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JULY/AUGUST 1992

# CALIFORNIA GEOLOGY

CALCAREOUS TUFA FORMATIONS



California's Geology  
Our Resources - Our Hazards

CALIFORNIA  
DEPARTMENT OF  
CONSERVATION

Division of Mines  
and Geology

PETE WILSON, Governor  
STATE OF CALIFORNIA  
DOUGLAS P. WHEELER, Secretary  
THE RESOURCES AGENCY  
EDWARD G. HEIDIG, Director  
DEPARTMENT OF CONSERVATION

# CALIFORNIA GEOLOGY

A PUBLICATION OF THE  
DEPARTMENT OF CONSERVATION  
DIVISION OF MINES AND GEOLOGY

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*Governor*

The Resources Agency           DOUGLAS P. WHEELER  
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## CALIFORNIA GEOLOGY

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CALIFORNIA GEOLOGY (ISSN 0026 4555) is published bi-monthly by the Department of Conservation, Division of Mines and Geology. The Records Office is at 1059 Vine Street, Suite 103, Sacramento, CA 95814. Second class postage is paid at Sacramento, CA. Postmaster: Send address changes to CALIFORNIA GEOLOGY (USPS 350 840), Box 2980, Sacramento, CA 95812-2980.

Reports concerning Division of Mines and Geology projects, and articles and news items related to the earth sciences in California, are included in the magazine. Contributed articles, photographs, news items, and geological meeting announcements are welcome.

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Subscriptions: \$8.00/1 yr. (6 issues); \$15.50/2 yrs. (12 issues); \$23.00/3 yrs. (18 issues). Send subscription orders and change of address information to CALIFORNIA GEOLOGY, P. O. Box 2980, Sacramento, CA 95812-2980.

JULY/AUGUST 1992/Volume 45/Number 4  
CGEOA 45 (4) 97-132 (1992)

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## REMOTE SENSING AND GLOBAL ENVIRONMENTAL CHANGE SYMPOSIUM

The 25th International Symposium on Remote Sensing and Global Environmental Change will be held April 4-8, 1993 in Graz, Austria.

The meeting will be conducted by the Environmental Research Institute of Michigan (ERIM), the Consortium for International Earth Science Information Network (CIESIN) USA, and Joanneum Research, Austria. For more information contact:

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**Cover photo:** Exposed tufa formations along shoreline of Mono Lake, South Tufa Area, Mono Lake Tufa State Reserve. *Photo by Ted Rieger.*

# CALCAREOUS TUFA FORMATIONS

## Searles Lake and Mono Lake

TED RIEGER, Writer and Photographer



Photo 1. Tufa spires at South Tufa Area, Mono Lake Tufa State Reserve. Narrowed diameters on two spires at left indicate a former lake surface where tufa was reduced, possibly by waves or solution in lake water. *Photos by author.*

### INTRODUCTION

Tufa formations, while not unique to California, are represented here by some of the most picturesque and diverse examples known (front cover and Photo 1). Tufa, often called calcareous tufa, is a sedimentary rock composed of calcium carbonate (limestone) deposited as calcite, aragonite, or high-magnesium calcite. The hard, dense variety of tufa is travertine. Tufa has been quarried and cut for building stone, most notably from sources in Italy (Putnam, 1971), but extraction of tufa in California has been limited.

Tufa deposits occur in several forms, and the factors and variables involved in tufa formation may differ by location. Although substantial research has been done on the subject, particularly at Mono

Lake, the specific mechanisms for tufa formation are still not fully understood. However, the basic process for the formation of tufa towers and pinnacles is discussed below.

Calcareous tufa forms underwater in saline or alkaline lakes when calcium-bearing spring water wells up from the lakebed. When the calcium-containing spring water comes in contact with carbonate in the lake water, precipitation into calcium carbonate, or the formation of tufa, occurs around the opening of the spring (Figure 1). Although springwater temperature may influence tufa formation, deposition can occur with geothermal or cold-water springs. Lake level fluctuation influences tufa formation by altering the mineral concentration in the lake water and can also change the rate and location

of springwater discharge from a tufa formation. Receding lake levels eventually halt tufa deposition, leaving exposed formations appearing as towers, cones, domes, ridges, knobs, or more intricate shapes.

Tufa deposits also occur as pavements or concretionary deposits in sedimentary lakebeds, and along shorelines of alkaline lakes throughout the world. Tufa is sometimes found in terraces of former shorelines that have been exposed by evaporation or by receding lake waters. Calcium-bearing streams and rain runoff may also contribute to tufa precipitation in some locations. Another form, sand tufa, found at Mono Lake in intricate structures of calcite-impregnated columns, tubes, and other configurations, forms beneath and adjacent to the lake in sands and silts saturated with brine.

For many years, published research has discussed whether tufa is formed by physicochemical precipitation, biological precipitation, or a combination of these two processes. Algal remains in older exposed tufa, and the occurrence of algae with freshly formed tufa at Mono Lake, raise the issue of the role of algae in tufa formation. Researchers differ as to whether algae play a biological role, being required to form certain types of tufa, or if algae only affect tufa structure and texture, and possibly enhance tufa precipitation that would also occur without their presence. Although deposition of sand tufas and concretionary deposits appear to be purely physicochemical, there are indications of biological influences on the deposition of tufa towers, particularly in shallower lake water.

Ongoing research reveals potential influences on the formation of tufa, and there are indications that tufa, under certain conditions, can precipitate and build deposits faster than was previously known. The present understanding of tufa precipitation is perhaps best summarized by the observations of David Herbst (Sierra Nevada Aquatic Research Laboratory [University of California], Mammoth Lakes, California, oral communication, 1992) and Scott Stine (California State

University, Hayward, oral communication, 1992) who have stated that it appears to be more complex than simply the mixing of spring water with lake water.

#### TUFA APPEARANCE AND STRUCTURAL TYPES

The exposed tufa formations discussed in this article generally have the surface appearance and texture of white, tan, light gray, or cream-colored porous limestone. Russell (1883, 1889) was one of the first to describe tufa types based on structural varieties and age of deposition, from his observations of weathered cross sections of formations at Pyramid Lake and Mono Lake. He described three basic types: lithoid, dendritic, and thinolitic. Lithoid tufa forms the inner core of a tufa formation, or the entire formation. It has been described as a stony variety, and may form as porous and tubular masses. Dendritic tufa has a structure of tightly packed columns of upward branching stems. Thinolitic tufa is made of thinolite (a variety of calcite) that appears as tetragonal pyramids that can form a lattice-work crystalline deposit. All three types can occur in layers of varying thicknesses to form a tufa tower. While the central core of a tower is always a lithoid variety, the subsequent order of dendritic and thinolitic

layers can vary, and there may be more than one layer of each of the three varieties.

#### REGIONAL GEOLOGIC HISTORY

In California, tufa is associated with Pleistocene lakes and dry lakes of the Basin and Range province. Water levels of these lakes have fluctuated during geologic history due to variations in precipitation and glacial melt runoff from the Sierra Nevada during the Pleistocene ice ages. During wetter periods, these lake basins overflowed and fed one another from runoff flowing north to south from western Nevada through the Mono Basin and the Owens Valley, through China Basin and Searles Basin, then into Panamint Valley and Death Valley (Figure 2). These lakes, most of which are dry, are also associated with the former Lake Lahontan system of the Pleistocene that ranged across the Great Basin to the Great Salt Lake in Utah. During the ice ages, vast inland seas filled the troughs between mountain ranges. Without outlets, the basins accumulated saline and alkaline minerals that formed thick sedimentary deposits. Evaporation has concentrated saline and alkaline minerals in the remaining lakes, as in Mono Lake and the Great Salt Lake.

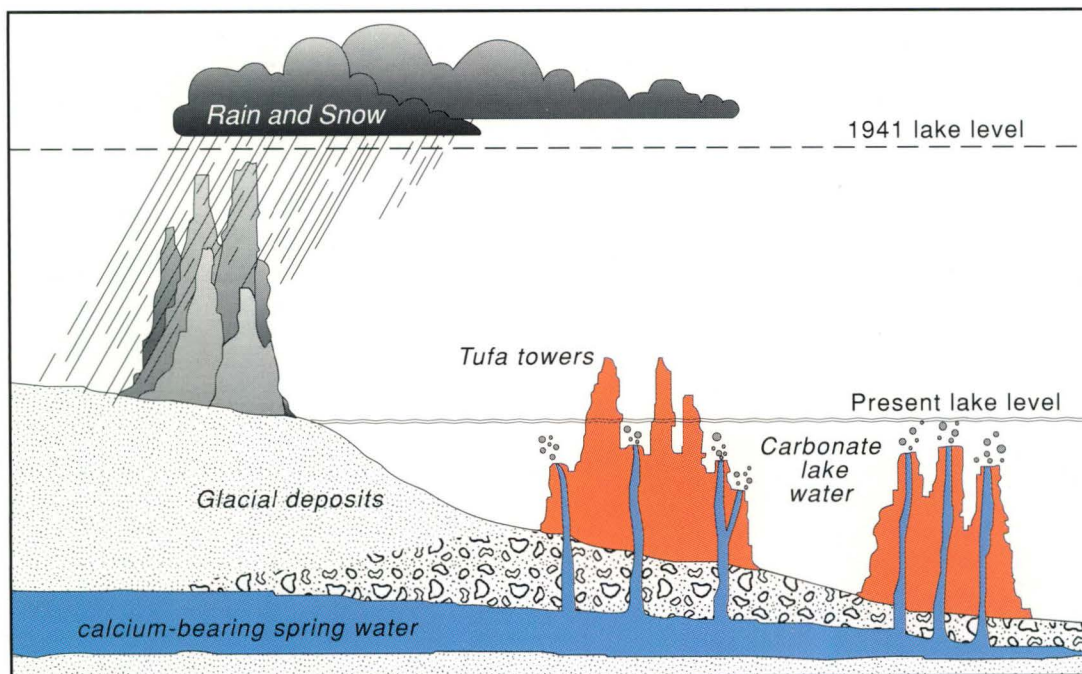


Figure 1. Stylized cross section of Mono Lake showing tufa deposition by interaction of lake and spring water. Tops of tufa spires at left mark the lake's level in 1941. Courtesy of the California Department of Parks and Recreation.

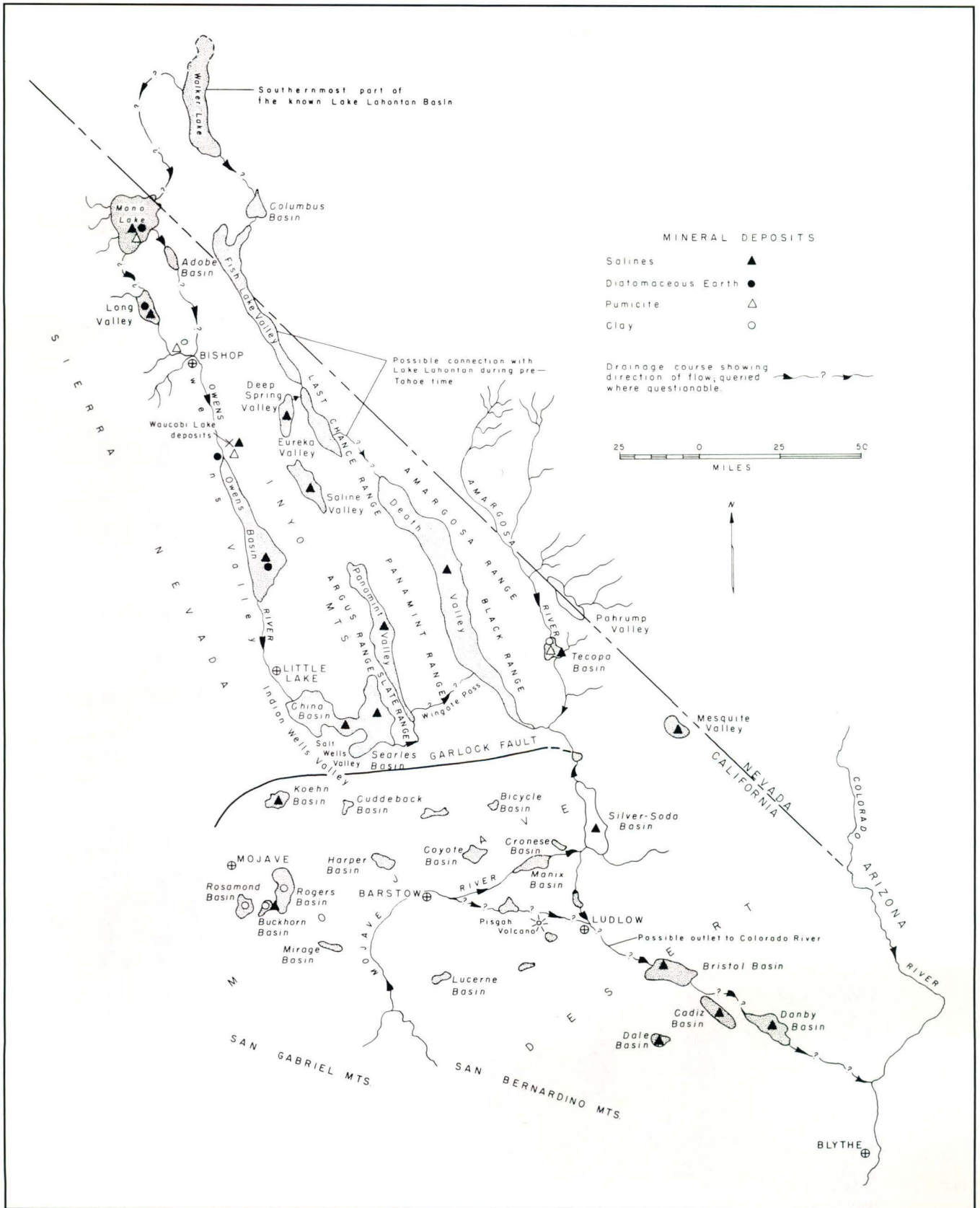


Figure 2. Map showing basins probably occupied by lakes during the Tahoe stage of the Pleistocene. Modified from Blackwelder (1954).

The locations of tufa formations at Searles Lake and Mono Lake present an interesting contrast in present-day conditions. The tufa known as the Searles Lake or Trona Pinnacles occurs at the southern end of Searles Lake, a playa or dry lakebed in northwest San Bernardino County. The youngest of these pinnacles are estimated to have formed at least 10,000 years ago. At Mono Lake, in Mono County near Lee Vining, which holds the largest volume of water of any natural lake entirely within California, the process of tufa formation still occurs. Good examples of tufa domes, towers, and terrace deposits are also found at Pyramid Lake, Nevada, another Great Basin lake of Pleistocene origin. Tufa deposits have also been found in the Salton Trough in southern California, and at a number of alkaline Quaternary lakes of the Great Basin.

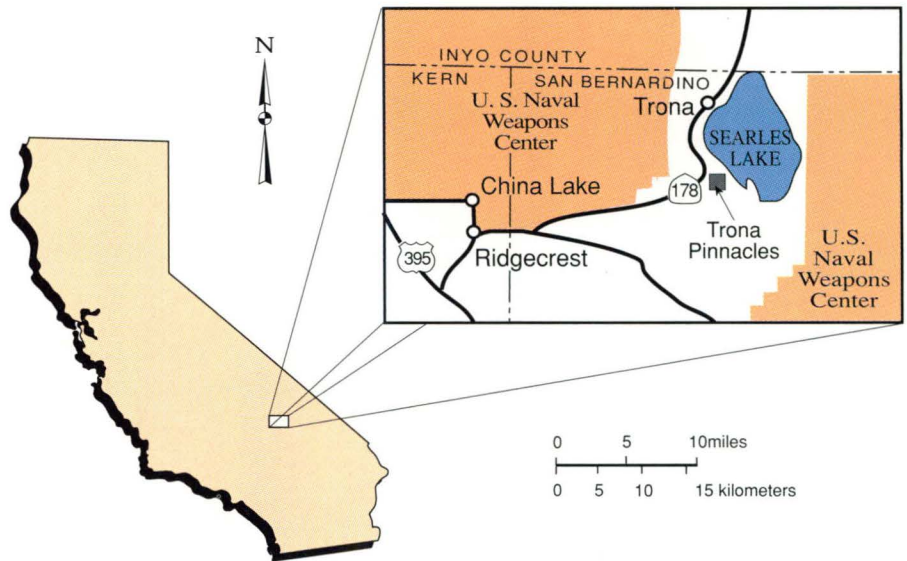


Figure 3. Location map of the Trona Pinnacles tufa area.

#### DISCUSSION OF SEARLES LAKE PINNACLES OR TRONA PINNACLES

##### Location and Distribution of Pinnacles

The Trona Pinnacles tufa area is 10 miles (16 km) south of the town of Trona and 20 miles (32 km) east of Ridgecrest (Photo 2 and Figure 3). The pinnacles are visible from State Highway 178 between Ridgecrest and Trona south of the high-

way, and reached by a graded dirt road that meets Highway 178 about 7.7 miles (12 km) east of its junction with the Trona-Red Mountain road. Trona Pinnacles, designated a National Natural Landmark by the U.S. Department of the

Interior in 1968, is managed by the Bureau of Land Management (BLM) as an Area of Critical Environmental Concern within the California Desert Conservation Area.

There are about 500 tufa spires spread over the Trona tufa area, which is roughly 4 miles (6 km) wide by 10 miles (16 km) long. They range in height from 1 to 140 feet (0.3 to 43 m), averaging 10 to 40 feet (3 to 12 m). Basal widths or diameters range up to 500 feet (150 m), but average only 20 to 30 feet (6 to 9 m). They occur at the south end of Searles Basin in what was an arm-like bay on the southwest side of the former lake, and generally straddle what is now Teagle Wash (Figure 4). Scholl (1960) noted that the occurrence of tufa formation indicates that tufa precipitated around the orifices of springs issuing along the strikes of faults in the igneous and metamorphic rocks that underlie the lacustrine (lake-deposited) sediments.

The pinnacles occur in three separate groups varying in age and elevation. The southern group is the oldest and corresponds to the lake's highest elevation of 2,260 feet (690 m) during the Tahoe ice age (between 100,000 and 32,000 years ago) (Scholl, 1960). At this



Photo 2. Northern group of Trona Pinnacles with castellated summit of ridge pinnacle, and smaller tower pinnacles to the right.

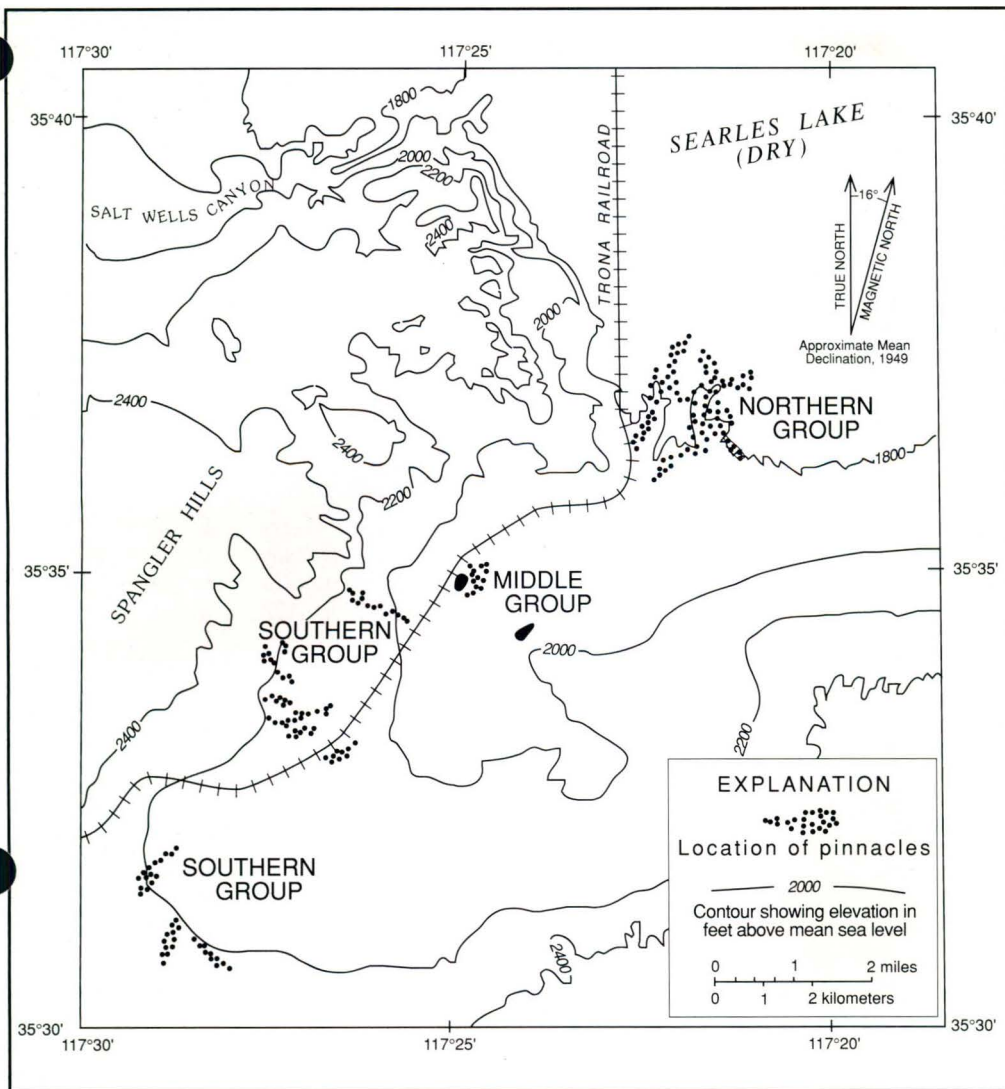


Figure 4. Sketch map showing distribution of most of the pinnacles at the southwest end of Searles Basin; however, less than half of the pinnacles in the southern group are shown. The two enlarged black areas in the middle group are the large limestone ridges. From Scholl (1960).

time, Searles Lake reached its maximum depth of 640 feet (195 m) (Blanc and Cleveland, 1961), and was connected to the west with waters of China Basin through Salt Wells Valley, where weathered tufa towers are also found at elevations of 2,200 to 2,260 feet (670 to 690 m). The southern group of Trona Pinnacles contains about 200 formations that range from 1 to 25 feet (0.3 to 8 m) high and 5 to 40 feet (1.5 to 12 m) in diameter. These are the most severely weathered and many are damaged from

blasting activity (Scholl, 1960). They range in elevation from 2,100 to 2,260 feet (640 to 690 m).

The middle and northern groups are younger and more similar in age. They formed during the Tioga ice age between 25,000 and 10,000 years ago, when Lake Searles had a maximum depth of 460 feet (140 m) and lake level elevation of 2,000 feet (610 m). The middle group contains about 100 formations and the northern group about 200.

#### Pinnacle Shapes and Structure

Generally, the pinnacles rise vertically from gently sloping basal mounds composed of sublacustrine talus material and more recently eroded tufa talus. Scholl (1960) has classified the pinnacles into four general shapes—tower, tombstone, cone, and ridge (Photos 2 and 3). The tower structures occur in all three groups, and are among the most common and noticeable type, with roughly circular horizontal cross sections and summits that may be pointed, rounded, or flat. Their heights exceed their diameters. The tombstone pinnacles occur only in the northern group and are characterized as ellipsoidal in cross section. Scholl's cone type is actually a mound structure that occurs in all three groups and is the smallest and shortest type, commonly fewer than 10 feet (3 m) high. The ridge type of tufa is the most massive. Only three of these structures exist in the Trona area—one in the northern group and two in the middle group. One in the middle group is 800 feet (240 m) long, 500 feet (150 m) wide, and 140 feet (43 m) high, making it the tallest and largest tufa formation in the area.

Scholl (1960) states that the sizes and shapes of the pinnacles probably reflect the size, flow, and chemical composition of the springs, the spacing of the springs, the depth of lake water, and the rate of rise or fall of the lake level. Tombstone and ridge structures may have developed around a number of closely spaced springs of higher flow; tower and cone pinnacles developed around one or just a few springs.

While the Trona Pinnacles would primarily be classified structurally as lithoid, Scholl (1960) has adapted Russell's terms and added his own to list seven tufa classifications at Searles Lake. They are: 1) stony lithoid—a porous and somewhat cavernous cream-colored tufa; 2) cavernous lithoid—a highly porous cream-colored tufa; 3) massive lithoid—a light-gray somewhat porous



Photo 3. Tombstone pinnacles in northern group of Trona Pinnacles.

compact tufa; 4) dendritic—a rather dense branching or arborescent tufa; 5) nodose—a cream-colored tufa; and 6) tubular—a chalk-white to cream-colored tufa which grades upward into 7) lobate—a banded tufa.

Buried tufa deposits within fine-grained to gravelly lacustrine sediments are also exposed on the northern side of the northern pinnacles as bedded lens-shaped deposits 5 to 15 feet (1.5 to 5 m) thick. They are composed of stony lithoid

tufa. While there have been no reports of thinolitic tufa in the Searles Lake area, Cloud and Lajoie (1980) report that sand tufa structures have been observed in older deposits in the Searles Valley that were interpreted as older shoreline indicators.

Scholl maintains that algae were principal agents causing deposition of tufa at the Trona Pinnacles (1960) and at Mono Lake (Scholl and Taft, 1964). Based on microscopic examinations of pinnacle tufa

sections, Scholl found abundant small ellipsoidal to polygonal bodies that he believed to be molds of algal cells. He noted that these occurred primarily in the stony and cavernous lithoid tufas which constitute between 50 and 95 percent of most of the pinnacles. While he concludes that calcium carbonate would have probably accumulated without the aid of algae, it may not have been in the form of pinnacles (Scholl, 1960).

#### Uses of Trona Pinnacles, Searles Lake

Trona Pinnacles, in particular the northern group, have been a filming location for science fiction and fantasy movies because of the bizarre landscape. The pinnacles were seen in the *Star Trek V* movie, and have also been used for music videos, TV commercials, and magazine modeling layouts. BLM personnel report that shafts have been drilled at the bases of some pinnacles for unknown reasons, but it appears that only the southern group, which shows signs of weathering and blasting activity, has been quarried commercially for limestone (BLM, 1972). The pinnacles tufa is now protected from mining and collecting activity. Nearby, the dry lakebed of Searles Lake has been the site of commercial extraction and processing of mineral brines—including borax, potash, sodium carbonate, sodium sulfate, potassium chloride, lithium carbonate, and bromine—dating back to 1874. Kerr-McGee Chemical Corporation extracts lake deposits and operates processing facilities at Trona.

The northern group is the most accessible by a dirt road suitable for 2-wheel drive vehicles. However, the road should not be used in wet weather. A 1/2-mile loop trail takes hikers through this group of pinnacles. BLM's Ridgcrest office can be contacted for further information on visitation and recreation at the pinnacles.

#### DISCUSSION OF MONO LAKE TUSA FORMATIONS

##### Location, Age, and Former Levels of Mono Lake

Mono Lake is in a basin below the eastern escarpment of the Sierra Nevada (cover photo, Photo 4). The lake and basin area is bordered roughly on the west by Highway 395, on the north by Highway 167, and on the south by Highway 120 (Figure 5).



Mono Lake, dated to 730,000 years ago, is one of the oldest continuously existing lakes in North America. While the lake level has fluctuated throughout its existence, it reached its maximum depth of over 900 feet (275 m) when Mono Basin was filled by Pleistocene Lake Russell to an elevation of 7,180 feet (2,190 m), covering 338 square miles (875 km<sup>2</sup>). This level may have occurred more than once during glacial advances of the Tioga ice age, 12,500 to 22,000 years ago (Mono Basin Ecosystem Study Committee, 1987). The lake is believed to have reached its lowest level (6,365 feet or 1,941 m) during the past 5,000 years, but it probably contained a higher volume of water than it would today at the same elevation. Since first recorded in 1857 at an elevation of 6,407 feet (1,954 m), lake levels have reached a high of 6,428 feet (1,960 m) in 1927 and a low of 6,372 feet (1,943 m) in 1982. Fluctuations are due to water diversions from tributary streams by the Los Angeles Department of Water and Power, wet winters, and drought. The lake level is 6,374.5 feet (1,944.2 m) (April 1992) with a maximum depth of about 150 feet (45 m).

#### Tufa Types and Locations in Mono Basin

Russell (1889) reported that compact stony tufa (lithoid) occurred as a cement in the gravel of some of the terraces and beaches around the lake basin, ranging from the present lake level to former water lines. According to Dunn (1953) the greatest quantity of tufa deposits occurs as a thin crust on the Sierran fault scarp that bounds the west side of the lake. He described it as light gray, tan to white, a very porous lithoid variety, and rather typical of that found in many parts of the world. Remnants of tufa deposits can be seen north of Lee Vining on the mountainside west of Highway 395. Scott Stine (California State University, Hayward, oral communication, 1992) reports tufa plasters and crusts at elevations up to 7,070 feet (2,150 m) in Mono Basin. While some of the highest deposits of tufa are about 13,000 years old, tufa deposits older than 40,000 years have been found within the Mono Basin (Scott Stine, University of California, Hayward, oral communication, 1992).

Thinolithic tufa deposits along an ancient shoreline nearly 6,800 feet (2,075 m) in elevation and over 400 feet (120 m) above the present shoreline are relics of some of the highest-elevation tufa towers, formed about 13,000 years ago. They can be found just south of State Highway 167, about 1.3 miles (2 km) east of its junction with Highway 395 and just inside the Mono Basin National Forest Scenic Area boundary.

The more spectacular tufa formations described by various sources as towers, crags, knobby spires, castle-like structures, pillared ruins, and toadstool-like masses occur at Mono Lake (Photos 4, 5, and 6). Towers may have single or multiple trunks, and range in height from a few inches to about 30 feet (9 m). They tend to be clustered in "groves," most notably along the northwest, western, and southern shores of the lake (Figure 6). Towers also protrude from the surface of the lake in these areas. The groves tend to be where water flows underground along faults, or at the sides of "deltas" within the lake where tributary streams provide



Photo 4. Exposed tufa formations at shoreline and in lake at South Tufa Area, Mono Lake Tufa State Reserve.

sources of fresh water to feed and charge lake-bottom springs. Two of the largest groves occur along the southern shore of the lake—South Tufa Grove and Lee Vining Grove. Exposed towers in the South Tufa Area are estimated to be 200 to 900 years old.

The towers in the lake and near the present shoreline tend to be of the lithoid variety of tufa. Dendritic and thinolitic tufa can be found in older towers at higher elevations, and in some cases, all three varieties may occur in the same formation.

When Russell visited the area in 1883, he explored the lake by canoe, and described tufa towers and domes in the Black Point area near the northwest shore of the lake: "They rise in water that is ten or twelve feet deep, to a height of about twelve feet above the lake surface.... The tops of several are hollowed out so as to form basins, and in a few instances these depressions are filled with clear, fresh water that rises through the porous and tubular tufa composing the submerged shaft of the structure. These are typical specimens of sublacustral spring deposits, which have been left partially exposed by a recession of the lake waters, but are still

points of discharge for the springs that built them." Russell (1889) further described one that contained water of "exceptional purity," saying, "This spring fills a bowl three or four feet in diameter, in the top of a tufa dome which rises about three feet above the lake surface and overflows, fountain-like, into the surrounding alkaline waters. The interior of the basin, and portions of its exterior, are coated with white, calcareous tufa, which is still being precipitated from the outflowing waters." Russell (1889) also talked of canoeing over the tops of submerged towers that were releasing spring water into the lake in flows that were "sufficiently strong to deflect a boat when allowed to float over them."

Scholl and Taft (1964) confirmed the presence of tufa with summit springs, but more commonly found spring water seeping from cracks in the sides of formations, or from the bases of exposed formations. Lithoid towers near the shoreline and those in the lake sometimes have circular openings in their summits from which spring water has flowed or continues to flow (Scholl and Taft, 1964). Today, these springwater features are associated more with the tufa of Black Point and the north shore than with that of other areas.

Fluctuating water levels at Mono Lake have been found to affect the formation and shape of tufa in several ways. Russell (1889) noted that partially submerged tufa columns and towers would have circular contractions, or reduced diameters where the water's surface level was in contact with the tufa. He speculated that this was caused by the dash of waves, or by solution of the tufa's calcium carbonate by lake water. In some mushroom-shaped towers, spring water continued to flow from the top and down the flanks of a partially exposed formation. Upon contact with the lake surface, calcium carbonate precipitated to form flat-bottomed shelves on the sides of the formation.

A drop in lake level can alter the flow rate as well as the location from which spring water flows from a formation. Towers near the shoreline can be found with spring water bubbling from the base of the formation. At the South Tufa Area, what appear to be "oily upwellings" (Mono Lake Committee, 1980) just offshore are the locations of fresh water rising through brine from lakebed springs. Tufa towers that become completely exposed eventually cease to "grow." Some exposed shoreline towers have toppled due to fluctuating lake levels that undermine the formations, or waves that erode their bases. Scuba divers who have explored submerged tufa groves report the existence of many fragile tufa columns and formations whose weight could not be supported on land.

#### Sand Tufa

Sand tufas occur primarily along the southern and southeastern shores of the lake, but have also been found in Mill Creek stream cuts above the northwest shore of the lake (Figure 7). They range in height from a few inches to 6 feet (2 m). The sand tufa figures consist of tubes, columns, and associated structures of calcite-impregnated pumice sand, formed in beach and lake-bottom sediments near the shore of the lake. The carbonate-cemented sand is exposed by a drop in lake level and subsequent wind erosion of loose sand around the formation. Cloud and Lajoie (1980) state that the younger sand structures may have formed within the past century. Sand tufas are found between elevations of 6,374 feet (1,944 m) and about

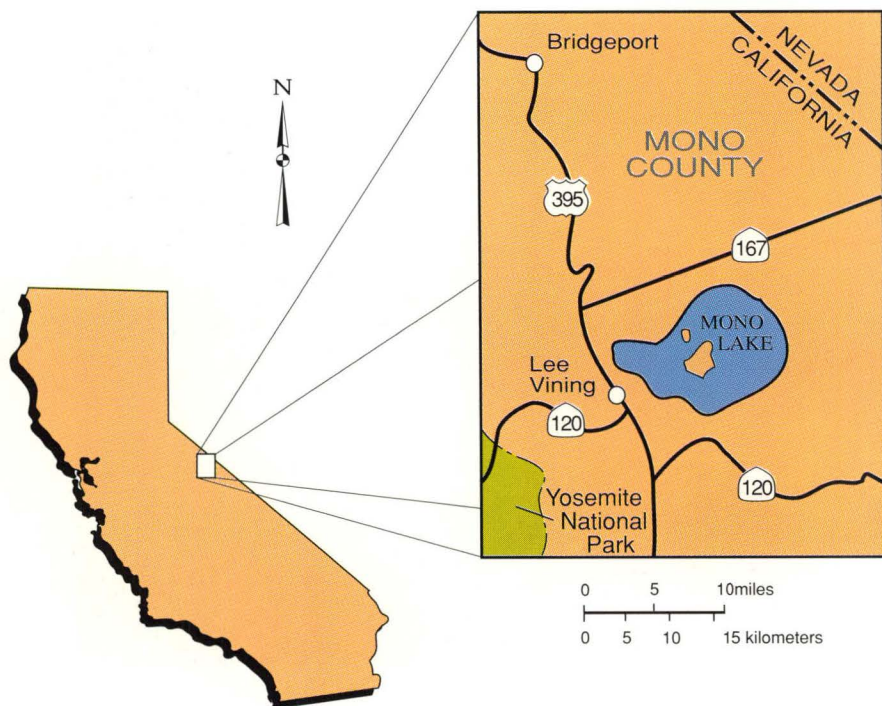


Figure 5. Location map of Mono Lake.

6,432 feet (1,962 m). They can be observed at Navy Beach near the South Tufa Area. Because of their fragile structure, they are probably more susceptible to erosion and toppling from rising lake levels and wave action than are the lithoid tufa formations.

#### Biological Influences on Tufa Formation

The remains of filamentous and spherical algal cells occur in lithoid tufa of dry towers at Mono Lake. Scholl and Taft (1964) have reported calcareous mat-forming algae on the surface of, and partially embedded in, lithoid tufa that is beneath spring water cascading from the summits of pinnacles above the lake surface. They also determined that the algal mat is calcareous due to an abundance of microcrystalline calcite accompanied by calcite pellets, immeshed in the filamentous algae. The mat-forming algae in Mono Lake are primarily filamentous green algae, diatoms, and blue-green algae. Scholl and Taft (1964) believed that due to the close association of algae and freshly-deposited tufa, precipitation of lithoid tufa could be botanically induced. Precipitation results from the photosynthetic withdrawal of carbon dioxide, which lowers the solubility of calcium carbonate near the algae.

Divers in Mono Lake have found that underwater tufa formations provide rocky substrates for the attachment of organisms such as blue-green algae, and for alkali fly larvae and pupae that have specialized lime gland tubules capable of precipitating carbonate/bicarbonate with calcium (Herbst and Bradley, 1989). While chemical precipitation could theoretically occur at depth in Mono's waters under the right conditions, the biological influences of algae, or insects, would have to take place within a photic zone of probably no more than about 30 feet (9 m) below the lake surface. The complexity of tufa formation continues to be investigated, but research at Mono Lake indicates that biological processes influence at least the morphology of some types of tufa formations.

#### Historic Tufa Uses and Current Tufa Area Management

Historically, the extraction of Mono Basin tufa for human use has been very limited. Stone lime kilns that date to the

1870s have been found in the Cedar Hill area northeast of the lake where it is believed that tufa extracted from older lakeshore terraces may have been calcined to form lime (Mono Lake Committee, 1980). Individuals have collected tufa chunks for souvenirs and for ornamental use in gardens, but collection for any purpose is now prohibited.

The Mono Lake Tufa State Reserve encompasses state-owned lakebed lands below the elevation of 6,417 feet (1,957 m)—the lake's surface elevation in 1941. This includes about 17,000 acres (6,900 hectares) that have been exposed since that year by the diversion of fresh water from tributary streams by the Los Angeles Department of Water and Power.

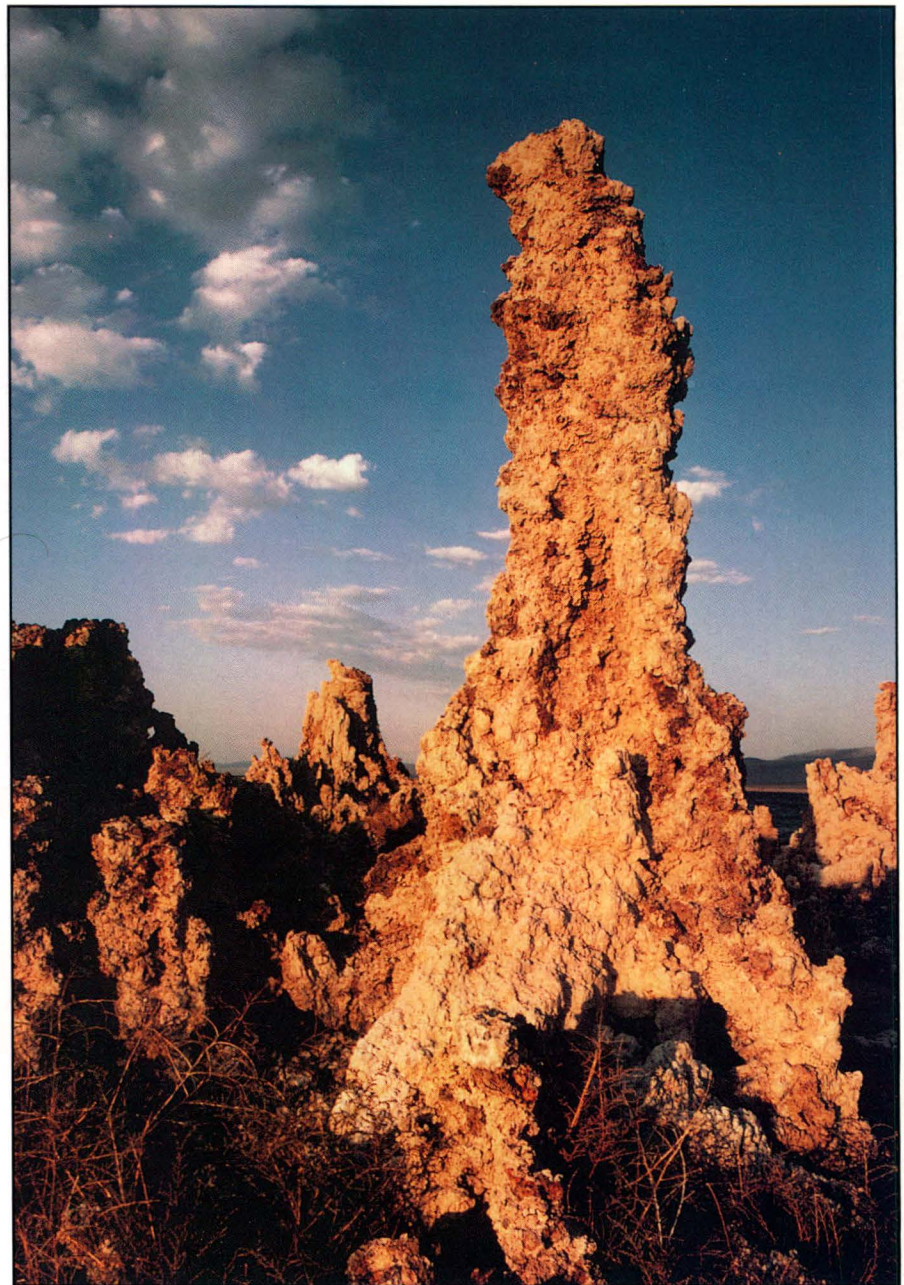


Photo 5. Lithoid tufa tower at South Tufa Area, Mono Lake Tufa State Reserve.



Photo 6. Tufa formations at South Tufa Area, Mono Lake Tufa State Reserve. Mushroom-shaped tufa (center) formed by spring water that continued to flow from the exposed summit and down the sides of the formation to interact with lake water and form the flat-bottomed "shelf" at lake surface.

The reserve, established in 1982, is managed by the California Department of Parks and Recreation (CDPR) to preserve the tufa formations and other natural shoreline features of Mono Lake.

The Mono Basin National Forest Scenic Area, encompassing 116,000 acres (46,800 hectares) was designated by Congress in 1984 to protect the natural, cultural, and scenic resources of the Mono Basin. The U.S. Forest Service operates the recently opened Mono Basin Scenic Area Visitor Center 1/4 mile (400 m) north of Lee Vining on the east side of Highway 395. The center has exhibits about the Mono Basin, and personnel can provide information on tufa groves, nature programs, and tours.

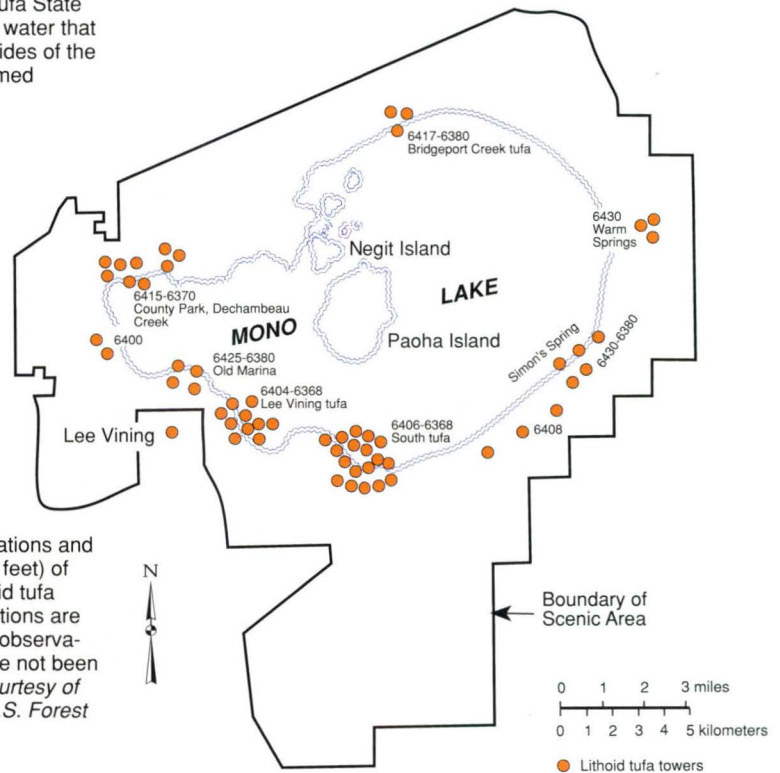


Figure 6. Locations and elevations (in feet) of bases of lithoid tufa towers. Elevations are estimated by observations and have not been surveyed. Courtesy of N. Upham, U.S. Forest Service.

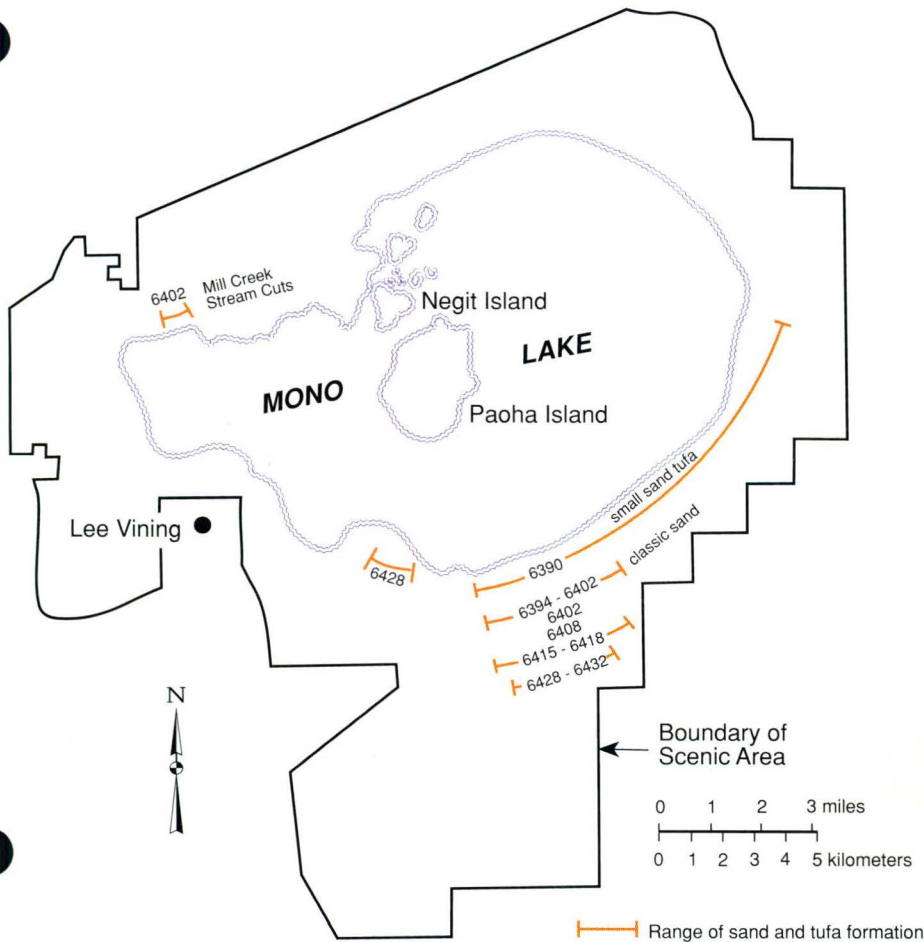


Figure 7. Locations and elevations of bases of sand tufa. Elevations are estimated by observations and have not been surveyed. *Courtesy of N. Upham, U.S. Forest Service.*

The Mono Lake Committee operates the Mono Lake Visitor Center in Lee Vining which has exhibits and information about the Mono Lake and Basin area.

#### Observing Tufa at Mono Lake

The South Tufa Area, managed by CDPR, is one of the most easily accessible locations for tufa observation. It is reached by a one-mile dirt road that turns north from Highway 120, about 5 miles east of the Highway 395 junction south of Lee Vining. There is a self-guided trail through the tufa formations, and CDPR regularly conducts naturalist-led tours. At Mono Lake County Park, about 4 miles north of Lee Vining on the east side of Highway 395, there is a boardwalk trail through the tufa grove.

Ted Rieger is a freelance writer and photographer in Sacramento, California. He specializes in natural history, geology, and historical subjects, and produces technical and business articles for trade publications. Ted has varied experience in outdoor recreation and resource management with federal and State agencies.

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# Geometry of Normal Faulting in Tecopa Valley, California from Magnetic Surveys

MICHAEL R. GROSS, Pennsylvania State University  
JOHN N. LOUIE, University of Nevada, Reno



Photo 1. Normal faults exposed in a roadcut on Route 178, 3.7 miles east (6.0 km) of Shoshone (Heydari, 1986). View is to the northeast. These west-dipping faults offset tuffaceous rocks of the Chicago Valley Formation. At first glance the main fault in the center of the photograph appears to be a reverse fault. However, the yellow and orange tuffs truncated by the fault are not the same stratigraphic horizon. *Photo by David L. Wagner.*

## INTRODUCTION

Late Cenozoic tectonism in the Basin and Range Province is dominated by east-west crustal extension, which is reflected in a series of north-south trending horsts and grabens and abundant normal and strike-slip faults. Estimates for the amount of crustal extension vary from 20 percent (Stewart, 1971) to 100 percent (Wernicke and others, 1988). Several mechanisms have been proposed to account for the larger amounts of extension, including listric normal faults (curved, downward-flattening faults) (Wright and Troxel, 1973) and a shallow, gently-dipping regional detach-

ment extending from Pahrump Valley west to the Sierra Nevada (Wernicke and others, 1988). Ellis and others (1989) suggest that lateral displacement along intersecting, complementary strike-slip faults may account for a large portion of the net extension.

**Magnetic surveys\*** can identify subsurface structures related to normal faulting in areas where volcanic rocks with high **magnetic susceptibilities** are juxtaposed with low-susceptibility sedimentary rocks. Tecopa Valley provides an excellent locality for such a study since it

contains faulted Tertiary rhyolites and basalts as well as abundant evidence for extensional tectonism. Evidence for normal faulting includes the prominent range-front fault at the base of the Resting Spring Range, numerous normal faults in a roadcut on Route 178 in the same range (Heydari, 1986) (Photo 1), an offset welded tuff marker horizon in the Tertiary rhyolite, and rotated fault blocks exposed in Tecopa Valley (Figure 1). The purpose of this study was to conduct a series of ground-based magnetic surveys perpendicular to regional strike in order to understand the geometry of normal faulting in Tecopa Valley.

\* Terms in **boldface** type are explained on page 116.

## GEOLOGIC SETTING

Tecopa Valley is in eastern California, approximately 20 miles (30 km) east of Death Valley in the Basin and Range Province (Figure 1). The north-south trending valley, covering an area of approximately 200 square miles (500 km<sup>2</sup>), is flanked to the east by the Resting Spring Range and to the west by the Dublin Hills, both composed of Precambrian and Cambrian sedimentary rocks

(Nilsen and Chapman, 1971; Jennings, 1977). Tertiary rhyolites at least 787 feet (240 m) thick are exposed in Resting Spring Pass (Heydari, 1986). Tertiary basalt crops out as rotated fault blocks near Shoshone and possibly as fault-related intrusions at the base of the Resting Spring Range. The center of Tecopa Valley is filled with flat-lying, relatively undeformed, late Pliocene and early Pleistocene Lake Tecopa sediments (Photo 2). The sediments are at least

235 feet (72 m) thick and consist of mudstones interbedded with layers of volcanic ash (Sheppard and Gude, 1968; Hillhouse, 1987).

A prominent normal fault at the western base of the Resting Spring Range is marked by a series of west-dipping **flat-irons** composed of fault-gouge material (Photo 3). Exposed within the valley are east-dipping, normal-fault blocks of either Precambrian-Cambrian sedimentary rocks or Tertiary volcanics (Figure 2, Photo 4).

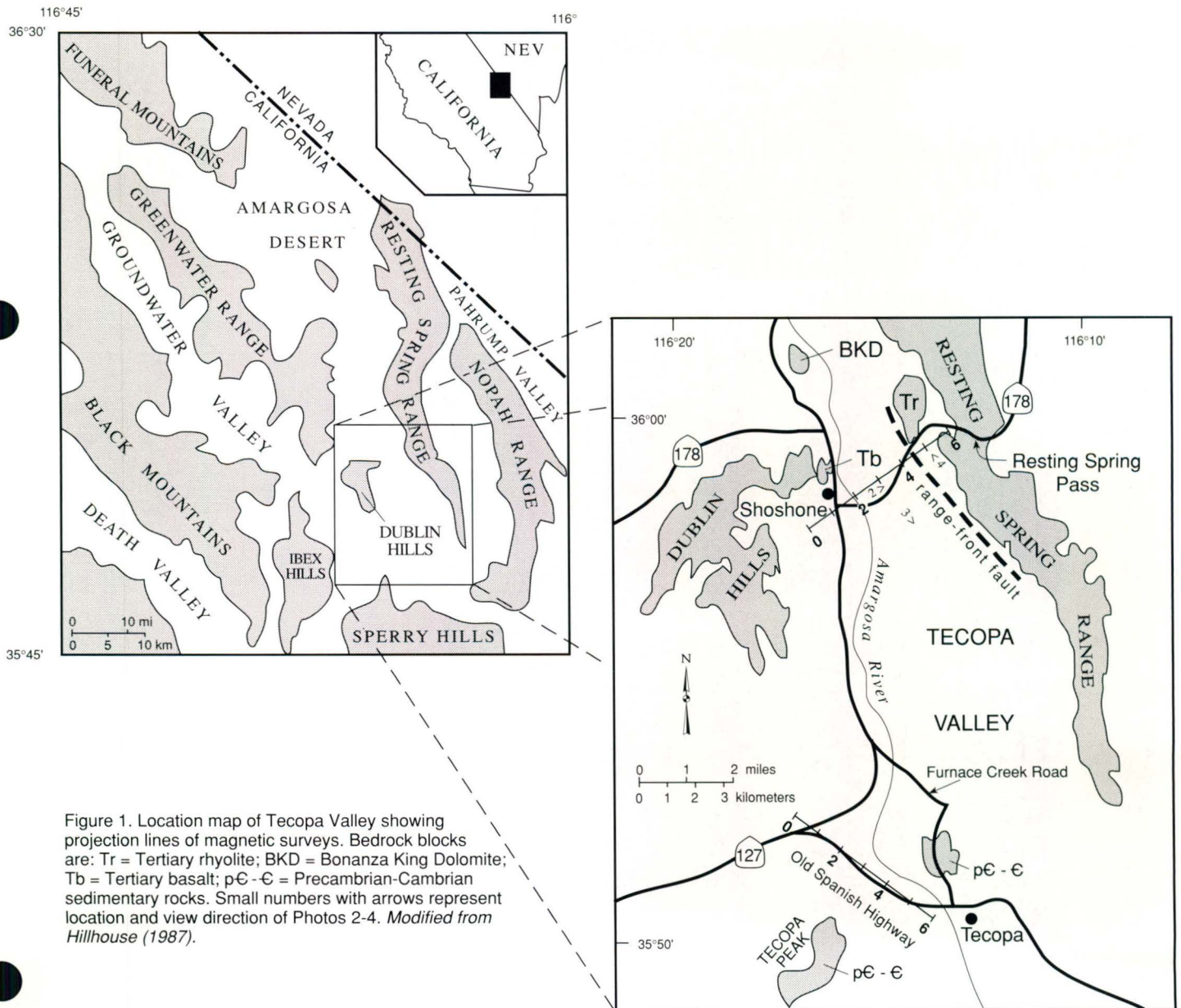


Figure 1. Location map of Tecopa Valley showing projection lines of magnetic surveys. Bedrock blocks are: Tr = Tertiary rhyolite; BKD = Bonanza King Dolomite; Tb = Tertiary basalt; pЄ-Є = Precambrian-Cambrian sedimentary rocks. Small numbers with arrows represent location and view direction of Photos 2-4. Modified from Hillhouse (1987).



Photo 2. Tecopa Lake beds near Route 178. The flat-lying mudstones indicate that major extensional tectonism stopped before the deposition of lake sediments at approximately 3 Ma. *Photo by Michael Gross.*



Photo 3. View of the Resting Spring Range looking southeast from the center of Tecopa Valley. The Precambrian-Cambrian sedimentary rocks of the Resting Spring Range dip to the east in the background. The west-dipping flatirons at the base of the Resting Spring Range are exposures of resistant fault-gouge material of the range-front fault. *Photo by John Louie.*



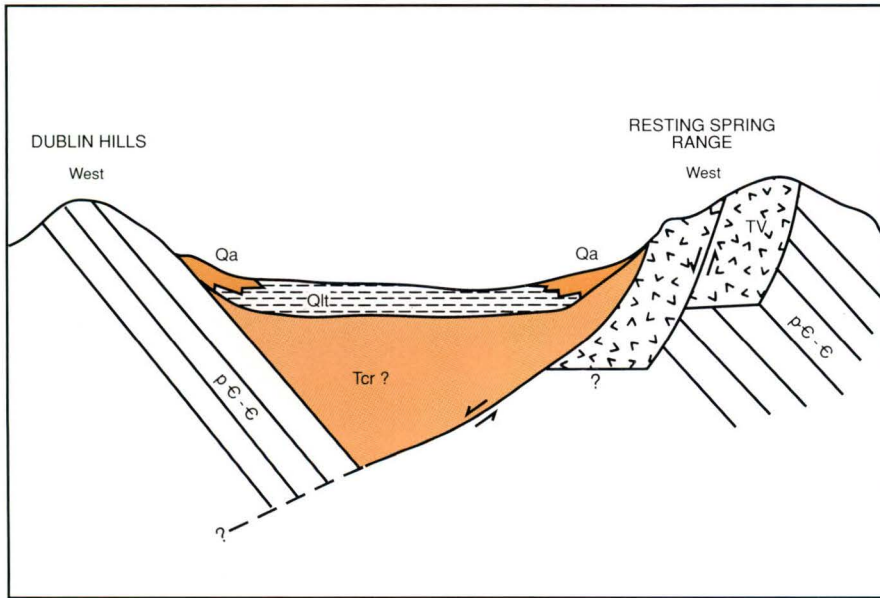


Figure 2. Generalized schematic cross section through northern Tecopa Valley. Lithologic units are: Precambrian-Cambrian sedimentary rocks (pE-C); Tertiary China Ranch equivalents (Tcr ?); Tertiary volcanics (Tv); Pliocene-Pleistocene Lake Tecopa sediments (Qlt); and Quaternary alluvium (Qa).



Photo 4. Tilted Tertiary rhyolite block north of Route 178 (Figure 1). Photo by Michael Gross.

## METHODS

Two magnetic surveys were conducted in Tecopa Valley (Figure 1). Data were collected along a northern line from mid-valley eastward across Route 178 toward the base of the Resting Spring Range, past a block of Tertiary rhyolite (Figure 1, Photo 4). Data were collected along a southern line eastward along Old Spanish Trail Highway between Route 127 and the town of Tecopa.

An EG&G model G-856 **proton precession magnetometer** measured total-field values at 54 stations spaced 165 feet (50 m) apart in the northern profile and at 20 stations with 655-foot (200-m) spacing in the southern profile. At least two readings were taken at each station to assure repeatability, and **diurnal variations** were measured at one station at least once every 2 hours throughout each day.

Diurnal variation is a large source of error in a magnetic survey. Corrections in this survey were accomplished through linear interpolation between repeat station data points and normalization of repeat station measurements to a consistent value (Figure 3).

Sunspot-induced magnetic storms, another large source of error, occurred during the survey. We received measured storm intensity values for our survey dates of February 25 and 27, and March 1, 1990 from the Fredericksburg, Virginia Geomagnetic Center (B. Odell, personal communication, 1990). Storm activity for these dates ranged from 30 **nanoteslas** (nT) to 40 nT, introducing a fundamental uncertainty in the profiles of Figures 4 and 5. While the activity is larger than the diurnal variations, fortunately it is significantly smaller than the variations caused by basin structure.

We used a computer-based software package to calculate theoretical **magnetic field intensity** values matching major features of the observed profiles. Figures 4 and 5 show susceptibility contrast models and their corresponding magnetic intensity profiles. The Tertiary rhyolites and basalts are assigned magnetic susceptibility values (in **cgs** units) of 0.00068 and 0.004, respectively, whereas the sedimentary rocks and basin fill are assigned susceptibilities of zero.

## RESULTS AND DISCUSSION

Figures 4 and 5 present the results from the two magnetic surveys. The top portion of each figure shows magnetic field measurements (squares) along with the theoretical values computed from susceptibility models (filled circles). The lower portion of each figure is a schematic geologic cross section representing the model.

### Northern Profile

The northern profile (Figure 4) begins at 3.5 km along the line of projection and initially shows a decrease in magnetic field values progressing northeast. At approximately 4.5 km there is a sharp positive anomaly which then decreases toward the end of the profile. The 1000-nT magnitude of the anomaly measured by closely-spaced ground-based magnetic surveys is much larger than the 100-nT variation over the length of Tecopa Valley determined from aeromagnetic surveys (Blake and others, 1977). It is also considerably larger than the 40 nT of error introduced by magnetic storm activity. Both the magnitude and location of the anomaly suggest that the profile crosses a major structural boundary between low-susceptibility sediment in the center of Tecopa Valley and high-susceptibility bedrock along the eastern side of the valley.

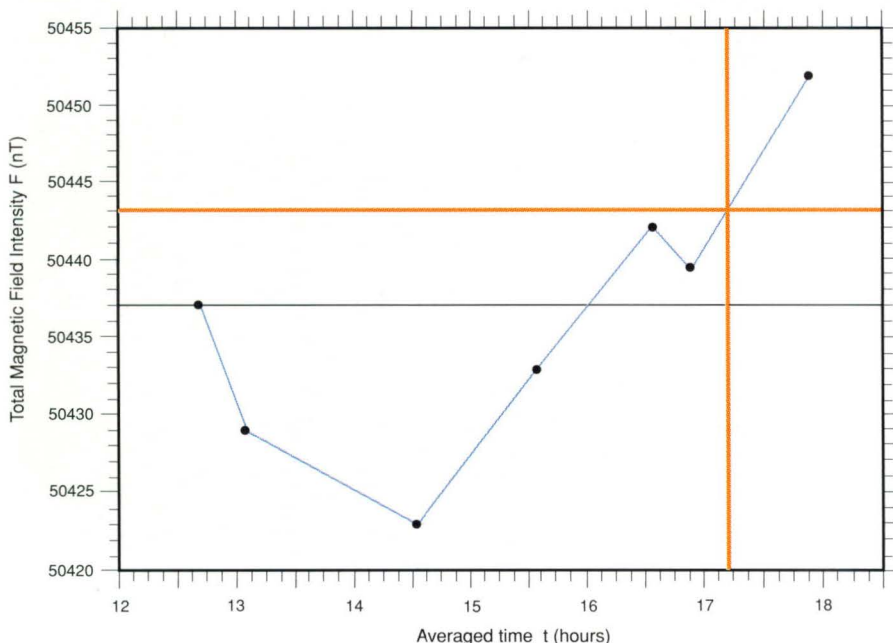


Figure 3. Plot of diurnal variation in the total magnetic field measured at the repeat station for the northern line on February 25, 1990. The first measurement at the repeat station, 50,437 nT, was taken at 12.692 hours. This graph shows the curve drawn through all the measurements taken at the repeat station throughout the day. Measurements taken along the line were corrected for diurnal variation as in the following example.

line station measurement	50,492 nT	17.163 hours
first repeat station measurement	50,437 nT	12.692 hours

A line station measurement was taken at 17.163 hours. The vertical orange line drawn at 17.16 intersects the curve at 50,443 nT. This differs from the first repeat station measurement by 6 nT. To correct for diurnal variation, 6 nT was subtracted from the line station value to give 50,486 nT.

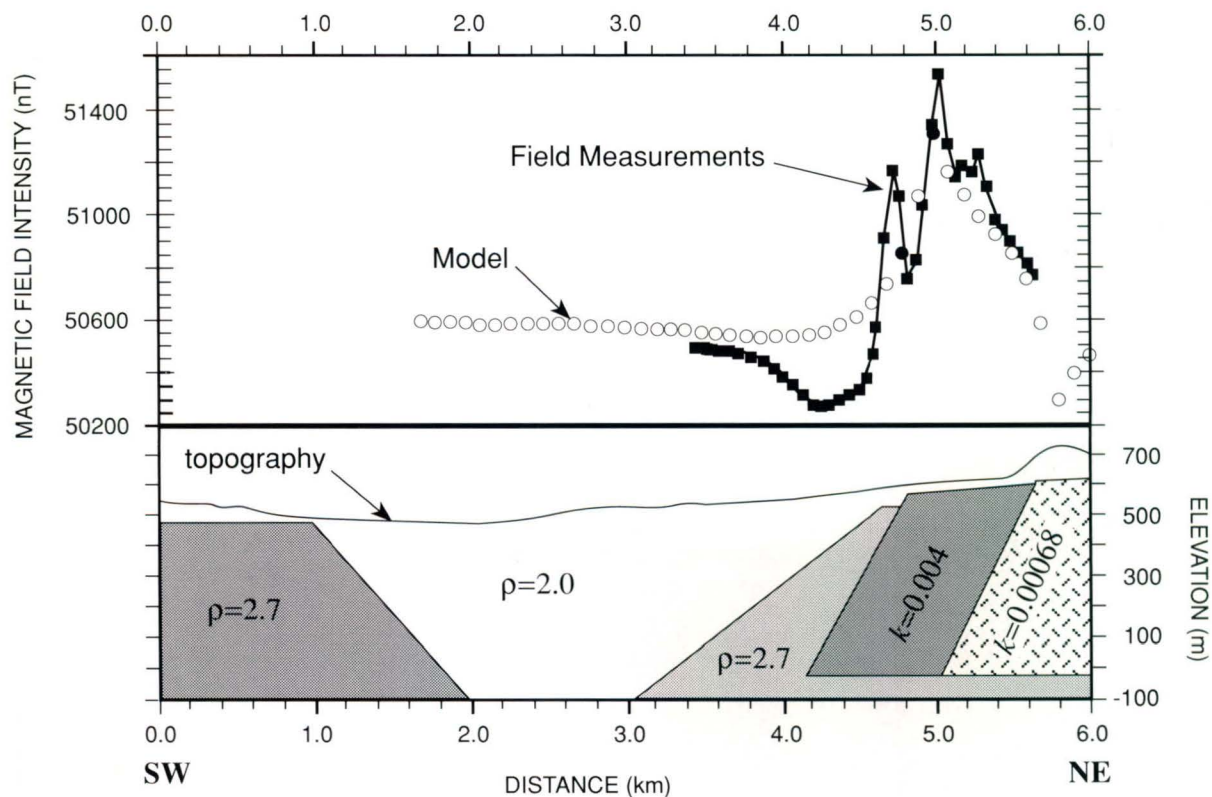


Figure 4. Magnetic field data, model results, and schematic geologic cross section for the northern profile.  $\rho$  = density,  $k$  = magnetic susceptibility in cgs units.

The large magnetic anomaly west of the tilted block of rhyolite north of Route 178 (Photo 4) appears to represent subsurface continuation of the range-front fault. The model which best corresponds to the observed magnetic field data is a normal fault dipping 45 degrees to the west, with highly susceptible volcanics in the footwall to the east (Figure 4).

We assigned a susceptibility ( $k$ ) value of 0.00068 and a thickness of 2,000 feet (600 m) to the rhyolitic material in the footwall. The magnitude of the anomaly suggests there is a very highly susceptible ( $k = 0.004$ ) block 1,800 feet (550 m) wide along the fault. This might represent a layer of basalt intruded along the fault zone. There are outcrops of basalt associated with the range-front fault exposed along the western flank of the Resting Spring Range that would further support this model. A problem with the magnetic

model is that it requires a rhyolite thickness of about 2,000 feet (600 m) which is not entirely compatible with field evidence. Heydari (1986) measured a thickness of only 787 feet (240 m) for the Resting Spring Pass Tuff.

**Gravity surveys** along the northern profile in Tecopa Valley suggest a model of low density sediments in the basin and high density bedrock along the eastern and western flanks (Gross and others, 1990). The result of gravity modeling is shown in conjunction with the magnetic model in Figure 4 and depicts the range-front fault as a west-dipping structure with dense bedrock on the east and less dense basin fill on the west. Both the magnetic and gravity data place the range-front fault at approximately the same location along the profile, though the gravity model infers a shallower dip of 18 degrees.

#### Southern Profile

Magnetic field measurements along the southern profile exhibit two peaks, one at approximately 0.5 km and the other at 3.4 km (Figure 5). The maximum at 3.4 km is located along the strike of Tecopa Peak (Figure 1). The range in values is less than 100 nT, which is much smaller than the anomaly observed along the northern profile. Magnetic storm activity measured 30 nT. A model that corresponds to the data consists of a pair of buried east-dipping slabs with magnetic susceptibilities of 0.00068. The slabs are 425 feet (130 m) thick and dip 23 degrees to the east, with the western slab at a depth of 145 feet (105 m) and the eastern slab at a depth of 510 feet (155 m). These slabs may be Tertiary volcanics which have been rotated along west-dipping normal faults. This structure is consistent with all of the bedrock exposures in Tecopa Valley, as well as the dip of the Resting Spring Pass Tuff (Heydari, 1986). Also, it implies an irregular surface along the bedrock/basin-fill contact.

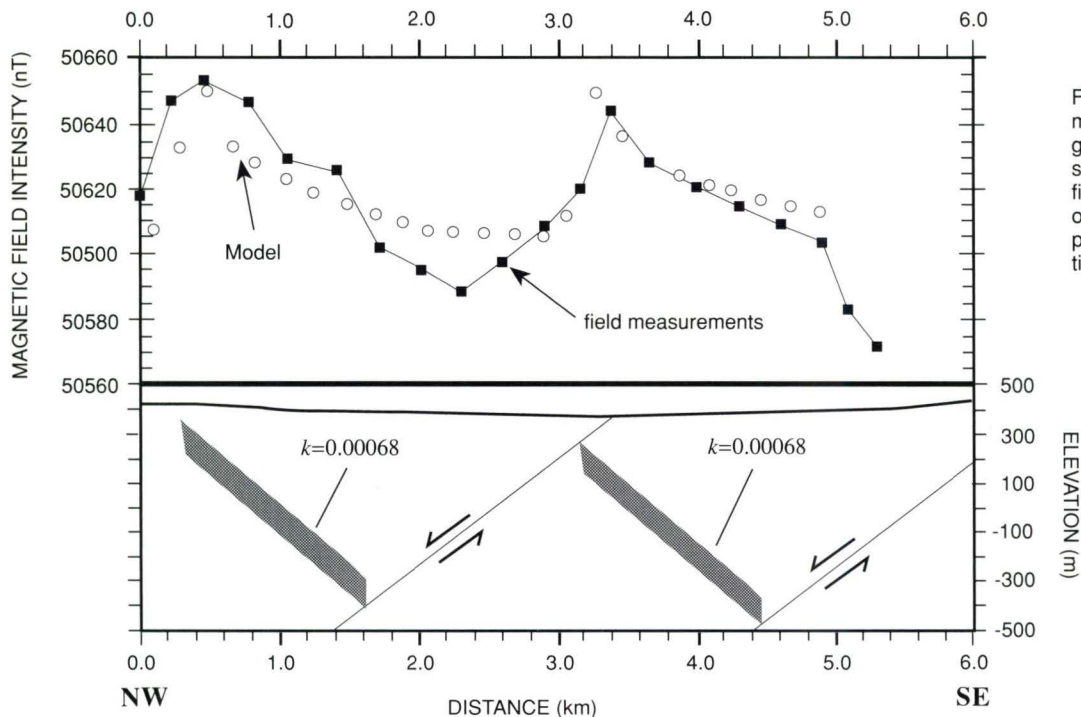


Figure 5. Magnetic field data, model results, and schematic geologic cross section for the southern profile. Data from field stations are projected onto northwest-southeast profile.  $k$  = magnetic susceptibility in cgs units.

## CONCLUSIONS

Magnetic surveys have identified structures in the subsurface of Tecopa Valley related to extensional tectonism. The range-front fault along the western flank of the Resting Spring Range can be accurately mapped by virtue of its strong magnetic signal in areas where it is not exposed. The magnetic data and models suggest the presence of a basaltic intrusion on the order of 1,000 feet (300 m) thick along the range-front fault. In addition, a series of east-dipping fault blocks were identified in the subsurface along a profile in southern Tecopa Valley, which is consistent with the overall geometry of fault blocks exposed in the valley. Ongoing research by groups from Penn State and Nevada-Reno will improve our understanding of the subsurface geology in Tecopa Valley.

## ACKNOWLEDGMENTS

We are grateful to R. Laird, S. Nichols, D. Verdonck, N. Yonkers, and J. Zhang for their assistance in the field. We would also like to thank L. Wright for his valuable discussions on Tecopa Valley geology. This research was supported by the Pennsylvania State University Department of Geosciences and generous donations from Chevron USA, Inc., Mobil Corporation, and British Petroleum Corporation.

## Glossary

**flatiron:** The cross section of a triangular ridge of steeply inclined resistant rocks on the flank of a mountain.

**gravity survey:** Measurements of the gravitational field at different locations. Variations denote differences in rock type.

The earth's magnetic field consists of three parts: 1) the internal, or secular, field which varies over decades or centuries and is attributable to the basic properties of the earth; 2) the external field, which varies rapidly and is due to sources above the surface; and 3) the nearly constant anomaly field, which is caused by sources within the near-surface crust of the earth, such as magnetic minerals. The anomaly field is isolated in data processing by removing the other two components.

A **proton precession magnetometer** is a highly sensitive, accurate, portable instrument that measures **magnetic-field intensity**, the force exerted by a magnetic field on a magnetic substance. Magnetic field intensity is expressed in international system (SI) units as teslas and in centimeter-gram-second system (**cgs**) units as gauss or gammas ( $10^{-5}$  gauss). A **nanotesla** (nT) is  $10^{-9}$  tesla, and is equivalent to a gamma. The magnetometer displays the measurement

digitally, in gammas. In general, the more magnetic minerals present, the larger the magnetic anomaly.

**Magnetic surveys** locate magnetic anomalies, irregularities in the distribution of magnetized material in the crust of the earth. **Magnetic susceptibility** is a measure of the ease of magnetization. Most sedimentary rocks are less magnetic than igneous rocks and therefore have relatively low susceptibilities. Magnetic surveys are often used to define a fault by measuring the difference in magnetic fields on either side of the fault. The fault may also be defined by low magnetic readings caused by the leaching of magnetic minerals in the fractured rock, or by high magnetic readings caused by intrusion of igneous material along a fault in a sedimentary basin.

**Diurnal variations**, the more or less daily cycle of changes in the magnetic field, must be measured during a survey to correct for the external field. Also, any magnetic storms (violent and rapid changes in magnetic intensity) occurring during the survey must be recorded. This is accomplished by taking a magnetometer reading at one location at intervals during the day of the survey. The variation in the measurements reflects magnetic changes in the external field that day. Survey measurements can be corrected after these changes are plotted on a graph (Figure 3).

Michael Gross will receive his Ph.D. in structural geology in the fall of 1992 from Penn State University. His research focuses on the analysis of fractures and faults in sedimentary rocks, and relating these features to the state of stress in the earth's crust. Michael has been involved in detailed field studies in the Appalachian Plateau of western New York and southern Ontario, the Transverse Ranges of California, and the Salt Ranges of Pakistan.

John Louie is an associate professor at the Seismological Laboratory at the University of Nevada's Mackay School of Mines in Reno. His research interests involve imaging the structure of major faults in California such as the San Andreas and Garlock. John leads an annual field trip to Death Valley to conduct geophysical surveys.

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## SPECIAL PUBLICATION 114 RELEASE

FIELD GUIDE TO THE GEOLOGY AND METAMORPHISM OF THE FRANCISCAN COMPLEX AND WESTERN METAMORPHIC BELT OF NORTHERN CALIFORNIA. SPECIAL PUBLICATION 114. Peter Schiffman and David L. Wagner, editors. 1992. \$10.00.

Special Publication 114 contains five chapters that discuss metamorphism and tectonics affecting Mesozoic and Paleozoic rocks in the Coast Ranges and Sierra Nevada provinces of northern California. The publication was prepared for an international symposium, The Transition from Basalt to Metabasalt: Environments, Pro-

cess, and Petrogenesis, held at the University of California, Davis.

Four of the chapters are guides for field trips held in conjunction with the symposium. Chapter 1 is a guide for a trip in the San Francisco Bay area where metabasalts of the Franciscan Complex are exposed. Chapter 2 is an overview of the western Metamorphic Belt of the Sierra Nevada. Chapters 3, 4, and 5 are guides for field trips in the northern part of the Western Metamorphic Belt. These trips are in an area covered by the soon to be released 1:250,000 scale Geologic Map of the Chico Quadrangle, California. This map will be the latest of the Division of Mines and Geology Regional Geologic Map Series. (RGM 007A).

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# APRIL 22 JOSHUA TREE, and JUNE 28 LANDERS and BIG BEAR EARTHQUAKES, 1992

TOUSSON R. TOPPOZADA, Seismologist  
RICK I. WILSON, Engineering Geologist

Earthquake	Date	Time (PDT)	Lat °N	Long °W	Depth (km)	Mag
Joshua Tree	April 22, 1992	21:50	33.95	116.32	12	M <sub>s</sub> 6.3
Landers	June 28, 1992	04:57	34.20	116.44	9	M <sub>s</sub> 7.5
Big Bear	June 28, 1992	08:05	34.20	116.83	10	M <sub>s</sub> 6.6

## JOSHUA TREE EARTHQUAKE

The Joshua Tree earthquake occurred at a depth of 7 miles (12 km) on a subsurface north-trending, right-lateral, strike-slip fault (California Institute of Technology [CIT] and U.S. Geological Survey [USGS], written communication). No surface faulting was observed, but aftershocks extended northward to near Landers. This event is now considered to be the start of a major earthquake sequence that peaked with the two June 28 events (see map).

## LANDERS AND BIG BEAR EARTHQUAKES

The Landers earthquake occurred along a near vertical, north-northwest trending, right-lateral, strike-slip fault. Faulting propagated mostly northward from the epicenter, generating about 50 miles (80 km) of surface fault rupture on four previously mapped faults: the Johnson Valley, Homestead Valley, Emerson, and Camp Rock faults (see map). These faults had been zoned over most of their extent by the Division of Mines and Geology's (DMG) Alquist-Priolo program and thus had been recognized as being capable of inflicting damage by fault rupture. Rupture also occurred along minor faults near the town of Yucca Valley, and in step-over areas between the zoned faults (see map).



Main trace of Johnson Valley fault at the Country Gospel Church in the Flamingo Heights area. Zone of fracturing is approximately 30 feet (10 m) wide. More than 6 feet (2 m) of right lateral displacement was measured at the parking spaces (upper left). *Photo by Jack McMillan.*



Surface rupture on unnamed fault in Homestead Valley. *Photo by William A. Bryant.*

Minor sympathetic movements were triggered on nearby faults including the Pisgah, Calico, and Galway Lake faults. Displacements varied greatly along the fault rupture. Apparent vertical displacement of up to 4 feet (1.2 m) was observed on the Emerson fault (lower left photo). A maximum right-lateral displacement of about 20 feet (6 m), one of the largest surface fault displacements observed historically in California, was measured along the Emerson fault (photo below). This illustrates that some of the right-lateral slip between the Pacific and North American plates that is not occurring on the San Andreas fault is occurring on faults in the Mojave Desert.



Wide zone of deformation along the Emerson fault in the area of maximum right-lateral offset (west of Galway Lake). *Photo by William A. Bryant.*



Vertical scarp of the Emerson fault, west side down, near the zone of maximum fault displacement. Although there is a vertical component of displacement along this portion of the fault, some of the vertical separation in this photo can be attributed to right-lateral juxtaposition of a ridge and a swale. *Photo by Tim McCrink.*

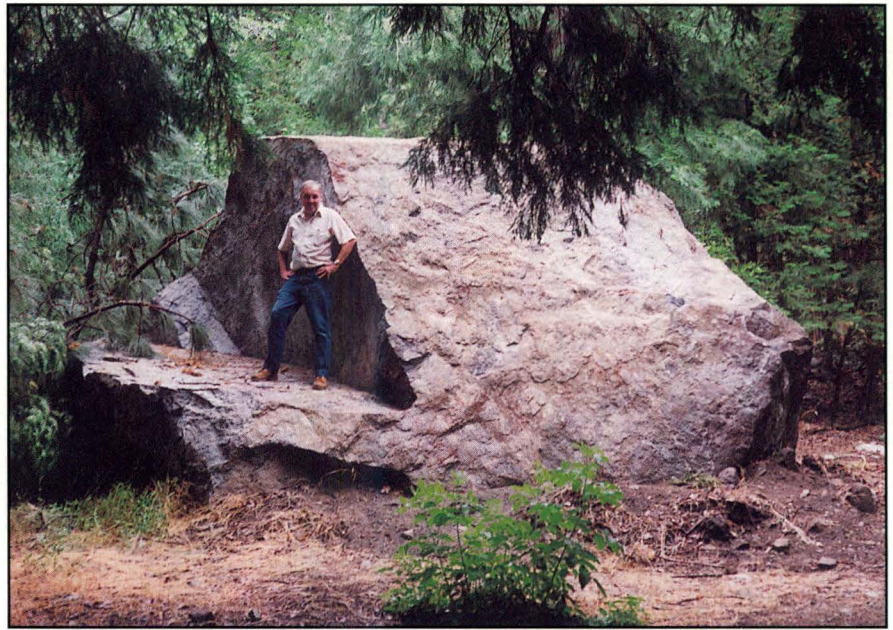
Historical earthquake activity in the area includes the 1975  $M_L$  5.0 Galway Lake earthquake (see CALIFORNIA GEOLOGY, October 1975) and the 1979  $M_L$  5.3 Homestead Valley earthquake (see CALIFORNIA GEOLOGY, March 1980), both of which resulted in surface fault rupture. Faults that ruptured during the 1975 and 1979 events ruptured again during the Landers event.

The maximum Modified Mercalli Intensity was IX at Landers (Glenn Reagor, National Earthquake Information Service, oral communication).

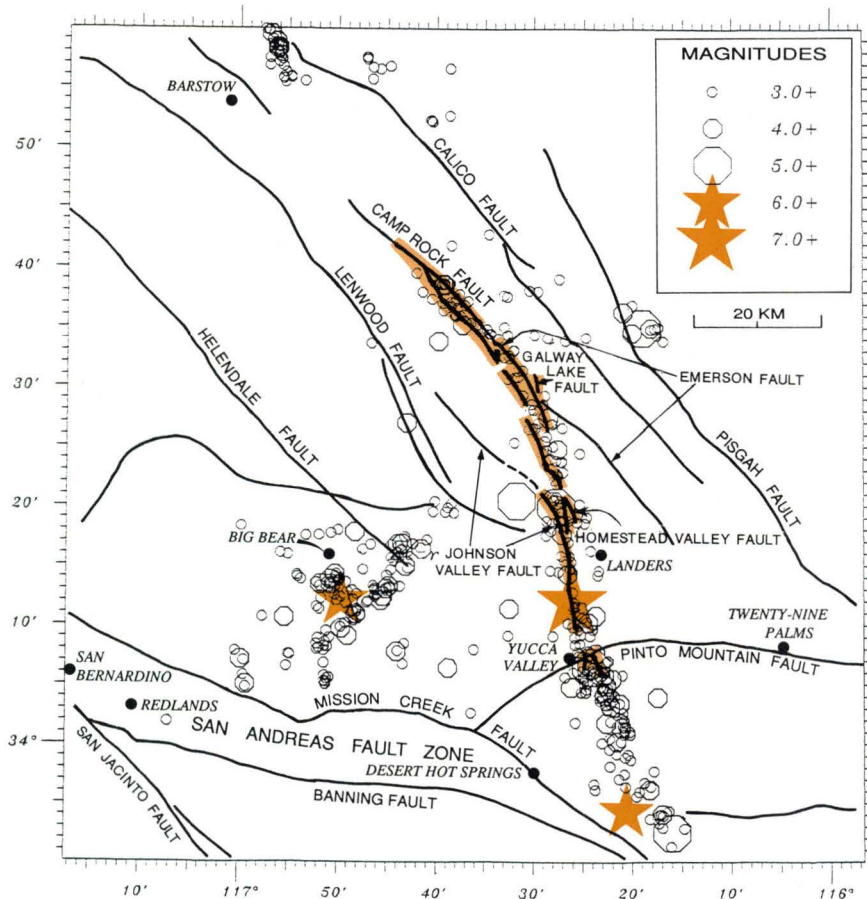
The Big Bear earthquake occurred at a depth of 6 miles (10 km) along a subsurface northeast trending, left-lateral, strike-slip fault (CIT and USGS, written communication). No surface fault rupture was found.

Approximately 500 aftershocks of  $M_L$  3.0 or greater occurred (see map) (CIT and USGS, written communication) during the month following the Landers and Big Bear earthquakes. These include related seismicity to the northeast near the Pisgah fault and to the northwest near the Calico fault.

The earthquakes occurred in sparsely populated areas so damage and casualty totals were low. The Landers earthquake caused major damage to buildings and to



This boulder rolled down the steep south side of Mill Creek Canyon into the back yard of a home in the community of Forest Falls. It is one of the larger boulders set in motion by the  $M_S$  6.6 Big Bear earthquake and its aftershocks. *Photo by Tim McCrink.*



the lifeline infrastructure in the communities of Landers and Yucca Valley. Strong ground-shaking, landslides, and rockfalls caused by the Big Bear earthquake damaged buildings and roadways in the Big Bear Lake area. There were 377 minor and 25 major injuries and one fatality from the June 28 earthquakes.

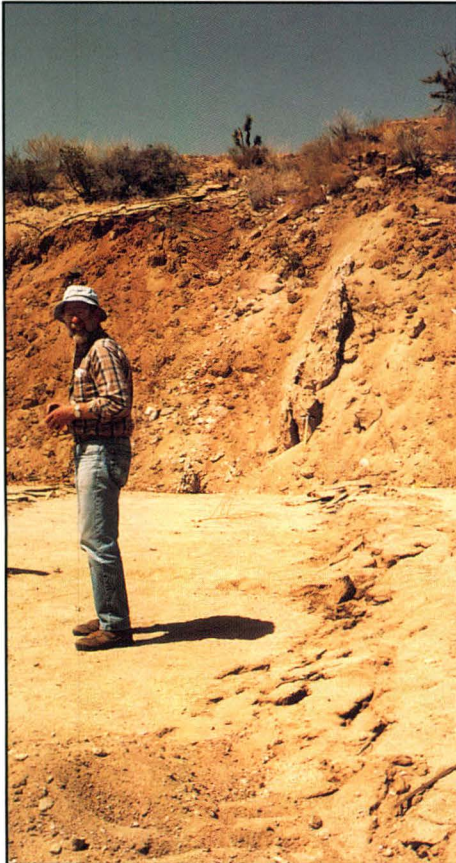
#### ACKNOWLEDGMENTS

Bill Bryant and Mike Reichle (DMG), and Egill Hauksson (CIT) reviewed the manuscript. Claudia Hallstrom (DMG) assembled the earthquake reports that were used in this article. Katrin Douglass from CIT provided the epicenter map.

Epicenters of  $M_L$  3.0 and greater earthquakes for the month following the June 28, 1992 Landers and Big Bear earthquakes (CIT and USGS). The epicenter of the April 22, 1992 Joshua Tree earthquake has been added to the map (southernmost star). Major faults are shown in black, while the June 28, 1992 fault rupture is highlighted in orange. Emerson and Camp Rock fault rupture details have been added. *Courtesy of CIT and USGS.*



# Earl Hart Receives 1992 Alfred E. Alquist Award for Achievements in Earthquake Safety in California



STATE OF CALIFORNIA—THE RESOURCES AGENCY

PETE WILSON, Governor

DEPARTMENT OF CONSERVATION  
DIVISION OF ADMINISTRATION  
DIVISION OF MINES AND GEOLOGY  
DIVISION OF OIL AND GAS  
DIVISION OF RECYCLING



801 K Street, MS 24-01  
Sacramento, CA 95814-3528  
Phone (916) 322-1080  
(916) 322-1080

June 9, 1992

Mr. Earl W. Hart  
Department of Conservation  
Division of Mines and Geology  
1145 Market Street, Third Floor  
San Francisco, CA 94103

Dear Earl:

Congratulations on being selected by the California Earthquake Safety Foundation as the recipient of the 1992 Alquist Award for achievements in earthquake safety in California.

You have been a fine example of the dedicated, hard-working civil servant we like to see in State Government. Your tireless efforts are also well recognized throughout the geologic community and by others involved in seismic safety. With only a small staff, you have prepared 534 Special Studies Zones Maps and revised 124. In addition, as Manager of the Fault Evaluation and Zoning Program since its inception in 1973, you have provided valuable information and guidance to cities and counties throughout the State.

Again, congratulations for a job well done.

Sincerely,

Edward G. Heidig  
Director

cc: B. Guerard  
J. Davis

## GEOLOGICAL SOCIETY OF AMERICA OFFERS SHORT COURSES October 1992

The Geological Society of America (GSA) will offer the following courses at its annual meeting in Cincinnati, Ohio in October 1992:

- Geographic Information System Software: Facts and Fiction ..... October 23-25
- How to Do Anything with Mohr Circles (Except Fry an Egg):  
    A Short Course About Tensors for Structural Geologists ..... October 24-25
- Introductory Rock and Paleomagnetism ..... October 24-25
- Environmental/Engineering Geology and Land-Use Planning—An Interface  
    Between Science and Regulations ..... October 25
- Paleosols for Sedimentologists ..... October 25
- Phase I — Preliminary Site Assessments (PSAs) ..... October 25
- Practical Tracing of Ground Water, with Emphasis on Karst Terranes ..... October 25
- Environmental Applications of Shallow Seismic Reflection ..... October 30

For more information, contact: Edna A. Collis, Meetings Coordinator, Geological Society of America, 3300 Penrose Place, Boulder, CO 80301, (303) 447-2020, FAX (303) 447-1133.

# THE MINERAL INDUSTRY OF CALIFORNIA-1991

FRED V. CARRILLO, U.S. Bureau of Mines



Hayden Hill, Lassen County. Photo by John Burnett.

According to the U.S. Bureau of Mines, California was the nation's largest producer of nonfuel minerals in 1991, accounting for nearly 10 percent of the total U.S. production. The value of nonfuel mineral commodities produced during the year was estimated at \$3.02 billion, an increase of more than 8 percent from 1990. The State led in the production of asbestos, boron minerals, portland cement, diatomite, calcined gypsum, construction sand and gravel, rare-earth concentrates, and tungsten.

Industrial mineral production in portland cement, clays, crude gypsum, lime, construction sand and gravel, and crushed stone mirrored the continuing decline in construction activity. Declines are expected to continue. However, metallic minerals, particularly the precious metals

and molybdenum, as well as asbestos and pumice, were responsible for the increase in estimated value over that of 1990. Increased gold production allowed California to retain its rank as the second largest gold-producing State.

**Employment.** The California Department of Economic Development states that the nonfuel mining industry employed 9,000 workers in October 1991, unchanged from October 1990. Approximately 2,200 workers were employed in metal mining and 6,800 workers in non-metallic mineral mining.

**Exploration.** Precious metals were explored in several areas throughout the State, despite lower silver and gold prices. Exploration was begun at the Idaho-Maryland mine near Grass Valley, Nevada

County. The program included water removal, mine rehabilitation, and underground exploration drilling. Kennecott Corporation and Canyon Resources explored in the Panamint Range west of Death Valley. Arizona Star Resource Corporation drilled its Imperial County project 40 miles (65 km) northwest of Yuma, Arizona, outlining two gold prospects: the Indian Rose deposit and the Ocotillo deposit. Tenneco Minerals drilled a U.S. Forest area near Antelope Valley.

**Legislation.** A new California law dictates the elimination of plastic or PVC pipe for mining claim markers. Only wood, stone, or solid metal markers can now be used to mark claims on federal lands in the State. The law also reduces to five the markers required for outlining a claim. Another law clarified the type of mining wastes that are exempt from hazardous waste management laws.

San Benito was the first county to initiate a per-ton "business license" tax on minerals. This new 5-cent-per-ton tax on minerals mined in the county will be used to pay for road repair. It was initiated under Senate Bill 2557 which granted counties new authority to raise revenues.

**Review of Nonfuel Mineral Commodities.** In September, construction at Amax Gold Inc.'s Hayden Hill mine in Lassen County began. In April, Goldfields Operating Company celebrated the pouring of the one millionth ounce of gold at its Imperial County Mesquite mine with the opening of the Mesquite Mine Overland Trail. The trail introduces the public to the gold mine and its unique desert environment. The self-guided Overlook Trail is a cooperative venture of Goldfields and the U.S. Bureau of Land Management.

Primary Steel Company discontinued its Antoch Flat rolled steel plants. This resulted in the Tricon division of Reliance Steel and Aluminum Company, Fremont, as the only high-volume flat rolled steel

distributor in the San Francisco Bay area. Reliance Steel & Aluminum combined its two carbon specialists, Tricon and Feralloy West Company, to form the region's major flat rolled processor.

The U.S. Borax Company consolidated its Los Angeles headquarters and Anaheim research offices with a move to the Valencia area. This location is more convenient to its mining operations at Boron, north of Edwards Air Force Base. In February, Newport Mineral Ventures

of Maryland acquired the Death Valley Bille mine from American Borate Company and began limited operations in April. Manville Corporation sold its Celite subsidiary to New York-based Alleghany Corporation. South of Lompoc, Celite operated the world's largest diatomaceous-earth mining facility.

Some sand and gravel operations were started or enlarged. Hillsdale Rock Company was granted a 50-year permit to mine sand and gravel from the Lomerias

Muertas hills north of San Juan Bautista in San Benito County. XTRA Power Company was granted a 30-year use permit to mine sand and gravel from Cottonwood Creek in Tehama County. Granite Construction Company began building a paving material plant at its quarry on Pacheco Pass Highway in San Benito County. Calmat Company was granted permission to double the size of its operations at the South Poway quarry in San Diego County.

## NONFUEL MINERAL PRODUCTION IN CALIFORNIA <sup>1/</sup>

MINERAL	1989		1990		1991e/	
	QUANTITY	VALUE (thousands)	QUANTITY	VALUE (thousands)	QUANTITY	VALUE (thousands)
Boron minerals ..... metric tons	562,311	\$429,806	1,093,919	\$436,176	1,093,919	\$436,176
Cement (portland) ..... do.	10,911	642,020	10,032	604,080	8,788	527,280
Clays ..... metric tons	2,195,830	39,243	2/2,163,515	2/40,217	2/2,160,685	2/36,897
Gem stones .....	NA	2,982	NA	1,501	NA	1,500
Gold <sup>3/</sup> ..... kilograms	29,804	366,595	29,607	368,300	33,362	396,866
Gypsum (crude) thousand short tons	1,734	13,066	W	W	W	W
Lime ..... do.	395	24,503	345	19,425	298	16,674
Mercury ..... metric tons	W	W	4/	4/	4/	4/
Pumice ..... do.	79,000	4,612	71,739	5,088	W	W
Sand and gravel:						
Construction thousand short tons	e/138,300	e/670,800	132,214	626,000	115,000	546,300
Industrial ..... do.	2,426	43,863	2,452	48,055	2,000	40,000
Silver <sup>3/</sup> ..... metric tons	21	3,650	21	3,209	27	3,466
Stone:						
Crushed .... thousand short tons	54,887	238,034	e/42,500	e/200,600	34,500	162,900
Dimension ..... short tons	28,829	5,564	e/30,077	e/5,213	30,000	5,300
Combined value of asbestos, barite (1990-91), calcium chloride (natural), cement (masonry), clay (fuller's earth 1990-91), copper (1989-90), diatomite, feldspar, iron ore (by-product 1989, and usable), magnesium compounds, mica (crude 1991), molybdenum, perlite, potash, pumice (1991), rare-earth metal concentrates, salt, soda ash, sodium sulfate (natural), talc and pyrophyllite, titanium concentrates (ilmenite 1989-90), tungsten ore concentrates, and values indicated by symbol W .....	XX	369,664	XX	421,935	XX	843,826
Total .....	XX	2,854,402	XX	2,779,799	XX	3,017,185

e/ = Estimated. NA = Not available. W = Withheld to avoid disclosing company proprietary data; value included with "combined value" figure.  
XX = Not applicable.

<sup>1/</sup> = Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

<sup>2/</sup> = Excludes certain clays; kind and value included with "Combined value" data.

<sup>3/</sup> = Recoverable content of ores, etc.

<sup>4/</sup> = Less than 1/2 unit.

## Highlights of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area.

Glenn Borchardt  
and  
Patrick McClellan

This highly successful Second Conference was held at California State University, Hayward (CSUH) March 25-29, 1992. Over 400 earth scientists, engineers, and planners attended the 90 oral and poster sessions.

The first conference was in 1982 and its findings were published in the Division of Mines and Geology (DMG) Special Publication 62. In the intervening 10 years, many advancements have been made in the study of East Bay earthquake hazards. Some that were reviewed and updated include:

- Estimates of the Holocene slip rates of the Hayward, Rodgers Creek, and northern Calaveras faults (all about  $8 \pm 3$  mm/yr). Estimates of probabilities for major earthquakes on the Hayward and Rodgers Creek faults (all are about 0.25, or one chance in four, over the next 30 years).
- Vast improvements in the measurement precision of creep rates, strain, and geodesy along most East Bay faults.
- New geophysical and seismological data revealing the nature of the connections between the Hayward and Rodgers Creek faults and between the Calaveras and Concord faults.
- Recognition that NE-SW tectonic compression across the Bay region, as well as right-lateral strike slip on the major NW-trending faults, plays an important role in the tectonic regime in the East Bay.
- Numerous Alquist-Priolo Special Studies pinpointing the locations of active fault traces. These led to a detailed map of the Hayward fault (USGS Miscellaneous Field Studies Map MF-2196) and to the recommendation that the Antioch fault be removed from the list of Holocene-active faults.

- Recognition that the northern Calaveras fault is a likely source of a major earthquake in the near future.

- Improved knowledge of the late Quaternary sedimentation of San Francisco Bay and its influence on earthquake damage.

- Development and refinement of earthquake planning scenarios for the Hayward and Rodgers Creek faults.

- Progressive State and local programs to abate earthquake hazards of unreinforced masonry buildings, schools, and other public buildings that lie on or near East Bay faults.

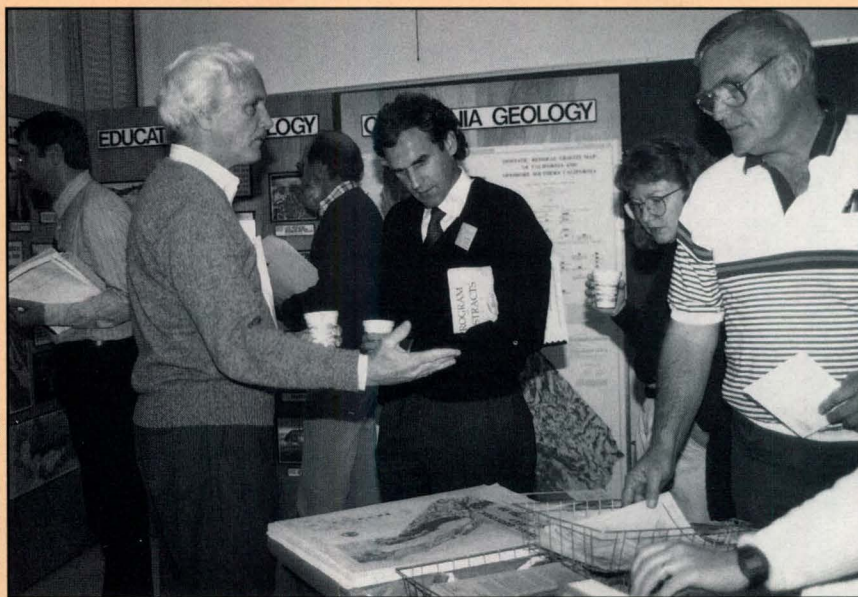
During the conference, a two-day field trip was conducted along the Hayward fault. The corresponding field trip guidebook, which includes 34 contributions in 225 pages, describes the vast amount of knowledge gained about the Hayward fault, particularly during the last decade.

The guidebook is based on the new USGS map.

Another important component of the Second Conference was a special non-technical forum for 350 Bay area science teachers, officials, and citizens. The forum featured earthquake exhibits and a panel presentation by the scientists who attended the previous technical sessions.

The proceedings of the Second Conference will be published by the Division of Mines and Geology. The Pioneer Bookstore at CSUH sells the 1992 field trip guidebook (\$16.00), the 1982 field trip guidebook (\$9.00), and the new USGS map of the Hayward fault (MF-2196) (\$3.50). Shipping and handling is \$4.50 for the first item and \$2.50 for each additional item.

Pioneer Bookstore  
California State University, Hayward  
25976 Carlos Bee Boulevard  
Hayward, CA 94536  
(510) 881-3507



Division of Mines and Geology exhibit at Second Conference on Earthquake Hazards.

# Book Reviews

## Commemorative Photographs

IN THE FOOTSTEPS OF JOHN WESLEY POWELL: An Album of Comparative Photographs of the Green and Colorado Rivers, 1871-72 and 1968. By Hal G. Stephens and Eugene M. Shoemaker. 1987. Johnson Books, 1880 South 57th Court, Boulder, CO 80301. 286 p. \$19.95, soft cover.

John Wesley Powell's 1869 and 1871-72 expeditions down the Green and Colorado rivers provide views of some of the most extraordinary exposures of geology anywhere in the world. Beginning at Green River, Wyoming in rocks of Tertiary age (fewer than 60 million years old), the route travels one vertical mile down the geologic column to exposures of the Precambrian Era (more than 1.5 billion years old) in the Inner Gorge of the Grand Canyon. To commemorate the centennial of the first voyage, the U.S. Geological Survey, along with the Smithsonian Institution and the National Geographic Society, sponsored an expedition to retrace the route of Powell's 1871-72 survey. The purpose was to rephotograph the views from the same camera stations used by Powell expedition photographers E.O. Beaman and John K. Hillers. The result is an album of comparative photographs which illustrates the canyons of the Green and Colorado rivers over the intervening 100 years.

Surprising little change may be evident in the canyon walls in terms of geologic time, however the erosional impact of the river and its tributaries is apparent. Most dramatic is the pervasive spread throughout the Colorado River region of tamarisk, a Middle Eastern tree planted as a windbreak in the Imperial Valley during the early part of the century.

A combination of research into Powell's expedition diaries, detailed examination of the original photographs, and extensive knowledge of canyon geology enabled the U.S. Geological Survey crew to identify 150 original camera stations. In a few cases rockfalls, shifting tributaries, thick vegetation, or inundation by lake waters prevented the team from reaching the exact site.

The book is divided into six chapters covering different river segments. Opening

essays provide both historical and geologic context for 110 pairs of photographs. Each pair of photographs is accompanied by a more detailed description of visible geologic features and a commentary on the changes that have taken place. A glossary, tables of geologic formations, topographic map references, and a list of selected readings provide additional documentation. *Review by Sylvia Bender-Lamb.* ∞

## Geophysics

APPLIED SUBSURFACE GEOLOGICAL MAPPING. By Daniel J. Tearpock and Richard E. Bischke. 1991. Prentice Hall, Prentice Hall Building, Englewood Cliffs, NJ 07632. 648 p. \$84.00, hard cover.

The increasing use of oil and gas creates a need for well-trained, well-educated petroleum geologists. This book is a comprehensive work designed for geologists, geophysicists, and engineers who prepare subsurface geological maps. It would also be beneficial to those who use or evaluate subsurface maps, to petroleum geology students, and to experienced geologists who want to learn more about subsurface mapping.

The techniques are applicable to related fields such as mining, groundwater, and waste disposal. Chapter topics include: contouring techniques, directionally drilled wells and directional surveys, log correlation techniques, integration of geophysical data in subsurface mapping, cross sections, fault maps, structure maps, structural geometry and balancing, isopach maps, and field study methodology. ∞

EXPLORATION GEOPHYSICS OF THE SHALLOW SUBSURFACE. By H. Robert Burger. 1992. Prentice Hall, Prentice Hall Building, Englewood Cliffs, NJ 07632. 489 p., two 3-1/2" diskettes. \$56.00, hard cover.

This textbook is appropriate for advanced undergraduate geology students and students of other disciplines who require some knowledge of geophysical methods. Examples, illustrations, problem sets, and applications focus on shallow exploration. After a discussion of the fundamentals of seismic exploration, the text introduces the basic theory for each geophysical method: refraction, reflection, electrical resistivity, gravity, and magnetism.

Although equations are developed in detail, mathematical expertise is not necessary. Discussion of data collection and reduction procedures is sufficient to allow the planning of field surveys. Although nine computer programs written for the Macintosh® accompany the text, the text does not depend on their use. They are designed to aid comprehension of the topics and to work with field data. They perform direct and inverse modeling and support all the major exploration methods covered in the book. Microsoft® Excel spreadsheet templates which produced most of the tables in the book are also on the diskettes. Students can access the templates, change values in certain cells, and study the effects. The programs require at least System 6.0. Microsoft® Excel Version 2.2 is required to access the templates. ∞

® Macintosh is a registered trademark of Apple Computer, Inc. Microsoft is a registered trademark of Microsoft Corporation.

VIBROSEIS. By Nigel A. Anstey. 1991. Prentice Hall, Prentice Hall Building, Englewood Cliffs, NJ 07632. 171 p. \$65.00, hard cover.

Vibroiseis is a seismic method used to determine the nature and configuration of rock layers deep in the earth. Its major advantages are that it can be used along roads and can generate a reflection pulse as sharp or sharper than that associated with dynamite. Vibroseis provides the required energy in a long signal of low power which is later compressed into a short pulse. A baseplate is lowered into contact with the ground from a series of trucks called vibrators. The command signal comes by radio from the recording truck and the baseplates and ground vibrate. Sound waves reflecting off subsurface rock layers are received by geophones and recorded. The vibrator operators lift the baseplates, drive forward, and repeat the process.

This book documents the history and technical aspects of vibroseis. Some of the subjects covered are vibrator electronics, the effect of distortion, practical considerations in the field, and the problem of optimizing resolution. There are five appendices that provide equations for various calculations. The book is addressed to anyone interested in geophysical exploration: students, technicians, processors, interpreters, field geophysicists, and exploration directors. ∞

## more book reviews...

### Dating Methods

DATING METHODS APPLICABLE TO QUATERNARY GEOLOGIC STUDIES IN THE WESTERN UNITED STATES. Utah Geological and Mineral Survey Miscellaneous Publication 89-7. Edited by Steven L. Forman. 1989. Utah Geological and Mineral Survey, Department of Natural Resources, 606 Black Hawk Way, Salt Lake City, UT 84108-1280. 80 p. \$6.75 including postage, soft cover.

Except for volcanic extrusives, most Quaternary rocks cannot be dated by the popular isotope methods which date the moment of initial crystallization. Fossils are rare and seldom definitive except Holocene and Pleistocene fauna which have well-known distinctions between them. This handy volume presents a summary of a few techniques that are currently in use. They mostly rely on dating materials within a deposit or on tracing the progress of processes involving the surface of the deposit. Topics include: radiocarbon dating (using carbon-14, a radioactive isotope of carbon), dendrochronology (the study of tree rings), soil dating, slope-morphometric dating (estimating the age of scarp-like landforms), thermoluminescence dating (measuring the energy released as light upon heating), tephrochronology (the study of the dating and correlation of volcanic ash deposits), amino acid geochronology (the study of the dating of amino acids in carbonate fossils), and paleothermometry (the determination of temperature during the geologic past). There is also a discussion of the application of K/Ar and Ar isotope dating to Quaternary geology. Some of the chapters are much more comprehensive than others, but together provide a basic introduction to geochronology. *Review by Glenn Borchardt.*

### Gold Rush

THEY SAW THE ELEPHANT. By JoAnn Levy. 1990. The Shoe String Press, 925 Sherman Avenue, Hamden, CT 06514. 265 p. \$25.00, hard cover.

The expression "seeing the elephant" predates the 1849 gold rush. There is a story of a farmer who, on hearing that a circus was in town, loaded his wagon with vegetables and headed for the market there. He had never seen an elephant

and this was an opportunity he could not pass up. When he met the circus parade which was led by an elephant, his horse bolted in terror and upended his wagon. Seeing his ruined vegetables, the farmer could only say, "I don't give a hang, for I have seen the elephant." To the gold rushers the elephant symbolized the vast possibilities of fortune or misfortune the journey to California represented.

In this medley of stories, the author shows the true extent of women's participation in the gold rush. Most gold rushers were young, single men. However, it is estimated (based on diaries, letters, and reminiscences) that 18,000 out of 180,000 forty-niners traveling overland were women. Some came with their husbands, fathers, or brothers. Some came alone.

Many women established homes in the towns and camps, others mined gold themselves. Females worked and lived in every quarter of society. They were gamblers, actresses, missionaries, church builders, innkeepers, school teachers, and prostitutes. One woman, Eliza Farnham, wrote a book describing how the captain of the ship that was bringing her around the Horn abandoned her in South America and sailed off with her children. She found her way to California where she built a two-story house with her own hands, planted potatoes, and discussed philosophy. Mrs. Farnham discoursed on many subjects. One issue dealt with the exaggerated status many miners achieved simply by claiming it. Pointing out this tendency for misrepresentation, she said, "If he could blow a fife on training days, he will be a professor of music here; if he have built a pigsty or kennel at home, he will be a master-builder in California." In the youthful land of California one was uniquely free from the censure of Eastern restrictions and societal expectations. Consider that when John Sutter arrived in California from Switzerland he immediately deemed himself "captain." It was never determined that he had any military experience at all.

Women often took on the practical jobs in business. Twelve of the 23 women living in Nevada City in 1850 took in boarders or ran hotels, the other three worked in family-run taverns that accepted boarders. Apparently there was some

competition in the hotel industry. The proprietor of Nevada City's El Dorado Hotel, Luzena Stanley Wilson wrote, "I determined to set up a rival hotel. So I bought two boards from a precious pile belonging to a man who was building the second wooden house in town. With my own hands I chopped stakes, drove them into the ground, and set up my table. I bought provisions at a neighboring store, and when my husband came back at night he found, mid the weird light of the pine torches, twenty miners eating at my table. Each man as he rose put a dollar in my hand and said I might count him as a permanent customer...From the first day it was well patronized, and I shortly after took my husband into partnership."

This book is a fascinating testimonial to the feelings and achievements of women living on the frontier and how they met and dealt with adversity in a land as exotic and new as the experience of seeing an elephant for the first time. *Review by Max Flanery.*



General pattern of sedimentation in Paleozoic time.

Texas

ROADSIDE GEOLOGY OF TEXAS. By Darwin Spearing. 1991. Mountain Press Publishing Company, P.O. Box 2399, Missoula, MT 59806. 418 p. \$15.95, soft cover.

The geologic panorama of Texas includes volcanic mesas and thrusting mountains in the west, red canyons in the Panhandle, tropical sand barriers along the Gulf Coast, and the limestone plateaus on hard granitic terrain in the center of the state. Rock of all ages and major types, from Precambrian crystalline gneiss to the loose sands of Holocene beaches, is found at the surface in the state.

Texas also has an incredible array of natural geologic resources, ranging from its

famous oil and gas fields through practically every rock and mineral resource, including geothermal. There is a vast potential for development of resources in the Trans-Pecos region of West Texas, in the Gulf Coast area, and in a belt across central Texas.

*Roadside Geology of Texas* explains how common geologic processes shaped and molded the landscapes you see today. In nontechnical language, the author leads you on a journey through geologic time, interpreting the rocks along the highways of the Lone Star State.

The seven sections in the book divide the diverse terrain into cohesive units of similar geology and geography. Each section begins with an introductory review followed by descriptive road logs.∞

### Hydrology

**ELEMENTARY HYDROLOGY.** By Vijay P. Singh. 1992. Prentice Hall, Prentice Hall Building, Englewood Cliffs, NJ 07632. 973 p. \$68.00, soft cover.

Hydrology is a part of the undergraduate curricula of agricultural engineering, civil engineering, environmental sciences, climatology, meteorology, forestry, geography, and geology. *Elementary Hydrology* requires no previous background in hydrology. It deals principally with surface water hydrology with emphasis on the drainage basin as the origin of surface water.

This book is divided into the following parts: 1) the preliminaries including the hydrologic cycle, the hydrologic budget, types of watersheds, and the application of hydrology to environmental and water resources problems; 2) drainage-basin characteristics, weather, and the measurement and analysis of precipitation data; 3) basic concepts of groundwater hydrology including infiltration, soil moisture, and baseflow; 4) above-surface flow and hydrologic abstractions, and shows the hydrology's relationship to aerodynamics, botany, and agricultural and forest sciences; 5) streamflow measurement and hydrograph analysis; 6) the relationship between precipitation and runoff; 7) methods of flow routing through reservoirs and open channels; 8) watershed simulation and development of watershed models by integration of the concepts in preceding

sections; 9) hydrologic design involving statistical methods. Exercises follow each chapter. References are limited to those the author deemed most pertinent to the beginner.∞

### Natural History

**NATURAL HISTORY OF THE WHITE-INYO RANGE, EASTERN CALIFORNIA.** Edited by Clarence A. Hall, Jr. 1991. University of California Press, 2120 Berkeley Way, Berkeley, CA 94720. 536 p. \$24.95, soft cover.

This natural history guide is modeled after the now-classic *Sierra Nevada Natural History* by Storer and Usinger and covers physical features including climate and geology, plants, animals, and archaeology.

The White-Inyo Range—rising sharply from the eastern edge of Owens Valley—is one of the most extraordinary landscapes in the world. High, dry and amazingly diverse, it boasts an expansive alpine tundra and features one of the oldest living species on earth—the 4,000-year-old bristlecone pines. This colorful and authoritative volume is a wealth of information to hikers and scientists attracted to the White-Inyo's altitude and isolation. There are descriptions of more than 650 kinds of living things, an eight-color geologic map, and a roadside guide that enable the visitor to make sense of the area's complex geological history.

For anyone who wishes to visit this astonishing area or do research, this volume is a unique, comprehensive resource.∞

### Mojave Desert

**GHOST TOWNS OF THE MOJAVE DESERT: A Concise and Illustrated Guide.** By Alan Hensher. 1991. California Classics Books, P.O. Box 29756, Los Angeles, CA 90029. 64 p. \$14.50, soft cover.

This concise and illustrated guide has drawn on years of research to chronicle the histories of nearly 100 southern California desert ghost towns. Much of it has never been published. Dozens of rare photographs document the rise and fall of settlements such as Crackerjack, Avawatz, Minneola, Vontrigger, Crow Town, Toeglcity, and Saltdale as well as larger towns such as Calico and Ivanpah.

Detailed maps pinpoint the locations of camps and townsites so the reader can visit them. Histories of the towns and the reasons for their downfalls are provided.∞

**THE CAMP CADY LOCAL FAUNA:** Paleoenvironment of the Lake Manix Basin. By George T. Jefferson; and **ABSTRACTS OF PROCEEDINGS: 1987 Mojave Desert Quaternary Research Symposium.** Quarterly, v. 34, no. 3 and 4. Compiled by Jennifer Reynolds. 1987. San Bernardino County Museum Association, 2024 Orange Tree Lane, Redlands, CA 92374. 65 p. \$7.39 including shipping and tax, soft cover.

The first part of this publication is a study of the vertebrate and invertebrate fossils recovered from lake and river deposits east of Barstow, San Bernardino County, California. The fossils found in the late Pleistocene Manix Formation include birds, fish, turtles, and other forms which lived along the margins of Lake Manix. Nearby valleys and slopes that surrounded the lake contain fossils of ground sloths, mammoth, cats, horses, camels, and bison.

The second part includes abstracts of 13 papers presented at the 1987 Mojave Desert Quaternary Research Symposium. The papers include topics on paleontology, radiocalcium dating, archaeology, desert soils, and geomorphology.∞

**QUATERNARY HISTORY OF THE MANIX FAULT, LAKE MANIX BASIN, MOJAVE DESERT, CALIFORNIA.** By Sally F. McGill, Bruce C. Murray, Kevin A. Maher, Jay H. Lieske, Jr., Linda R. Rowan, and Fred Budinger; and **ABSTRACTS OF PROCEEDINGS: 1988 Mojave Desert Quaternary Research Symposium.** Quarterly, v. 35, no. 3 and 4. Compiled by Jennifer Reynolds. San Bernardino County Museum Association, 2024 Orange Tree Lane, Redlands, CA 92374. 56 p. \$7.39, soft cover.

The first part of this publication describes the deformation related to movement along the Manix Fault east of Barstow in San Bernardino County. This evidence suggests that movement on the fault began before middle Pleistocene time and may have continued into the Holocene.

## and more book reviews...

The second part contains abstracts of 17 papers presented at the 1988 Mojave Desert Quaternary Research Symposium including titles on paleontology, geomorphology, stratigraphy, geoarcheology, and phosphate deposits.

**NELSON LAKE:** Important Early Sites. By Claude N. Warren and Joan S. Schneider; and **ABSTRACTS OF PROCEEDINGS;** 1989 Mojave Desert Quaternary Research Symposium. Quarterly, v. 36, no. 2. 1989. Compiled by Jennifer Reynolds. San Bernardino County Museum Association, 2024 Orange Tree Lane, Redlands, CA 92374. 68 p. \$7.39 including shipping and tax, soft cover.

The first part of this publication is a description of Nelson Lake archeological sites at the Fort Irwin National Training Center, northeast of Barstow, San Bernardino County, California. The sites contain faunal remains, stone tools, and abundant debris from the production and maintenance of stone tools. The sites are thought to be early Holocene.

The second part of the publication contains abstracts of papers presented at the third annual Mojave Desert Quaternary Research Symposium. Topics include botanical lineaments, paleontology, geomorphology and landsliding, interpretation of earth satellite images, and paleomagnetic studies.✕

**THE MOJAVE RIVER FORMATION, MANIX BASIN, CALIFORNIA:** Stratigraphy, Correlation, Magnetostratigraphy, and Rotation. Quarterly, v. 38, no. 2. 1991. San Bernardino County Museum Association, 2024 Orange Tree Lane, Redlands, CA 92374. 63 p. \$8.89 including shipping and tax, soft cover.

The book contains four papers of various aspects of the Mojave River Formation. *Stratigraphy and Intra-basin Correlation of the Mojave River Formation, Central Mojave Desert, California*, by Elizabeth A. Nagy and Bruce C. Murray, describes the lithology, geologic age, and mode of origin of the formation. Active faults, including the nearby Manix, have played an important part in the history of the formation and the ancestral Mojave River.

*Magnetostratigraphy and Clockwise Rotation of the Plio-Pleistocene Mojave River Formation, Central Mojave Desert, California* is by Christopher J. Pluhar, Joseph L. Kirschvink and Robert W. Adams. One hundred forty-three samples of the Mojave River Formation were studied for natural remanent magnetism. Results suggest a net clockwise rotation of  $8 \pm 2.7$  degrees over the past 2 million years.

*Abstracts of Proceedings from the 5th Annual Mojave Desert Quaternary Research Symposium, May 17-18, 1991.* Jennifer Reynolds compiled abstracts of seven papers on plate tectonics, geomorphology, anthropology, stratigraphy, mineralogy, paleontology, and paleobotany.

*Ancient Astronomy of the Black Canyon Indians: The 1991 Mojave Desert Quaternary Research Symposium Evening Lecture* is by Wilson G. Turner. In this paper Indian petroglyphs at the base of Tortoise Mountain are interpreted as representing various heavenly bodies.✕

**THE WEST-CENTRAL MOJAVE DESERT:** Quaternary Studies Between Kramer and Afton Canyon. Edited by Robert E. Reynolds. 1989. San Bernardino County Museum Association, 2024 Orange Tree Lane, Redlands, CA 92374. 83 p. \$10.08 including shipping and tax, soft cover.

This publication is a collection of papers on the Mojave Desert near Barstow, California. The first paper is a guide for a 180-mile-long field trip from San Bernardino, through Helendale, Barstow, Calico, and Afton Canyon on the ephemeral Mojave River. Other topics include those on paleontology, formation of lakebeds, detachment faulting, hydrology, and tectonic and fault studies.✕

### Soil

**SOILS IN ARCHAEOLOGY:** Landscape Evolution and Human Occupation. Edited by Vance T. Holliday. 1992. Smithsonian Institution Press, Department 900, Blue Ridge Summit, PA 17294. 254 p. \$39.95 plus \$2.25 for postage and handling, hard cover.

This book is a collection of eight papers presented at the 1988 annual

meeting of the Society for American Archaeology. The papers cover a broad spectrum of soil science applications, including soil chemistry. The essays discuss the use of soils for reconstructing past landscapes and landscape evolution, for estimating the age of surfaces and depositional episodes, and for providing physical and chemical indicators of human occupation.

The first four chapters deal with soil geomorphology in archaeology. Specifically the use of soils for reconstructing landscapes and site settings and the use of soils as age indicators are studied.

The second group of four essays deals with the archaeological significance of particular attributes of soils and includes both soil geomorphology and soil chemistry.

Because of the potentially broad audience for this collection of essays, the editor included a useful glossary of some terms, largely from pedology and soil micromorphology. Also included are some terms used in soil description and classification, soil geomorphology, and soil geoarchaeology.✕



**SOIL PHYSICS,** Fifth Edition. By William A. Jury, Wilford R. Gardner, and Walter H. Gardner. 1991. John Wiley & Sons, Inc., 1 Wiley Drive, Somerset, NJ 08875-1272. 328 p. \$49.00, hard cover.

The book, designed for advanced undergraduates or graduate students as well as professional scientists, covers a rapidly changing field which has gained prominence with the growth of environmental engineering. Research on the chemical pollution of the environment is now a global priority. As a result, the once minor field of solute (solids or gases dissolved in water) transport through soil is now a mainstream research area of soil physics. The book covers the recent change from laboratory to field study of soil problems. It also addresses the increased use of mathematics and statistics to describe soils.



These general topics are covered: the physical and chemical properties of soil; the properties of water in soils; the theory of water transport through saturated and unsaturated soils; the transport of heat, gases, and dissolved solids in soil; solute movement in soil; and methods of assessing the properties of spatially variable soil.✕

**INTRODUCTION TO THE PETROLOGY OF SOILS AND CHEMICAL WEATHERING.** By Daniel B. Nahon. 1991. John Wiley & Sons, Inc., 1 Wiley Drive, Somerset, NJ 08875-1272. 313 p. \$59.95, hard cover.

This book covers the last 25 years during which petrographic, mineralogic, and geochemical analysis of soils has made great advances. The results of numerous investigations are summarized and synthesized, particularly on the weathering soil mantle in tropical areas. Translated from French and concentrating on examples in Africa, the book emphasizes the value of an interdisciplinary approach to the study of soils.

Illustrations include photographs and excellent line drawings. The reference list is extensive and includes all of the standard citations as well as newer, lesser-known ones.✕

**SOILS AS A TOOL FOR APPLIED QUATERNARY GEOLOGY.** Utah Geological and Mineral Survey Miscellaneous Publication 91-3. By Peter W. Birkeland, Michael N. Machette, and Kathleen M. Haller. 1991. Utah Geological and Mineral Survey, Department of Natural Resources, 606 Black Hawk Way, Salt Lake City, UT 84108-1280. 63 p. \$6.50 including postage, soft cover.

The last 15 years have seen a tremendous interest in the use of soils for dating geologic events. Newly deposited sediments undergo the ravages of climate near the surface of the earth. Percolating waters dissolve minerals crystallized at high temperature and pressure within the earth and precipitate still other minerals more in tune with the low temperature and pressure at the surface. Soil development takes time, and the Quaternary Period (the last 2 million years) has produced numerous land surfaces that have been abandoned by the geologic pro-

cesses that created them. Not surprisingly, the older surfaces generally have soils that are redder, deeper, more clayey, and more cemented than the younger surfaces.

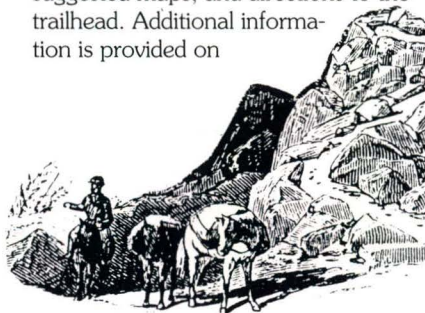
This short publication is a quick means for geologists to get an appreciation of soil and how its properties relate to its age. The authors first explain how different soils are recognized and described. Concentrating mostly on the western U.S. they illustrate the effect of time on the production and properties of soils in arid, semiarid, and subhumid regions. Lastly, they relate numerous case studies in which soils have been used to reconstruct past climates, map Quaternary surfaces, and study Quaternary faulting. Quaternary geologists in California cannot afford to be without a copy of this book. *Review by Glenn Borchardt.* ✕

#### Trailguides

**EXPLORING THE SOUTHERN SIERRA: EAST SIDE.** 3rd edition. By James C. Jenkins and Ruby J. Jenkins. 1992. Wilderness Press, 2440 Bancroft Way, Berkeley, CA 94704. 239 p. \$15.95, soft cover.

This book invites you to explore oak and pine forests, alpine meadows lined with aspen, and chaparral-framed vistas. The region covered includes the mountains east of the North Fork Kern River between the High Sierra and the Tehachapi Mountains. Offering 150 adventures that range from backpack trips to car tours, and from peak climbs to day hikes, this new edition includes several new trails and more information on day trips and car trips. Many of the trips are suitable for equestrians, bicyclists, and cross-country skiers.

Each hike description includes the distance of the hike, elevation gain, skills required, suggested season(s) of travel, suggested maps, and directions to the trailhead. Additional information is provided on



cultural history, geology, flora, fauna, and preservation. A "Tripfinder Table" summarizes the trips so the reader can find an appropriate trip easily. Included is a two-sided, four-color map depicting all the trips and trailheads. The map also has a grid system which indicates the U.S. Geological Survey topographic map needed for every trip.

Whether you are interested in the remote solitude of wilderness, exhilarating peak experiences, or accessible scenic picnic grounds, this book offers a range of year-round opportunities. *Review by C.L. Pridmore.* ✕

**AFOOT AND AFIELD IN LOS ANGELES COUNTY.** By Jerry Schad. 1990. Wilderness Press, 2440 Bancroft Way, Berkeley, CA 94704. 290 p. \$15.95, soft cover.

Los Angeles residents who are weary of the crowds, concrete, and smog will especially appreciate this guide to local getaways. Close to half of Los Angeles County's 4,083 square miles is wild or only lightly developed. The 175 hikes described in this book cover over 1,000 miles of trails in areas of diverse topography, climate, and plant and animal life. An index map outlines the 32 geographic areas that are introduced in separate chapters. A detailed area map accompanies the introductory text of each chapter. Special symbols and capsulized information preface each trip description and serve as a convenient means to choose hikes on the basis of difficulty, hiking time, or season. Distance, total elevation gain or loss, recommended maps and equipment, and agencies of jurisdiction are listed. Each route is described with additional notes on access, parking, camping, natural features, and scenic highlights. Some walks are recommended for families with children. A "best hikes" appendix lists favorites in various categories such as wildlife watching, autumn colors, wildflowers, waterfalls and swimming holes, views, and history. Best beach, canyon, and mountain hikes are also included. Additional chapters give an overview on the climate, geology, and native flora and fauna of Los Angeles County. Tips on safety, trail courtesy, and avoiding the smog are also provided. The guidebook is studded with numerous black-and-white photos.✕

# Teacher Feature

## THE QUICKSAND MODEL — AN EXPERIMENT

Level: upper elementary to senior high school

### ANTICIPATED LEARNING OUTCOMES

1. Students will describe the difference in stability between dry sand and sand that has become liquid-like.
2. Students will observe what happens when water-saturated sand becomes liquid-like.
3. Students will determine which sediment grain-sizes are prone to becoming liquid-like.
4. Students will discuss the social implications of building on sediments prone to becoming liquid-like.

### BACKGROUND

Quicksand is known to most of us only from mystery stories or horror movies; few people have first-hand experience with it. The word refers to a body of sand which, when given a shake or some other shock, acts like a fluid, not like a solid. In the stories or movies, the hapless victim steps onto the quicksand, sinks a little, becomes frightened, and struggles to get out thereby hastening the change to a fluidy mass. Then he or she sinks out of sight. Most sands do not become "quick" (subject to becoming fluid-like) when shaken; those which contain a lot of water are the culprits. That is why most quicksands are found near the ocean, streams, and swamps.

### HOW DOES IT WORK?

In loose, dry sand, the weight of the topmost sand grains is supported by the underlying grains. The tiny openings between grains are not filled. If all the openings between grains are filled with water, some of the weight of the

grains is borne by the fluid. So, the more water in the openings, the less the grains support each other. A very small shake or jolt on a saturated sand will dislodge the grains and the whole mass will begin to act like a dense fluid. Some of the water may be expelled in sand volcanoes. If a heavy object like a road, a building, or even a person is on this liquid-like mass, it may sink.

Sandy sediments subject to water-saturation and a change to a liquid-like state do not provide adequate support for building. However, the problem will only appear when the sediment is shaken or jolted. When these sediments are built on in regions prone to earthquakes, we can expect problems. Experiences in the Marina District in San Francisco during the 1989 Loma Prieta earthquake provide vivid examples (see photo). There, great damage was suffered by structures built on sandy sediment and loose fill material, all of it water saturated.

Less commonly, sand may also become quick as a result of water being forced into it. This might happen in a stream floodplain after prolonged rainfall or during flooding when water is suddenly injected into a previously unsaturated sandy sediment. In either instance, the sediment may become fluidized and behave accordingly.

### Materials:

- Wide-mouth Mason jar or clear plastic bottle, one quart or larger
- Enough fine sand to fill the jar or bottle about 1/3 - 1/2 (use sandbox sand or something similar)
- Quarter or rock small enough to fit into the jar
- 1-1/2-foot length of plastic, rubber, or glass tubing



An automobile lies crushed under the third story of this apartment building in San Francisco's Marina District. The first two stories are no longer visible because of structural failure and sinking due to liquefaction, the transformation of the soil from a solid to a liquid state. *Photo by John Nakata, U.S. Geological Survey.*

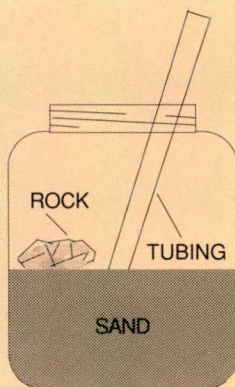
## Teacher Feature continued

### PROCEDURE

- Put the tubing into the jar so that one end of it rests on the bottom of the jar and the other end extends about a foot out of the jar.
- Pour all the sand into the jar to a depth of  $1/3 - 1/2$ , holding the tubing in position while you pour.
- Place the coin or small rock on the sand surface.
- Very gently pour water into the tubing until all the openings in the sand are filled and the water just reaches the top of the sand. You should be able to see the water fill the openings between sand grains and rise through the sand mass.
- Let the whole thing sit for a minute or so, then hit the table top on which the jar or bottle is resting several times. What happens to the object sitting on the sand surface? What happens to the sand?

### ADDITIONAL ACTIVITIES

- Try this experiment with marble chips, gravel, or mud. Did any of these sediments go quick?
- Build small structures of materials like clay or popsicle sticks and subject them to shocks like you did the sand in the jar. Why do these structures not behave like the water-saturated sand?
- Write a paragraph describing how quicksand gets its name.
- Imagine you had to build in a location where quicksand is known to develop. Can you think of a way that you might avoid its worst effects? Describe your plan in a paragraph.



This experiment was designed by:

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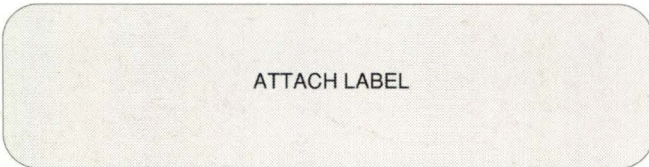
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