one or more lava domes of phenocryst-poor rhyolite (Tppr) which contain <5% micro phenocrysts dominated by quartz and feldspar, with trace biotite > hornblende. The third dome is a distinctly more phenocryst-rich porphyritic rhyolite (Tpr) containing abundant (20–30%) phenocrysts of quartz, feldspar, and sparse hornblende > biotite. It in turn, was followed by an exceptionally quartz-rich rhyolite (Tqr) with conspicuous large (up to 1 cm) quartz eyes plus feldspar and biotite. The youngest unit appears to be a large rhyodacite dome (Tfrd) east of Soledad Mountain which contains 30–35% phenocrysts dominated by plagioclase, biotite > hornblende, and sparse, <5% quartz.

New U-Pb single-grain zircon ages (n = 50–100) from 4 separate rhyolite bodies and one tuffaceous sediment using the LA-ICPMS facility at UCSB yielded the following preliminary ages: 22.0 ± 0.2 Ma for tuffaceous sediments flanking Tafr, 22.0 ± 0.2 Ma for Tafr, 21.3 ± 0.2 Ma for a highly altered, undifferentiated, rhyolite within the mine, 21.0 ± 0.2 Ma for a Tpr rhyolite, and 20.9 ± 0.15 Ma for Tqr. Many of these ages are within analytical uncertainty of each other and suggest the entire Soledad Mountain rhyolitic eruptive center was active over a very brief period in the Early Miocene.

The overall structure of the Soledad Mountain area remains poorly constrained. Intercalated and flanking volcaniclastic (tuffaceous) sedimentary intervals within and adjacent to the mine area typically dip ~15–30° to the SSW, suggesting southward tilting associated with NNE–SSW extension and a general younging of units towards the SW. The seeming repetition of some units (e.g. Tafr, Tppr) and the typical NW strike and predominantly dip-slip slickenlines on mesoscopic normal faults supports this interpretation. Laminar flow foliations in the rhyolites show much more variation but also dip predominantly to the SSW, though typically much steeper (~50–80°) than in the sediments. The steep dips and highly variable orientations of the laminar flow fabrics are attributed to internal flow-folding and the fact that many of these bodies appear to be steep-sided shallow intrusions and domes, rather than tabular lava flows. A prominent NNE striking fault transects the eastern flank of Soledad Mountain, east of which is a large rhyodacite body (Tfrd, as yet undated) that appears to dome the flanking older units into variable dip directions. The highest-grade epithermal Au-Ag mineralization is closely associated with NW striking sheeted quartz vein systems and faults that transect different lithologic units.

The entire rhyolite lava dome complex in the vicinity of Soledad Mountain appears to have been emplaced from ~22 to 21 Ma. Hydrothermal alteration and epithermal Au-Ag mineralization is not well dated, as there are no clear cross-cutting relations with younger (post-mineralization) intrusions, but likely occurred during the waning stages of this rhyolitic volcanism. Subsequent or coeval NNE–SSW extension along N-dipping normal faults and right lateral shearing associated with the San Andreas fault system further disrupted the area.

Additional geologic mapping, petrographic studies, and ongoing geochronologic work will further clarify the area's volcanic, structural, and hydrothermal evolution.

Evaluation of the characteristics, discharge, and water quality of selected springs at Fort Irwin National Training Center, San Bernardino County, California

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Eight springs and seeps at Fort Irwin National Training Center were described and categorized by their general characteristics, discharge, geophysical properties, and water quality between 2015 and 2017. The data collected establish a modern (2017) baseline of hydrologic conditions at the springs. Two types of springs were identified: (1) precipitation-fed upland springs (Cave, Desert King, Devouge, No Name, and Panther Springs) and (2) groundwater discharge-fed basin springs (Garlic, Bitter, and Jack Springs). Comparison of electrical resistivity tomography data collected at groundwater basin springs from 2015 to 2017 indicated that spring discharge and connection to the underlying groundwater system is highly focused, although the springs themselves appear diffuse and are spread out over a large area.

Spring discharge was consistently less than reported by Thompson (1929, https://doi.org/10.3133/wsp578), except at Garlic Spring where discharges and vegetation have increased in recent years. Multiple discrete flume and seepage meter measurements taken between October 2015 and April 2016 indicated that discharge changed predictably on diurnal and seasonal timescales in response to evapotranspiration. These preliminary results and the lush vegetation noted at some of the springs, particularly at Bitter, Garlic, and Jack Springs, indicated plant evapotranspiration accounts for a substantial part of the discharge from these springs.

The quality of water ranges from fresh in precipitation-fed upland springs (Cave, Desert King, Devouge, and Panther Springs) to slightly saline (Garlic and Jack Springs) and moderately saline (Bitter Spring) in groundwater-fed discharge springs. Nitrate concentrations from water at most of the springs were less than 3 milligrams per liter, except for samples from Devouge and Desert King Springs and one sample from Jack Spring. An analysis of delta nitrogen-15 in nitrate and delta oxygen-18 in nitrate indicates high nitrate concentrations in excess of the U.S. Environmental Protection Agency maximum contaminant level at Jack Spring and Desert King Spring resulting from the dissolution of nitrate-bearing caliche deposits; nitrate concentrations at Devouge Spring are a result of algal growth within the spring, and the source of nitrate concentrations in Garlic Spring are consistent with a treated wastewater origin from Langford Valley-Irwin subbasin upgradient. The source of water in upland springs, indicated by values of delta oxygen-18 and delta deuterium are consistent with recharge from winter precipitation. In groundwater basin springs, values of delta oxygen-18 and delta deuterium are consistent with groundwater sampled from nearby wells. Summer monsoonal precipitation appears to contribute little water to spring flow. Most spring water contains low levels of tritium and appears to represent primarily older (pre-1950s) groundwater. Groundwater basin springs with detectable tritium may result from occasional streamflow in nearby washes. These springs could be susceptible to decreases in flow during extended dry periods when the localized recharge may be reduced due to the loss of focused recharge through nearby washes.

Groundwater samples from Garlic and Bitter Springs contained arsenic concentrations above the U.S. Environmental Protection Agency maximum contaminant level. Groundwater samples from all springs, except Cave, Desert King, and Devouge Springs, exceeded the State of California maximum contaminant level for fluoride. Garlic Spring was the only sampled spring that contained vanadium concentrations that exceeded the State of California notification level. Only a single water sample from Jack Spring contained uranium at a concentration that exceeded the U.S. Environmental Protection Agency maximum contaminant level.

Many other constituents of concern were analyzed, including those from anthropogenic sources that may be a result of military activities. Most of these constituents were not detected above their respective reporting levels in spring water; only 15 were detected in spring waters. Diesel and gasoline degradants, many of which also occur naturally, were the most commonly detected compounds. Several other organic compounds, primarily solvents or their degradants, were detected in groundwater basin springs. Except for Garlic Spring, which is affected by discharges of treated wastewater, the quality of water from most springs appears to be relatively unaffected by activities at the Fort Irwin National Training Center.

Tephrachronology continued: updates on the chronostratigraphic architecture of the Miocene Barstow Fm, central Mojave Desert, CA

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The middle Miocene Barstow Formation of the central Mojave Desert preserves a detailed sedimentary, paleoclimatic, and paleontological record. Exposures of this unit on the south flank of the Mud Hills north of Barstow, CA are especially celebrated since they preserve fossils that record an important stage of mammalian evolution in North America (the "Barstovian" Fauna) which has been calibrated by Ar-Ar, K-Ar and U-(Th-)Pb geochronology of many interbedded tephras (MacFadden et al., 1990; Woodburne et al., 1990; Miller et al., 2022). Like similar continental extensional basin sequences, the Barstow Fm displays complicated stratigraphic relationships; different facies routinely interfinger and pinch out over only 100s of meters along strike. Furthermore, dextral shearing along strike-slip faults of the eastern California shear zone has segmented and, in some cases, intensely folded the Barstow Fm making comprehension of the original basin architecture challenging. We present updated zircon U-(Th-)Pb dates for 19 tephra layers from three conformable sections of Barstow Fm in the Mud Hills and accessory satellite samples to reconstruct a 3D history of the Barstow Basin. These ages are integrated into a Markov-Chain Monte Carlo stratigraphic model (Keller, 2018) and indicate that most of the Barstow Fm in the Mud Hills accumulated between 16.4 and 13.08 Ma. Accumulation rates vary along strike and through time but are generally <0.1 to 0.3 mm/yr, which is relatively slow compared to other Miocene continental basins in the North American Cordillera that developed synchronously with extension (e.g., Horsecamp Basin, Nevada at >1 mm/yr, Gans, pers. comm.; Panther Creek Basin, Idaho at ~3mm/yr, Janecke et al., 1997). In general, accumulation rates track energetic variability in sedimentary facies well. Uncertainty associated with the basin accumulation rates we present here is marked; we do not decompact or backstrip the stratigraphy in our calculations and sections of the Barstow Basin which accumulated rapidly tend to not preserve tephras due to energetic deposition. Therefore, these rates should only be used to interpret qualitative differences in basin sedimentation between different sections of the Barstow Fm. Our tephra ages are in broad agreement with published geochronology from the Barstow Fm but are more precise, much less vulnerable to contamination or alteration, and are better contextualized within the local stratigraphy. These results underscore the utility of a combined chronostratigraphic and lithostratigraphic approach to reconstructing the geologic history and architecture of sedimentary basins.

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The Old Spanish Trail in Nevada: managing a legacy transportation resource

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From ca 1829 to ca 1850 a series of transportation networks were used to move livestock and various trade goods through the desert southwest between Santa Fe, New Mexico and Los Angeles, California. These networks, never a formalized trail, became known as The Old Spanish Trail. The network followed existing Native American trail networks and those of early European explorers which now form the basis of many modern highway networks. In 2002 Congress designated The Old Spanish Trail as a National Historic Trail with the National Park Service and the Bureau of Land Management as co-administrators of this extensive trail network. Archival research and field surveys conducted to support the development of the Comprehensive Administrative Strategy identified segments of the trail that were eligible for the National Register of Historic Places, segments that could be used for public interpretation, and segments that exist outside of the Congressionally Designated Corridor that present different management challenges. Here we discuss ongoing research and new archaeological evidence of trail segments and local interactions in southern Nevada. We also highlight the recent rise in proposed developments in proximity to the Old Spanish Trail that present challenges to the ongoing management of this nationally significant resource in southern Nevada.

Factors controlling the growth of agricultural shoreline wetlands at the Salton Sea, California

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New agricultural runoff wetlands growing on the shoreline of the Salton Sea are ideal habitats for migratory birds and endangered species. Concern over potential selenium bioaccumulation risks within these new wetlands has prompted studies into selenium uptake within wetland food webs. There is poor understanding of the structure of these wetlands and how that structure

may impact wetland hydrology and habitat distribution within the wetlands. Additionally, the rapid growth rates of these wetlands have not been readily documented in the literature. We present an assessment of wetland topography and controls on plant growth rates, determined through a combination of remote sensing data and field visits.

The stability of water levels in the Salton Sea directly controls the contrasts between depressional lagoons and coarse barnacle beaches on the exposed playa. These structures result in a "shore-parallel" filling of the wetlands once drain water reaches the playa, instead of filling radially outward from the discharge point. The lagoons become deeper water habitat filled with tall (9–13 ft) cattails and dense prey species, while beach lines generally have pickleweed or tamarisk ridges mixed with short (less than 6 feet) cattails. Some depressional lagoons within the shoreline wetlands have water with atypical salinity and dissolved oxygen values; we show through the use of field parameters and stable isotope values that there likely is older Salton Sea water – formerly stored in the higher elevation sediments surrounding the Salton Sea – that is now discharging into these atypical wetlands and exposed beaches as the Salton Sea shrinks. Much of the exposed beaches shows some evidence of groundwater discharge deposits, with the thicker deposits corresponding to the most stable beach ridges on the shoreline. Younger beach ridges that are less well developed have small to insignificant groundwater discharge deposits. We hypothesize that this groundwater discharge interface will lag behind the active shoreline of the Salton Sea as it declines in elevation.

The implications of the declining Salton Sea elevation are twofold: 1) the loss of high salinity soil water currently underlying and discharging into the wetlands may result in enhanced infiltration of irrigation water, which will cause the wetlands to shrink and potentially convert to tamarisk; and 2) some studies suggest high salinity water can interfere with typical selenium uptake rates, therefore as the irrigation water infiltrates and replaces the high salinity soil water, the shoreline wetlands may potentially have higher selenium uptake rates in the future. As water allocations from the Colorado River come under greater scrutiny in southern California, habitat managers may need to consider alternative water sources to sustain wetland wildlife. Consideration of the wetland hydrology and linkage to the Salton Sea will be crucial for the long-term sustainability and success of the wildlife refuges around the Salton Sea.

Microclimatic refugia of chaparral relicts in mountains of the Mojave Desert

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Introduction – Climate relicts within arid environments may persist at isolated Pleistocene refugia if suitable conditions exist in microsites that differ enough from the regional environment to provide relief from drought and temperature stress. Disjunct populations of plant taxa associated with coastal and interior chaparral have persisted in just a few mountain ranges within the Mojave Desert. These mountain biotic communities are ecological confluences where plant species characteristic of distant floristic regions co-occur. Some of these species are widespread in chaparral of the species-rich California Floristic Province and in the warmer Madrean Floristic Province of Arizona. While the Mojave Desert does not fall within the California or Madrean Floristic Provinces, the occurrence of coastal and interior chaparral species within this region is an interesting exception.

Methods – The plant community composition of sites where several of these relict species occur were surveyed in 6 mountain ranges across the Mojave Desert landscape using 50 x 1 meter belt transects (41 total). GIS methods were used to extract relevant environmental variables for each site and implemented in Canonical Correspondence Analysis to explore localized ecological influence on the distribution of 8 focal taxa. Additional modeling using k-means clusters and non-metric multidimensional scaling (nMDS) was used to analyze these occurrences at the community and landscape scale. Global Biodiversity Information Facility records for each focal taxon were used to perform species distribution models in Maxent that projected the effects of future climate change by 2070 on the range of their suitable habitat.

Results – The distributions of 8 focal chaparral species were found to be influenced by topographic variables including slope position, aspect, and terrain wetness, in addition to climatic variables such as summer monsoon precipitation and temperature. A k-means clustering analysis pointed toward community assemblages characterized by species associated with each other along a transitional gradient from xeric shrublands to relatively mesic woodlands where chaparral occurs in the desert. The ordination plot produced using nMDS indicated that differences in the species composition among these mountain ranges was explained by regional floristic variation, and a few species that were frequently associated with more mesic woodland assemblages. Species distribution models predicted that, over the next 50 years, the availability of suitable habitat for most of these focal species is likely to contract within the Mojave Desert under the projected Representative Concentration Pathway 4.5 climate change scenario. These results demonstrate how the distribution of relict plant populations can be influenced in an arid environment and illustrate challenges that chaparral taxa face with prolonged environmental stress.

Bonanza Spring groundwater catchment, stratigraphy, structure and discontinuity with Fenner Valley Aquifer, western Clipper Mountains, Mojave Desert, California

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Bonanza Spring in the southwestern Clipper Mountains occurs at the geomorphic boundary of the mountains to the north and a gently sloping erosional pediment surface to the south. The pediment surface extends from Bonanza Spring for ~2.5 miles where it is overlain by thin Holocene active and Pleistocene alluvial deposits. These alluvial deposits extend beyond the pediment ~2 miles to a termination along the southwest-flowing Fenner Wash. A hydrologic infiltration catchment area upgradient and within the western Clipper Mountains is proposed for Bonanza Spring based on topography, fault and joint structure, and stratigraphy. The southeast-flowing groundwater from the Bonanza Spring catchment feeds into the Fenner Valley aquifer system near the termination of the pediment erosion surface (Kenney and Foreman, 2018).

The proposed catchment area is rectangular in shape and extends 3.5 to 4.5 miles northwest of Bonanza Spring and is 1.0 to 1.5 miles wide in a northeast–southwest direction. The total aerial extent of the catchment region is estimated to be between 2,350 to 2,620 acres, which is ~4 square miles. Topographically, the rocky hills in the catchment area exhibit a central northwest trending series of high peaks that trend parallel to the northwest trending mapped catchment region. Elevations within the catchment area exhibit a total relief of 1,290 feet as measured from the highest peak (3,810-ft) to Bonanza Spring (2,100-ft). The highest peak is located approximately 3.2 miles northwest of Bonanza Spring in the upper reaches of the watershed catchment.

An early Miocene dominantly hypabyssal igneous suite is exposed at the surface within the western Clipper Mountains including the entire catchment area (Bedford et. al., USGS, 2010). These rocks are referred to as the Western Clipper Mountains Igneous Intrusive Suite (WCMIS, Kenney and Foreman, 2018 and Kenney, 2023). Most units were intruded vertically as northwest trending, tabular bodies possibly during early stages of basin and range extension. Rock compositions are intermediate to mafic with some mafic members possibly occurring as extrusives. These rocks are exposed at the surface and under thin soils, colluvium, and alluvial fan deposits throughout the catchment area. The rocks of the WCMIS exhibit a high density of steeply dipping conjugate fractures and faults that allow for efficient bedrock water infiltration. Thus, precipitation in the catchment area primarily lands on exposed fractured and faulted bedrock or thin cover that transmits water to rock efficiently.

The WCMIS likely experienced counter-clockwise tectonic block rotation during later stages of basin and range extension as demonstrated by a high density (10s to 100s foot scale spacing) conjugate northwest and southwest striking fault and joint/fracture system. None of these faults offset local Quaternary or older alluvial deposits. Most faults are nearly vertical and exhibit less than 10 feet of apparent lateral or dip-slip separation, however some exhibit up to hundreds of feet of slip. Northeast-striking faults often exhibit apparent left-lateral separation. Evaluating whether or not the northwest striking fault zones are right-lateral is problematical as the intrusive members of the WCMIS strike parallel to these faults. Many drainages in the catchment area are fault controlled, and thus in many areas, swales and drainages probably have water flow along fault zones, which turns nearly 90 degrees at intersecting conjugate faults. Flowing surface water along the faults and fractures provides conduits for the infiltration of groundwater although the fault zones at depth impede and govern the direction of groundwater flow due to fault gouge semi-impermeability.

Two fault zones occur in the western Clipper Mountains exhibit larger apparent offset (i.e., 100-ft or more) than other identified faults and both appear to extend a minimum of 4 miles laterally. These two fault zones are generally over 40 to 100 feet wide, exhibit numerous smaller scale en echelon faults, and fault gouge of crushed rock and secondary clays. They are referred to as the Bonanza Spring catchment boundary faults as the northwest-striking fault occurs along southwestern boundary of the catchment, and the northeast-striking fault along the southeastern boundary of the catchment. These two larger fault zones, in addition to the pervasive small-scale faults and fractures in the catchment area, drive groundwater progressively "downgradient" toward Bonanza Spring. This groundwater model is consistent with Bonanza Spring occurring at the intersection of the two fault zones and at the lowest elevation of the catchment area.

Contrails over the Mojave

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Contrails (CONdensation TRAILS) are man-made clouds composed of water drops and ice crystals. They form when high altitude airplanes—usually jets—fly through cold, relatively moist portions of the troposphere. When hot water vapor from engine exhaust meets the cold upper atmosphere, it cools rapidly and condenses. Water drops form first and these quickly freeze into ice crystals. Soot from the engine also accumulates water by nucleating water vapor to condense into droplets. If the upper troposphere is dry, contrails do not form.

Most contrails over the Mojave are from planes going to or from Los Angeles area airports, but they form only when the planes are at cruising altitudes high enough to produce them. At lower altitudes near the airport, the planes don't produce contrails because the air is warmer.

Contrails influence climate, at least in the shorter term (decades to centuries). They tend to warm the planet by the greenhouse effect. Contrails are more common in the northern hemisphere than in the southern hemisphere because there is more land, higher population, more industrialization, and jets are more abundant in the north. Air travel is expected to grow by about 4.3% each year and so too should the frequency of contrails.

A potpourri of trails, ancient to modern, in the Mojave Desert

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Trails and tracks in the desert, along with the locations those trails lead to, have long fascinated desert wanderers. Over 44 years of desert travel, much of it on foot in remote locations, I've been fortunate to find and puzzle over many tracks made by humans, wildlife, and even processes such as bouncing boulders and blowing wind. This pictorial presentation will feature tracks of human origin, starting with the oldest.

Paths made by Native Americans have received study but remain underappreciated. I stumbled across one such path along the north shore of East Cronese (dry) Lake, apparently used at times when the Mojave River was flowing nearly continuously and maintaining a lake. This forced travel away from Afton Canyon and around the playa we see today. Similarly, paths near Travertine Point in the Salton Trough apparently were used at times that Lake Cahuilla was full. The paths are perched on steep slopes above the cliffs formed by the lake's waves. I walked very wide paths and saw nearby 'sleeping circles' in the Santa Rosa Mountains, grateful for easy walking after an arduous day of scrambling on steep slopes. How long do our footpaths last after abandonment? Why were the paths so well used?

Early historic trails were established across the Mojave Desert by Spanish colonial groups during the 1820s, primarily for trade purposes. These trails, including the Old Spanish Trail and its several alternate routes, have been written about and are well explored. Spanish Canyon in Alvord Mountain is named for this trail, which traverses the seemingly odd route of cresting the mountain and proceeding steeply south down this canyon, bound for the distant Mojave River. If one climbs to that crest, the origin of the route is clear. The north side of the mountain is a gentle gradient down into a broad valley containing Bitter Spring. The approach from the north was logical.

Later (1840–1870) trails were created by early American explorers and settlers, and further developed by the military, miners, and trading companies. These trails, as well as the Spanish trails, mostly linked water sources (such as Soda Springs, at Zzyzx), where food for beasts of burden could also be found. Exceptions were spurs from the trails to mines. During this time, abodes and work buildings, forts, and developed springs started to influence travel. Maps of routes may have become available. A famous trail is the twenty mule team route from Death Valley mines to the processing center near Boron.

Railroads were the transportation method of choice for a short time (1870s–1910s), soon to be overtaken by the automobile for much of the travel. In contrast with earlier trails and roads, railroad construction involved modifying the landscape considerably: grading a berm across ridges and swales, constructing water crossings that diverted most streams, and constructing bridges. The resulting engineered railbed obstructed animal crossings and bladed wide clear areas, as well as markedly changing stream hydrology and its influence on plants and animals. Roads followed this altered landscape, free of the numerous stream crossings. Route 66 is a famous example of such a road. Towns and watering facilities were needed at regular spacing to keep the locomotives running. Each location was served by water lines run from distant springs, changing water distribution in the desert drastically.

Agriculture came to the desert, much of the development being during a climatically favorable period in the 1910s to 1930s. This led to dispersed dwellings in the western desert, as well as in higher eastern desert places such as Lanfair Valley, which still have many foundations that were built during this boom. Some of the dispersed dwellings in the desert were very well built with local rock and are largely intact. Government policies encouraged settling on 5 acre parcels via the Small Tract Act of 1938, and road grids spaced at one-quarter mile blanket much of the west desert, decorated by remnants of building pads that in many cases mark faded dreams. Overuse of groundwater led to their demise in some areas.

Many of the towns along early roads have decayed into near invisibility with the development of freeways in the 1950s. Some major routes were completely abandoned, such as Route 66 through Amboy, where I-40 diverged to a high crossing of the Bristol Mountains. In fact, this route was proposed to be excavated by Project Carryall, detonating 23 nuclear bombs during the days when nuclear was going to make life wonderful for all. Relic buildings, many of which are the canvas for modern spray paint artists, can be found in numerous former towns along freeways. A few hardy souls persist in some towns.

An instructive example is Ludlow, a current exit on I-40 and home to little more than gas stations, fast food restaurants, a motel and a café. Alongside the freeway is old Route 66, but interestingly its name is not Main Street. Main Street borders the railroad, and is probably the original highway through Ludlow. Ruins of concrete buildings can be found along Main Street. Evidently, the railroad was the first route across an inhospitable wide valley. The railroad was followed by an adjacent road. Ludlow grew to a small town with the addition of two spur line railroads, and later Route 66 was developed along the north margin of the town. Gas stations, a motel, and a café as well as dwellings lined the highway. The development of the freeway led to fewer people needing to stop in town, and, coupled with decreases in numbers of railroad workers living there, led to rapid decay of the town.

Mojave Trails National Monument is the latest effort to preserve and inform the public about the wide variety of trails in the desert and their importance. It encompasses much of Route 66 and the Santa Fe Railroad line and swaths of adjacent lands. We now live in a desert crossed by numerous trails of various ages and modes of transportation. Truly wild areas are hard to find. If you drive really bad roads for half a day, then hike away from the roads for a full day, you may find wilderness.

Chasing the high shorelines: Preliminary results for a much larger late Pleistocene precursor to Lake Cahuilla in the Salton Trough

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The Salton Trough currently contains a sizeable water body at ~ -70 masl, the Salton Sea, which is small in comparison to Lake Cahuilla that episodically filled the basin to ~13 masl. Lake Cahuilla formed prominent shorelines in many places around the trough, and its history over the last ~2 ka is well established; its earlier history is not clear. The 13 masl shoreline is nearly coincident with the elevation of a threshold near Cerro Prieto, Baja California, Mexico. The lake has been primarily fed by the Colorado River, which built a broad distributary fan across which the river coursed to both the Gulf of California and the Salton Trough. That fan also formed the threshold that controlled highstand lake level. *During Lake Cahuilla time overflow drained southward across the threshold to the Gulf of California.*

Reports by Thomas and Stanley published in the 1960s described fragmentary shoreline deposits that locally bear fresh water gastropods and pelecypods but are located at a much higher level than Lake Cahuilla, near 48–50 masl. These reports attributed the deeper lake to an ancient threshold that has since been warped downward tectonically. Our studies of the deposits of this older lake identified several new exposures and indicate that shoreline deposits can be followed discontinuously for >100 km along both sides of the Salton Trough at ~48-50 masl. The deposits represent beaches formed by wave action near and at the highstand lake shoreline and, less commonly, nearshore deposits of sand, silt, and carbonate rock. We also found a few preserved lagoonal deposits that formed behind barrier beaches. The lake deposits are less than 8 m thick and lie on various substrates: old alluvial fan deposits, deformed Pleistocene to Pliocene mudstone, and granite.

Previous studies employed radiocarbon dating for the high shoreline deposits, but inconsistent results for 3 shells and 15 tufa samples, which ranged from 26 cal ka BP to >50 cal ka BP, led to much uncertainty. We are using several geochronological methods to try to improve this uncertainty. At this time we offer the following: The consistent elevation of beach deposits at ~48-50 masl indicates no measurable deformation along the margins of the Salton Trough since the lake existed. This lack of evidence for tectonic warping requires that a barrier in Mexico, higher than the present Colorado River fan, once existed. The simplest explanation is that the fan aggraded to a level ~35 m above the modern fan, impounding a lake much larger than Lake Cahuilla. If so, remnant higher Colorado River fan deposits must exist and they are indeed present along the eastern margin of Sierra El Mayor, southeastern Sierra Cucapah, and around the flanks of the Cerro Prieto volcano in Mexico. In the Sierra Cucapah, a study of alluvial terrace evolution by Armstrong and others dated underlying Colorado River fan deposits by luminescence methods at 30-40 ka. Presently, this age range is a reasonable solution for the observed erosion of landforms, soils in overlying alluvial fan deposits, and the assortment of radiocarbon dates. We conclude that, despite the presence of major plate-boundary faults such as the southern San Andreas, Imperial, and Cerro Prieto faults, as well as volcanically active spreading centers along the axis of the Salton Trough, its margins in the United States have been relatively stable for >30 ka. The modern basin shape is a reasonable analog for late Pleistocene physiography except in the Colorado River fan area, where the fan has been dynamically aggrading and degrading relatively quickly, perhaps on a time scale of a few thousand years.

Validating *Dipodomys* (kangaroo rat) data from premolar measurements

Tabbatha Ostlie

Anza-Borrego Desert State Park® Paleontology Society, 2024

Anza-Borrego Desert State Park® (ABDSP) is rich with a variety of fossil specimens, including multiple species of kangaroo rats (*Dipodomys* spp.). However, the high diversity of genera and species within the ABDSP collection can lead to errors in interpretation if inaccurate taxonomic information was entered into the database. Some of the types of errors affecting the database include mislabeled or misidentified specimens and data programming errors. Because of this, several *Dipodomys* specimens were labeled as *Sylvilagus* (rabbit) or *Geomys* (pocket gopher) or *Anzanycteris* (a bat). Such errors may affect statistical analyses due to incorrect sample sizes. The purpose of this project is to validate previous taxonomic identifications and to accurately enter new specimens into the database.

A detailed study by Gregory Cunningham (Idaho State University MS thesis, 1984) recorded upper and lower premolar measurements (in mm) of fossil ABDSP *Dipodomys*. Upper and lower premolars are the most diagnostic teeth. Based on Cunningham's measurements, five species were recognized: *D. compactus*, *D. hibbardi*, a tentative ID of *Dipodomys* sp., cf. *D. minor*, *Dipodomys* n. sp. A, and *Dipodomys* n. sp. B. The specimens studied were not entered into the database until now. The ongoing database improvement project added over 100 ABDSP specimens. To validate the original *Dipodomys* species assignments in this project we used state-of-the-art methods to evaluate the results of measuring both the Cunningham specimens and the more recently added premolar teeth measurement data. *Dipodomys* has proven to be an important taxon for validating the database because it is a manageable subset that will aid the project further.

Over 150 specimens were checked against standardized taxonomic names to make sure the information matches both collection notes and individual descriptions. Antero-posterior length, transverse width, and the greatest height of premolars were measured. The lower premolar antero-posterior length is the focus of this project. Each specimen was positioned at a specific, consistent angle and photographed using a digital microscope with its corresponding computer program. Automatic calibrations and measurements were done with the digital scale bar included with the program. In contrast, Cunningham (1984) manually calibrated hand-held calipers. Various scale bars were inserted among his figured drawings, which were used to verify the measurements in the associated tables. Because Cunningham used an observed range that did not specify specimen numbers, it became problematic to validate each measurement. This difference in technology and methodology can lead to noticeable variation in observed ranges due to accuracy errors, positioning of the specimen, and calibration irregularity. The range in this project was determined by listing the smallest and largest measurement values. These values were compared to those in Cunningham's thesis and are what determined the deviation between both studies. Smaller deviations would help validate Cunningham's taxonomic assignments to our database, while larger deviations would display possible misidentifications by Cunningham. We found that the recorded ranges showed small deviations from Cunningham's thesis.

Dipodomys n. sp. B displays the smallest deviation from Cunningham's values of premolar tooth thickness by 0.046 mm. *Dipodomys* n. sp. A displays the largest deviation from Cunningham's values by 0.310 mm due to database inaccuracy and newly added specimens. *D. hibbardi* and *D. compactus* showed similar amounts of deviation by 0.227 mm. By validating and correcting this information, we have found that the size variation of premolars for *Dipodomys* n. sp. A is larger than what Cunningham recorded. The project shows a range in width of 0.711 mm, compared to a smaller range of 0.470 mm recorded by Cunningham. This is important because the size variance of *Dipodomys* n. sp. A has now expanded due to the corrected database. Because of this expanded size range, we see that smaller size variation within the other *Dipodomys* species might be due to the studied sample size. The database errors affected the average of ranges due to additional specimens of *Dipodomys* n. sp. A, and corrected taxon names of *D. hibbardi* and *D. compactus*. The corrected taxon names caused some specimens to be removed from or added to this study. By validating and gathering information, we can build a distinctive resource for the scientific community. Researchers can access these updated and corrected data for future taxonomic, ecological, climate, population, and biogeographic studies.

Mountain Pass, California area: impacts of exploration booms for base metals, gold, uranium, and rare earth metals

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Gold and base metal prospectors after the Civil War followed trails and pathways to explore outcrops considered favorable which usually meant quartz veins or silicified country rock on ridges or hills. In the Mountain Pass area, mines and prospects from this era included the Copper World mine, the Mohawk mine, and prospects on Mineral Hill, all within several miles of Mountain Pass. Railroads played a role in the early prospecting with the arrival of the Santa Fe line about twenty miles SE of Mountain Pass in 1892. An increase in the price of gold to $35 stimulated additional prospecting in the Mountain Pass area, resulting in the rediscovery of lead prospects at Mountain Pass within quartz veins that contained gold, leading to the establishment of the Sulfide Queen gold mine. In 1942 the War Production Board halted all non-essential gold mining in the U.S. which included the Sulfide Queen gold operation.

After WWII, the U.S. Atomic Energy Commission guaranteed the price of uranium ore in the U.S. which stimulated exploration for uranium throughout the U.S. Prospectors explored some of the same areas as the early prospectors, this time using Geiger counters. The Mountain Pass (MP) rare earth element deposit was discovered in 1949 by uranium prospectors who noticed anomalously high radioactivity using their Geiger counter on some gold and lead ore samples from the Sulfide Queen gold mine. After visiting the Sulfide Queen Hill and finding it radioactive along a vein, they located a few claims which they called the Birthday claims. Review of the samples by the U.S. Bureau of Mines identified the radioactive mineral as bastnaesite (REE-CO3-OH/F where REE=rare earth elements). Additional work showed that the radioactivity was caused by minor amounts of thorium (not uranium) in the rock.

Molycorp acquired the claims in 1950. The property was scheduled to be the world's leading lighter flint mine! Lighter flints are mischmetal, a pyrophoric mixture of rare earth metals. But the real money maker was the use of europium as an activator in an yttrium-based compound for the red phosphors in color TVs.

The Mountain Pass mine in California is one of the only locations extracting rare earth elements in the U.S. and is now owned by MP Materials (NYSE:MP). Bastnaesite concentrate was and continues to be shipped in one ton bulk bags to a Chinese company (Shenghe). Production of separated rare earths at Mountain Pass is now beginning. A facility to convert neodymium/praseodymium oxides to metal and then to alloy and magnets is being constructed in Fort Worth, Texas.

Fossil trackways of desert-sand-dune-dwelling amphibians and reptiles at a newly discovered tracksite in the Lower Permian Coconino Sandstone of Grand Canyon

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I report here a previously unstudied tracksite within the Lower Permian Coconino Sandstone, in the North Fork of Soap Creek Canyon, a seldom visited, difficult-to-access tributary of the Colorado River in northern Arizona. Ichnotaxonomy of the vertebrate ichnofauna of the Coconino Sandstone has recently undergone a comprehensive revision. Based on the revised taxonomic nomenclature, I identify two ichnospecies that are exposed at this site: (1) *Varanopus curvidactylus* (the track of a captorhinid reptile), and (2) *Ichniotherium sphaerodactylum* (the track of a diadectid-reptiliomorph amphibian). Both types of trackways occur within a very thick set of crossbeds that dip 16° toward the west.

The *Ichniotherium sphaerodactylum* tracks at this site are especially significant. With a high degree of confidence, this ichnospecies has previously been interpreted to represent the tracks of the Lower Permian diadectid-reptiliomorph amphibian *Orobates pabsti*. Several other trackways of this ichnospecies have been reported within the Coconino Sandstone, however all of the previously reported occurrences are in fallen blocks of rock. The *I. sphaerodactylum* tracks reported here occur in a very conspicuous, well preserved, 4-meter-long, *in situ* trackway. This is the longest known trackway of this ichnospecies, and its *in situ* presence in the strata permits an analysis of the steepness of the slope the trackmaker was traversing; it was headed straight up the west-dipping slope.

In quadrupedal trackways, if all four feet were on the ground simultaneously, the gleno-acetabular distance (GAD)—the distance between the pelvic and pectoral girdles—can be estimated based on the length of the line segment that unites the midpoints of lines between two contralateral manus prints and two contralateral pes prints that belong to the same step cycle. Measurements of the *I. sphaerodactylum* trackway at this site reveal that the trackmaker's GAD was 28 cm. Reconstructed skeletons of *Orobates pabsti*, the putative trackmaker, show that the total body length is 3.6 times the GAD. Using this multiplier, the trackmaker that created the trackway exposed at this site had an estimated total body length of 1.01 m.

I'm happy to acknowledge assistance from hiker Richard Radomske, who alerted me about this tracksite and led me there, as well as from Wayne Ranney for discussions about stratigraphy, and from Lorenzo Marchetti for discussions about ichnotaxonomy.

Comparing the archaeology and environment of two deserts, the Mojave and the Gobi: View from Ikh Nartiin Chuluu Nature Reserve, Mongolia

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Having the opportunity to work for 12 years at the northern edge of the Gobi Desert in eastern Mongolia has provided me the opportunity to compare and contrast the environments, archaeology, geology, ethnography, and past and present means of "making a living" with that of the Mojave Desert -- two areas on opposite sides of the world. While aridity, fauna, and vegetation have commonalities, there are many differences including: the trajectory of stone tool-making, the availability and uses of water, traditions of pastoralism, and empire formation. Join me on a trip to eastern Mongolia's Desert-Steppe Interface.

First known fossils from the Cabazon Fanglomerate relict soil, Riverside County, CA

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The Cabazon Fanglomerate is a Pleistocene formation up to 400 m thick. It was named by Vaughan in 1922, and the type area is the foothills of Cabazon. The present note was occasioned by paleontological mitigation activities associated with the replacement of the 1987-1997 wind turbines of the Mesa Wind Repower Project with a few much larger wind turbines. These turbines are part of a windfarm easily recognized on the north side of the San Gorgonio Pass. These paleontological resource mitigation efforts took place in 2022 and 2023. The parts of the project that produced the fossils reported here lie in section 4, T3S, R3E on federal land overseen by the Bureau of Land Management.

The Cabazon Fanglomerate was laid down in tectonically active lands and the Mesa project is near the junction of the San Gorgonio - Garnet Hill and Banning fault strands and the San Bernardino strand of the San Andreas Fault, and has been studied in the context of Quaternary fault movements in that area. The mid-late Pleistocene alluvial fan of that area constitutes the Cabazon Fanglomerate which hosts a deeply weathered zone (soil) in the upper several meters of the formation. While traveling I-10, a casual glance at the cliffs to the west and to the east of Whitewater Canyon will reveal the red-brown relict soil on the Cabazon Fanglomerate. The last decade has seen several published studies dealing with vertebrate faunas in Late Pleistocene paleosols in the Mojave Desert. These studies were the impetus to search for vertebrate fossils in this much older relict soil. Paleosols and relict soils are formed during periods of stasis. Multiple lines of evidence indicate that the period of stasis during which this relict soil has formed dates back at least to the last interglacial period and possibly farther. The suggested age of this surface is 120–240 ka (marine isotope stage 7-8 or 6-5 transitions).

Some consider the surface of the fanglomerate to be the highest terrace of the Whitewater River. The fanglomerate clasts are igneous, metamorphic, volcanic, and rare sedimentary rocks. The matrix is sand to coarse pebbles. The relict soil at the top tends to show a brick red matrix due to intense weathering. Rhizoliths were preserved in several samples, but because they were silicified, it was not possible to radiocarbon date them.

No bones were visible in cuts or outcrops. Five-gallon sediment samples were taken from the upper 30 cm of cuts for roads, turbine pads, and the laydown yard. Cobbles and larger clasts were excluded from the samples. The samples were wet-screened through 20-mesh screens. The dried concentrates were sorted with the aid of a 10x dissecting scope. The most common potential fossil found in these samples were bits of amber. Some seemed pristine and some were oxidized to varying degrees from the cortex inward. It is possible that some of the amber was generated by *Juniperus californicus* (California juniper), whose lower limits are currently a bit higher than the elevation of these localities, but it is more likely that the majority of these amber bits belongs to *Encilia farinosa* (brittlebush). The plant is common at these sites and produces significant amounts of resin. No data exist on how long such amber bits can remain on and/or within the soil. The substance is appropriate for radiocarbon dating.

Of the permineralized fossils recovered were one cheektooth of *Thomomys* sp. (pocket gopher) and the distal half of a metatarsal of *Dipodomys* sp. (kangaroo rat). Some permineralized bone fragments were not identifiable. One partly permineralized vertebra belongs to some as-yet unidentified reptile.

Although the ground surface in many parts of the California deserts show occasional recent rabbit and rodent bone fragments, ground surfaces in the project area rarely held any bone fragments. In addition to the vertebrates, two snail taxa were recovered that are not thought to be ancient. They are nonetheless of significance to biologists as malacological collections have very few snail specimens from the mountains of this area.

It is the nature of the formation of soils of long duration to contain fossils of variable age, and that is the case in the findings of this study. Some bone fragments and teeth are dark, highly permineralized, and host abundant manganese oxide. Other bone fragments are lighter in color and less permineralized. Essentially all the vertebrate remains belong to species that burrow or live in burrows. Such organisms often die underground, thus improving the chances of fossilization.

Just as today's soils follow the contour of the land, so do ancient soils. Thus, some of the exposures producing fossils were cut into the relict soil on steep hillsides.

Paleontologists charged with mitigating effects to paleontological resources from projects impacting the Cabazon Fanglomerate should expect significant paleontological resources in its relict soil. The potential to produce paleontological resources in two older paleosols within the formation remains untested.

We thank the California Bureau of Land Management Palm Springs – South Coast Field Office and particularly Jeffrey Johnston for assistance in permitting the paleontological resource mitigation efforts that formed the basis of this report. The work was done under Paleontological Resource Use Permit CA-20-04P to Aspen Environmental Group.

The distribution of dermal ossification in giant ground sloths

Harrison Sturgeon
Anza-Borrego Desert State Park® Paleontology Society, 2024

Among extinct giant ground sloths a select few species exhibit integumentary armor. These sloths had small bones called dermal ossicles distributed within their skin, providing defense. The bones vary in shape, size, and distribution. Dermal ossicles are rarely found directly associated with other skeletal elements, making the study of their distribution relative to the body difficult. Many ossicles are found with fossil ground sloths, but they are often scattered and isolated due to early degradation of soft tissue. They are held in place by skin alone, which is generally lost before the process of fossilization.

Studies to date hypothesize that dermal ossicles demonstrate patterns such as rows around elongate skeletal elements like the ribs and spine, and mosaics (stars and rosettes) around rounded ones like the pelvis. Definitive evidence of this correlation requires a specimen with ossicles in their original orientation and a clear link to a portion of the ground sloth's skeleton. A fossil satisfying these conditions is currently housed in the collection at Anza-Borrego Desert State Park® (ABDSP).

In November of 1960 paleontologists from Los Angeles County Museum collected a fossil specimen of *Paramylodon harlani* from ABDSP. The fossil was stabilized and stored until 1997, after which it was returned to ABDSP. Consisting of a partial innominate resting on a mat of fossilized dermal ossicles, this find is noteworthy due to its preservation of the ossicles in their original orientation (without the skin) and the innominate in life position relative to them.

Utilizing 3D photogrammetry, the fossil was photographed and rotated incrementally to capture its shape from a variety of angles. The photos were uploaded into the 3D modeling software Agisoft Metashape, which uses overlapping images to create a realistic digital copy of the fossil. This copy was overlain onto a digital model of a complete Paramylodon skeleton using the innominate as a reference. Combining the two models places the ossicle mat approximately where it would have been on a living giant ground sloth. After examining the distribution of dermal ossicles relative to skeletal regions, patterned areas of the ossicle mat appear loosely correlated with structures such as the spinal column and pelvis.

The impact of the construction and operation of railroads in the Mojave Desert

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In 1853 Congress appropriated funds to survey potential routes for a transcontinental railroad. Four routes were chosen, and the Mojave Desert was in the path of one of them. The route was called the "35th Parallel" or Southern Route which was explored by Lieutenant A.W. Whipple in 1854. In 1862 Congress passed the Pacific Railroad bill which designated a Central Route along the 38th and 39th parallels which pushed west from Ogden Utah over Donner Pass to the San Francisco Bay. However, interest in building a railroad on the southern route continued and in the late 19th century two major railroad mainlines were constructed through the Mojave Desert: the Atlantic and Pacific Railroad and the San Pedro, Los Angeles and Salt Lake Railroad. The rail lines followed the routes set by the early explorers to Southern California and were engineered along the paths of least resistance simply to move freight and passenger traffic to the burgeoning metropolitan areas of Los Angeles and San Diego.

The two rail lines have long since been absorbed into the two major railroads that now serve California. The San Pedro, Los Angeles and Salt Lake Railroad is now part of the Union Pacific, while the Atlantic and Pacific Railroad, later the Santa Fe, was merged with Burlington Northern Railroad in 1996 to form the Burlington Northern Santa Fe Railway.

In addition to playing a critical part in crossing the arid expanse of the Mojave Desert, railroads provided new settlers to the region with the means to live in an extreme climate. As a result, most of the human activity in the late 19th and early 20th century in the Mojave Desert was intimately connected with the railroad. The railroads were instrumental in the growth of industries such as mining, agriculture, and tourism. On a more basic level, the railroads delivered one of the most basic human needs for survival in the desert – water, thereby enabling the creation of settlements and the development of agriculture in an otherwise unhospitable environment. Regarding social needs, the railroads created a source of local employment by working for the railroads themselves. Most of the existing communities in the eastern Mojave Desert began as railroad "jerk-water" towns. Goffs, Fenner, Essex, and Needles were all started by the Atlantic and Pacific RR while Nipton, Cima, and Kelso were started by the Union Pacific.

This presentation will provide a brief history of railroad activity in the Mojave Desert in three phases: from the early exploration for a suitable route, to the completion of the two major routes across the Mojave Desert, and finally to the current status of the two trans-Mojave railroad lines. The impact of the railroads on the mining companies in the Mojave Desert will receive a special focus.

Structure and stratigraphy of the Barstow Formation adjacent to the Waterloo silver deposit in the Calico Mountains, Mojave Desert, CA

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The epithermal Waterloo Ag-(Au) deposit is located along the southern flank of the Calico Mountains adjacent to the Calico ghost town and north of Barstow. Detailed mapping, stratigraphic and structural analysis, and U-Pb zircon geochronology were conducted on exposures of the Barstow Formation (BF) and upper Pickhandle Formation (PF) to the east and south of the deposit. The right-lateral E-W striking, steeply N-dipping Calico Fault transects the area, juxtaposing a generally N-dipping section of relatively unaltered lacustrine BF beds in the footwall against intensely altered and folded BF deposits to the north. North of the Calico Fault, another E-W striking but S-dipping fault separates altered and mineralized BF beds from highly altered and silicified PF volcaniclastic rocks north of the fault. Previous work in this area interpreted the entire BF section south of the Calico Fault as homoclinal (N-dipping) and overturned, and it was not clear how this section of Barstow Formation correlated with other sections.

The ~2.3 x 1.7 km study area was mapped at scales ranging from 1:2000 to 1:4000, taking care to subdivide the exposed section into as many different lithostratigraphic intervals as possible. Key lithofacies within the exposed BF south of the Calico Fault include: (a) bluish mudstone/shale with thinly interbedded fine-grained sandstone and micritic limestone; (b) coarse-grained thick- to medium-bedded sandstone and conglomerate with interbeds of laminated silty limestone; (c) fine- to medium-grained sandstone and siltstone with well developed cross beds; (d) white to cream-colored reworked tephra (ash fall) deposits up to 1 m thick that are best preserved within the shale intervals. A particularly distinctive horizon up to 1 m thick of tubular tufa/stromatolites occurs within the interval of coarse-grained sandstone. It quickly became apparent that this is not a homoclinal section ~ 600 m thick as previously interpreted, but rather a tightly folded and faulted section in which the same stratigraphic intervals reappear several times. This was evident from reversals in facing direction as indicated by cross beds in sandstone intervals and by symmetric mirroring of distinctive intervals. Many of the fold hinges expected at the sites of facing reversals are not exposed, likely due to later or synchronous faulting along the axial surfaces of these tight folds. Our revised structural interpretation is that the original stratigraphic section exposed in this area is only ~120 m thick, and has been repeated by nearly isoclinal folding and steeply north dipping thrust faults associated with north-south shortening along this restraining bend in the Calico Fault system (e.g., Singleton and Gans, 2008). Additional support for this interpretation is that a tephra horizon exposed at several elevations within the exposed structural section yielded identical (within analytical error) U-Pb ages from the youngest population of sparse zircons. Five ages obtained from distinct beds within the structural section yield a weighted mean age of 16.8 ± 0.2, suggesting it may correlate with or be slightly older than the Rak Tuff that has been dated elsewhere.

The sections of Barstow Formation south of the Calico Fault appear to have experienced significant shortening by folding and faulting, similar to what has been reported for sections immediately N of the fault along this restraining bend. The interval south of the Calico Fault and east of the Waterloo deposit appears to correlate in age with the older part of the BF exposed in Rainbow Basin but is slightly younger than the 19-17 Ma "Calico Member" of the Barstow Formation to the east (and north of the Calico Fault) (Singleton and Gans, 2008). The age of hydrothermal alteration and epithermal silver mineralization remain somewhat ambiguous, but given the relatively unaltered appearance of this section, compared to the intense alteration in the Barstow and Pickhandle rocks immediately to the north of Calico Fault, may indicate that it is older than 16.5 Ma. Future work will expand this mapping into the Pickhandle and Barstow formations north of the fault and to the west, to better understand the age and controls on mineralization.

Trail angels, geology, helicopters, plants, animals, and water? Hiking the Pacific Crest Trail through the Mojave

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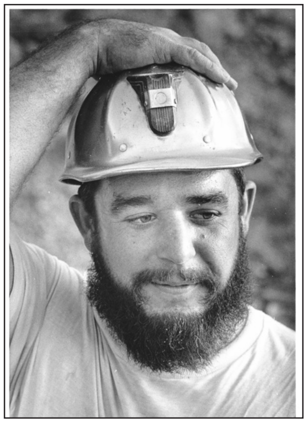
The Pacific Crest Trail (PCT) is 2,650 miles long, running from the Mexican border near Campo, California to Manning Park, British Columbia. Though it eventually reaches a height of 13,153 feet at Forrester Pass in the Sierra, one of the biggest challenges is the scarcity of water in southern California and particularly through the Mojave Desert. At about PCT Trail Mile 518, one reaches Hwy 138 and a bizarre compound known as Hikertown. This is the beginning of the trek across the Mojave Desert, notable for its Joshua trees. For many miles, one travels along the Los Angeles and California aqueducts, and then the trail heads north paralleling Hwy 14 to the east. Though the designated California Desert Conservation Area continues further north, it is considered that the PCT leaves the Mojave portion of the desert at Hwy 178 at a place called Walkers Pass. One can often leave the trail to get food and water, or trail angels will leave water caches along the way, but there are portions that either require at least 3 days of backpacking carrying up to 3 gallons of water (which means one is carrying 25 pounds without considering food, clothing, and other required items) or finding a trail angel who is willing to carry some of that weight. Trail angels are special people that are not necessarily hiking the trail but are willing to provide support which may include hiking portions of the trail with you and giving you a place to get cleaned up and get some sleep. Some will even do your laundry and cook meals for you. Though one worries about encountering a bear, rattlesnake, or mountain lion, it turns out that plants such as poodle-dog bush and poison oak are more problematic. Unexpected things can happen, and one might find themselves getting a ride out by helicopter or finding out that someone that you are hiking with is not a good match, which can lead to some unusual events. Even with the challenges, it is still an amazing adventure with magnificent scenery, fields of wildflowers, peaceful mornings, meeting people from around the world, and discovering places that one would not have ever visited if it weren't for the trail.

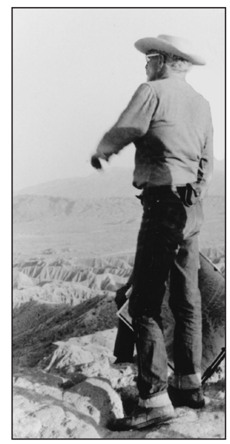
Notes

Student Awards

Robert E. Reynolds Desert Symposium Student Research Award



Bob Reynolds was the driving force behind the Desert Symposium for over 30 years. Beginning even before Bob Adams's 1989 gathering (see Jefferson and Budinger paper on our Publications page), Bob was organizing field trips, directing large fossil excavations, exploring for minerals, and mentoring anyone interested in the Mojave. He inspired students and PhDs to become desert rats, many of whom are still with the Desert Symposium today. In the early days, he singlehandedly solicited contributors, organized the meeting, and ran the field trip. Bob had a gift for finding interesting projects and motivating people to work on them. This award acknowledges, honors, and thank sBob for his decades of service.



Bob and Bobbe Adams Best Student Presentation Prize

Bob and Bobbe Adams helped found the Mojave Desert Quaternary Research Conference that has evolved into the Desert Symposium. Bob and Bobbe's influence continues through the scholarship they established for the best student paper presented at each year's symposium.

Friends of Desert Symposium

Ronald Blom	Bruce Bridenbecker	David Buesch
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Jeff Hull	Dave Lynch	Anthony "Shay" McGhee
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Friends of Desert Symposium was initiated in 2023 to support development of the General Fund for DSI. As with the Founders Circle, donations support operational needs and enable continued meetings and field trips.

Visit http://desertsymposium.org for information on joining Friends of Desert Symposium; to learn how to apply for and support these student awards; and for information about past award recipients and donors. Desert Symposium Inc. is a non-profit 501(c)3 organization. Contributions are tax-deductible as allowed by law.

The Woods Mountains viewed from Wild Horse Mesa, 1973. R. E. Reynolds photo.

Picnicing in the Mojave with what is probably a Santa Fe train running between Cajon Pass and Victorville, circa 1910.
Scanned from a W.A. Vale glass plate negative, San Bernardino County Museum collections.