

# NEVADA BUREAU OF MINES AND GEOLOGY

## REPORT 26

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### GUIDEBOOK: LAS VEGAS TO DEATH VALLEY AND RETURN

(Prepared in conjunction with American Institute of Mining, Metallurgical, and Petroleum Engineers annual meeting, Las Vegas, Nevada, February 1976)

A road log of the geology, geography, and history from Las Vegas to Death Valley and return by another route, and articles on Death Valley, the Tenneco borate mines and mill, and the Grantham Talc Mine.

MACKAY SCHOOL OF MINES  
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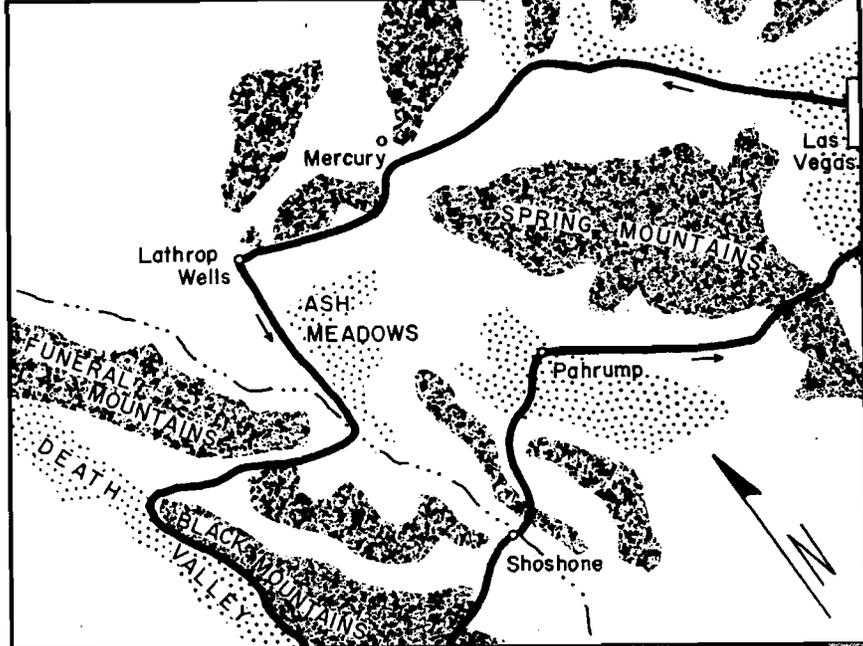
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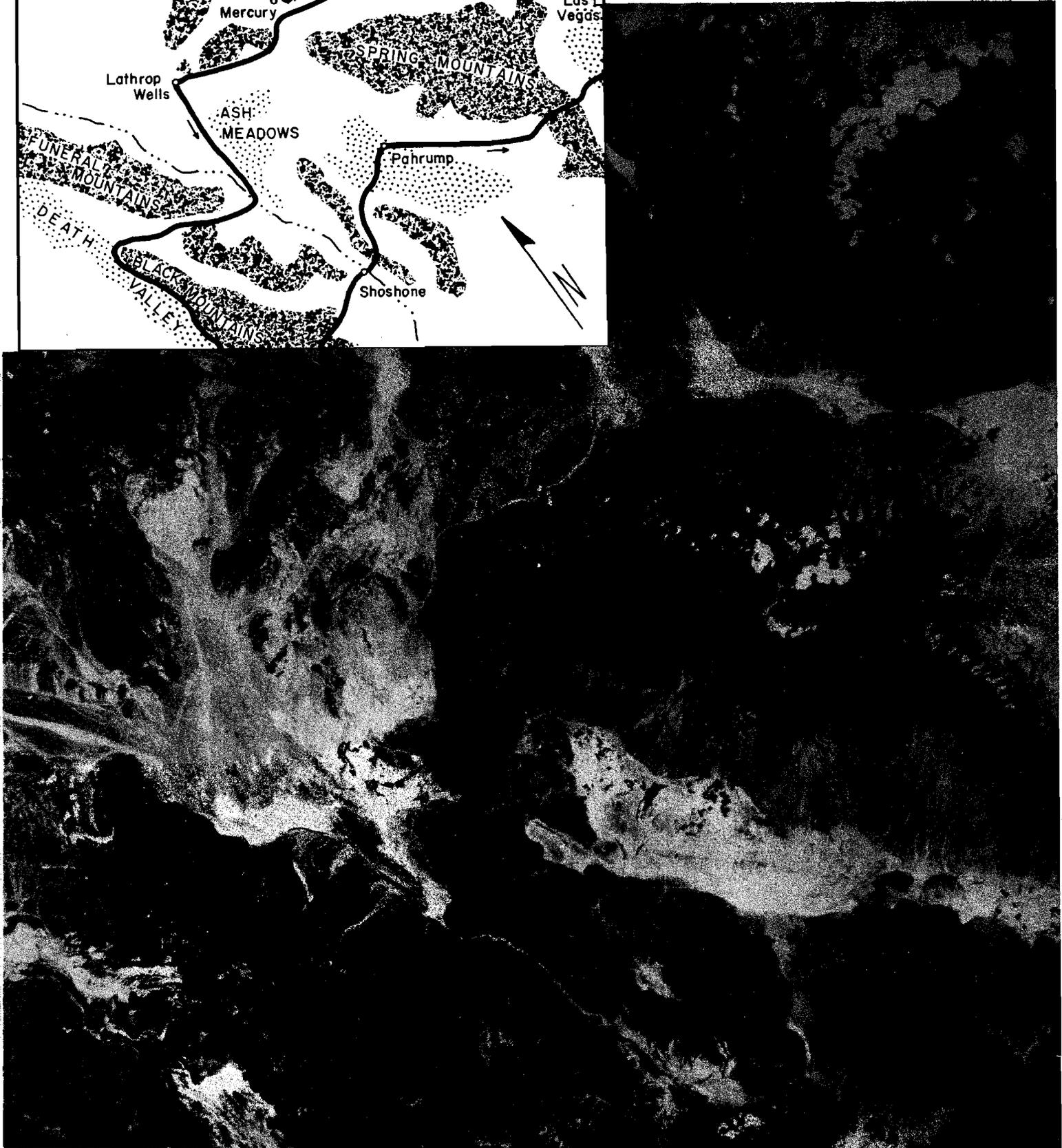
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Vertical aerial photograph showing the field-trip route. Approximate scale: 1" = 11.5 miles. Skylab photograph, 1973.

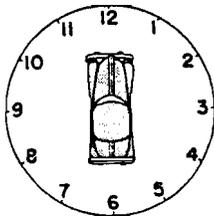


# ROAD LOG: LAS VEGAS TO DEATH VALLEY AND RETURN

Keith G. Papke and John H. Schilling

Nevada Bureau of Mines and Geology, Reno, Nevada

This is the road log for the route shown on Figure 1. It was prepared for a field trip that was part of the annual meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers, held in Las Vegas in February, 1976, but is intended to be of interest to both the technically-trained person and the layman. The total route distance is 304 miles (excluding any side trips to points of interest). It is suggested that the trip be made in at least two days, if possible, to allow one to learn more about this fascinating region. Articles on the mines and mill visited during the field trip, an article on Death Valley, and references to other publications are included for anyone wishing to learn more about these subjects.



On the left side of the road log, mileages are given in both increments and total distance to that point. A system similar to a clock is used to designate the direction to an object being described: thus, 12 o'clock is used when an object is directly ahead of the vehicle, and 3 o'clock when one is on the right perpendicular to the direction of travel.

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## Mileage

- 0.0 Intersection of Sahara Ave. and Las Vegas Blvd. Go west on Sahara Ave.
- (0.7) Turn right (north) onto Interstate Highway 15.
- 2.8 Turn right and then left onto U.S. Highway 95 North (toward Tonopah).
- (1.2) Turn right off freeway. Continue to follow U.S. Highway 95 North.
- 4.0

Las Vegas is the largest city in Nevada, with a population in 1970 of 125,787; it and the rest of Clark County had a population of 273, 288, or 56 percent of the total for the State. Las Vegas means "The Meadows" in Spanish. Flowing springs in the area were first used by white men about 1830, and became a stopping place on the Old Spanish Trail from Santa Fe to southern California. After a brief attempt by the Mormons to colonize the valley in 1855, the area was operated for many years as a large ranch. Las Vegas was formally established in 1905 when William A. Clark (Montana copper millionaire and former senator) built the

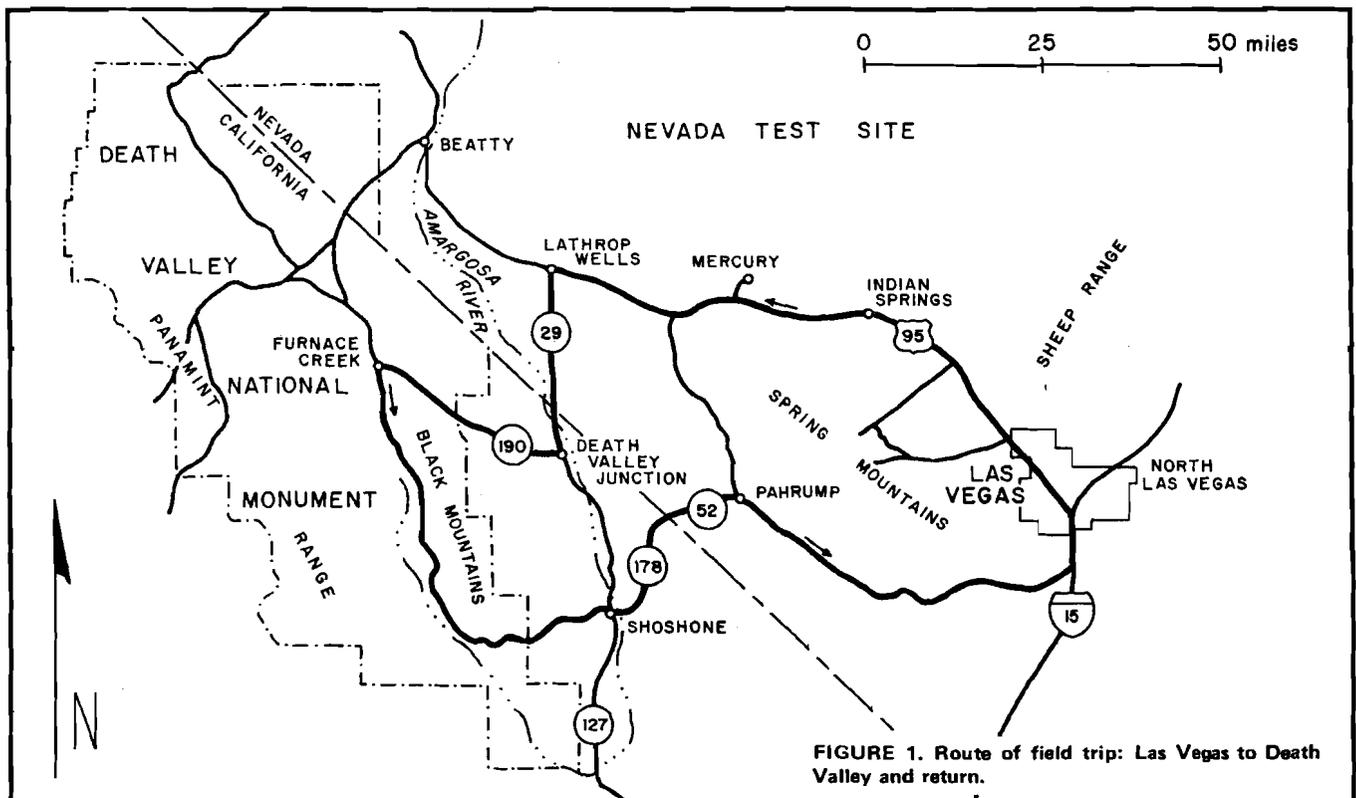


FIGURE 1. Route of field trip: Las Vegas to Death Valley and return.

San Pedro, Los Angeles, and Salt Lake Railroad (now the Union Pacific) through the valley. Las Vegas got a boost in population when Hoover Dam was built in the 1930's, but in 1942 it was still mostly a railroad community with a population of 10,000. After 1946 large casinos and hotels were built, and the tourist industry became important. (For more details of the geology on the first 58 miles of the trip see **Geology and mineral deposits of Clark County**, by C. R. Longwell and others: Nevada Bureau of Mines Bulletin 62, 1965).

- 6.0 From 9 to 11 o'clock are the Spring Mountains. The Keystone thrust is exposed for more than 45 miles in the eastern part of the mountains.
- (8.4) bright-colored Jurassic (?) Aztec Sandstone is in thrust contact with the overlying dark-gray Cambrian Goodsprings Dolomite.
- 14.4 Tule Springs and the Las Vegas Zoo on the right. At 3 o'clock the Las Vegas Range, which consists of Devonian to Carboniferous sedimentary rocks overthrust on the west by Cambrian sedimentary rocks.
- An archeological site east of Tule Springs is in sediments of the Pleistocene Las Vegas Formation.
- (3.1) Charcoal from this area gave a radiocarbon date in excess of 23,000 years, but extensive work by the Nevada State Museum in 1962-1963 failed to show evidence of human occupation more than 12,000 to 13,000 years ago. Even so, this is the earliest known archeological site in southern Nevada.
- 17.5 Junction with the Kyle Canyon road on the left. The forested Mount Charleston area, reached by this road or the Lee Canyon road farther north, is a favorite outdoor recreation and winter sports locality for people in southern Nevada. Charleston Peak, with an elevation of 11,918 feet, is the third highest peak in Nevada.
- The vegetation in this area, and throughout most of the trip, is predominantly creosote bush with some Joshua trees and Spanish bayonet. The climate in Las Vegas, at an elevation of 2,160 feet, is typical of the valleys in this area: average annual precipitation is about 4 inches, the extreme measured temperatures were 8°F and 117°F, and the frost-free period is about 200 days (**Nevada's weather and climate**, by J. G. Houghton and others: Nevada Bureau of Mines and Geology Special Publication 2, 1975).
- 22.0 White beds at the right in valley bottom are clays and silts of the Las Vegas Formation of Pleistocene age.
- (4.0)
- 26.0 At 9 o'clock complexly folded and faulted rocks, see Figure 2.
- (0.9)
- 26.9 Road to right leads to the headquarters of the Desert National Wildlife Range. This range,

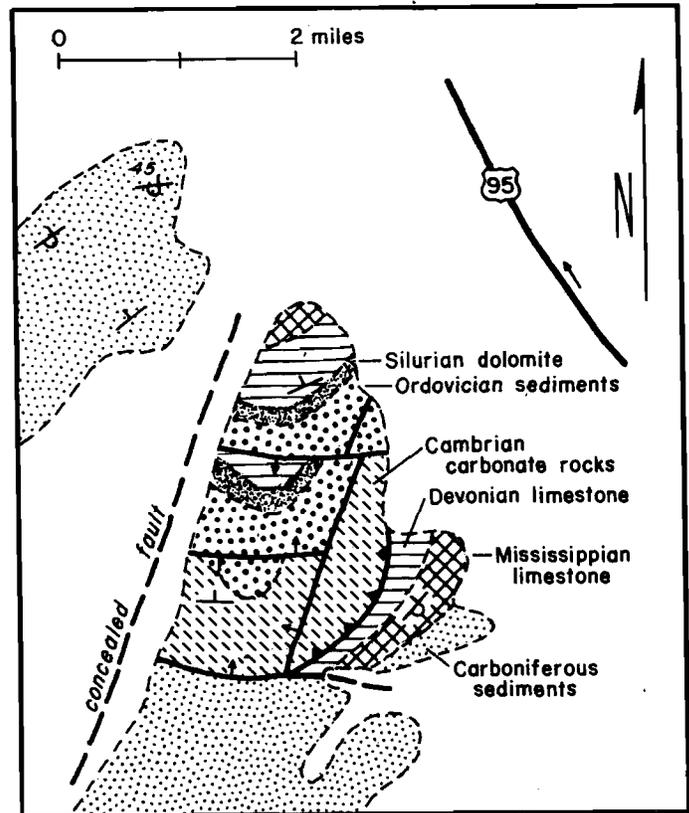


FIGURE 2. Geology of a portion of the northern Spring Mountains opposite road-log mileage 26. After Longwell, 1965.

- which covers a large area in northwestern Clark County and adjacent counties, was established in 1936 to preserve the desert bighorn mountain sheep.
- (4.5) At 2 o'clock is the Sheep Range, composed mostly of Cambrian through Devonian sedimentary rocks. These rocks generally dip eastward, but high-angle faulting has formed an irregular mosaic of fault blocks.
- 31.4 Junction with the Lee Canyon road on the left, leading up to the Mount Charleston recreation area.
- (6.6)
- 38.0 To the right, the lighter colored flat is a playa (dry lake); these are common topographic features in closed valleys in Nevada. The playa is bordered on the right (east) by the Desert Range and on the left (west) by the Pintwater Range. Both of these have rocks and structures similar to the larger Sheep Range farther east.
- (0.2)
- 38.2 On the right is a facility of the Nellis Air Force Bombing and Gunnery Range. This range and the adjacent Nevada Test Site cover an area about 130 miles long and 50 miles wide, which is closed to the general public.
- (4.8)
- 43.0 The road begins to turn more westward, approximately following a bend in the Las Vegas shear zone. This structure is concealed in the 80-mile-long, northwestward-trending valley

which we have been following since leaving Las Vegas. The shear zone was named and described by Longwell (**Possible explanation of diverse structural patterns in southern Nevada**: American Journal of Science, v. 258-A, p. 192–203, 1960). The shear zone had right-lateral movement (the northeast side moved right relative to the southwest side); Longwell estimated that it had a strike-slip movement of 25 miles. Its existence is postulated on structural and stratigraphic evidence: bending of the mountain ranges and structures near the valley (especially on the north side where the generally north-south ranges curve abruptly toward the southwest near the valley); and differences in facies and thickness of formations on the opposite sides of the valley.

45.0 Indian Springs. Originally a ranch owned by a small group of Indians, later a station on the Las Vegas and Tonopah Railroad, and now an Air Force base. Ground water is encountered at less than 100 feet in sand and gravel layers beneath the valley floor.

48.2 Cactus Springs. On the left is the northwestern part of the Spring Mountains, which in this area consists of Cambrian through Devonian sedimentary rocks (mostly carbonates). Folding, high-angle faulting, and thrust faulting have made this a structurally complex area.

(4.4) At 2 o'clock is the Spotted Range. The ridges in this range consist of Cambrian through Mississippian sedimentary rocks, and the intervening valleys are partly underlain by water-lain, volcanic-rich sediments of Tertiary age.

From here to Lathrop Wells, U.S. Highway 95 is along or near the old roadbed of the Las Vegas and Tonopah Railroad.

52.6 The mounds on right of road are outcrops of the Las Vegas Formation.

56.7 Outcrops to right of road are Ordovician carbonate rocks.

57.9 Nye County—Clark County line. Nye County, the third largest county in the United States, was named for James Nye, the Governor of Nevada Territory before it became a State in 1864. (For additional geological information on Nye County see **Geology and mineral deposits of southern Nye County, Nevada**, by H. R. Cornwall: Nevada Bureau of Mines and Geology Bulletin 77, 1972).

61.0 Nearest hills on the right are carbonate rocks of the Pogonip Group of Ordovician age.

63.8 Continue ahead. The road to the right leads to Mercury, the headquarters for the Nevada Test Site (NTS) of the U.S. Energy Research and Development Administration (formerly the Atomic Energy Commission). The NTS was established in 1950 and covers about 1350 square miles. Through September 15, 1968,

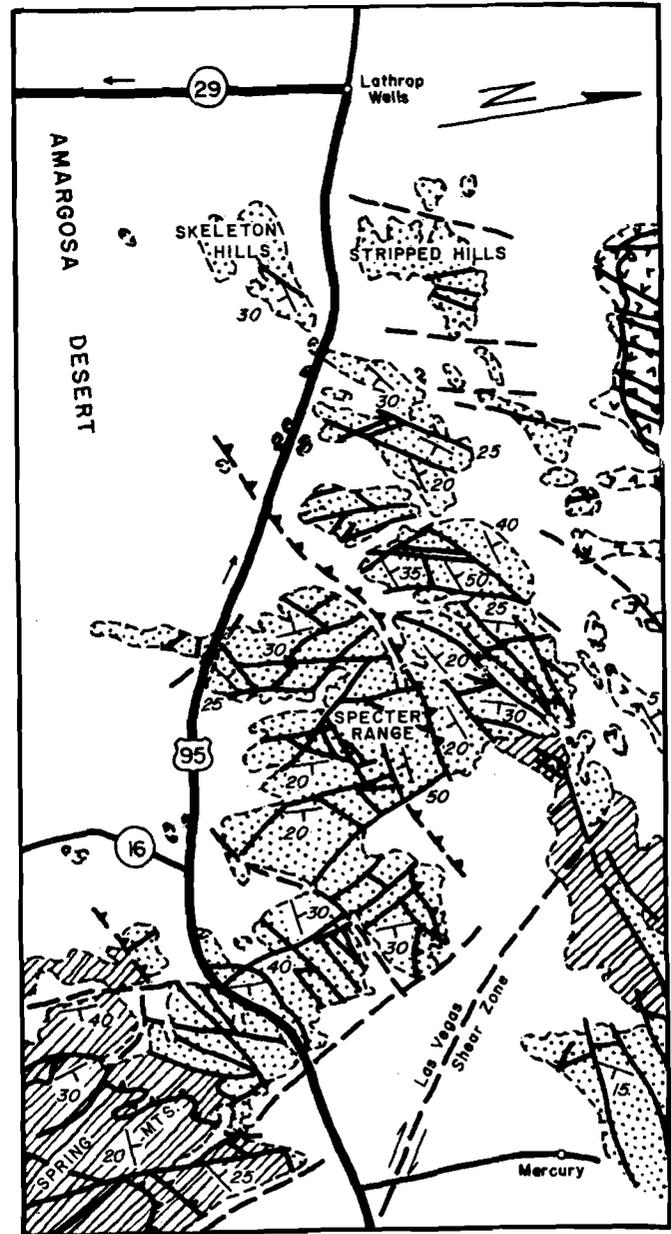


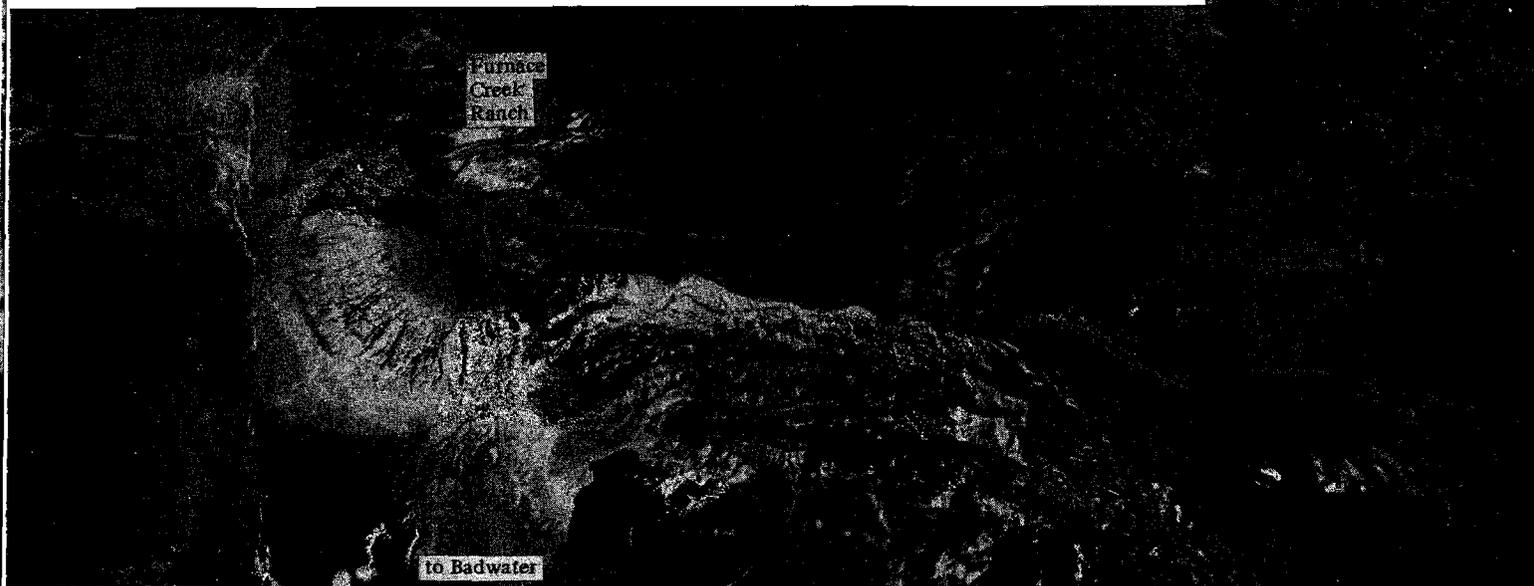
FIGURE 3. Geologic strip map: Mercury to Lathrop Wells. After Cornwall, 1972.

- 315 nuclear devices had been detonated (including 19 under the Plowshare program); since July 1962 all have been underground. Most of the people employed here live in Las Vegas. Use of the facility for underground nuclear experiments led to very detailed geological studies, especially of the Tertiary volcanic rocks, by the U.S. Geological Survey. (Part of this work is summarized in Nevada Test Site: Geological Society of America Memoir 110, 290 p., 1968).
- (3.7) The NTS and adjacent Bombing and Gunnery Range are near the thickest part of the Paleozoic Cordilleran miogeosyncline, and the uppermost Precambrian and the Paleozoic sedimentary rocks total about 40,000 feet in thickness. In the eastern and southern parts, where most of the pre-Tertiary rocks are exposed, two major thrust-fault systems of Mesozoic age are recognized, each with displacements of several tens of miles. Normal faults are abundant, and those on the edges of major valleys have movement of several thousand feet. The central and western parts contain numerous volcanic centers, including at least five calderas. The composite Tertiary section exceeds 30,000 feet, with ash-flow tuffs of rhyolitic and quartz latitic composition the most abundant volcanic rocks. Most of the volcanic rocks are Miocene and Pliocene in age.
- 67.5 Road goes through gap between the Spring Mountains on the left and the Specter Range. The lower hills on both sides of the road for the next 3 miles are mostly carbonate rocks of Cambrian age. In the Specter Range high-angle faulting is the most characteristic structural feature, and many of the faults have topographic expression (**Structural geology of the Specter Range quadrangle, Nevada, and its regional significance**, by B. C. Burchfiel: Geological Society of America Bulletin, v. 76, p. 175-191, 1965).
- (4.4)
- 71.9 Paved road to left goes to Pahrump, and on to Las Vegas. At 10 to 12 o'clock is the eastern end of the Amargosa Desert, and beyond is the Funeral Mountains. The Specter Range to the right of the road is composed here of Ordovician, Silurian, and Devonian sedimentary rocks.
- (4.1)
- 76.0 Hills from 10 to 12 o'clock are of Cambrian carbonate rocks. At 9 o'clock Amargosa Flat. This playa is underlain in places by a several-foot-thick bed of sepiolite (a magnesium-silicate clay mineral = meerschaum) believed to have formed as a chemical precipitate in a playa lake (**A sepiolite-rich playa deposit in southern Nevada**, by K. G. Papke: Clays and clay minerals, v. 20, p. 211-215, 1972).
- (6.0) To the left near the road is the old grade of the Las Vegas and Tonopah Railroad built in 1905-1907 by Senator William A. Clark. The 196-mile railroad ran from Las Vegas to Goldfield, but was never extended farther northwest to Tonopah. It made money only in its first year of operation, owing to decline of gold mining in Goldfield and the Beatty area and to competition from other railroads (Beatty was served by 3 different railroads), and was dismantled in 1919.
- 82.0 Skeleton Hills at 10 to 12 o'clock. Both these and the hills north of the road are underlain by the Bonanza King Formation of Cambrian age.
- (2.0)
- 84.0 Stripped Hills to right of road ahead are composed of Cambrian through Devonian sedimentary rocks.
- (2.0)
- 86.0 From 9 to 12 o'clock are the Funeral Mountains with the Amargosa Desert in the foreground. The Amargosa Desert is a southeastward-trending valley 60 miles long and as much as 20 miles wide; its floor ranges from 2200 to 3000 feet in elevation. The Amargosa (Spanish for bitter) River goes through the central part of the valley. At 12 to 2 o'clock is Yucca Mountain which is underlain by the Paintbrush Tuff of late Miocene age.
- (2.8)
- At 4 o'clock is a more spectacular view of the Stripped Hills.
- 88.8 Lathrop Wells. Turn left on State Highway 29. The road ahead goes to Beatty, Goldfield, and Tonopah (all of which were established during the precious-metal boom in the early 1900's), and eventually to Carson City and Reno.
- (8.3)
- 97.1 Farm roads to both left and right. On the left from here to the state line is Ash Meadows, so-named because of the ashen color of salt crusts and clays in the area.
- On the east side of Ash Meadows, 30 springs are present in a narrow, northwestward-trending belt 10 miles long that may be fault controlled. The total spring discharge was 17,000 acre/feet annually (about 10,600 gpm) before pumping was begun in 1968. Most of the springs discharge from Cenozoic lake beds and have roughly circular pools as much as 30 feet in diameter; these pools are the home of the Desert Pupfish. There is good evidence that the water recharge to Ash Meadows is by subsurface, interbasin flow from an area of about 4500 square miles and as far as 90 miles away. Interbasin flow appears to be an important hydrologic feature of this region, with large amounts of ground water moving laterally through fractured and permeable Paleozoic carbonate aquifers (**Interbasin ground-water flow in southern Nevada**, by R. L. Naff and others: Nevada Bureau of Mines and Geology Report 20, 1974).
- (5.4)
- Devil's Hole, which is part of Death Valley National Monument, is within the spring area

- east of Ash Meadows. It is a large solution cavity in Cambrian carbonate rocks. Water fills the cavity to within 50 feet of its rim, and the cavern is known to extend at least 315 feet below the water level.
- Extensive farming is done in Ash Meadows and in the Amargosa farm area west of the highway, utilizing the shallow water supply. The principal crop is alfalfa; 5 or 6 cuttings are obtained each year during a frost-free period of about 210 days.
- 102.5 Road to right goes to offices and mill of Industrial Minerals Ventures (I.M.V.). They hold a large number of mining claims in the Ash Meadows area, and have done extensive exploration on them. The company has a dry-processing plant to handle bentonite (from eastern Ash Meadows) and sepiolite (1.9) (from the Amargosa Flat area). More recently a wet-processing plant was completed to separate hectorite from a fine-grained calcium carbonate, and recover both products. This material comes from a deposit in California a few hundred feet southwest of the mill.
- 104.4 At 9 o'clock central Ash Meadows, and in the distance beyond the Spring Mountains. Road to left leads to the colemanite (borate) processing plant of Tenneco Mining Co. (see the article in this guidebook for a description of the mill). (2.7)
- 104.8 Several miles farther to the left, near the ruins of the settlement at Clay Camp, about 250,000 tons of non-swelling montmorillonite (fuller's earth) was mined between 1918 and (0.4) 1952 and used to decolorize and filter oils. The clay occurred in nearly horizontal, shallow beds, and was formed by alteration of volcanic ash that fell into alkaline lakes (**Montmorillonite, bentonite, and fuller's earth deposits in Nevada**, by K. G. Papke: Nevada Bureau of Mines Bulletin 76, 1970).
- 104.8 Tenneco trailer park on left.
- 105.3 State line, entering California on State Highway 127. Two miles ahead the road crosses the Amargosa River. Normally the river has no surface flow; its course is marked by mesquite trees. (The **Death Valley Sheet, Geologic Map of California**: California Division of Mines, 1958, covers the next 75 miles of this road log). (5.7)
- 111.0 Road bends left. The abandoned railroad grade along the left side of road was the right-of-way of the Tonopah and Tidewater Railroad, which ran from Goldfield on the north to Ludlow on the south where it connected with the Santa Fe Railroad. Built mainly from 1905 to 1907, by "Borax" Smith to serve his borax properties, it was abandoned in 1943 never having reached Tonopah, or tidewater either (1.6) for that matter!
- 112.6 At 9 o'clock, in the distance, are the Spring Mountains; at 10 to 11 o'clock, the Resting Spring Range; at 11 o'clock Eagle Mountain; and at 12 to 3 o'clock, the Greenwater Range. Turn right onto California Highway 190, just before Highway 127 enters Death Valley Junction. The piles of debris around the town are waste from the borax (colemanite) operations. Pacific Coast Borax built a modern town here in 1928 with paved streets, flush toilets, and steam-generated heat and electricity. (4.1)
- 116.7 At 9 o'clock, the light-colored area at the base of the Greenwater Range is the Lily C Mine at (old) Ryan, one of the main sources of the colemanite processed at Death Valley Junction. For the next few miles the hills to the left of the road are capped by basalt lava flows of the Funeral Formation. The abandoned right-of-way of the Death Valley Railroad Company parallels the road for the next 10 miles (the railroad bed will be visible to the left). By 1913 the ore reserves at the Lily C Mine were nearly exhausted and operations were moved to the Bidley McCarty Mine at (new) Ryan. In 1914, the 17-mile narrow-gauge (three-foot) line was built to connect the new mine with the standard-gauge branch of the Tonopah and Tidewater Railroad which ran from Death Valley Junction to the Lily C Mine. A third rail was added on part of this branch line so that the narrow-gauge cars could haul the ore all the way to the mill at Death Valley Junction. After mining ceased in 1927, the railroad handled tourists until its abandonment in 1931. (For more about this and other railroads of this area, as well as many scenic pictures, see **Railroads of Nevada and Eastern California**, by David Myrlich: Howell-North Books, Berkeley, California, 1963). (2.7)
- On the right are the Funeral Mountains. A large strike-slip fault, the Furnace Creek fault, extends northwest along the base of the Funeral Mountains paralleling our route and Furnace Creek Wash. The fault separates highly-faulted Precambrian and Paleozoic rocks in the Funeral Mountains from Tertiary and Quaternary volcanic and sedimentary rocks in Furnace Creek Wash and the Greenwater Range; the Tertiary-Quaternary rocks are subdivided into the older Artist Drive Formation, the Furnace Creek Formation, and the younger Funeral Formation.
- 119.4 Continue ahead. Road to left to Tenneco's abandoned open-pit Terry Mine. Colemanite was the main ore. It is a good collecting locality. (7.6)
- 127.0 Road follows Furnace Creek Wash to the floor of Death Valley. This is the route followed by the Death Valley Party of 1849 in their tragic crossing of Death Valley while trying to find a shortcut to the California gold fields. (2.0)

- 129.0 Roadcuts are in lacustrine mudstones and sandstones of the Tertiary Furnace Creek Formation. This formation contains the major borate deposits of this area. (This area is described in **Geology of the Furnace Creek Borate area, Death Valley, Inyo County, California**, by J. F. McAllister: California Division of Mines Map Sheet 14, 1970).
- (0.4)
- 129.4 Entering Death Valley National Monument. The cliffs ahead, to the right, are conglomerates of the Pliocene-Pleistocene (?) Funeral Formation; the white, vertical veins in the cliffs are travertine (calcite).
- (1.6)
- 131.0 Continue ahead. Paved road to left to (new) Ryan and Dantes View (13 miles). At 10 o'clock are dumps of Tenneco's Boraxo Mine; the pit is behind the hill. When the pit is abandoned the dumps will be contoured to blend into the landscape (for more about this mine see the article in this guidebook). The Black Mountains behind the mine are made up in this area mostly of rocks of the Furnace Creek Formation.
- (3.0)
- Dantes View (elevation 5,475 feet) on the crest of the Black Mountains gives a spectacular vista of Death Valley, especially in the morning light — well worth a side trip.
- As we continue ahead the floor of Death Valley comes into view.
- 134.0 Outcrops to the left are in the lower part of the Furnace Creek Formation; the dark-colored area is a sill of basalt. In this area, many of the light-colored mudstones and sandstones of the Furnace Creek Formation contain commercially significant borate beds.
- (3.1)
- 137.1 Twenty Mule Team Canyon entrance to left. The Badlands on both sides of the road are in the Furnace Creek Formation.
- (1.3)
- 138.4 Zabriskie Point turnoff. A short road leads to an overlook of spectacular badlands in the Furnace Creek Formation.
- (1.8)
- Just to the east of the Point, the U.S. Park Service cut a channel through the divide between Furnace Creek Wash and Gowers Gulch, diverting the natural flow of the Wash into the Gulch in order to prevent damage from flash-flooding at the settlement of Furnace Creek. This has scarred the landscape, and by changing nature's balance caused considerable erosion especially at the mouth of the Gulch. Just think of the hue and cry this would have caused if it had been done by anyone else! (For more details see **Man-made diversion of Furnace Creek Wash, Zabriskie Point Death Valley**, by B. W. Troxel: California Geology, Oct. 1974, p. 219–23).
- 140.2 Travertine Springs, marked by palm trees and mesquite. The Death Valley Party refreshed themselves at these warm springs before crossing Death Valley.
- (1.6)
- 141.8 On the right, the famous Furnace Creek Inn.
- 142.0 Turn left on the paved road to Badwater and the south end of Death Valley. The road you have left continues on to Furnace Creek Ranch (1 mile) and the many other attractions in the northern part of Death Valley (see the article on Death Valley in this guidebook). Furnace Creek is the National Monument headquarters — with a store, gas station, restaurant, cabins and camping facilities, and a visitor's center where you can learn more about Death Valley and what to see.
- For the next 45 miles the road will be below sea level, and will follow the edge of the Black Mountains. Across the floor of Death Valley,

Death Valley (at left), Furnace Creek Wash (across center of photo), Funeral Mountains (upper right), and Black Mountains (lower center). Light-colored rocks just south of Furnace Creek Wash are the Furnace Creek Formation which contains the borate deposits. Furnace Creek Ranch is on the alluvial fan formed by debris carried down Furnace Creek Wash.



to the west, looms the Panamint Range capped by Telescope Peak (elevation 11,049 feet).

The Death Valley area shows the classical features of the Basin and Range physiographic province which is characterized by uplifted, fault-block mountain ranges separated by down-faulted basins filled by eroded debris from the ranges. The Black Mountains and Panamint Range are uplifted fault blocks; Death Valley is underlain by a down-faulted block which has been covered by as much as 10,000 feet of sand and gravel eroded from the mountains on each side.

(6.1)

The many faceted spurs and wine-glass shaped canyons in the mountain front along the road give indications of the huge frontal fault (Death Valley fault zone) along the edge of the Black Mountains. The road passes over a series of alluvial fans, one at the mouth of each canyon. These fans have merged into a continuous apron or bajada. Fresh scarplets, visible in the gravels of many of the fans, indicate movement has continued along the frontal fault up to the present time, each of the many small one-side up jerks that took place were accompanied by an earthquake. Death Valley and its surrounding mountains are hardly finished products of nature – the only permanent thing in this world is change. (For a detailed discussion of the geology of Death Valley see **General Geology of Death Valley, California**: U.S. Geol. Survey Professional Paper 494, 1966; or the shorter **Death Valley: Mineral Information Service, California Division of Mines, October 1958**).

148.1

Junction with the unpaved Westside road which crosses the floor of Death Valley and continues south along the foot of the Panamint Range. Before reaching this area the ill-fated Death Valley Party of 49ers had split up into groups – everyone for themselves. A group of young men had headed north from Furnace Creek crossing the Panamint Range through the pass west of Stovepipe Wells. A slower-moving group of families headed southwest across the salt flats, roughly following the Westside road. Unable to find a route across the Panamint Range, they camped for 26 days at one of the springs at the valley's edge, while two young men walked 600 miles to bring back supplies. Abandoning their wagons, they were then able to make the terrible hike to safety.

(2.6)

The ruins of the Eagle Borax Works – one of the early plants that produced from playa deposits rather than older rocks – is also along this road.

150.7

Entrance, to left, to Artists Drive, an interesting loop drive of 9 miles through fantastically-eroded, multicolored badlands cut in sedi-

(2.5)

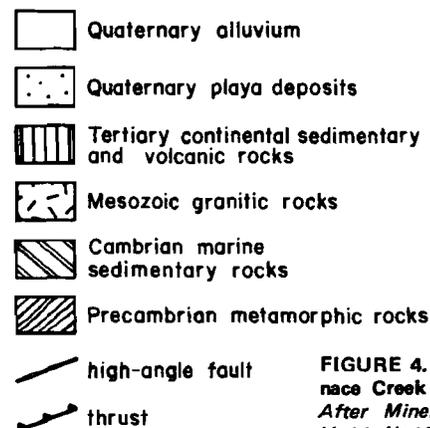
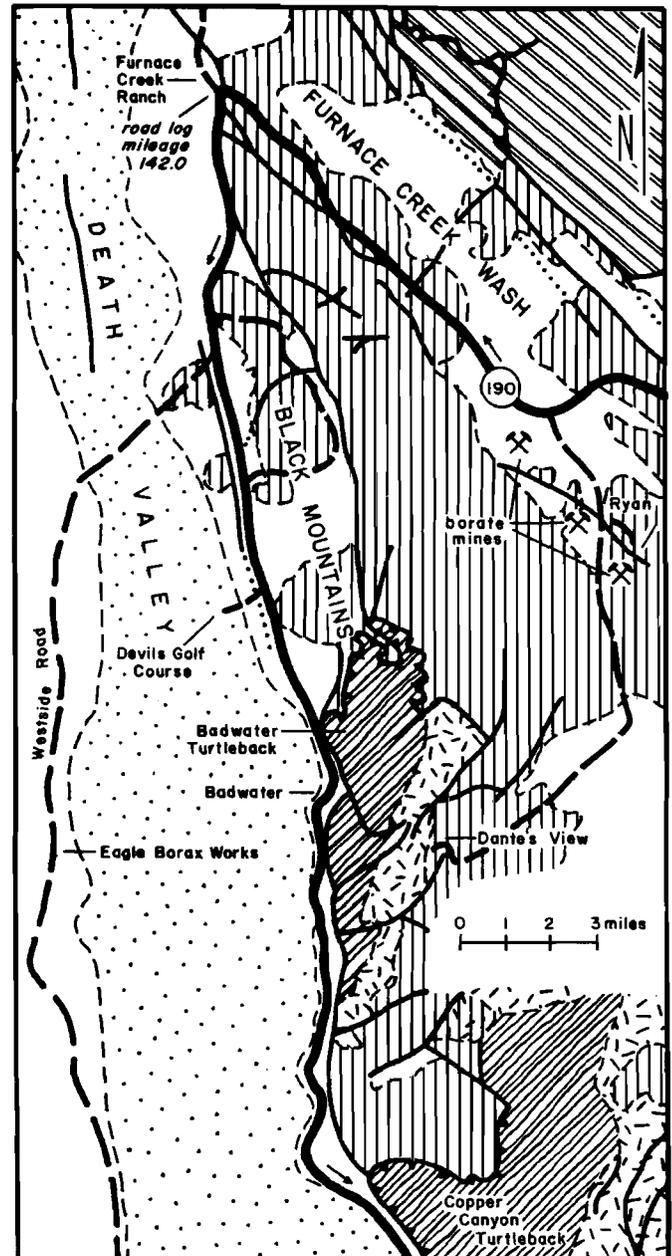
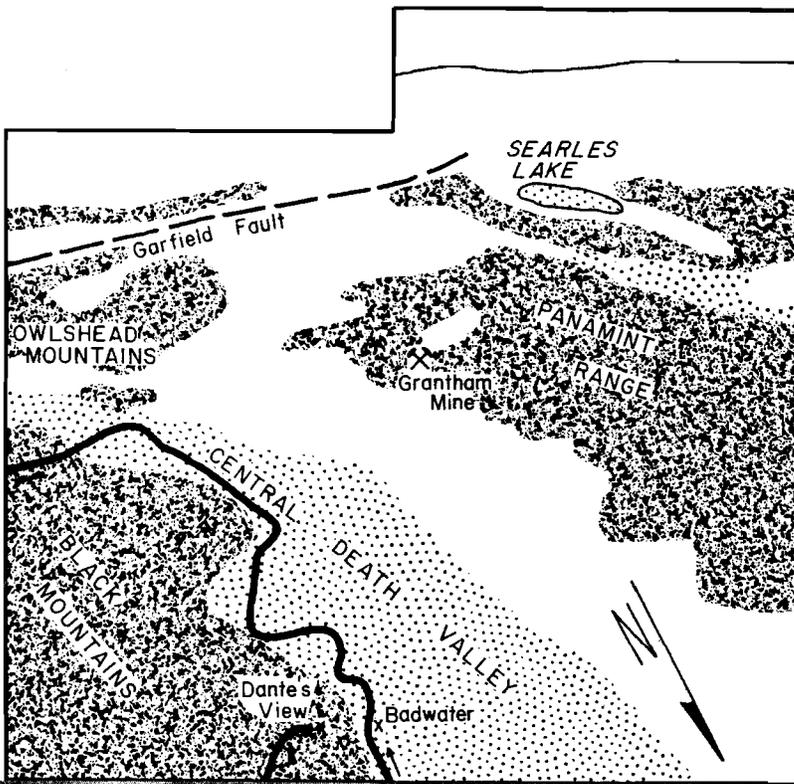
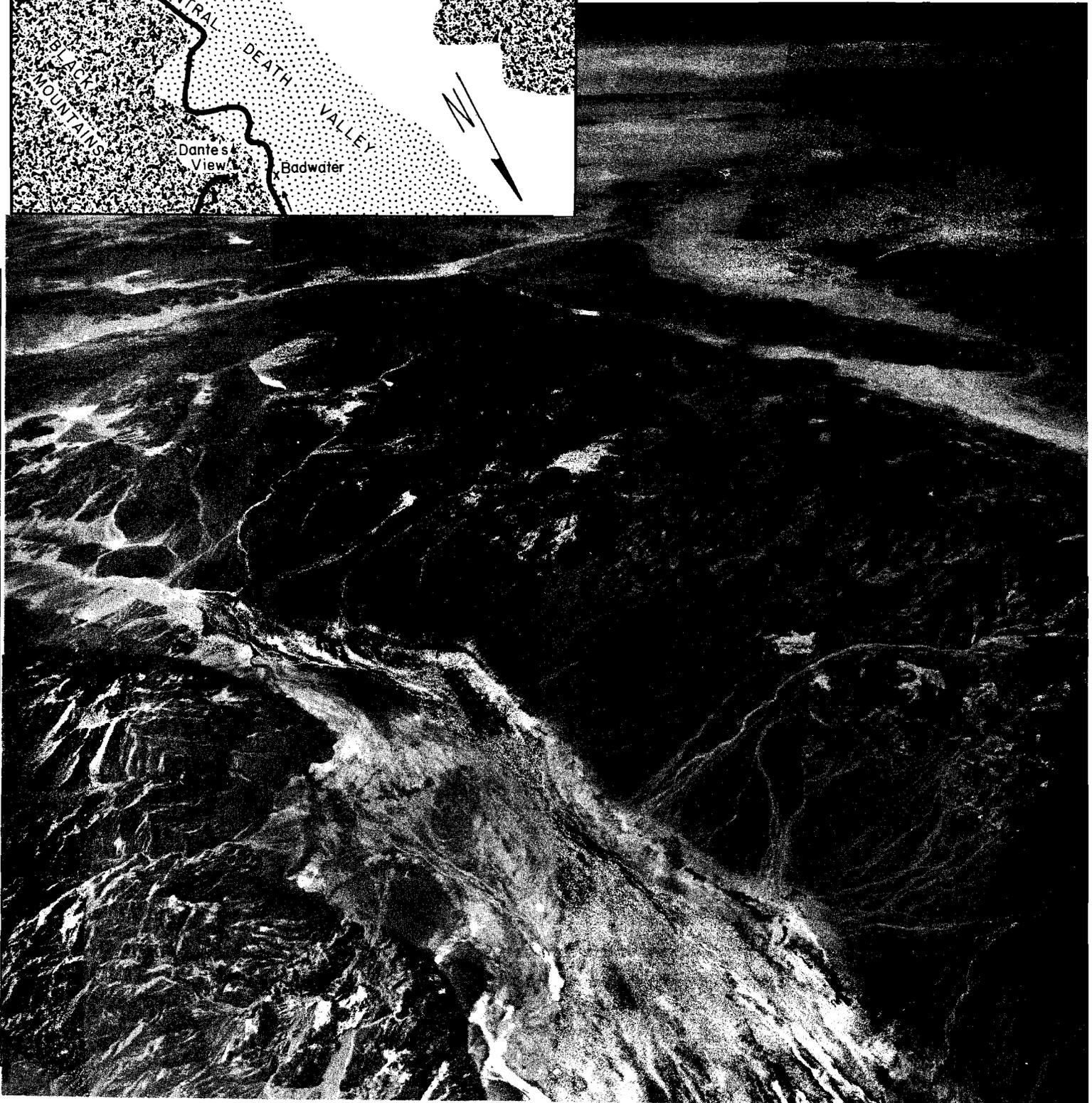


FIGURE 4. Geologic strip map: Furnace Creek Wash and Death Valley. After Mineral Information Service, V. 11, N. 10, 1958.



Oblique aerial photograph looking southwestward across Death Valley. U.S. Geological Survey—U.S. Air Force photograph.



- mentary and volcanic rocks of the Artist Drive Formation and the fanglomerates of the Funeral Formation.
- 153.2 Road to right leads to the Devils Golf Course (1 mile). A shallow lake covered this area about 2000 years ago; the 3 to 4-foot thick halite (table salt) layer at the surface precipitated from this lake as it dried up, forming a "salt-pan". The salt has been cracked by expansion during the recrystallization process; cracking noises can be heard on hot days. The characteristic pinnacles grow as salt in solution is carried up by capillary action from the water table below, the water evaporating and the salt crystallizing on the surface of the pinnacle. Below the surface is at least a thousand feet of alternating layers of salt and silt deposited from older lakes that once covered this area.
- (5.6)
- 158.8 Badwater, the lowest point (279.8 feet below sea level) that one can drive to in the Western Hemisphere; the lowest point (282 feet below sea level) is four miles west of here. The pool is fed by a spring along the fault that follows the mountain front. The water certainly tastes bad, but is not poisonous.
- (3.7) Badwater may be the hottest spot in the world. The temperatures usually are a few degrees hotter than at Furnace Creek where 134°F was recorded. The world record is 136°F! (Temperatures as high as 190°F have been recorded in Death Valley at ground level in the sun). Life exists even in this inhospitable spot — the "wrigglers" in the water are larvae of the Soldier Fly; bronze water beetles eat the algae; clumps of Ditch Grass grow in the water; and clumps of Pickleweed are found at the water's edge.
- Continuing ahead note the fine example of fault scarps in the alluvial fan ahead, to the south.
- 162.5 Ahead, to the left, are good examples of "wine-glass" canyons in the mountain side (the alluvial fan, the narrow gully, and the wider valley above together resemble a wine glass).
- (6.0)
- 168.5 As the road curves back toward the Black Mountains, a fine example of a "turtleback" surface — the turtleback-shaped surface of a folded thrust fault exposed by erosion — can be seen in the mountain ahead. These structures were described originally by H. D. Curry. This particular example is known as the Copper Canyon Turtleback. It consists of a core of Precambrian metamorphic rocks below an anticlinally folded fault separating them from remnants of Tertiary rocks (easily distinguished by their variety of colors, especially red and brown) which are exposed around the margins of the turtleback. Other turtlebacks occur in the Black Mountains at Badwater and Morman Point, but are more difficult to recognize.
- (11.5)
- 180.0 On the skyline, ahead to the south, are the Owls Head Mountains. (**The Trona Sheet, Geologic Map of California:** California Division of Mines, 1962, covers the next 40 miles of this road log).
- (3.3)
- 183.3 At 3 o'clock, small cinder cone along a branch of the Death Valley fault system. The cone is sliced apart by later right-lateral movement on the fault.
- (0.7)
- 184.0 For a mile along the left side of the road, there is a fault scarp in the black Funeral Basalt.
- (0.5)
- 184.5 Junction with the south end of the Westside road. The Grantham Mine (see article in this guidebook) and other talc mines are accessible from this road. (To reach the Grantham Mine go 3 miles along the unpaved Westside road, then turn left onto a well-travelled road for 9 more miles. **Do not visit the mine without permission.**)
- (1.8) Continuing ahead, at 2 o'clock is Shoreline Butte with traces of the many shoreline benches of Pleistocene Lake Manly, formed as the lake slowly dried up. In its prime, Lake Manly was over 100 miles long and 600 feet deep. The Amargosa River is at the base of the Butte. Surface flow of water is rare along its circuitous course from north of Beatty to Death Valley — it's mainly an underground stream!
- 186.3 The ruins of the Ashford Mill (gold) are just west of the road.
- (2.0)
- 88.3 The paved road turns left, heading east out of Death Valley. A dirt road continues southeast along the Amargosa River. At 1 o'clock are the white dumps of a talc prospect; the talc deposits in this area are in carbonate rocks.
- (1.7)
- 190.0 Rocks south of the road are Precambrian, part of the Virgin Spring phase of the Amargosa chaos. The Amargosa chaos is a breccia believed to have formed when sheets of rock were shoved over the ground surface along the very-low-angle Amargosa thrust fault (**Structural features of the Virgin Spring area, Death Valley, California,** by F. L. Noble: Geological Society of America Bulletin, v. 52, 1941). The breccia consists mostly of Precambrian rocks, with individual blocks as large as 1000 feet long and 300 feet thick. Three phases of chaos are recognized, each associated with an episode of faulting: the Virgin Spring, Jubilee, and Calico. The origin of the chaos is poorly understood and controversial.
- (1.4)
- 191.4 Cavernous material on the right side of the road is the Jubilee phase of the chaos.
- (1.7)
- 193.1 Jubilee Pass, elevation 1317 feet. Outcrops are of chaos.
- (2.6)
- 195.7 On the right, one of the surfaces of the Amargosa thrust separates Precambrian rocks from the overlying chaos.
- (3.1)

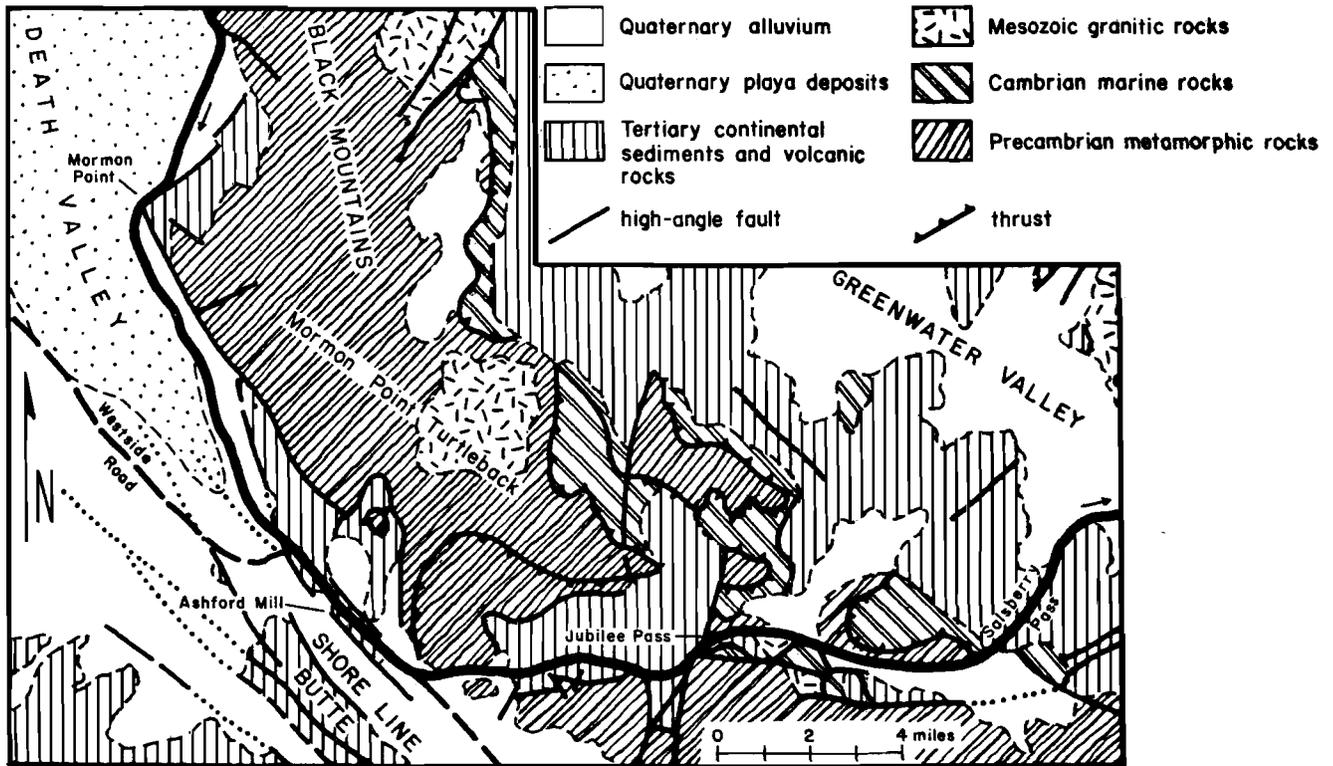


FIGURE 5. Geologic strip map: Death Valley to Greenwater Valley. After Mineral Information Service, V. 11, No. 10, 1958.

- 198.8 Eastern boundary of Death Valley National Monument. (4.1)
- 202.9 Salsberry Pass, elevation 3315 feet. The rocks on both sides of the road are Tertiary rhyolitic volcanic rocks. The road begins to descend into Greenwater Valley. (4.5)
- 207.4 Floor of Greenwater Valley. On the left dark-colored basalts of the Pliocene Funeral Formation are exposed on both sides of the valley, and dip toward the valley. The highway continues along the north side of the Dublin Hills which consists mostly of Cambrian sedimentary rocks overlain by Tertiary rhyolite flows. (6.5)
- 213.9 Junction with California Highway 127; turn right. On the left is the Resting Spring Range. At 8 o'clock the white dumps are at the Gerstley borate mine. (0.6)
- 214.5 On the right side of the highway is basalt of the Funeral Formation. (0.8)
- 215.3 Shoshone. (0.3)
- 215.6 Junction. Turn left on California Highway 178. (0.5)
- 216.1 Cross the Amargosa River again. This river is about 140 miles long, but most portions seldom have any surface flow. However, flash floods — usually in mid-summer — occasionally cause disasters along its course.

- (2.2) The cliffs on the left are sediments that were deposited in a lake caused by temporary damming of the Amargosa River in Pleistocene time. Volcanic tuffs interbedded in the mudstones grade laterally from unaltered glass shards near the edge of the former lake into rock replaced by zeolites (mostly phillipsite, clinoptilolite, and erionite), and into rock replaced by potash feldspar and searlesite ( $\text{NaBSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$ ) near the center of the former basin. The mineralogical changes occurred soon after deposition of the tuff, and can be correlated with changes in the lake from relatively fresh water near the margins to alkaline and saline water near the center (**Distribution and genesis of authogenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California**, by R. A. Sheppard and A. J. Gude III: U.S. Geological Survey Professional Paper 597, 1968).
- 218.3 Crossing the Resting Spring Range, consisting here of eastward-tilted Cambrian sedimentary rocks overlain by Tertiary volcanic rocks. (1.1)
- 219.4 Roadcut is in a sequence of Miocene volcanic rocks that contains a layer of black obsidian. (0.2)
- 219.6 Road goes through pass in the Resting Spring Range and starts descent into Chicago Valley. The Nopah Range beyond is composed (2.7)

mostly of Cambrian sedimentary rocks.

222.3 (8.0) Nearly all the rocks exposed in the Resting Spring Range to the left are Cambrian in age.

230.3 (4.8) Begin descent into Stewart Valley and Pahrump Valley beyond. Range in the far distance ahead is the Spring Mountains.

235.1 Nevada-California state line. Begin Nevada Highway 52. The road cuts ahead are in landslide blocks of dolomite from the Cambrian Bonanza King Formation (see **Geology and mineral deposits of southern Nye County, Nevada**, by H. R. Cornwall: Nevada Bureau of Mines and Geology Bulletin 77, 1972).

(7.9) Ahead are Pahrump Valley and the town of Pahrump, one of the oldest settlements in southern Nevada. The valley is one of the most productive farming areas in Nevada. The principal crop is alfalfa, with 5 or 6 cuttings a year. Cotton raising formerly was important, but the acreage planted has been declining in recent years.

243.0 Pahrump. Turn right onto Nevada Highway 16. For the next few miles the highway goes along the toe of alluvial fans from the Spring Mountains to the northeast. The original water source for Pahrump valley was major springs that discharged along the toe of the fans, but heavy water withdrawal since the mid-1940's from artesian and pumped wells has caused the springs to dry up. Almost all the irrigation water is now pumped, generally from a depth of about 200 feet. The deepest wells are about 900 feet, and these penetrated silt, clay, and occasional sand or gravel lenses in the valley

(6.1)

fill. Most of the water is of the calcium-magnesium bicarbonate type, has less than 300 ppm total dissolved solids, and is satisfactory for both irrigation and domestic use.

249.1 Manse. This was one of the earliest ranches in this part of Nevada. Prior to settlement by white men, the Southern Piute Indians gathered mesquite beans, pine nuts, and wild seeds, hunted deer, mountain sheep, and rabbits, and had limited horticulture near some streams and springs.

(0.3)

249.4 Clark-Nye County line. (see **Geology and mineral deposits of Clark County, Nevada**, by C. R. Longwell and others: Nevada Bureau of Mines Bulletin 62, 1965).

(12.7)

262.1 At 9 o'clock southward-plunging anticline involving Permian redbeds and the overlying Triassic Moenkopi Formation.

(8.6)

270.7 At 9 o'clock medium-gray cliff-forming Permian carbonate rocks with underlying Permian redbeds.

(3.3)

274.0 Road curves to the right, and the hills on both sides are in a westward-dipping sequence of the Bird Spring Formation of Mississippian to Permian age. For the next 2 miles the sedimentary rocks dip westward, and successively older rocks are encountered.

274.9 Contact of the Bird Spring Formation and the underlying Mississippian Monte Cristo Limestone. The Bird Spring is darker gray than the Monte Cristo.

(0.3)

275.2 Road cut is in Devonian Sultan Limestone which underlies the Monte Cristo.

(0.7)

275.9 Mountain Springs Summit, elevation 5493

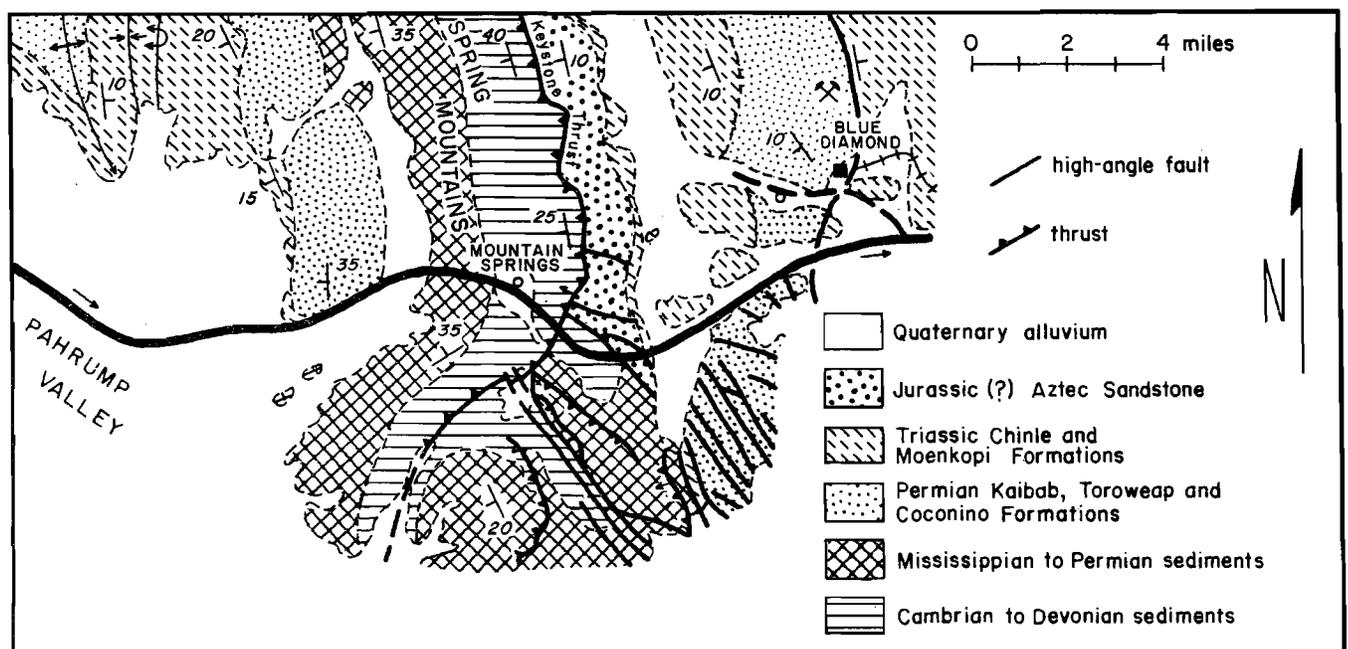
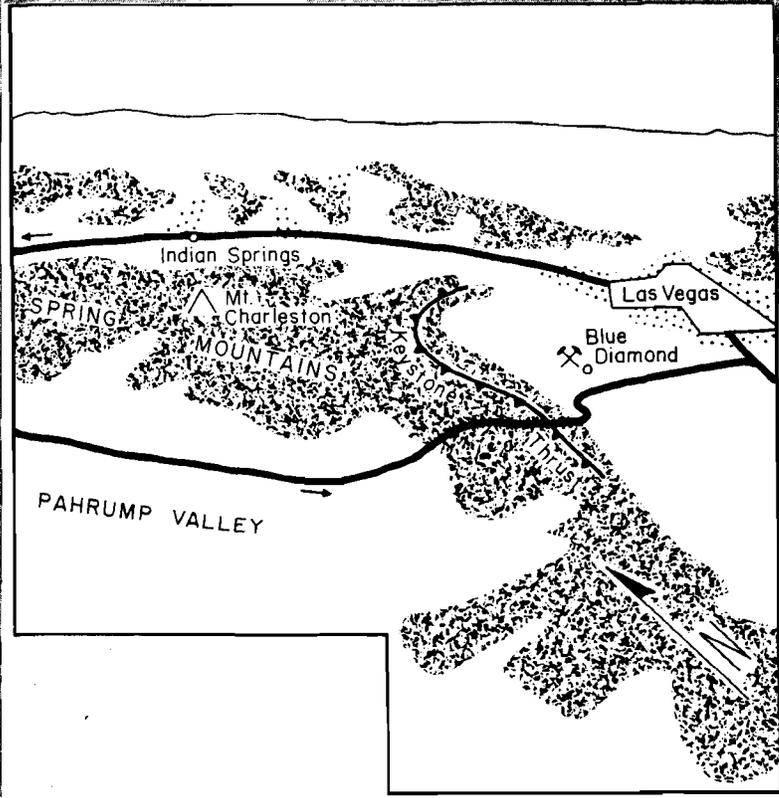
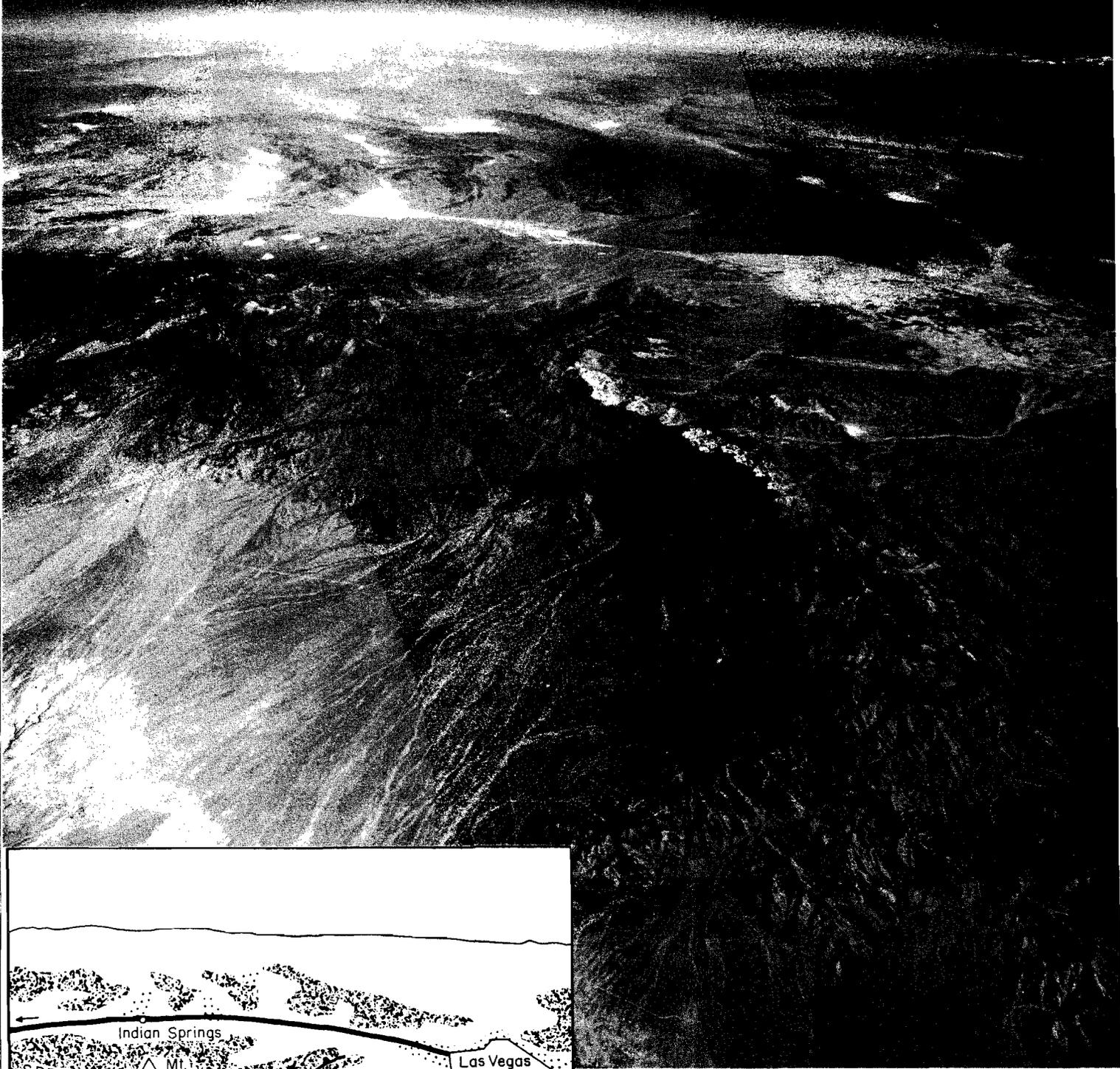


FIGURE 6. Geologic strip map: southern Spring Mountains. After Longwell, 1965.



Oblique aerial photograph looking northeastward across southern Nevada. U.S. Geological Survey—U.S. Air Force photograph.

- feet. This pass was on the Old Spanish trail, which was first used by Antonio Armijo in 1830. The trail from Santa Fe to Los Angeles was used to transport goods by pack animals in caravan. Two days were required to cover the distance from Las Vegas springs to here.
- (0.4) The springs just north of the road and the high altitude made this one of the favorite camping points on the trail.
- The trees in this area are juniper and pinyon pine. The difference in vegetation from that in the valleys reflects the greater precipitation (perhaps as much as 16 inches annually here) and cooler climate in the mountains.
- 276.3 The gray rocks on both sides of the road are Goodsprings Dolomite of Cambrian to Devonian(?) age. Beyond is the bright-colored Aztec Sandstone of Jurassic(?) age. The two formations are separated by the westward-dipping Keystone thrust which moved the Goodsprings eastward over the Aztec. The Keystone thrust is the eastern-most of three major thrust faults in the Spring Mountains that are believed to have caused a crustal shortening of tens of miles.
- (1.0) Road cuts are in a fault block of Sultan Limestone below the thrust.
- 277.3 Road crosses a high-angle fault that separates Sultan Limestone on the right from Aztec Sandstone on the left.
- (0.9) At 9 o'clock, redbeds of the Chinle and Moenkopi Formations of Triassic age partly covered by talus from the Aztec Sandstone.
- 278.2 At 10 o'clock, Red Rock Canyon State Park.
- (0.4) At 11 o'clock, the light-colored dumps are from the Blue Diamond gypsum mine of the
- (6.0) Flintkote Co. Gypsum is mined by open pit from the upper member of the Kaibab Formation of Permian age. The road begins descent into Cottonwood Valley.
- 285.1 At 8 o'clock gypsum and wallboard plant of the Blue Diamond Division of the Flintkote Co. The gypsum is brought from the mine by an aerial tram. The plant is served by a branch line from the Union Pacific main line. Gypsum has been mined in this area since 1909, originally from underground mines about 4 miles east of Blue Diamond.
- (0.6) The road to left goes to Blue Diamond and Red Rock Canyon.
- 285.7 At 2 o'clock, the road on the mountain in middle distance is just north of the operation of U.S. Lime Division of the Flintkote Co. A dolomite member of the Monte Cristo Limestone of Mississippian age is mined by open pit.
- (4.4) Most of it is shipped to Henderson, 12 miles southeast of Las Vegas, to make dolomitic quicklime and hydrated lime.
- 290.1 Crossing the railroad line to Blue Diamond. Ahead on the right is the small town of Arden, once the site of the Arden Plaster Co. mill.
- (1.6) Crossing the main line of the Union Pacific railroad between Los Angeles and Salt Lake City. This line was built in 1905 by Senator William A. Clark as the San Pedro, Los Angeles, and Salt Lake Railroad, and later sold to the Union Pacific.
- 291.7 Turn right onto Interstate 15 North. Continue into Las Vegas. Ahead are the big hotels and casinos of the Las Vegas Strip.
- (1.8) Las Vegas. End of road log.
- 293.5
- (3.0)
- 296.5
- (7.0)
- 303.5

## DEATH VALLEY

(excerpts from a booklet published by the National Park Service)

This will introduce you to Death Valley, its features, and their story — read through it before you begin your trip. As you visit Death Valley's natural and historical features, you can refer back to their descriptions in the text. If there are subjects that you would like to know more about, there is a list of suggested reading at the end of the article. Points of interest are **boldface** when they are first mentioned in the text. Other points of interest are listed in the free pamphlet handed out by the National Park Service.

### GEOLOGICAL STORY

From Utah to the Sierra Nevada, north-south trending basins and mountain ranges parallel one another. Geologists call this the Basin and Range province. It is also known as the Great Basin because its rivers have no outlets to the sea.

Death Valley is the outstanding example of basin and range topography. The valley floor lies below sea level. The surrounding ranges reach as much as two miles into the sky. The valley is a "graben," a sunken block of the earth's crust. The surrounding mountains are uplifted blocks, or "horsts." The combination of raised and lowered fault-blocks has created a 3,000 square-mile geological museum.

This museum includes Precambrian rocks like those in the Black Mountains. These are sediments over a billion years old — altered by subterranean heat and pressure into gneiss, schist, and marble. Younger Precambrian rocks record the erosion and redeposition of some of the oldest rocks.

During the Paleozoic Era, 600 million to 200 million years ago, seas covered much of this part of the world. The continents were elsewhere. Sand, silt, and calcium deposits accumulated on the bottom of these seas, building layer upon layer until they exceeded 30,000 feet in thickness. Compressed into rock, faulted and folded through 300 million years of earth history, these layers form the multi-colored walls of **Death Valley**.

During the Mesozoic Era which came next there were four separate episodes of mountain building, each distorting the record of the rocks.

During the Cenozoic Era, which started 60 million years ago, the **Death Valley** of today was formed. The basin and range topography began to take shape about 35 million years ago. Faults, trending north and south, developed in the earth's crust. Along these cracks the fault-block mountains and basins began to assume their present form. Volcanoes poured out cubic miles of lava and exploded rock fragments into the atmosphere to settle as dust on the forming land. The blocks, whether mountain or basin, are highest on their west sides. As you can see from **Dantes View**, the western fronts of **Death Valley's** mountain ranges are much steeper than their gently sloping east sides.

As the mountains lifted higher they met increasing erosion. Canyons were cut into the mountains. Basins filled

with rock debris washed from above. The rock fill in **Death Valley** is 10,000 feet thick beneath **Mesquite Flat** — that is the depth to the bedrock floor of the basin.

Geologists are still unraveling the details of the story and the origins of the forces that created **Death Valley**. The earth's crust is broken into "plates," which move slowly across the face of the globe. These plates are rafted on convection currents that rise from the molten center of the earth. As the plates move, they are subject to forces that both stretch and compress them. The result is the varied and often spectacular surface of the planet earth.

Volcanism, mountain-building, and erosion have gone on together in **Death Valley** for millions of years. **Ubehebe Crater** was formed by a massive volcanic explosion. This happened recently — it could have been a few hundred years ago; at the most, a few thousand. The colorful rocks of the **Artists Drive** are faulted and folded layers of both sedimentary and volcanic rock. The badlands of **Zabriskie Point** are carved from muds washed into a shallow lake that existed when the **Black Mountains** began their rise. The pinnacles in **Furnace Creek Wash** are the eroded remnants of an alluvial fan that issued from the **Black Mountains** when they were younger and lower.

The climate has shaped the surface of the land. As the Ice Age ended, the glaciers of the Sierra Nevada melted, releasing the water that had been stored as ice. The water flowing off the Sierras was impounded in a series of lakes, each filling and overflowing into the next lower desert basin. Glacial melt-water progressed from **Owens Valley** to **China Lake** and **Searles Lake**, to **Panamint Valley** where a lake reached a depth of over 900 feet, and finally, into **Death Valley**, forming **Lake Manly**. Waves from **Lake Manly** carved a bench on the north side of **Shoreline Butte** that is 600 feet higher than **Badwater**. Wave action continued as the short-lived **Lake Manly** evaporated. Now several shorelines are visible as horizontal lines across the face of the butte.

Another climatic change produced a shallow lake in **Death Valley** about 2,000 years ago. This lake was only 30 feet deep, but it covered 200 square miles. When the lake evaporated, it left the vast expanse of salt-pan that is one of **Death Valley's** great geological exhibits. Such lakes must have formed many times in the past because cores from well drillings reveal many alternating layers of mud and salt.

**Death Valley's Sand Dunes** are composed of sand gathered near **Stovepipe Wells** by the interaction of wind with the surface of the land. South winds, crossing the salt-pan, carry little sand, but north winds gather sand the length of **Death Valley Wash**. These winds are forced to climb over **Tucki Mountain**. The sand is left behind as the winds sweep up, forming sand dunes in the center of **Death Valley**.

The alluvial fans in the valley are classic in shape, im-

mense in volume. Fans issue from each canyon. As they grow they meet their neighbors and coalesce to form aprons along the foot of each mountain range. Each fan is formed of material washed from its canyon; each rain adds to their volume.

The Death Valley of today is the product of random geologic forces that have operated for billions of years. Because the same forces are still at work, Death Valley is unfinished — a land continually changing into something different.

## PLANTS AND ANIMALS

How can life exist in this, the hottest of deserts? Summer shade temperatures frequently exceed 120°F.; ground temperatures soar to 180°. Yet some winter nights are below freezing. Much of the water and soil is salty. The average rainfall is 1½ inches a year.

The plants are adapted to these conditions. Roots are either deep or wide-spreading to capture as much precious moisture as possible. Leaves are small, curved, or have been dispensed with entirely. Resins, spines, and hairs reduce water loss from evaporation. Shallow-rooted plants, such as creosote bush, are regularly spaced. The available water determines their distance apart. Wildflower seeds may lie for years in the dry soil, awaiting the proper combination of rainfall and temperature to trigger growth. Some seeds germinate, grow, flower, produce seeds, and die within just a few short weeks.

Deep-rooted plants that require a lot of water grow here, too — but only if they are salt-tolerant species like mesquite or arrowweed. The most salt-tolerant plant of all is pickleweed, which grows at the very edge of the saltpan.

Most animals forage and hunt at night, or at dawn and dusk. Many reptiles hibernate during the winter. Wildlife is concentrated around the many springs dotting both the valley floor and the surrounding mountains. Some rodents such as kangaroo rats are not tied to the water supply. They manufacture their own water by combining hydrogen and oxygen molecules from the seeds they eat, producing H<sub>2</sub>O. Predators — coyote, kit fox, and bobcat — obtain much of their water from the bodies of their prey.

Five species of pupfish, *Cyprinodon*, live within the monument. The length of the pupfish, depending on the species, varies from an inch to two and one-half inches. They feed on algae, plankton, crustaceans, and insects. Pupfish are descendants of fishes that swam in Ice Age lakes. As the lakes evaporated thousands of years ago the pupfish adapted to smaller habitats, to warm water, and to waters that vary in temperature and salinity with the seasons. Bighorn sheep live in the mountains around Death Valley. Shy creatures, inhabiting the most inaccessible peaks and canyons, they are seldom seen by man. Their minimal water requirements and “nervous” feeding habits allow them to range widely, with little damage to the fragile plant community.

Bighorns share portions of their range with burros, descendants of animals that carried prospectors’ gear to Death Valley and then escaped or were turned loose. They have no natural enemies here, and they have badly over-grazed many areas.

Because of Death Valley’s topographic extremes, from 282 feet below sea level to 11,049 feet at the summit of Telescope Peak, there are a great number of different habitats. Sidewinder, lizard, ground squirrel, and kangaroo rat share the valley floor with kit fox, coyote, and hawk. They live in and around the creosote bush and desert holly, the mesquite, arrowweed, and salt grass. Bristlecone pines, some over a thousand years old, are found on the highest peaks. Limber pine, pinyon pine, and mountain mahogany provide cover for mule deer. Desert shrubs, sage, and cactus cover the middle elevations. Golden eagles and falcons soar high above the desert.

## HISTORY

**The First People.** Four distinct Indian cultures have been identified from archeological sites in Death Valley. The oldest artifacts may be 9,000 years old. Death Valley never supported a large human population. Families camped at water sources on the valley floor during the winter and migrated to the cooler mountains with the coming of hot weather each spring.

Shoshone Indians have lived in Death Valley for almost a thousand years. Their staple foods were mesquite beans and pinyon nuts, augmented by other edible plants.

**The New People.** In December, 1849, pale-skinned newcomers, with oxen and wagons, “discovered” Death Valley. On their way to the gold fields, they had taken a shortcut that almost cost them their lives. They came down Furnace Creek Wash and out onto Death Valley’s saltpan. They looked up from the saltpan to see their route blocked by the massive bulk of the Panamint Mountains. One Forty-Niner died here; the rest escaped. The Wade family drove their wagon out the low south end of the valley; all of the other wagons were abandoned. The Bennett and Arcan families camped for a month on the west side of the saltpan while two courageous young men, William Lewis Manly and John Rogers, walked to the San Fernando Valley for supplies, and returned to lead the despairing families to safety. As they crossed the Panamint Range, one weary traveler looked back and named Death Valley.

**Miners.** One of the Forty-Niners left Death Valley with a piece of silver, from which grew the legend of the Lost Gunsight lode. The first prospectors returned to Death Valley in 1850; the “single-blanket jackass prospector” roamed the desert with burro, pick, and pan. Boom towns grew up and disappeared almost overnight; Panamint City in 1873, Chloride City in 1878, Rhyolite and Harrisburg in 1905, Greenwater and Skidoo in 1906, and Leadfield as late as 1925. Ashford Mill and the Wildrose Charcoal Kilns are other sites associated with metals mining in the Death Valley region. Some silver and gold were recovered, but most investors were left with unrealized dreams and unfulfilled hopes.

**Borax.** Borax was an exception to Death Valley’s boom-and-bust history, although Isadore Daunet, who first mined borax in 1881, went bankrupt and committed sui-

cide in 1884. Almost nothing remains of his **Eagle Borax Works**.

Borax belongs to a group of boron-minerals (called borates) that form quartz-like crystals, fibrous cottonballs, or an earthy white powder. The borates originate in hot springs or the fuming vapors associated with volcanoes. Water moved soluble borates to the floor of Death Valley. Evaporation there left a mixed white crust of salt, borax, and alkalies.

Many California and Nevada salt flats were claimed by prospectors during the borax boom of the 1870's. Aaron Winters located borax on a Death Valley saltmarsh in 1881. His claims were soon purchased by W. T. Coleman, builder of the **Harmony Borax Works**, where marsh muds sledged in by coolies were refined until 1889. Coleman's company beat the heat by moving summer operations to the Amargosa Works near less-torrid Shoshone. To reach the railhead at Mojave, Coleman hitched 20-mule teams to gigantic borax wagons with a payload in tandem of over 20 tons.

By 1890, saltmarsh operations were obsolete, and F. M. "Borax" Smith consolidated most claims into the Pacific Coast Borax Company, which then concentrated upon mining glassy veins of a rich new borate in the Calico Mountains. Not until 1907 did this same new mineral, colemanite, bring the miners back to Death Valley, first at the Lila C. Mine and after 1914 at **Ryan**. The famous mule teams of the '80's saw temporary use in the Calicos and a brief revival at the Lila C., but each operation eventually replaced them with a narrow-gauge railroad. From 1928 to 1971 Death Valley's borax was again closed down. Tenneco, Inc. began an open pit operation near Ryan in January, 1971. The colemanite is hauled for processing to a plant north of Death Valley Junction (see the articles in this guidebook).

Uses of Borax: Ceramic industries use over half America's borax in producing pottery glazes, china, and porcelain enamel. Heat-resistant borosilicate glass goes into ovenware, lenses, fibreglass. As a flux and deoxidizer, borax is used in welding, soldering, brazing, smelting, and refining of metals. As a mild antiseptic, it is used in disinfectants, gauze, salves, and eyewash: as a mold-retarding wash on citrus fruits, leathers, and textiles; and as a preservative in cosmetics, glues, and foods. As solvents and emulsifiers, borax solutions are used in manufacturing coated papers, playing cards, plywood, plaster, paint, and leathers. In fertilizers it prevents boron-deficiency diseases of celery, turnips, apples, tobacco, sugar beets, and alfalfa; yet, high concentrations produce a weed-killer toxic to plants. Boron-steel alloys go into armor plate. A new boron fibre developed by the space program is lighter than aluminum, yet stronger than steel. Boron carbide for cutting tools is an abrasive second only to diamond in hardness.

In the 1920's the Pacific Coast Borax Company, taking advantage of the scenery and ideal winter climate, started to promote tourism in Death Valley and built Furnace Creek Inn. By 1933 Death Valley was sufficiently popular that President Herbert Hoover proclaimed Death Valley National Monument.

## SEASONS

Death Valley's climate is ideal for six months of each year, from November through April. Daytime temperatures are mild. There are a few nights below freezing each winter.

### TEMPERATURES (degrees Fahrenheit)

	Lowest	Highest	Average	
			Minimum	Maximum
January	15	87	40	65
March	30	101	53	81
May	42	120	70	100
July	52	134	88	116
August	65	126	85	114
October	32	110	61	92
December	19	86	40	66

The same storms that blanket the Sierra Nevada with snow bring wind and a little rain to the valley each winter. Windstorms become more common in the spring.

Death Valley's summers are hot, and there is little nighttime cooling. The 134° temperature, recorded July 1913 at Furnace Creek, is the second highest shade temperature ever recorded in the world. A weather station at Azizia, Lybia, in North Africa, recorded 136° in 1922. Summer visitors are urged to obtain free copies of **HOT WEATHER HINTS**, available at the Furnace Creek Visitor Center, at ranger stations, and at major monument entrances.

## SERVICES

### COMMERCIAL SERVICES AVAILABLE WITHIN DEATH VALLEY NATIONAL MONUMENT

	Gas	Meals	Rooms	Store	USPO
Furnace Creek Ranch	x	x	x	x	x
Furnace Creek Inn		x	x		
Stovepipe Wells Village	x	x	x	x	
Scotty's Castle	x	Snacks			

## MUSEUMS

**DEATH VALLEY MUSEUM**, Furnace Creek visitor center. Exhibits outline the geological, climatic, biological, archeological, and historical themes. A slide program is presented hourly every day. Park rangers present day and evening programs through the winter season.

**BORAX MUSEUM**, Furnace Creek Ranch. The building was once a miner's bunkhouse in Twenty Mule Team Canyon. Open only in winter, the museum features twenty-mule team wagons, mining equipment, the history of borax mining in Death Valley, and an excellent mineral collection.

## FURTHER READING

### BIOLOGY

- Bighorn of Death Valley*, by Ralph E. Wells and Florence B. Wells: National Park Service, 1961, 242 p.
- Birds of Death Valley National Monument*, by Monument Staff: Death Valley Natural History Association, 1971. Checklist.
- California Desert Wildflowers*, by Phillip A. Munz: University of California Press, 1969, 120 p.
- Death Valley Wildflowers*, by Roxanna S. Ferris and Jeanne R. Janish: Death Valley Natural History Association, 1973, 147 p.
- Fishes, Amphibians, Reptiles, and Mammals of Death Valley National Monument*, by Monument Staff: Death Valley Natural History Association, 1972. Checklist.

### GEOLOGY

- Death Valley Origin and Scenery*, by John H. Maxson: Death Valley Natural History Association, 1972, 60 p.
- Guidebook, Death Valley Region*: Death Valley Publishing Co., 1974, 97 p.
- (other geologic reports on the area covered by this guidebook are mentioned in the roadlog and other articles)

### HISTORY

- Camels and Surveyors in Death Valley*, by Arthur Woodward: Death Valley '49ers Inc., 1961, 75 p.
- Fifty Years in Death Valley*, by Harry P. Gower: Death Valley '49ers Inc., 1969, 145 p.
- Goodbye Death Valley*, by L. Burr Belden: Death Valley '49ers Inc., 1956, 61 p.
- Indians of Death Valley*, by Lydia Clements; Cloister Press, 1953, 25 p.
- Rhyolite*, by Harold O. Weight and Lucile Weight: The Calico Press, 1972, 40 p.
- Twenty Mule Team Days in Death Valley*, by Harold O. Weight: The Calico Press, 1955, 45 p.
- Wildrose Charcoal Kilns*, by Robert J. Murphy: Death Valley '49ers Inc., 1972, 23 p.

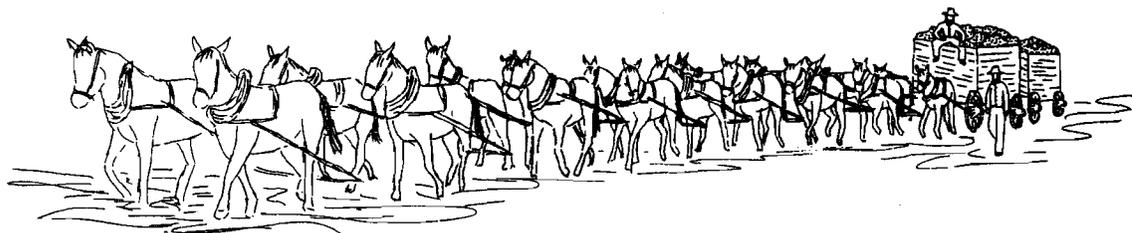
### GENERAL WORKS

- Death Valley, The Story Behind the Scenery*, by William D. Clark: K. C. Publications, 1972, 32 p.
- Exploring Death Valley*, by Ruth Kirk: Stanford University Press, 1969, 88 p.
- Badwater, a self-guiding auto tour*: Death Valley Natural History Association, 1968, 15 p.

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These, and other, books and pamphlets on Death Valley may be purchased at the Visitor Center or by mail. For a price list and order form write: Death Valley Natural History Association, Box 188, Death Valley, California 92328.

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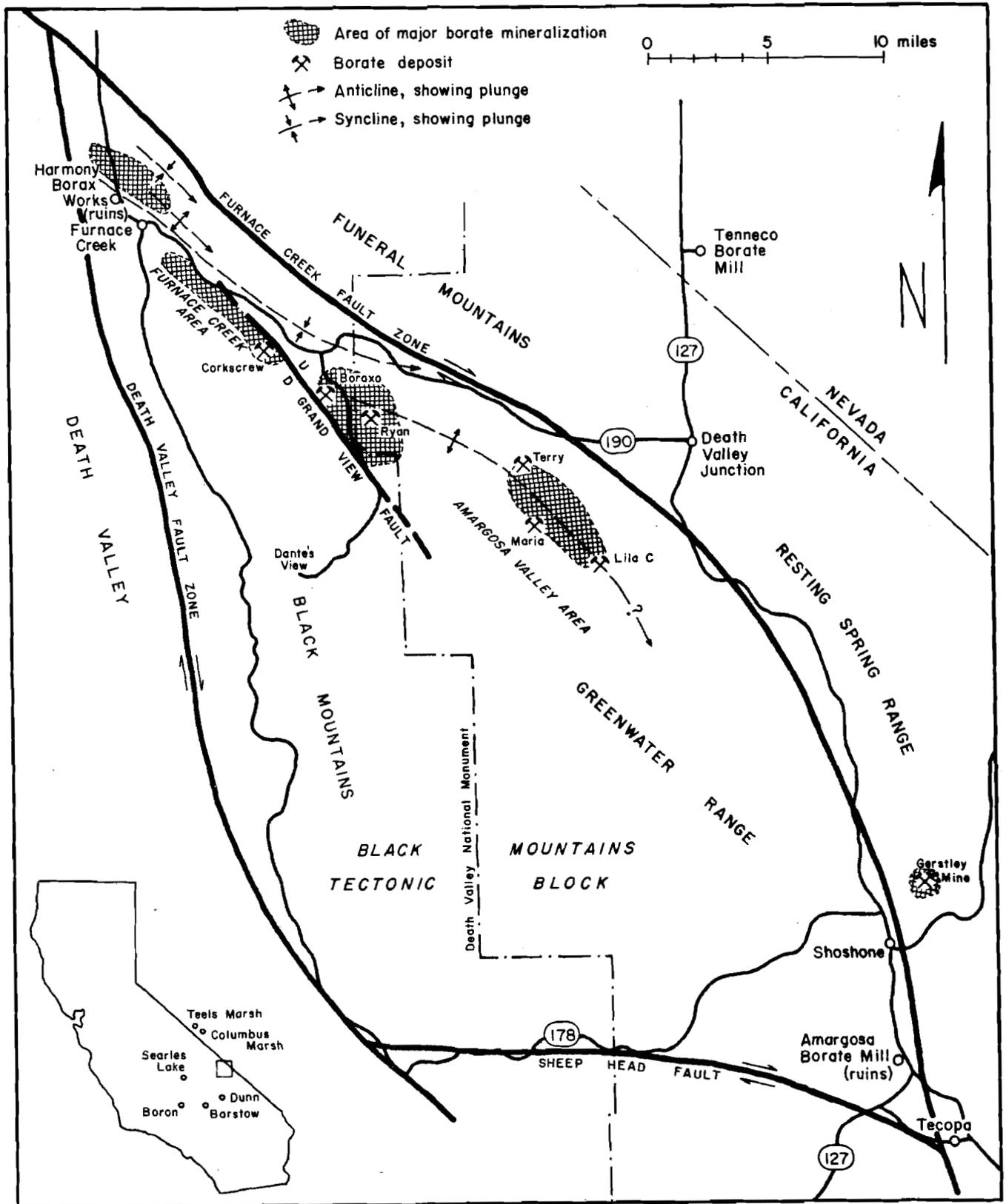


FIGURE 1. Map showing borate areas and structural features in the Death Valley area.

## BORATE DEPOSITS IN THE DEATH VALLEY REGION

James M. Barker and Jeffrey L. Wilson

Tenneco Mining, Inc.

Borates occur in three areas comprising 315 square miles in the Death Valley region (fig. 1). The Furnace Creek and Amargosa Valley areas together form a zone 7 miles wide and 30 miles long in the Greenwater Range and Black Mountains. The Shoshone area is 15 miles to the southeast on the southwestern flank of the Resting Spring Range and is 7 miles wide and 15 miles long. A thick sequence of volcanic rocks covers the intervening terrain.

### HISTORY

Borate mining in the Death Valley region has been an on and off affair. Those involved had an understandably strong desire to produce borates under less demanding conditions anywhere else, even for short periods. This is demonstrated in the following account which draws heavily on the centennial booklet issued by U.S. Borax Co. (1972) and a paper by Ver Planck (1956).

American borate mining can be separated into three periods: (1) **Playa Surface Mining** (to 1890) during which new discoveries were rapid and initial market penetration was achieved; (2) **Underground Mining** (1890–1957) first of colemanite, which was harder to process than the playa borates (borax and ulexite), but occurred in much larger and more concentrated deposits, and later of borax and kernite; and (3) **Open Pit Mining** (since 1957) dominated by the economics of the huge deposit of borax and kernite at Boron, Calif.

**Playa Surface Mining (to 1890).** The first commercial borax production in the United States was at Borax Lake, Calif. from 1864 to 1868. At about the same time, minor borax production began at Columbus Marsh in southwestern Nevada, and in 1872 Frances M. Smith discovered abundant ulexite in nearby Teels Marsh. After gaining control of both Teels and Columbus Marshes, Smith's company became the leading borate producer in the United States although the total production to 1892 was only 17,000 tons. Searles Lake, Calif. was a close second in production following its discovery in 1874.

In 1881, Aaron Winters found ulexite on the playa near the mouth of Furnace Creek Wash in Death Valley. He sold his find to William T. Coleman who built Harmony Borax Works to compete against Smith. This discovery initiated a shift in borate mining dominance from Nevada to California. At Harmony Borax Works the ulexite was boiled and borax allowed to crystallize upon cooling. Summers were so hot that crystallization would cease and operations had to be moved seasonally to cooler Amargosa, just south of Shoshone.

Twenty-mule-team wagons, making a 20-day round trip, hauled up to 37 tons of product plus supplies 165 miles to the nearest railroad. Other methods were tried, but only a railroad could outperform the reliable wagons.

**Underground Mining (1890–1957).** In 1890, Frances Smith acquired the borax properties of the bankrupt William Coleman, and formed the Pacific Coast Borax Co. The focus of mining left Death Valley and centered near Barstow, Calif., where colemanite had been found in 1883 but had remained undeveloped due to Coleman's financial crisis. These mines became the first major underground borate workings and the principal borate source in the United States until 1907.

When ore ran out near Barstow in 1907, the Lila C Mine (fig. 1), near Death Valley Junction, began production that lasted only 7 years. During 1914, mining shifted to the large orebodies at Ryan near Death Valley. A railroad was built to haul the ore to Death Valley Junction for concentration by calcining. Ore from the Gerstley Mine, discovered near Shoshone in 1920, also fed this mill via rail.

In terms of tonnage this period represented the apex of activity in the Death Valley region, although the older playa surface activities have received greater historical note. Current Tenneco Mining, Inc. and future U.S. Borax and Chemical Co. activities will generate larger total production and may initiate a second underground mining period.

In 1913 borates were struck while drilling a water well near Kramer, Calif. Development began after World War I, and underground mines were producing 5,000 tons per month by 1927. Owing to this production at what later became Boron, borate mining in the Death Valley region was largely phased out by 1928, except for low tonnages for special uses.

**Open Pit Mining (since 1957).** Open pit mining was initiated at Boron in 1956, and when the first ore was uncovered in 1957 the Death Valley deposits of U.S. Borax became reserves.

Tenneco Mining, Inc. presently operates two small open pits (Boraxo and Sigma) near Ryan in Death Valley National Monument (fig. 1). A history of the Boraxo Pit, formerly the Thompson Mine, is presented below as described by Minette and Muehle (1974) with updating comments.

About 1915, the Boraxo deposit was first claimed as the Clara Lode by Pacific Coast Borax Co. Patent was applied for but, through error, was not granted. Unaware of this defect, Pacific Coast Borax began paying taxes on the claim and ceased annual assessment work.

In 1921, Russell, Monaghan, Barlow, and Hill discovered the title flaw and filed the Boraxo No. 1 and Boraxo No. 2 claims over the area. A classic court battle ensued and the new claimants were granted title, but very limited mining was done.

Pacific Coast Borax repurchased the property in 1935. However, antitrust charges concerning restriction of trade were filed by the U.S. Government. In 1945, after drawn-out litigation, Pacific Coast Borax Co. was ordered to divest itself of what had now become the Thompson Mine.

No buyers could be found until 1960 when Kern County Land Co. purchased the mine for \$200,000. Kern County Land Co. sank a 120-foot shaft and during the early 1960's shipped a few thousand tons of colemanite ore, the first significant production from the property.

They merged with Tenneco Oil Co. in 1967. Tenneco reopened the mine in 1970 as a small open pit about 0.25 miles west of existing shafts. Called the Boraxo Pit, the mine was excavated from west to east in a sequence of three adjoining elongate pits. Renewed drilling proved up a sizable extension of the orebody, and stripping for a new pit was completed by mid 1975. This pit will ultimately be 400 feet deep (cross section, fig. 2) with a scavenge operation to collect deeper ore. Colemanite is trucked to a washing-calcining plant north of Death Valley Junction (fig. 1). Ulexite/probertite is trucked to a grinding facility on the railroad at Dunn, Calif.

### STRATIGRAPHY

Rocks ranging from Precambrian to Quaternary are present in the Death Valley region. Only the Tertiary rocks that bear directly on borate geology are discussed.

**Artist Drive Formation.** T. P. Thayer (Noble, 1941, p. 955) originally defined the Artist Drive Formation at its exposure along the west face of the Black Mountains, north of Artist Drive. Correlatives (Shoshone Volcanics) crop out in the Shoshone area (Haefner, 1974, p. 59).

McAllister (1970, p. 3-4) divided the Artist Drive into five informal sedimentary members with a total thickness exceeding 4000 feet: (1) lower sedimentary member - brown to gray or red calcareous mudstone and sandstone with lesser conglomerate and minor limestone, together making up nearly half the total thickness; (2) lower pyroclastic member - massive, green to buff, partly zeolitized tuff-breccia; (3) middle sedimentary member - pale olive to light brown tuffaceous mudstone, sandstone, and conglomerate; (4) upper pyroclastic member - massive pale blue-green or grayish-pink tuff-breccia; and (5) upper sedimentary member - well-stratified, dark brown conglomerate and basalt in lowest portion with increasing amounts of greenish to reddish sandstone and mudstone upward in the Furnace Creek area, and greenish mudstone with intercalated red-weathering tuff stringers in the Amargosa Valley area.

Felsite and basaltic flows, sills, and dikes recur within the formation. Many portions of the Artist Drive appear similar to the Furnace Creek Formation, particularly where exposures are limited or igneous rocks occur. Difficulties in identification plus abundant intrusions and faults make correlations difficult and unsure (Drewes, 1963, p. 23).

Both fish fossils (Noble, 1941, p. 955-6) and diatoms (McAllister, 1970, p. 4) have been found in the Artist Drive Formation, suggesting respectively an Oligocene and early Pliocene age. Volcanic rocks referred to as Artist Drive Formation have been dated by the potassium-argon method as being 6 to 9 m.y. old (Fleck, 1970) suggesting a middle Pliocene age. The exact age of the formation remains unclear, but from the above evidence, we conclude that the

Artist Drive is possibly early Oligocene but is most likely early Pliocene in age.

**Furnace Creek Formation.** The Furnace Creek Formation is widely distributed within the Furnace Creek and Amargosa Valley areas, and is perhaps equivalent to the Gerstley Lake Beds in the Shoshone area.

Keyes (1923, p. 78) mentioned "Furnacean series" as the principal borate-bearing strata in Death Valley and as typically exposed in "Furnace Canyon". The chief borate bed and several interbedded diabase sheets were informally known as the "Mesa Negra" beds (Keyes, 1923, p. 61). Curry (Axelrod, 1940, p. 527-528) made first mention of the Furnace Creek Formation and briefly described the strata as several thousand feet of lavas, pyroclastics, and terrestrial sediments in the area drained by Furnace Creek Wash. More recently, McAllister (1970, p. 4-6) divided the formation into five informal sedimentary members and three types of volcanic rocks having a total thickness of 7000 feet in the Furnace Creek area. In the Amargosa Valley area, only two sedimentary members are present.

The lower portion of the Furnace Creek Formation is characterized by conglomerates, with varying constituents including borates, often termed "basal conglomerate member" though occupying slightly different stratigraphic positions. In the Furnace Creek area, the conglomerate may exceed 400 feet thick and is composed of either Artist Drive or Paleozoic detritus (McAllister, 1970, p. 4). In the Amargosa Valley area, the basal unit usually is thinner. It commonly is breccia or conglomerate composed of flat limestone chips ("chipstone") and minor Paleozoic carbonate and quartzite pebbles, although granule conglomerate with similar Paleozoic clasts in a tuff matrix also occurs. The imperfect distribution and diachronism of the basal conglomerate confuses distinction between Furnace Creek mudstone and similar-appearing mudstone in the upper sedimentary member of the Artist Drive Formation.

Borate-bearing horizons are prevalent in the lower portion of a lacustrine sequence above the basal unit. This is the main member of the Furnace Creek Formation and is predominantly tuffaceous mudstone, shale, and sandstone, with minor tuff and limestone. It generally is yellowish gray where weathered but is pale olive or darker at depth. The member typically consists of imperfect cyclic repetitions of thin- to medium-bedded calcareous mudstone and sandstone. The mudstone and shale are chiefly volcanic debris, montmorillonite, and subordinate illite, with small amounts of quartz, hornblende, biotite, feldspar, and calcite. Iron stain and dendritic pyrolusite are present along mudstone partings. Limestone laminations, chiefly micrite with minor sparite, are up to 0.20 inches in thickness, and are conspicuous in drill cores. They are dispersed in varying amounts within the sequence, but are typically more abundant near or within the borate horizons. Microfaults, brecciation, fractures, convolute bedding, and plastic deformation are common and conspicuous in zones with limestone laminations and borate mineralization. Interbedded tuff beds recur throughout the sequence and are usually lenticular and discontinuous. Load and flowage structures are found along the base of sandstone units which may also show grading.

Three additional sedimentary members occur in the Furnace Creek area, but are generally not discernible in the Amargosa Valley area: the gypsiferous member; the upper conglomerate member; and the upper Furnace Creek member.

The gypsiferous member is within the main lacustrine member and is composed of thin beds of fibrous gypsum interlayered with varying amounts of mudstone and minor borates. Gypsiferous horizons are commonly 100 to 200 feet thick but perhaps are not all in the same stratigraphic position.

The upper conglomerate member consists of poorly sorted, grayish-red conglomerate. It is massive to crudely stratified, and has Paleozoic clasts in a calcareous matrix. The conglomerate interfingers with lacustrine sediments and grades laterally into mudstone within a few tens of feet.

The upper Furnace Creek member contains distinctive white to orange pumiceous tuff beds and yellowish mudstone. It is opalized locally in irregular thin zones. McAllister (1970, pl. 1) noted that the unit is marked at its base by a pumiceous tuff and grades upward into sandstone and conglomerate. The upper Furnace Creek member is lighter colored than the underlying main member.

Fresh to deeply weathered, greenish-gray basalt flows and sills, which recur within the sequence, are often in near stratigraphic proximity with borate-bearing strata of the main lacustrine member. Dikes of similar composition are prevalent and may also cut the Artist Drive Formation. Fragmental and altered (palagonitic) basaltic sills or flows locally contain secondary borates or overlie large borate deposits.

A leaf fragment discovered in the upper portion of the formation by H. D. Curry was dated by Axelrod (1940, p. 531) as late Miocene to early Pliocene in age. Footprints of horses and other animals in beds correlative to the Furnace Creek Formation were dated by Curry (1941, p. 1979) as of probable middle Pliocene age. Diatom studies by K. E. Lohman (McAllister, 1970, p. 6) indicate that the upper Furnace Creek Formation is clearly middle Pliocene and the lower part is probably early Pliocene in age. Using potassium-argon dating techniques, Fleck (1970) obtained a minimum age of 5.4 m.y. and a maximum age of 6.3 m.y., approximately late middle Pliocene, for the Furnace Creek. From these data we conclude that the Furnace Creek Formation is early to middle Pliocene in age.

**Gerstley Lake Beds.** The Gerstley Lake Beds crop out only in the southern Resting Spring Range east of Shoshone, and have a total thickness in excess of 1000 feet. Wilhelms (1963, p. 123) named the unit and suggested that the lake beds occur only in the topographic "embayment" at the Gerstley Mine, but Tenneco geologists have traced them southeastward into Chicago Valley. The lake beds buttress against and partially overlie Paleozoic rocks in the Resting Spring Range. Drill data indicate that the lacustrine strata are present under surficial debris and may extend for several miles to the west and north of the Gerstley area.

The Gerstley Lake Beds are here divided into three informal members: (1) conglomerate — pale red to dark orange, with clasts of siltstone, quartzite, and carbonate in

a mud matrix; (2) breccia — white to yellow-gray, with borates, fragmented limestone laminations, occasional fine-grained sedimentary clasts, and abundant shale, tuff, clay, and cherty limestone interbeds; and (3) mudstone and shale — yellow to pale olive, calcareous and tuffaceous, with interbeds of tuff, basaltic sandstone, and limestone which increase in abundance and thickness near the base of the member.

The age of the Gerstley Lake Beds is uncertain. Wilhelms (1963) made no correlation or age estimate other than Tertiary. If the borates here are correlative to those in the Furnace Creek-Amargosa Valley areas, an early to middle Pliocene age is indicated.

**Gerstley Volcanics.** The Gerstley Volcanics overlie the Gerstley Lake Beds. The volcanics are rhyolitic but minor variations in cooling rate, composition, and thickness yield differences in the Gerstley area that allow division into four informal units: (1) lapilli tuff — blue gray but locally cream yellow, and partially welded but becoming extremely welded upward and laterally where thin; (2) welded tuff — black, thinning laterally to obsidian, with elongated glass inclusions and secondary silica nodules; (3) welded tuff — pink to lavender, with a fine-grained texture, pronounced lineation, some vesicles and amygdules, and a gradational upper contact; and (4) welded lithic tuff — pink with a fine-grained groundmass, abundant clasts (pumice, obsidian, and pyroclastic feldspar and hornblende), and vesicles and amygdules.

Age and correlation is uncertain beyond a limited area around the Gerstley Mine although the Gerstley Volcanics are clearly younger than the Gerstley Lake Beds and are apparently younger than the nearby Shoshone Volcanics.

## STRUCTURE

The borates of the Death Valley region are mainly in the triangular Black Mountains tectonic block which is bounded by the Death Valley, Furnace Creek, and Sheephead fault zones (fig. 1). This block differs from bordering ones by a widespread occurrence of Tertiary rocks and great disorder, particularly along the western edge. The elongate distribution of the borate deposits is conspicuously subparallel to the Furnace Creek fault zone, suggesting a structurally controlled Tertiary basin or line of basins. The Furnace Creek and Amargosa Valley areas are much folded and faulted.

Most faults within the Furnace Creek and Amargosa Valley areas trend northwest or east-west and are normal faults (McAllister, 1970, pl. 1; 1973), although lateral movement is significant on some. The Grand View fault is a major interior structure which runs along the western edge of the Greenwater Mountains and into the Furnace Creek area. Here it offsets areas of major borate mineralization between the Boraxo Pit and Corkscrew Mine. The Grand View fault has dip separation that may total several thousand feet with the Black Mountains (southwest) side down.

Folding is common in the Furnace Creek and Amargosa Valley areas, but is subordinate to the faulting. The folds generally trend northwestward and tend to be poorly de-

finned except near faults. The major anticlines and synclines plunge southeastward, but the smaller folds are more variable. Many of the borate deposits occur along a large, poorly defined, and much-faulted anticline truncated by the Grand View fault northwest of Boraxo Pit.

The Shoshone area is outside the Black Mountains tectonic block and is less deformed than the other borate areas. The Tertiary rocks form a homocline dipping gently south-eastward with little variation except near faults.

### ORIGIN OF DEPOSITS

The Death Valley deposits have formed in three ways: (1) by precipitation from a permanent or semi-permanent shallow lake; (2) by recrystallization, on the Death Valley playa, of borates derived mostly from erosion of pre-existing lake deposits; and (3) by recrystallization at depth of borates mobilized by changes in the micro-geochemical environment. Deposits formed by the latter two modes of deposition are small and now uneconomic, and only the lake deposits are discussed further.

Large-scale borate formation in lakes requires several factors to be in operation simultaneously. Borates have relatively high solubilities, so an arid environment helps produce boron supersaturation in a lake and allows the borates to remain solid after deposition. An interior drainage system with a relatively small drainage area (to minimize borate dilution by competing ions and clastics) are hydrologic requirements. A boron source is required, and usually is a nearby hot spring associated with late-stage volcanism. Borate precipitation may be aided by cooling of boron-rich hot-spring water.

The existing basin and range topography has characteristics suitable for the accumulation of borates. Basin and Range faulting began during Eocene time and is continuing today. Interior drainage developed in the Oligocene (Nolan, 1943, p. 16) and intensified later. Aridity increased, and remains today, due to blocking of marine moisture by mountain uplift to the west.

The crustal extension that formed the Basin and Range Province was accompanied by much Miocene to Pleistocene volcanism. The Artist Drive Formation is dominantly pyroclastic, whereas the lower part of the Furnace Creek Formation has only minor volcanic rock. This indicates that volcanism was temporarily waning in the Death Valley region by lower Furnace Creek time. Waning volcanic activity associated with boron-saturated magma would have hot-spring emission of boron (Krauskopf, 1967, p. 428; Chorlton, 1973, p. 6-7). The Basin and Range Province has many active hot springs, some of which emit boron, and hot-spring activity probably was more prevalent during the increased volcanic activity of the past. The close association of borates in the Death Valley region with the Furnace Creek fault zone suggests that a lake basin may have been related to movement along the fault, and that this structure was the avenue by which boron-rich hot water reached the surface. The association of large borate deposits with arid regions in the tectonic-volcanic belts of the eastern Pacific and Mediterranean (Kistler and Smith, 1975, p. 478-479) further support these views.

TABLE 1. Composition of some borate minerals.

Mineral	Chemical Composition	% B <sub>2</sub> O <sub>3</sub>
Colemanite	Ca <sub>2</sub> B <sub>6</sub> O <sub>11</sub> ·5H <sub>2</sub> O	50.8
Ulexite	NaCaB <sub>5</sub> O <sub>9</sub> ·8H <sub>2</sub> O	43.0
Probertite	NaCaB <sub>5</sub> O <sub>9</sub> ·5H <sub>2</sub> O	49.6
Hydroboracite	CaMgB <sub>6</sub> O <sub>11</sub> ·6H <sub>2</sub> O	50.5
Priceite	Ca <sub>4</sub> B <sub>10</sub> O <sub>19</sub> ·7H <sub>2</sub> O	49.8
Borax	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	36.5
Kernite	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·4H <sub>2</sub> O	51.0

The borates in the Boraxo, Maria, and Gerstley areas apparently were first deposited as the high hydrate ulexite (8H<sub>2</sub>O, see table 1). Later diagenesis and remobilization plus regional folding, faulting, and erosion altered and complicated the initially simple borate mineralogy and distribution. Probertite and colemanite are low hydrates (5·H<sub>2</sub>O) and are not found as primary minerals (Meussig, 1959, p. 495-496). Probertite forms directly from ulexite by burial-induced dehydration. Colemanite could form by removal of sodium from probertite or ulexite by groundwater.

### DESCRIPTION OF DEPOSITS

The borate deposits at Boraxo, Maria, and Gerstley have some similar characteristics. All are brecciated and have contorted and convoluted bedding due to volume decreases caused by alteration of primary ulexite to secondary colemanite or probertite. The brecciation extends upward from the borate zone with decreasing magnitude, but is not important below it.

The breccia contains fragments of the rocks enclosing the borate beds, but limestone fragments are more abundant than in rocks surrounding the borate zones. Increased limestone deposition should be associated with borate deposition because calcium carbonate becomes less soluble as salinity rises and increasing salinities would be expected before, during, and possibly after borate deposition.

The shallower portions of borate zones usually are colemanite which is granular and porous. In places it has been completely altered to limestone, which may retain colemanite crystal habits. These effects are apparently caused by weathering and changes in post-depositional groundwater geochemistry.

The data presented below for the Maria and Gerstley deposits were derived solely from 2 1/8-inch diamond-drill cores. The Boraxo data are derived from cores and, to a lesser extent, from rocks uncovered during mining.

**Boraxo Orebody.** The Boraxo orebody (fig. 2) is a stratified, lenticular mass of probertite, ulexite, and colemanite in a single main zone up to 100 feet thick. The en-

closing strata have a moderate ( $20^{\circ}$  to  $30^{\circ}$ ) southward dip, but the borate zone sometimes dips more steeply ( $40^{\circ}$  to  $45^{\circ}$ ). The Pit fault truncates the orebody at its northeastern edge; dip separation on the fault is about 100 feet with a minimal lateral component and the northeastern side up.

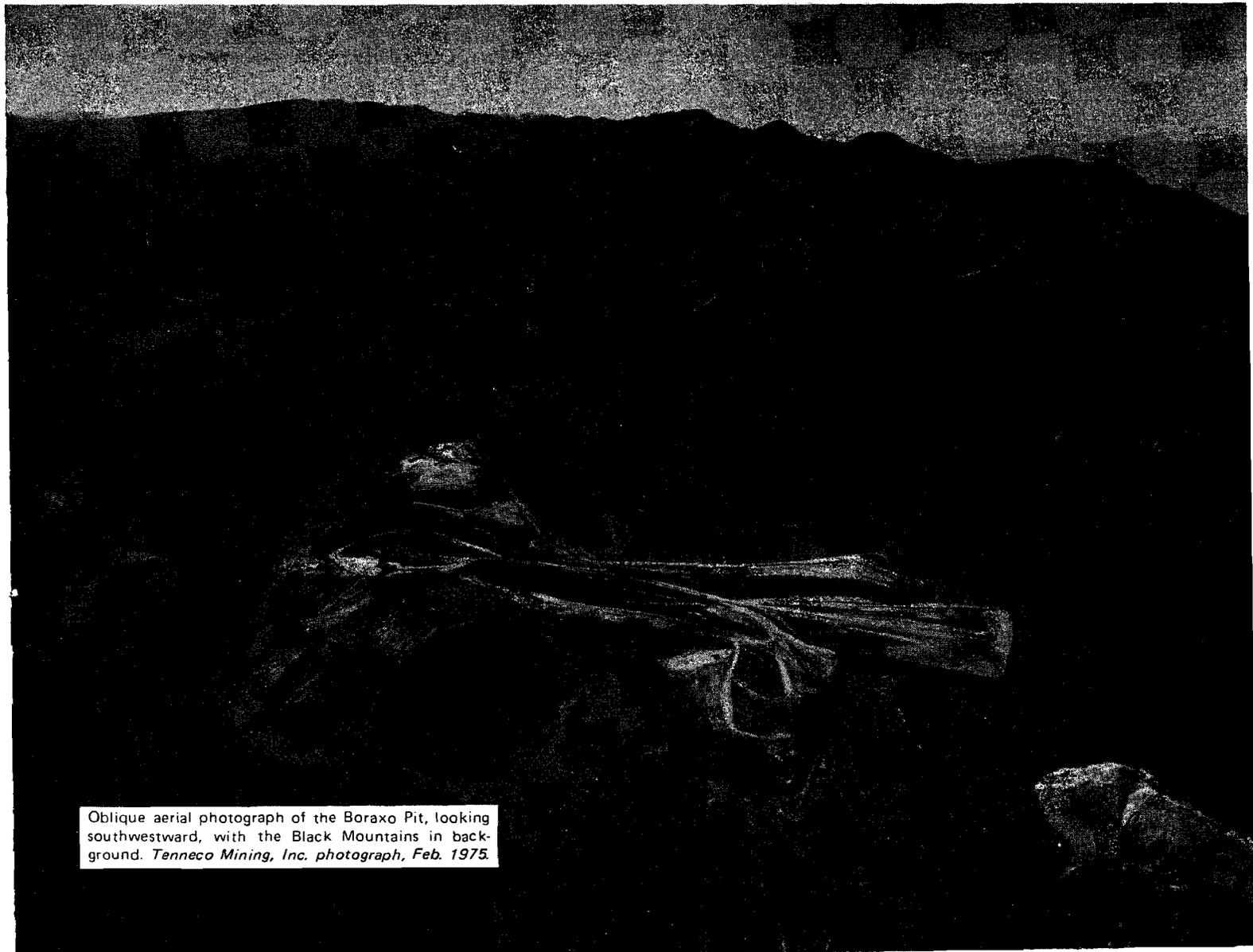
The borates are enclosed in well-indurated, calcareous, blue-gray shale with 10 to 20 percent white limestone laminations and scattered pebbles. Occasional thin interbeds of porous yellow-gray pebbly limestone and light-brown pebble conglomerate occur. The pebbles in these units are mainly red-brown to gray basalt, but green to white tuff, white to green quartzite, and gray shale also are present. Yellow-gray or brown waxy montmorillonite occurs in the conglomerate, and especially within the ulexite zones. Samples of this clay and clayey gouge along the Pit fault have high lithium and fluorine contents. Joseph R. Davis (1975, written communication) suggests this is due in part to hectorite, a lithium-bearing montmorillonite.

Within the borate zone, the shale and interbedded sediments are brecciated and mixed with borate minerals. The outer margins of the orebody interfinger with barren strata which are contorted and fractured, but are not brecciated.

The borate mass is chemically zoned and typically grades upward and laterally from probertite to mixed probertite and ulexite, then to ulexite, and finally to an envelope of colemanite. Substantial quantities of colemanite breach these general zones, and commonly occur as veins, fracture fillings, and cement. A very thin layer of colemanite with minor ulexite is common along the base of the deposit (cross section, fig. 2).

Colemanite makes up as much as 50 percent of the orebody, and at least 17 of its 64 known crystal habits are represented (Minette and Muehle, 1974, p. 71). Common forms in the Boraxo Pit include large equant, massive, radiating, and dog-toothed varieties as well as drusy, coarsely granular, and nodular types. Most of the high-grade colemanite is along the Pit fault where large, equant crystals line cavities and solution channels which are or were filled with water. Colemanite also occurs as cement in the conglomerate and as veins, pods, and vug fillings in the rocks near the ore zone.

White colemanite is most abundant although water-clear, golden-brown, and gray variations are present. The golden-brown coloration is due to a slight strontium content,



Oblique aerial photograph of the Boraxo Pit, looking southwestward, with the Black Mountains in background. *Tenneco Mining, Inc. photograph, Feb. 1975.*

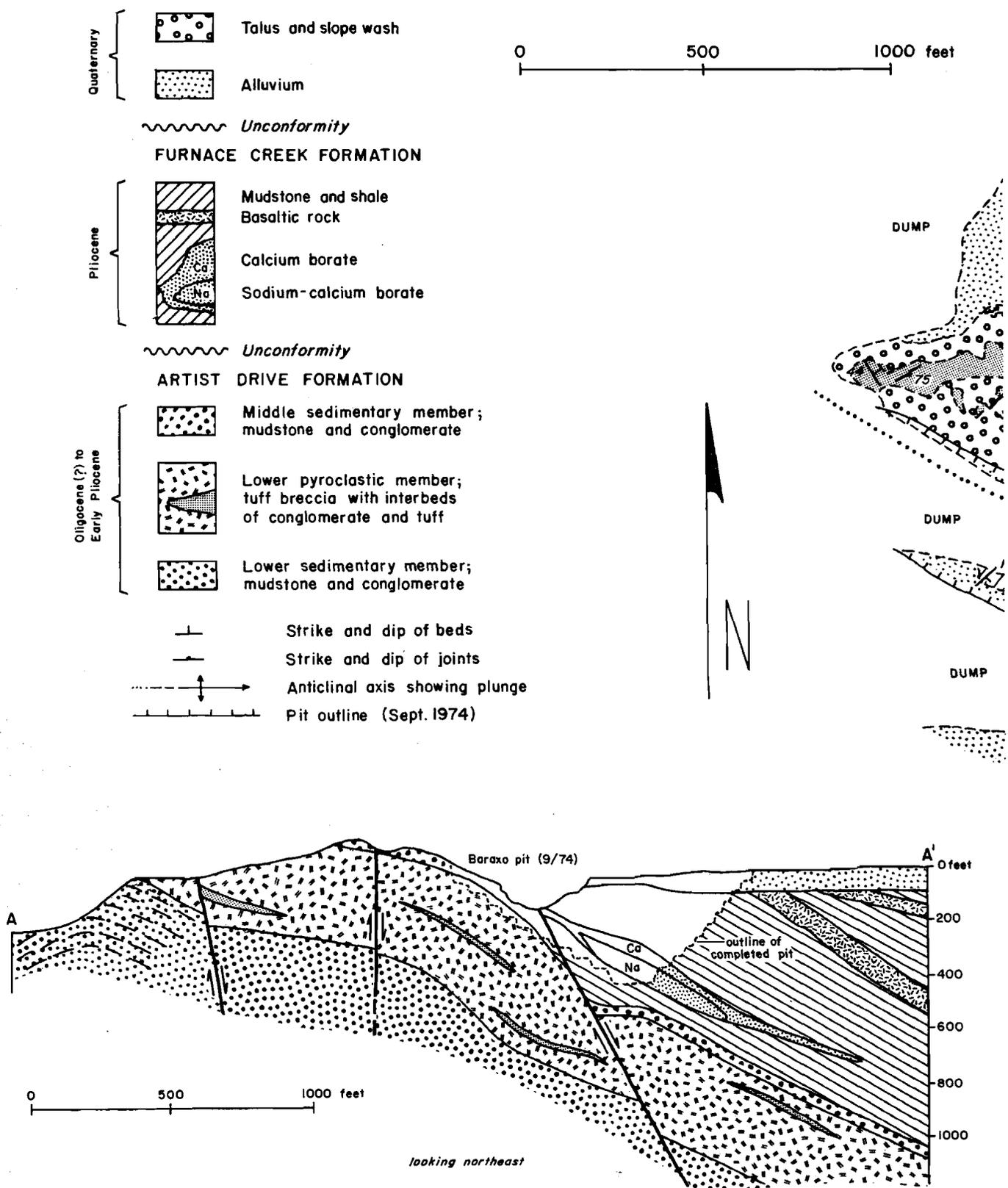
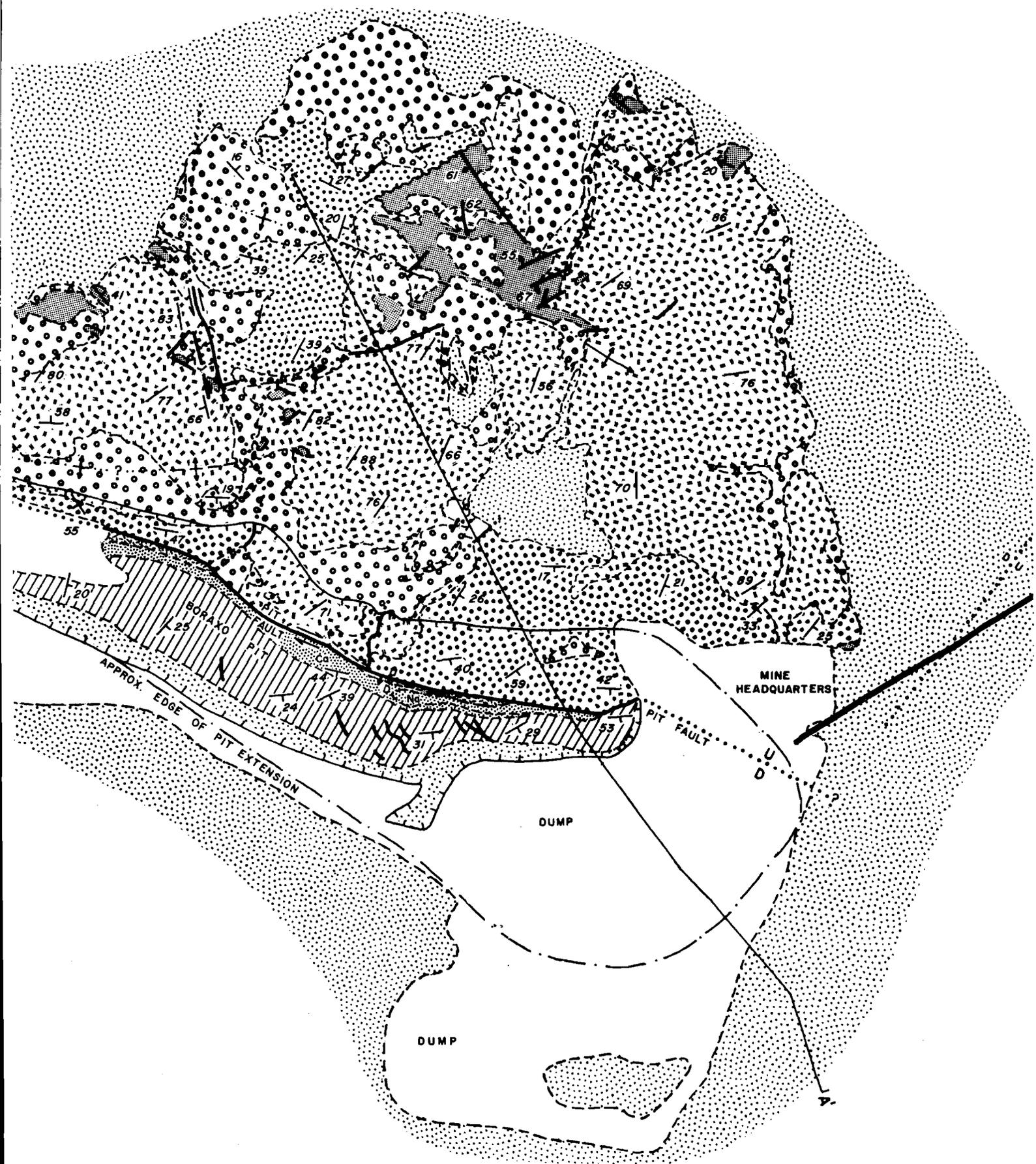


FIGURE 2. Geologic map and cross section of the Boraxo Pit area (S25 & 26, T26N, R2E SBM).



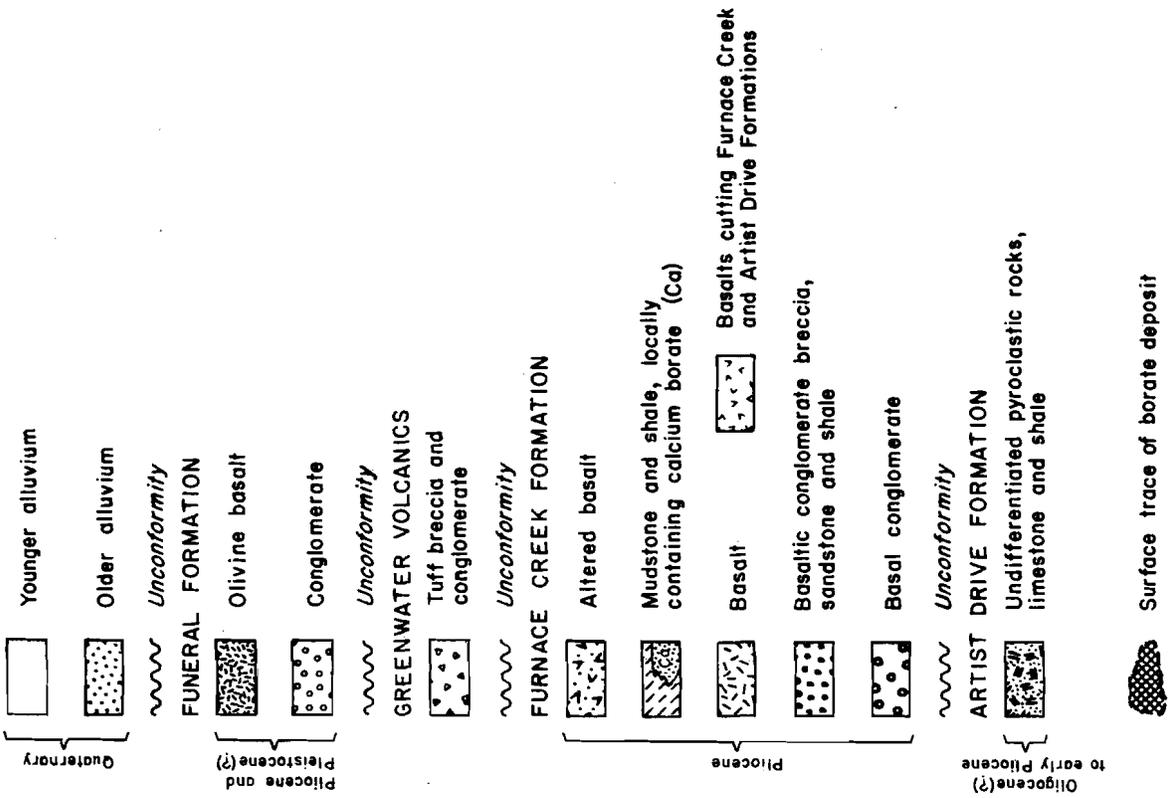


FIGURE 3. Geologic map and cross section of the Maria borate deposit (S3 & 4, T24N, R4E SBM).

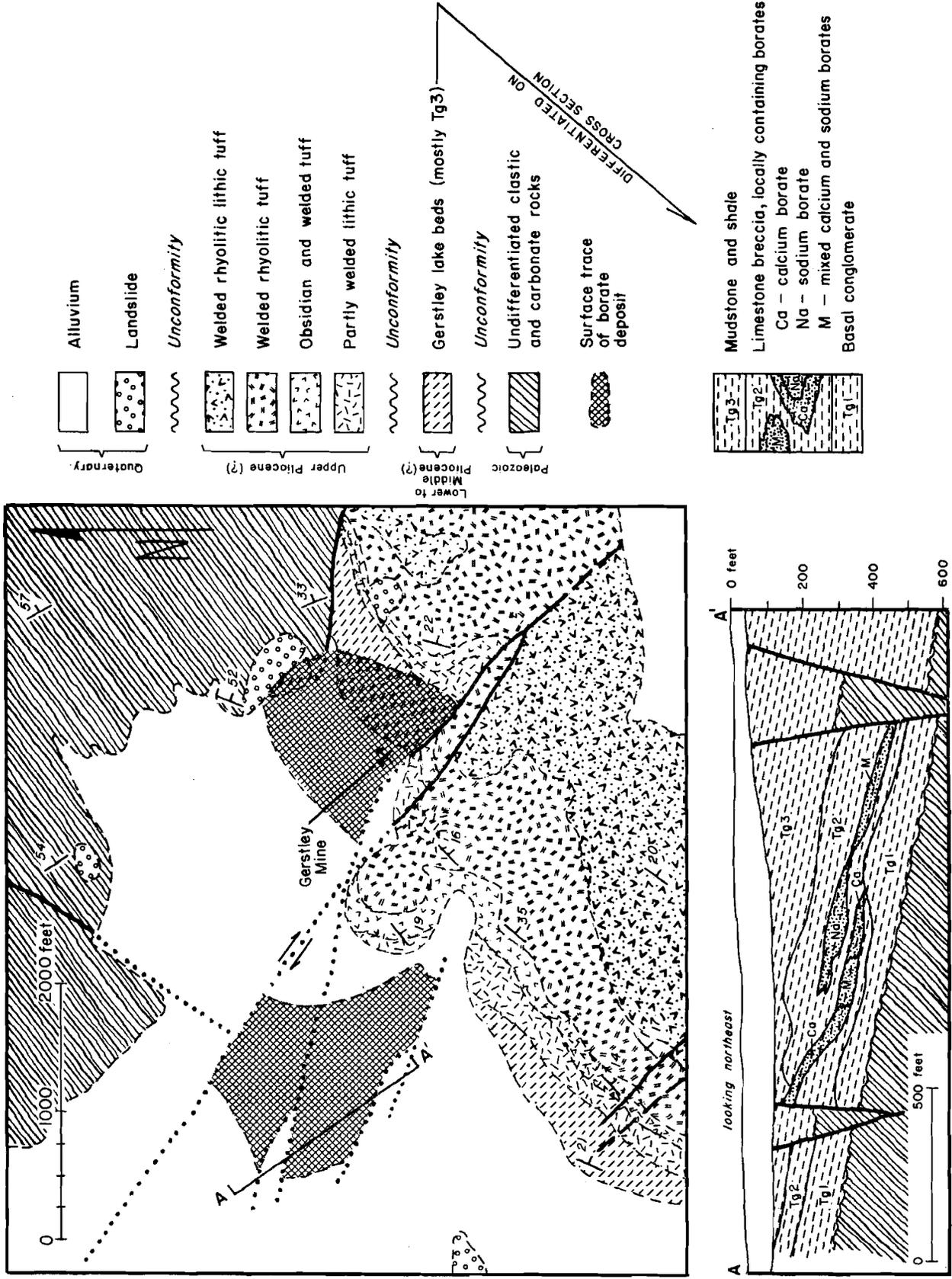


FIGURE 4. Geologic map and cross section of the Gerstley borate deposit (S8, 9, 16, 17, T22N, R7E SBM).

while the gray is a result of microscopic dispersions of clay (Minette and Muehle, 1974, p. 71).

Honey-colored probertite, in large radiating crystals, comprises 40 percent of the Boraxo deposit. Columnar, white ulexite, in massive-bedded bodies or thin veins, forms about 10 percent of the orebody. Several minor borates including white hydroboracite (radial) and white priceite (massive) are present along with sky-blue to white celestite and white calcite. The reader is referred to Minette and Wilbur (1973) and Minette and Muehle (1974) for additional discussions of mineralization at the Boraxo Pit.

The low arsenic content of the ores from the Boraxo Pit is a desirable commercial characteristic not shared by many borate bodies outside the Death Valley region.

**Maria Borate Deposit.** The Maria borate deposit (fig. 3) is a lenticular colemanite body in one main zone, up to 38 feet thick, that dips gently ( $10^\circ$ ) eastward. A fault with small (?) dip separation truncates the body along its eastern margin, with the west side down.

The colemanite body is enclosed in blue-gray calcareous shale with 5 to 20 percent gray to white limestone laminations and numerous interbeds of greenish-black basaltic sandstone. The shale, limestone, and sandstone are brecciated and highly contorted within the borate zone.

Gray to white colemanite comprises more than 99 percent of the borate body which has a very small core of primary (?) ulexite. Small amounts of secondary ulexite occur above the deposit in undistorted shale. Colemanite is most common as small radial clusters in massive irregular bodies within the mineralized zone, but also occurs as cement in the sandstone, matrix in the shale (up to 50–60 percent), lining small vugs, and filling fractures within the borate zone and in the shale and basalt breccia below it. Thin horizons of massive colemanite also occur in shale above the main zone and bladed crystals of golden-brown colemanite greater than 2 inches in length occur near the fault.

**Gerstley Borate Deposit.** The Gerstley borate deposit (fig. 4) is composed of colemanite (85%) and ulexite (15%), with minor probertite. Up to three main borate zones occur with a maximum combined thickness of 150 feet including thick waste zones. The deposit dips southeastward at about  $25^\circ$  and is truncated by a fault on its northeastern side. The offset portion is at the Gerstley Mine indicating a lateral fault separation of about 2000 feet. Lesser faults within the ore zone have juxtaposed borates and Paleozoic rocks. The Gerstley borate deposit is more complex than the Boraxo and Maria, and has many interfingering zones (cross section, fig. 4).

The borate-rich bodies are enclosed in light-brown to grayish-green shale, that has interbeds of white to orange limestone, brown clay, and green to gray basaltic sandstone/conglomerate. The amount of limestone increases near the borate zones, and it is both bedded and nodular. Fragments and highly contorted blocks of the above rocks make up the clasts of the breccia that comprises the borate zones.

Colemanite occurs as radial aggregates or massive cement within the breccia, and as vug and fracture fillings in beds

surrounding the main borate zones. Thin beds of massive colemanite mixed with ulexite also occur between the main zones.

Ulexite occurs in the main zones with colemanite (mixed zone) and in pure form in deeper zones. Secondary ulexite occurs in the shale and sandstone above the main zones. Minor probertite is encountered in deeper portions of the borate zones.

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# TENNECO OIL'S COLEMANITE MILLING OPERATIONS NEAR LATHROP WELLS, NEVADA

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Borate that contains little or no sodium is an essential raw material in the manufacture of textile grade fiberglass. Before Tenneco began production in 1971, the only sodium-free borates commercially available were boric acid and high grade Turkish colemanite ore. The Tenneco borate is a calcined concentrate, averaging 47 percent  $B_2O_3$ . It is produced from a colemanite ore mined in Death Valley National Monument.

The basis for the calcining process is an unusual property of colemanite ( $Ca_2B_6O_{11} \cdot 5H_2O$ ) whereupon being heated to its decomposition temperature it loses chemically combined water and decrepitates into a fine powder. When the powder is separated from the larger gangue particles, a colemanite-rich concentrate is obtained.

The Tenneco mill is in Nevada, about 16 miles south of Lathrop Wells and about 29 miles from the mine. Annual capacity is 30,000 tons of calcined product. The process is covered by U.S. Patent No. 3,865,541. Most of the plant production goes to satisfy the demand for textile grade fiberglass, a material used in the manufacture of glass belted tires and reinforced plastic goods. Some also is used as a raw material for the production of a fine dinnerware that exhibits exceptional resistance to thermal and mechanical shock.

## MILLING

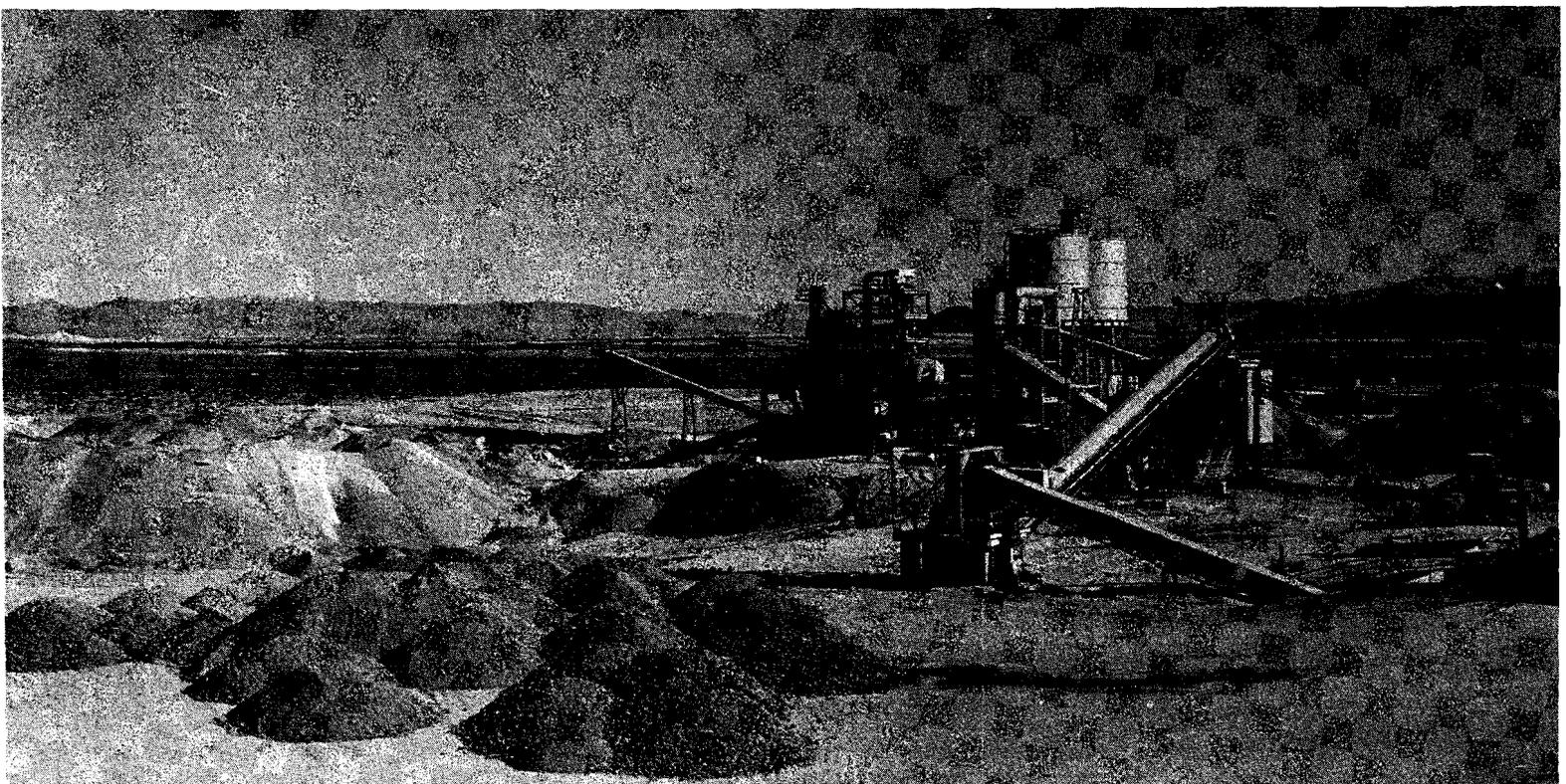
Figure 1 is the flowsheet for the mill which consists of a washing plant and a drying and calcining plant. Mine run ore, crushed to minus 6 inches and blended to 18 percent

$B_2O_3$  (35 percent colemanite) near the pit is trucked to the mill where it is weighed and stockpiled. Mill operations consist of reducing the ore to minus one inch, scrubbing and desliming at 150-mesh, drying, calcining, and separating the calcined colemanite from the larger gangue particles.

*Washing Plant.* The ore is crushed to minus one inch in a single pass through an impactor, weighed over a weightometer, scrubbed in water at 55 percent solids in two attrition cells operating in series, and deslimed in a spiral classifier. The classifier slimes are pumped to a cyclone where a 150-mesh separation is made. The cyclone underflow is returned to the sands end of the classifier. The cyclone overflow drains to a tailings pond where the minus 150-mesh slimes are settled. The clarified water is recycled to the attrition cells. Make up water requirements are supplied from two wells. The sands from the spiral classifier are stacked to drain before they are fed to the drying and calcining plant. They amount to about two-thirds of the dry-feed weight to the washing plant. Recovery of  $B_2O_3$  is typically 85 percent.

*Drying and Calcining Plant.* The product from the washing plant, containing about 9 percent moisture and 22 percent  $B_2O_3$  (dry basis), is moved by front-end loader to the feed end of the drying and calcining plant. Here the wet feed is rate-controlled over a belt scale feeder and conveyed to a mild steel rotary dryer where it is dried by contact with 650° F off-gas from the calciner. The 200° F exit gas from the dryer goes to a cyclone dust collector, then to a wet scrubber before it is discharged through the induced draft fan and stack to the atmosphere. Effluent from the

Tenneco colemanite-processing mill. Impactor and transfer point in the foreground, washing plant behind, and drying-calcining plant behind to the left.



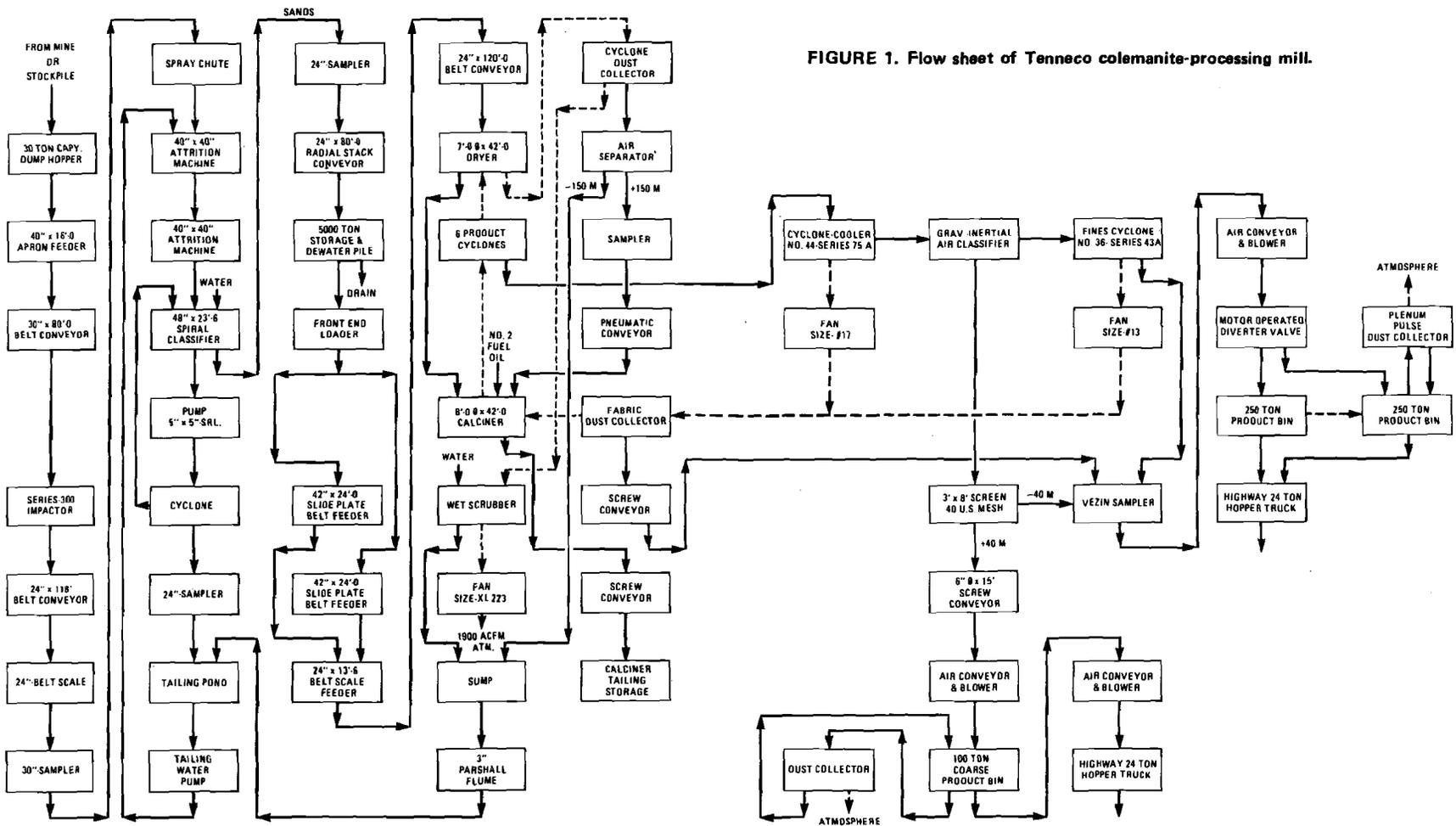


FIGURE 1. Flow sheet of Tenneco colemanite-processing mill.

scrubber is routed to the tailings pond. The dried feed, heated to about 350°F but still below the decomposition temperature of colemanite, and the material from the dryer dust collector are advanced to a stainless steel 8-foot diameter by 42-foot long counter-current calciner. In the calciner the feed contacts a hot gas stream whose exit temperature and velocity are held at 800°F and 550 to 600 feet per minute. The feed is heated to the point where the colemanite decomposes to a powder, the bulk of which is swept out of the calciner in the hot-gas stream. The calcined product is then separated from the gas in six stainless-steel cyclone dust collectors operating in parallel. The essentially dust-free gas from the cyclones, now cooled to about 650°F, goes to the dryer described earlier. The calcined concentrate discharged from the cyclones is pneumatically cooled to

about 130°F and pneumatically sized into plus and minus 40-mesh fractions. The oversize material is trucked to railroad loading facilities in North Las Vegas. The undersize is trucked to a Tenneco plant at Dunn Siding, Calif., where it is ground to minus 70-mesh before rail shipment.

Heat for calcining is provided by burning No. 2 fuel oil in a refractory-lined firebox. The preheated air from the product transportation, cooling and sizing operations supplies all of the secondary air requirements at the furnace.

The tailings discharged from the calciner still contain about 20 percent of the borate fed to the drying and calcining plant. These tailings had been stockpiled since start-up. A secondary recovery plant for extracting the calcined colemanite from the calciner tailings was started up in July 1975. But that is another story.

# THE GRANTHAM TALC MINE, INYO COUNTY, CALIFORNIA

(Summarized by Keith G. Papke from the references listed, with some additions concerning recent work by officials of Johns-Manville Corp.)

## INTRODUCTION

The Grantham (Warm Spring) Mine, the most productive talc mine in California in terms of both total and annual production, is in the Panamint Range in the southern part of Death Valley National Monument. The mine workings occur for 2 miles along Warm Spring Canyon, a major drainage on the west side of the valley. The original 11 claims in the mine area were located between 1931 and 1935 by Louise Grantham and Ernest Hume. The mine has been in operation since 1942; 310,000 tons of ore were produced through 1959. Since 1972 the property has been controlled by Johns-Manville Corp. of Denver, Colo.

## REGIONAL SETTING

The Grantham Mine is at the west end of a belt of talc deposits that extends 75 miles from southern Death Valley eastward to the Kingston Range and contains nearly 50 mines and prospects (fig. 1). These deposits are similar in that they occur as replacement bodies in the Precambrian Crystal Spring Formation, and that most of them are in car-

bonate rocks adjacent to a single, thick diabase sill (fig. 2). A large part of the California production comes from this belt.

In this region the term "talc" commonly is used for any talcose magnesium silicate mineral. Most of the ores contain major amounts of talc ( $Mg_3[Si_2O_5](OH)_4$ ) or tremolite ( $Ca_2Mg_5[Si_8O_{22}](OH)_2$ ), but chlorite, dolomite, calcite, and small amounts of other minerals commonly are present. About 50 percent of the talcose minerals produced in California is used in ceramics, about 20 percent is used in paints, and the rest is used in a wide variety of products.

## GENERAL GEOLOGY

The Precambrian rocks exposed in the Grantham Mine area (fig. 3) include schist and gneiss, the Crystal Spring Formation, and the Noonday Dolomite. A thick sequence of Tertiary volcanic rocks overlies the Precambrian on both sides of the valley. The Crystal Spring Formation, the host for the ore, is nearly 4,000 feet thick. It consists of marine sedimentary rocks intruded by sills of diabase soon after deposition of the sediments. Most of the sills are in a carbonate member.

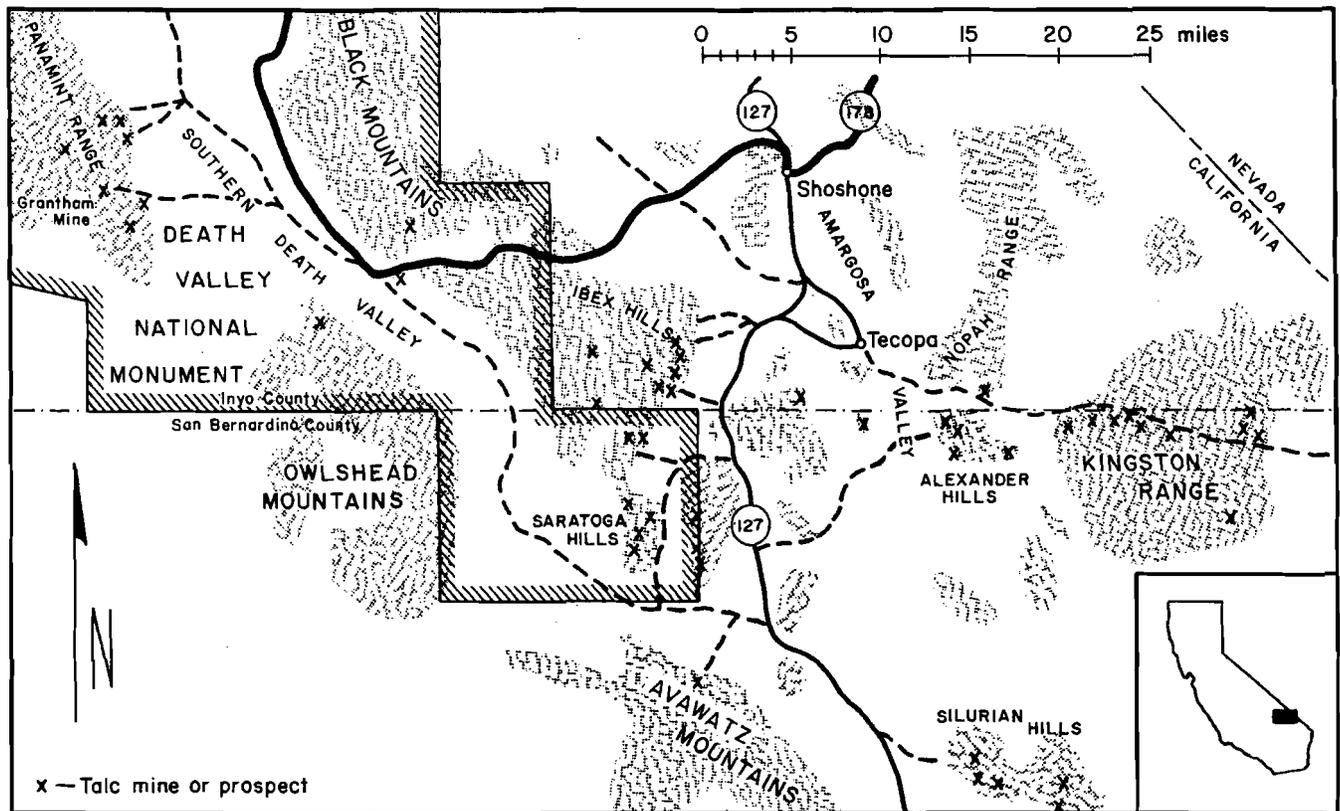


FIGURE 1. Map showing location of Grantham Mine and other talc mines and prospects in the Death Valley region (modified from Wright, 1968).

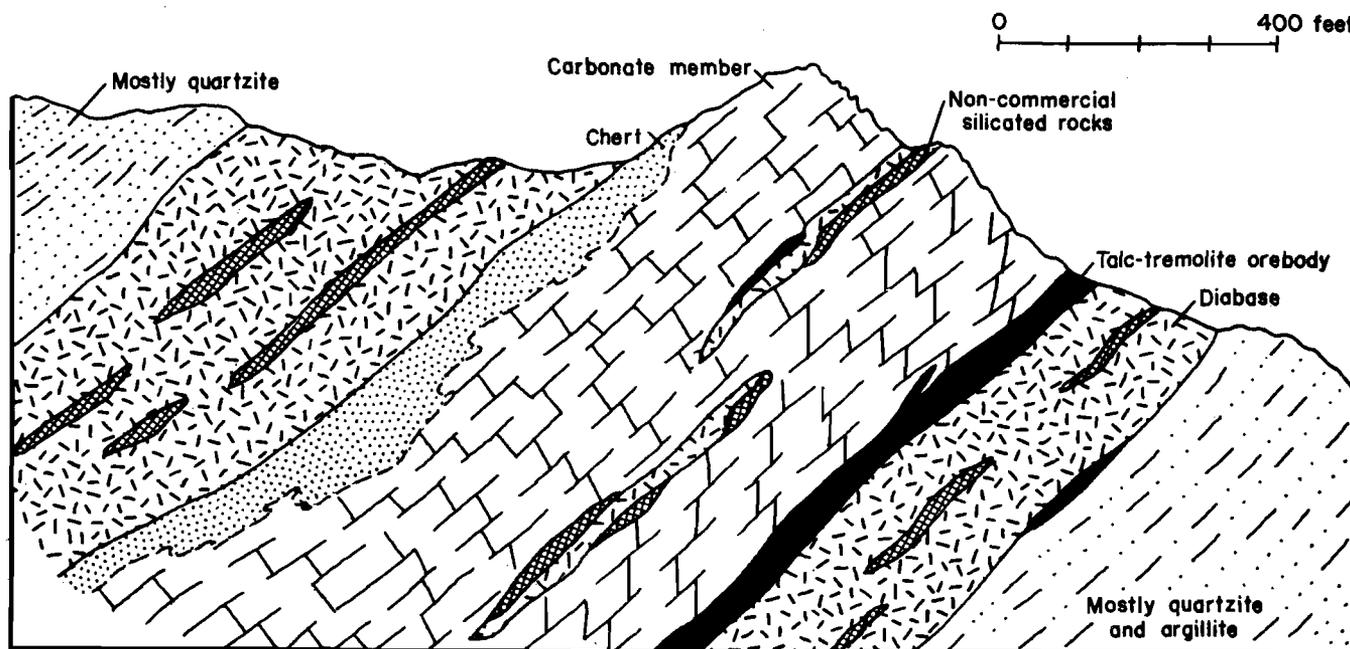


FIGURE 2. Idealized section through talc-bearing rocks of the Precambrian Crystal Springs Formation (after Wright, 1957).

In most of the mine area, the sedimentary rocks and sills of the Crystal Spring Formation generally strike northeastward and dip southeastward at low to moderate angles. A series of northwest-trending, high-angle faults are present; the four most prominent of these have apparent horizontal displacements of 1000 to 2000 feet, with the northeast side offset southward relative to the southwest side.

### ORE DEPOSITS AND MINING

In the Grantham Mine area, as well as at other mines and prospects in the 75-mile-long mineral belt, extensive silicification and the smaller commercial talc bodies were formed by contact metamorphism along the contacts of the lowest diabase sill and the carbonate member of the Crystal Spring Formation. Silicification occurs in the carbonate rocks on both sides of the sill, but most of it – and almost all of the commercial talc bodies – is on the upper side. On the south side of Warm Spring Canyon, the lowest diabase sill, a thick zone of silicified rock, and the overlying carbonate member form the lower slopes, unaltered dolomite and other sills of the Crystal Spring Formation form most of the intermediate slopes, and volcanic rocks form the upper slopes. The silicified zone is exposed at five localities on the south side of the canyon, each within a separate fault block, over a distance of 2 miles. Unmined and apparently smaller bodies are exposed at several places on the north side of the canyon.

Most of the mining has been on the Big Talc and Number 5 claims at the eastern end of the exposed talc-rich zone. In this area the zone is remarkably uniform in thickness, attitude, composition, and internal structure. The zone above the diabase sill is 60 feet thick and contains 3 talc-rich layers separated by massive, brown silicate-carbonate rock. The layers dip southeastward at about 13 degrees.

The First (lowest) layer was mined extensively underground, and has been the source of most of the ore. It is about 15 feet thick; the lower half is very thinly laminated and the upper half crudely bedded with a blocky fracture. Most of the material is white and consists of the mineral talc with subordinate carbonate, chlorite, and tremolite. Table 1 shows two chemical analyses of ore material from the Grantham Mine, presumably from the First layer.

The Second (middle) layer lies about 15 feet above the First. It generally is 12 to 13 feet thick, although only the lower 8 feet was mined underground. The lower part is white, crudely bedded, blocky, and consists mostly of talc. An iron-rich seam separates this ore from several feet of pale-brown talcose material that makes up the upper part.

The Third (highest) layer is separated from the Second by 15 feet of silicate-carbonate rock. It has not been extensively explored by underground workings, but it appears to be about 6 feet thick and to contain more carbonate than the lower layers.

Prior to 1974 all mining was by underground methods, principally in the First layer at the Big Talc and Number 5 workings. The orebodies in these workings are adjacent, but are separated by a high-angle fault with a vertical displacement of about 100 feet. Mining was done in an area with a strike length of about 1,200 feet and down-dip breadth of perhaps 1,000 feet. The underground mining was done by diesel loaders and trucks, with a maximum haulage slope of 10 degrees. Underground mining will be resumed in 1976.

Some production has come from the Warm Spring underground workings 4,000 feet west of the Big Talc-Number 5 area. The ore was produced from the Second layer and, to a lesser extent, the First layer. Since January 1974 an open pit in this area has been the source of all ore from the Grantham Mine.



TABLE 1. Chemical analyses of Grantham ore, and theoretical compositions of talc and tremolite.

Material	SiO <sub>2</sub>	MgO	Al <sub>2</sub> O <sub>3</sub>	CaO	FeO Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	H <sub>2</sub> O -105°C	H <sub>2</sub> O +105°C	CO <sub>2</sub>
Ore <sup>1</sup>	57.35	27.95	0.75	5.7	0.35	0.58	1.81	0.57	3.22	3.05
Ore <sup>1</sup>	56.62	27.75	1.14	5.91	0.18	0.44	1.13	0.10	3.94	4.40
Talc	63.36	31.89							4.75	
Tremolite	59.17	24.81		13.80					2.22	

<sup>1</sup>from Wright, 1968, p.17

The Warm Spring Number 2 and Number 3 workings lie about 5,600 and 7,200 feet, respectively, west of the Big Talc-Number 5 area. In each of these workings, the explored talc body appears to be at least 20 feet thick and resembles the First layer.

The westernmost exposures of the talc-bearing zone are in the Number 4 or White Point area, located about 9,200 feet west of the main workings. This deposit is better exposed at the surface than the four other principal occurrences on the south side of the canyon, and has an outcrop strike length of about 1,200 feet. Two talc layers of present commercial value occur in an altered zone 50 feet thick in

the dolomite above the diabase sill. The lower layer lies immediately above the diabase and is separated from the overlying one by 10 feet of brown silicate-carbonate rock; both layers are rich in talc and about 12 feet thick. Apparently there has been no production from this area.

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