CALIFORNIA GEOLOGY

JUNE 1991

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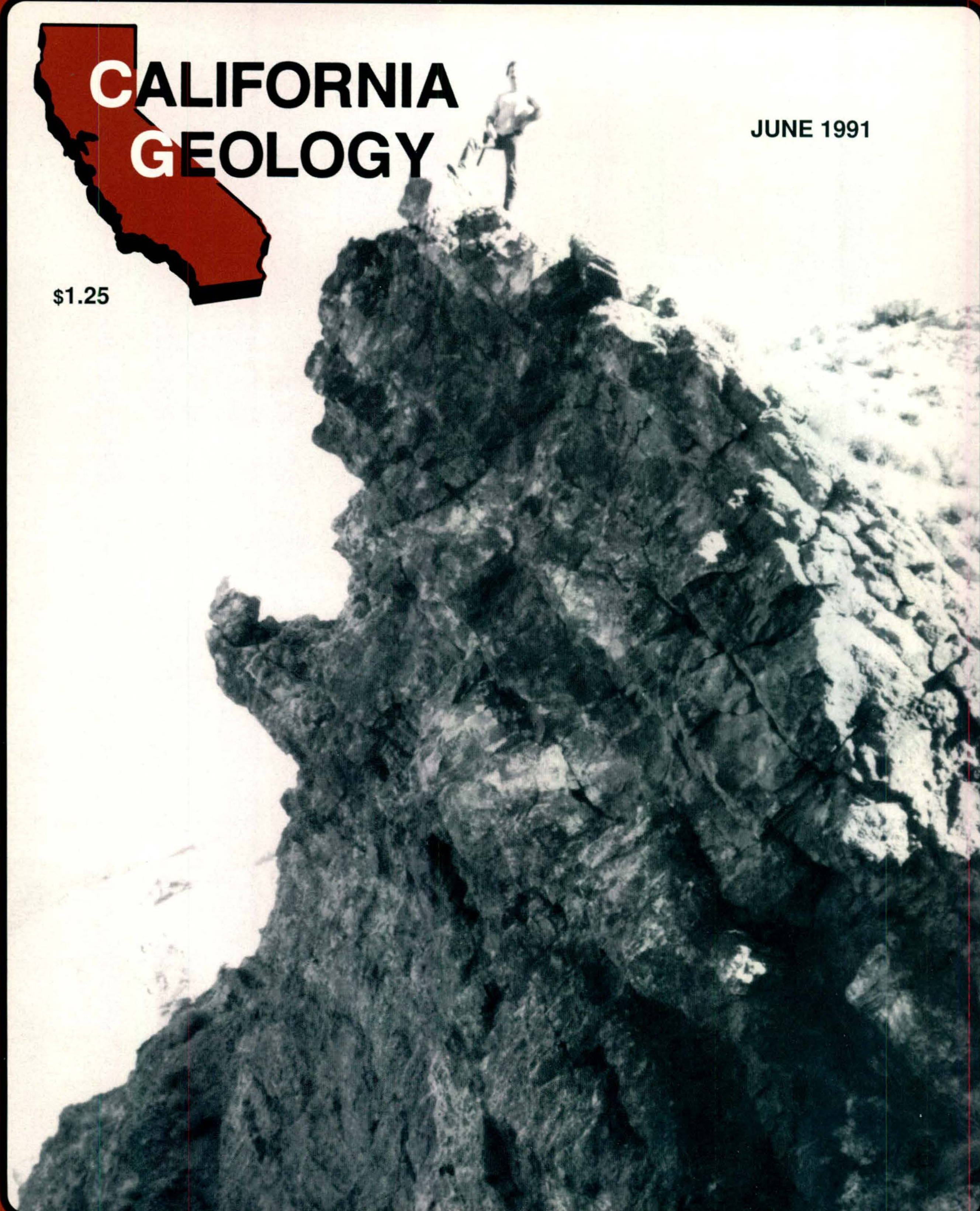

PETE WILSON, Governor
STATE OF CALIFORNIA

CALIFORNIA
DEPARTMENT
OF CONSERVATION

Division of
Mines and Geology

Understanding California's Geology

Our Resources - Our Hazards

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

State of California — PETE WILSON, *Governor*

The Resources Agency — DOUGLAS P. WHEELER, *Secretary for Resources*

Department of Conservation — EDWARD G. HEIDIG, *Director*

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In This Issue

Cover Photo: Paleozoic metamorphic rocks, northeastern Avawatz Mountains. The Avawatz Mountains have been uplifted thousands of feet since the Miocene. The geologist is standing on an upthrown block of Paleozoic metasedimentary rock.

Underwater Mining Conference

The 22nd International Underwater Mining Conference will be held from September 29-October 2, 1991 in Kahuku, Hawaii. This forum for ocean mining and related research will highlight recent developments and future projects along the Pacific Rim. Innovative computer applications in marine minerals exploration and a new underwater drilling system will be displayed. Speakers will discuss cobalt-rich crusts of central Pacific seamounts, sea floor chromite sands offshore Oregon, and offshore mineral deposits along the Alaska coastline. This forum is sponsored by the University of Wisconsin Sea Grant Institute in cooperation with the Ocean Basins Division of the Marine Minerals Technology Center, the Continental Shelf Division of the Marine Minerals Technology Center, and the International Mining Society. For further information contact:

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Correction: The third sentence in the first paragraph on page 68 of the March issue should read as follows. The oxygen liberated in photosynthesis is derived from water, however the oxygen incorporated into living plants is derived from carbon dioxide.

$$6\,CO_2 + 12\,H_2O \rightarrow C_6H_{12}O_6 + 6\,H_2O + 6\,O_2$$

Mines and Geology of Fort Irwin

San Bernardino County, California

By

JOHN S. RAPP, Geologist

and

LARRY M. VREDENBURGH, Geologist

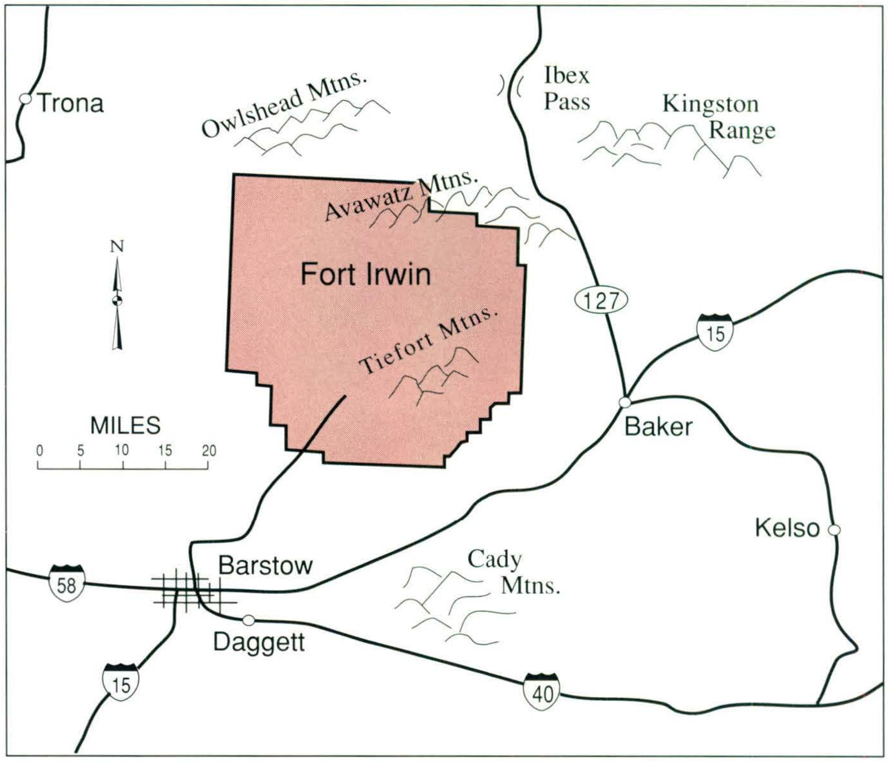

Figure 1. Location map of the Fort Irwin region.

INTRODUCTION

The examination of mines and mining prospects at Fort Irwin was done concurrently with Division of Mines and Geology (DMG) regional geologic mapping and other mineral resource studies in the region. Mapping, field checking, and geologic data of the Fort Irwin region were collected between January 1982 and May 1990. DMG conducted an investigation of the mineral resource potential of the Fort Irwin region to develop geologic and mineral information in a region of California where very little published mineral resource information exists. This article was adapted from an unpublished DMG Special Report that will be entitled *The mineral resource potential, geology, and abandoned mines of Fort Irwin, San Bernardino County, California.*

Photo 1. M-60 tank heading east from Bicycle Lake. *Photos by authors.*

LOCATION AND ACCESS

Fort Irwin is located in the central Mojave Desert, approximately 40 miles north of Barstow (Figure 1). The Fort Irwin National Training Center employs approximately 5,800 civilian workers (in-house U.S. Government documents, 1987). Part of the southern boundary of Death Valley National Monument is fewer than 3 miles north of the Fort, and the National Aeronautic and Space Administration's (NASA) Goldstone satellite tracking facility is located just west of Fort Irwin.

Fort Irwin is an important military training center that serves each branch of the armed services. Tens of thousands of American soldiers recently sent to Saudi Arabia received much of their desert warfare training at Fort Irwin. Civilian access is not permitted during training exercises. The main entrance of Fort Irwin, and the only authorized entry point, is on Fort Irwin Road.

Photo 2. Salt Basin prospect. The Salt Basin playa deposits are truncated and displaced by slivers of the Death Valley fault zone. These disrupted beds are underlain by basal conglomerate and breccia, and overlain by Plio-Pleistocene **fanglomerate***. The brown clay-rich salt beds contain layers of salt and gypsum, and nodules of celestite.

DESERT LAND USE DECISIONS

The Mojave Desert is a vast region with substantial mineral, energy, and agricultural resource potential. Thousands of Californians live, work, and vacation in the desert.

One of the most important desert land proposals pending before Congress involves the expansion of the Fort Irwin National Training Center (Fort Irwin) by 370,000 acres of Federal (public), State, and private land. Fort Irwin now covers 636,457 acres, and is one of the most active military training centers in the United States.

The Department of Defense would like to conduct larger and more comprehensive military field exercises at Fort Irwin. Military planners believe that a larger training area is required. Some environmental groups, miners, and others question the need for additional military land in the desert.

Photo 3. Cave Spring, northern Avawatz Mountains. Cave Spring is located adjacent to Cave Spring Road, just north of the Avawatz Pass summit. It was a well known geographic feature and watering hole from 1880 to 1920. In 1891 the outpost at Cave Spring consisted of a stone corral and a ruined hut. By 1991 all that remained at the Spring were rudimentary foundations and "tunnel dwellings." Ephemeral springs issue from weathered andesite flows that have been broken and displaced by movement along the Garlock fault zone.

The National Park Service (NPS) proposed that Death Valley National Monument be expanded to include the Owls Head Mountains, the Quail Mountains, the northern Avawatz Mountains, and the southern part of the Amargosa River Valley. The expansion would make the Monument contiguous with the northern boundary of Fort Irwin. The Monument expansion plan is designed to protect scenic and wildlife values of the southern Death Valley region.

This proposal however, is opposed by the mining community and various outdoor recreation groups. Many exploration geologists believe that the Fort Irwin region has good mineral resource potential. There are several dozen old mines and prospects within Fort Irwin, and hundreds of mineral location notices have been filed in the outlying region. Many of the new location notices have been filed in the proposed Fort expansion area.

***Bolded** terms are in Glossary on page 129.

Photo 4. Mining camp ruins, south of Avawatz Pass. A few stone ruins still exist within Fort Irwin, although many of these turn-of-the-century mining structures were dismantled and destroyed by military and civilian visitors several decades ago. These ruins are not identified or documented in the literature. The Army has diligently attempted to protect archeological sites since 1980, especially well-documented American Indian sites like Bitter Spring.

GEOMORPHOLOGY

The terrain of Fort Irwin is mostly barren and rocky, with rugged mountains that are separated by dry lakebeds and broad alluvial fans. A variety of cacti, desert shrubs, and grasses grow in the region and are abundant near the few isolated springs. Alluvial terraces and **bajadas** sustain sparse perennial vegetation, and the broad **playas** are completely barren.

Pale brown dune sand collects on the leeward sides of sharp ridges and ravines. Strong desert winds winnow poorly sorted fanglomerate terraces, leaving a mosaic of angular reddish-brown clasts called "desert pavement." Although it is called desert pavement, these iron-stained clasts are generally ineffective in supporting off-road vehicles because they often conceal deep, unconsolidated, wind-blown sand.

HISTORY

The mountain passes and valleys of Fort Irwin were well traveled by early Californians. The Old Spanish Trail, which was a lucrative trade route between Santa Fe and Los Angeles, passed through the southeastern part of Fort Irwin. It passed through Red Pass, skirted just north of Bitter Spring, and turned south through Spanish Canyon at Alvord Mountain. Mexican-American trade continued from 1829 to 1848. John C. Fremont and Kit Carson were the most famous early Americans to use the Old Spanish Trail. In April 1844, while traveling northward on the Trail, Fremont and his men had a bloody encounter with Indians at Bitter Spring. Bitter Spring was one of the most important Indian rest and watering spots.

Mormon immigrants discovered placer gold near the Salt Springs Hills in December of 1849, just east of the Amargosa River, where the river changes course to the west. Early prospectors traced placer gold from the Salt Springs Hills to its source, the Amargosa lode gold deposit. The Amargosa mine, which produced about $300,000 in gold (Nolan, 1936, p. 52), was worked intermittently from the mid-1800s to 1902. During the 1860s, a route was established from the town of Visalia, across the Sierra Nevada through Walker Pass, the northern part of Fort Irwin by way of Leach Lake, then to the Amargosa mine.

Photo 5. Much of the tuffaceous country rock in the Fort Irwin region is weathered, bleached, and friable. Rock exposures near Goldstone and the northern Avawatz Mountains exhibit structural and lithologic features of a volcanic center. A sample of altered meta-volcanic rock from the Old Shadey mine, which is located near Cave Spring, assayed 3.06 ounces of silver and traces of gold. The sample also contained high concentrations of arsenic, copper, molybdenum, lead, antimony, and zinc.

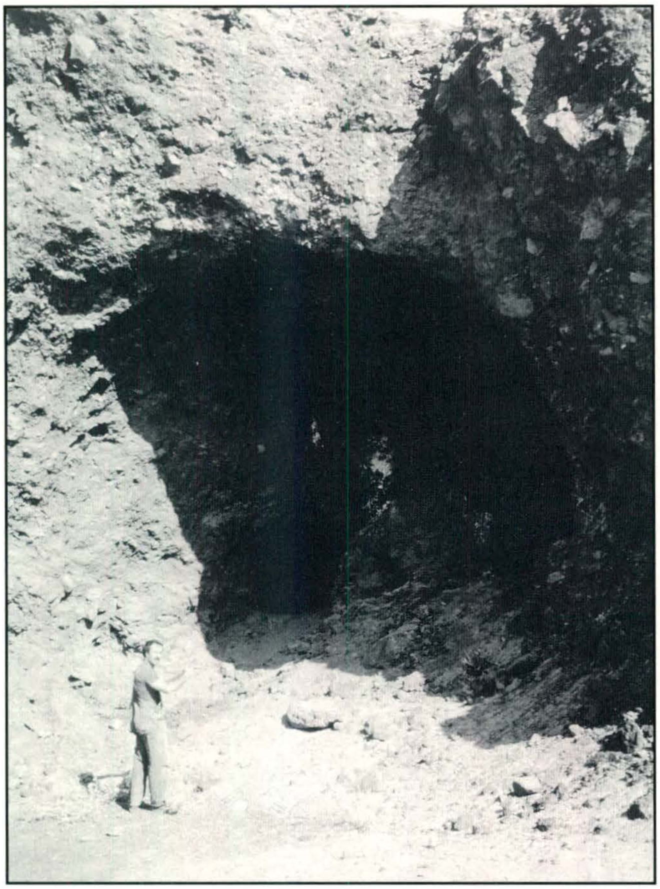

Photo 6. New Deal mine located in the Owls Head Mountains, approximately 2 miles north of Fort Irwin. Also known as the Owls Hole mine and the Owls Head mine, it was originally developed as an open-pit mine in 1914. One report estimates that about 4,000 tons of manganese ore was produced at the New Deal mine from 1916 through 1956. Trask (1950) reports 480 tons. The ore averaged 19 to 43 percent manganese and contained much hematite.

Cave Spring was an important way station for borax wagons from 1882 through 1887. The first shipment through Avawatz Pass came from the short-lived Eagle Borax Works, which was located at Bennett's Well in Death Valley. Borax was hauled from Death Valley through Avawatz Pass, to the Sante Fe Railroad siding at Daggett (Paher, 1973, p. 9). A fraudulent mining claim was filed by a desert entrepreneur at Cave Spring when the borax wagons began rolling. Teamsters were charged 25 cents per man and animal for each night of rest and water. The spring was abandoned when borax mining shifted from the Death Valley region to Calico, and travel through Avawatz Pass diminished.

Mineral prospectors came to the Fort Irwin region looking for gold and silver in the mid-1800s. It is very likely that the gold mines of Red Pass, the Avawatz Mountains, and the Granite Mountains were discovered during this period. The Desert Cave mining district was established by 1880, and the first mining claims were recorded within the Fort as early as 1872 (Quinn, 1981, p. 19). Silver was discovered in the Avawatz Mountains in 1872, and Frank Denning discovered gold at Denning Spring in 1884 (Mining and Scientific Press, 1884, p. 262). Gold was discovered in the Paradise Range and at Goldstone in the 1880s. Silver mines in the Avawatz Mountains and Soda Mountains were recording production in the late 1880s, and gold was discovered near Quail Spring before the turn of the century.

Several small mining camps sprang up in and near Fort Irwin. Crackerjack was the original camp of the Avawatz Pass area, and one of the few that lasted more than a few months. A post office was established in February, 1907, and a weekly newspaper, *Crackerjack News*, appeared a few months later. Regular automobile stage service connected Crackerjack with Silver Lake for a one-way fare of $15.00.

Avawatz City was located 1.5 miles east of Crackerjack, and 2.5 miles from Cave Springs. According to Van Dyke (1977), Avawatz City originated when eight men from Crackerjack ran a Chinese camp cook out of town with the legal authority of

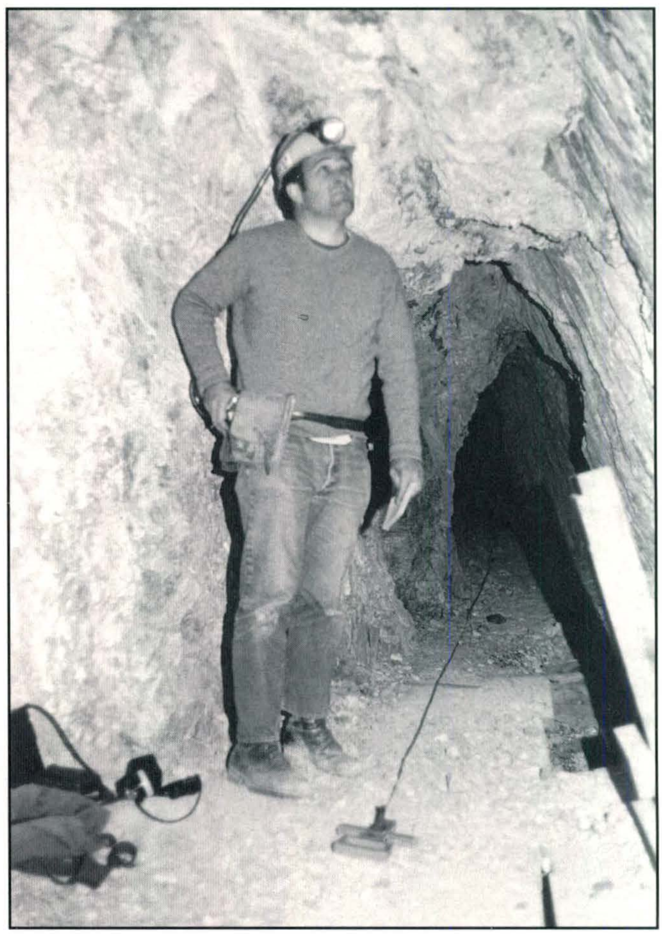

Photo 7. Fault-controlled vein at the Tungate mine. The Tungate quartz vein is discontinuous and relatively free of accessory minerals, including sulfides. The high-angle Tungate fault is roughly parallel to the nearby Garlock fault zone. Later northeast-trending faults distorted the mineralized Tungate fault. No gold was observed in hand specimens, but channel-cut samples of vein quartz assayed from 0.009 to 0.08 ounces of gold per ton, plus traces of silver.

Photo 8. Tiefort Mountain quarry. This aggregate quarry is located on the north slope of the Tiefort Mountains, 3 miles east of Bicycle Lake. It was developed by an independent contractor in about 1980, and produced aggregate base materials and concrete aggregate for numerous Army road and utility construction projects. The mine was idle in 1990.

an unwritten District ordinance prohibiting the permanent residence of persons of Chinese descent. San Bernardino County authorities worked out a plan that permitted the cook to return to Crackerjack, but division among local residents over the issue resulted in the creation of a new town, Dry Camp. Dry Camp later became Avawatz City (Van Dyke, 1977, p. 25-26).

CURRENT MINING

Other than aggregate borrow pits, mining has not been permitted within Fort Irwin since about 1941. However, mines and quarries dot the countryside of the surrounding area. Most historic activity in the area involved precious metal mining. Today, industrial minerals and construction materials are the principal commodities being mined in the region.

MINERAL RESOURCE POTENTIAL

The Fort Irwin region has undeveloped mineral resource potential. Precambrian talc deposits and gold-bearing quartz veins in the Avawatz Mountains are among the geologically oldest mineral deposits of the region. Most of the old workings and historic references of the Fort Irwin region relate to Mesozoic **calc-silicate skarn** and auriferous quartz vein deposits. Skarns of the region vary in mineral composition and may contain tungsten ore (scheelite), gold, iron ore, manganese ore, and calc-silicate minerals (wollastonite) that are used in ceramics and composites. Various accessory minerals also occur.

Undiscovered low-grade **epithermal** gold/silver deposits may be concealed under broad exposures of Tertiary volcanic rocks in the region. Miocene zeolite, clay, and saline deposits are among the youngest and most valuable undeveloped mineral deposits of the region.

VOLCANOGENIC GOLD DEPOSITS

Tertiary, volcanogenic, gold and silver-bearing veins occur in several places along the northern border of Fort Irwin. Epithermal deposits may be present in the Goldstone region west of the Fort, but there is little supporting documentation. Emplacement of mineralized epithermal veins depends on three fundamental factors: a suitable volcanic source, receptive host rocks, and an effective subsurface hydrothermal system. Fort Irwin, and its surrounding area, appear to have all three characteristics.

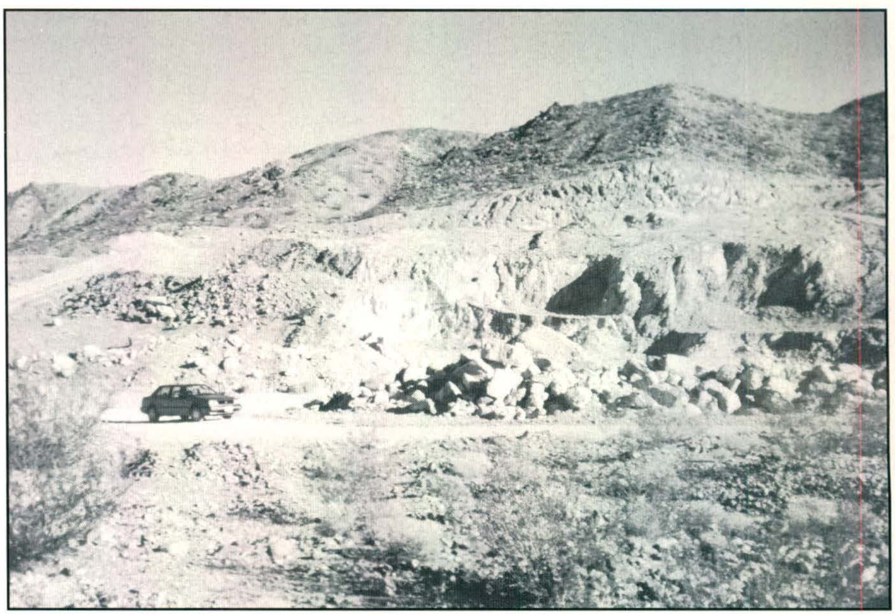

Photo 9. Midway Green quarry is located about 3 miles north of Dunn Siding. The quarry is currently operated by Calico Rock Milling Company. Metamorphic bedrock is drilled, blasted, and transported by truck to the company plant in Barstow where it is crushed, screened, and sold as decorative rock.

The most favorable areas for epithermal gold/silver deposits are in the northern Avawatz Mountains, the area immediately east of Goldstone Space Tracking Facility, the region northwest of Calico and the Red Pass Range. Each of these areas has broad expanses of Tertiary volcanic and sedimentary rocks.

MESOZOIC SKARN DEPOSITS

Small, mostly concealed, iron ore and calc-silicate skarn deposits exist throughout the Fort Irwin region. The most likely place to discover new iron or manganese skarn deposits of economic importance is the eastern and northern Avawatz Mountains where massive plutons of quartz monzonite come into contact with pre-Mesozoic carbonate roof pendants. Undiscovered iron ore and manganese deposits may exist, but regional gravity and magnetic data suggest that no major deposits lie hidden beneath the surface.

A relatively small iron and manganese ore deposit could be hidden somewhere in the region because Mojave Desert iron and manganese skarn deposits tend to be small. Although small, these skarn deposits are large enough to supply iron ore to the portland cement industry of southern California. Brightly colored rock from these skarns can also be marketed for decorative rock and specialty uses.

GOLD-BEARING QUARTZ

Cretaceous poly-metallic, sulfide-bearing, quartz veins occur throughout the Fort Irwin region. Auriferous quartz veins have been mined within Fort Irwin, and similar well-documented gold occurrences have been mined in the area surrounding the Fort.

Mineralized veins intrude, and appear to be derived from, Mesozoic quartz monzonite plutons that intrude metamorphic roof pendants. Most of the mineralized roof pendants appear to be Paleozoic meta-carbonate rocks, quartzite, siliceous meta-volcanic rocks, and quartz-mica schist.

Undiscovered Mesozoic poly-metallic, sulfide-bearing, quartz veins undoubtedly exist in the northern Avawatz Mountains, Granite Mountains, Quail Mountains, Paradise Range, and the Alvord Mountains. Only those mineral veins that have been exposed by tectonic uplift and erosion have been observed, prospected, and developed. Most of the existing mines were discovered more than 80 years ago because of **gossan** exposures. Unless concealed vein deposits have imposed an obvious geochemical signature to overlying rocks and **colluvium**, they are likely to remain hidden for the foreseeable future.

Photo 10. Red Pass Lake, southeast Fort Irwin. Red Pass Lake appears to have occupied a large area west and southwest of the Red Pass Range during the Pleistocene Epoch. Regional uplift has tilted the Tertiary section of Red Pass Lake to the west, thus confining the Holocene lakebed (usually dry) to its western limit against volcanic hills within Fort Irwin.

The volume and economic value of undiscovered mineralized vein deposits in the Fort Irwin region are difficult to estimate because of the scarcity of detailed geologic mapping and relevant mineral information. It is especially difficult to predict the occurrence and grade of auriferous quartz veins. However, if known mineral occurrences are representative of undiscovered and hidden quartz veins, the volume and economic value of these undiscovered mineralized quartz veins must be relatively small.

Based on limited assay data and mineral production statistics, it is assumed that ore grades, depending on the mining methods, might range from 0.10 to 1.0 troy ounces of gold per ton. Also based on limited field data, it is assumed that vein widths would range from a few inches wide to a few yards wide. Veins could range from a few yards to half-mile or more in length. There may be fault-brecciated zones with complex veins and more broadly mineralized areas. It is reasonable to assume that undiscovered mineralized veins of the Fort Irwin region could produce 100,000 ounces of gold.

CONSTRUCTION MATERIALS

The crushed stone mineral resource potential of Fort Irwin is limited by potentially high transportation costs. Until recently, it would have been unrealistic to consider developing large scale stone quarries in the remote Fort Irwin region. However, continuous suburban development of greater Los Angeles has already pushed eastward into the western Mojave Desert. It has become extremely difficult to acquire and develop mineral properties west of the San Gabriel Mountains, and it may now be reasonable to consider development of remote desert stone quarries.

Fort Irwin and the surrounding desert region has billions of tons of common stone that is suitable for dimension stone, construction aggregate, and decorative rock. Rock types that have potential commercial value—given a viable market and transportation options—include a wide variety of Paleozoic metamorphic rocks, Mesozoic granitic rocks, and Cenozoic volcanic rocks.

Non-foliated Paleozoic metamorphic rock types, such as marble, feldspathic hornfels, and quartzite make excellent construction aggregate materials, decorative rock, and dimension stone. Foliated metamorphic rock often makes attractive flagstone, decorative rock, and dimension stone. The best target areas for Paleozoic metamorphic rock deposits include the Alvord Mountains, the northern and eastern Avawatz Mountains, Owls Head Mountains, and the Soda Mountains.

Colorful Tertiary volcanic rock from the Pickhandle and Jackhammer formations are marketed extensively in the Barstow region. Similar, colorful, tuffaceous volcanic rocks are exposed in the Goldstone area, northern Avawatz Mountains, near Bitter Spring, and in the Red Pass area.

CONCLUSIONS

It is unlikely that the mineral resource potential of the Fort Irwin region will be developed during the 20th century. Fort Irwin plays an important role in maintaining the national defense, and mining is generally incompatible with intensive military training. In the 1980s, federal land-use decisions were heavily influenced by political action coalitions concerned for the environment and recreational assets of the desert region.

In the next decade, important desert land-use decisions will be made by the United States Congress. To assist in this effort, the Division of Mines and Geology, the U.S. Bureau of Mines, the U.S. Bureau of Land Management, and the U.S. Geological Survey have invested much time and effort into developing a body of mineral resource and economic information. Hopefully, this enhanced mineral information will be used by federal decision-makers in laying out the future of California's Mojave Desert.

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Glossary

bajada: A broad continuous alluvial slope extending from the base of mountain ranges into inland basins. It forms by the coalescence of a series of alluvial fans.

calc-silicate skarn: Rocks composed largely of calcium-bearing silicate minerals. Calc-silicate skarn minerals are derived from carbonate rocks into which large amounts of silica, alumina, iron, and magnesium have been introduced by adjacent igneous intrusions.

colluvium: A general term for loose and incoherent clastic deposits, usually deposited by gravity at the foot of a steep slope. In desert regions, such as Fort Irwin, bajadas form along the lower slopes of mountain ranges from the uniform coalescing of alluvial fans and colluvium.

epithermal deposits: Form within fissures and other rock voids through deposition of silica, calcite and other minerals at geologically shallow depths. Ore minerals are brought to the surface by means of ascending hot water solutions. Geologists divide the family of epithermal ore deposits into a fantastic array of "ore models," each with its own geochemical and mineralogical attributes.

fanglomerate: A sedimentary rock made of slightly waterworn heterogeneous fragments deposited in an alluvial fan and later cemented into a firm rock.

gossan: An old mining term that describes a cap of silica and iron oxide which commonly overlies sulfide-bearing ore deposits. Sulfide minerals exposed to atmospheric conditions tend to oxidize and liberate sulfuric acid. The acid then dissolves parts of the host rock and leaves a lattice of acid-resistent silica and iron oxides.

playa: A dry, vegetation-free, flat area at the lowest part of an undrained desert basin. ⚒

TAMARACK TUFF
A Devonian Submarine Pyroclastic Flow Deposit In The Northern Sierra Nevada
Plumas and Sierra Counties

By

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INTRODUCTION

The Sierra Nevada, dominantly composed of Mesozoic plutonic rocks, also contains a variety of metamorphosed volcanic and sedimentary rocks into which the plutons were intruded. Pre-intrusive rocks largely have been eroded in the central and southern Sierra, leaving only scattered remnants, referred to as roof pendants and screens. The northern part of the range contains more of the older rocks and some of the best exposures are found just west of Yuba Pass and north of Highway 49 in Plumas and Sierra counties. The popular Sierra Buttes-Lakes Basin area, located within the Gold Lake and Sierra City 7.5-minute quadrangles (Figure 1), is underlain almost entirely by Paleozoic volcanic and marine sedimentary rocks.

GEOLOGIC SETTING

The Paleozoic section in the Sierra Buttes-Lakes Basin area includes a stratigraphic unit formally designated the Sierra Buttes Formation (McMath, 1966; Hanson and Schweickert, 1986). These Upper Devonian (Anderson and others, 1974) rocks are mostly silicic to intermediate volcanic deposits, interbedded with phosphatic black chert or siliceous argillite and intruded by dikes and sills. The more silicic volcanic rocks are noted for abundant, large (to 1/2 inch) quartz phenocrysts and an absence of **mafic** phenocrysts. These quartz-bearing rocks were called "quartz porphyry" in early descriptions of Sierran geology (Diller, 1892; Turner, 1895). The Sierra Buttes Formation and other units in the Paleozoic section have been identified geochemically as the remnants of a **volcanic island arc** (Brooks and Coles, 1980).

The Paleozoic island arc and overlying deposits were accreted to the North American continent during the Late Jurassic Nevadan orogeny (Hannah and Verosub, 1980; Schweickert, 1981).

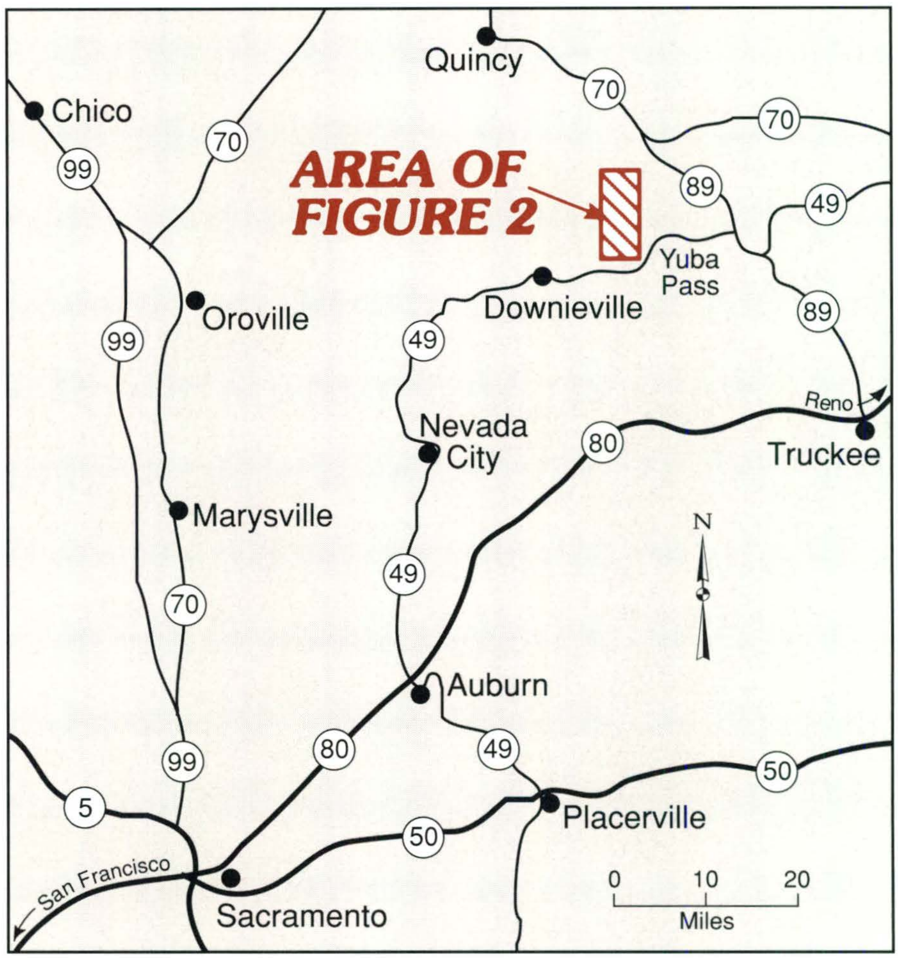

Figure 1. General location map of the Sierra Buttes-Lakes Basin area, Sierra and Plumas counties.

Bolded terms are in Glossary on page 137.

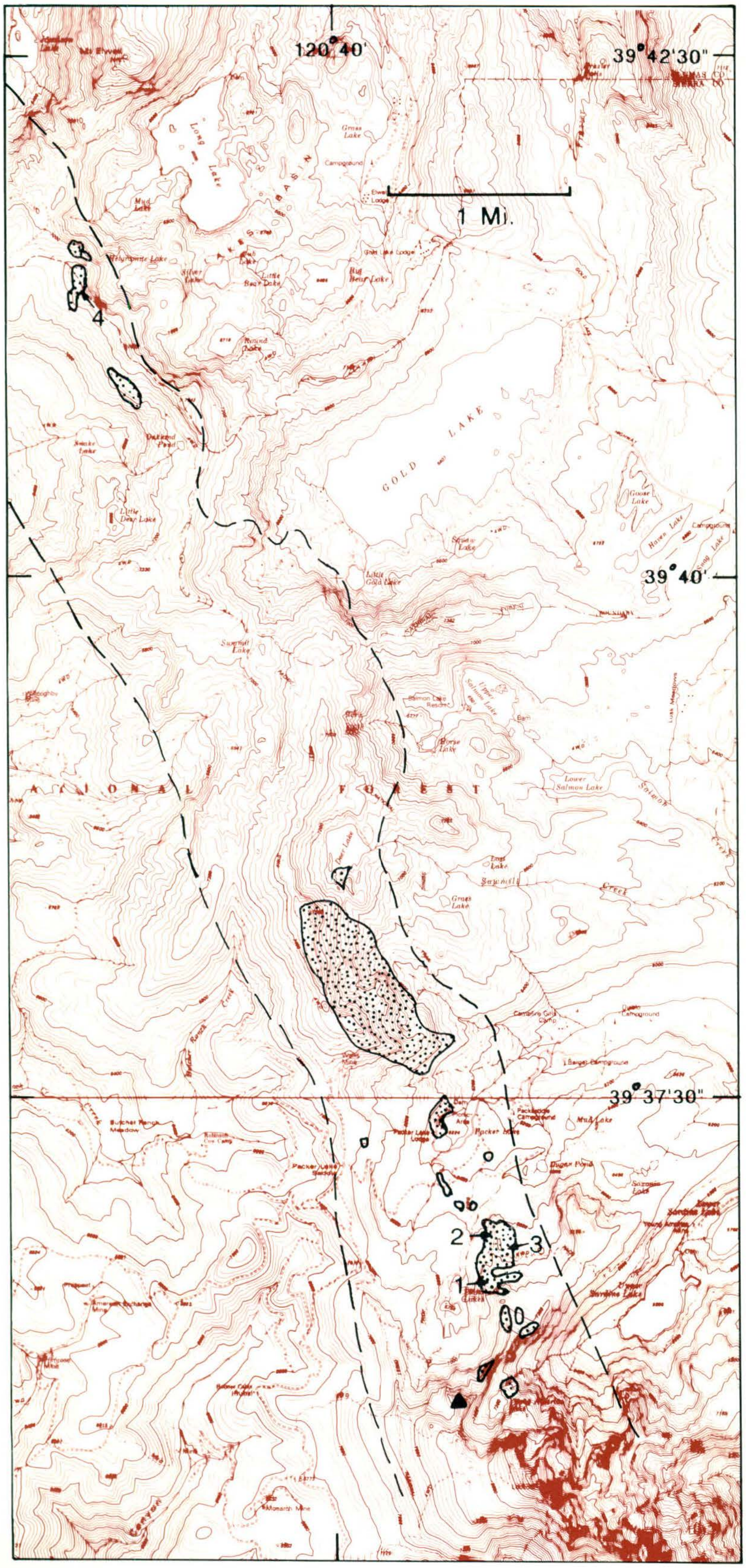

Figure 2. Outcrop map of the Tamarack tuff between Sardine Lakes and Lakes Basin, Sierra, and Plumas counties. Dashed line is the approximate limit of the Sierra Buttes Formation. Tips of arrows indicate sites shown in photos. Triangle shows the proposed vent site. Base map compiled from portions of Gold Lake and Sierra City 7.5-minute quadrangle topographic maps.

This tectonic event produced a northwest-striking, east-dipping orientation of the strata. The rocks are thoroughly recrystallized and metamorphosed to low grade, and locally are strongly foliated. Nevertheless, primary textural features of the rocks are preserved well enough in most places to provide the data for the interpretations which follow.

Tamarack Tuff

A significant portion of the Sierra Buttes Formation in the Sierra Buttes-Lakes Basin area consists of a particularly distinctive meta-andesitic layer, which we refer to informally as the Tamarack tuff (Legler, 1983; Legler and Brooks, 1983; Brooks and Legler, 1989), named for the two small lakes near the southern outcrops (Figure 2). Because of its relative resistance to erosion, the Tamarack tuff is well exposed for about 11 km (7 mi.) along strike (Figure 2), forming prominent ridges or the steep walls of glacial valleys. Unlike most of the other volcanic rocks in the Sierra Buttes Formation, the Tamarack tuff lacks the characteristic large quartz phenocrysts. Fresh rock surfaces are greenish, reflecting the presence of metamorphic minerals such as chlorite and epidote, and are unexceptional in appearance. However, the weathered surface of the tuff is spectacular; a work of abstract geologic art in which the vivid rusty-red matrix forms a background that is mottled by irregular whitish pumice fragments of various sizes and bizarre shapes (Photos 1 and 2).

Although the Tamarack tuff can be identified as a volcanic rock by its relict texture, the appearance of the weathered tuff is unlike that of other volcanic rocks in the Sierra Buttes Formation. Our analysis reveals that these peculiar rocks are a pyroclastic flow deposit produced by an explosive submarine eruption.

FIELD OBSERVATIONS

Outcrop Appearance of the Tamarack Tuff

The freshly broken rock is light to dark green and aphanitic so that few features are discernible even with a hand lens. Weathered surfaces reveal the blocks and coarse **lapilli** (collectively referred to as "clasts" from this point on) set in a matrix of fine lapilli and ash. The clasts, determined from thin-section analysis to be pumice, weather to light gray-green, cream, or gray-white smooth surfaces. In contrast, the weathered rusty-red matrix is mottled with dark red, shallow, irregular pits and pale-rimmed, angular raised patches.

Shapes and Textural Characteristics of Fragments

The pumice clasts have odd shapes, including ovoid, lensoid, spindle-shaped, amoeboid, ribbon-like, and irregular sinuous forms. Most clasts have ragged outlines with numerous inflections and wispy terminations (Photos 1 and 2). Less frequently, and unrelated either to size or shape, clasts have sharply-defined perimeters.

The pumiceous nature of the clasts is not apparent in outcrop, because the visible textural features are not characteristic of pumice. Most clasts are uniformly aphanitic and chert-like due to post-depositional silicification. Clasts are more resistant than the matrix and stand out in relief on outcrop surfaces, rather than weathering to cavities, as expected for pumice. Many clasts bear lineations (due either to flow lamination or to collapse under compression) which appear in the field to be fine stratification rather than pumiceous texture. Some clasts have hollow cores with a few ghost-like, spherical vesicles up to 2 mm in diameter. All vesicles are filled with quartz and/or chlorite, but those that are large enough to identify with a hand lens are too sparse to indicate pumiceous texture. The vesicularity of these rocks is mostly visible on the microscopic scale.

Some "clasts" are actually rounded xenoliths of quartz porphyry or angular fragments of chert that underlie the Tamarack tuff. The weathered appearance of these siliceous xenoliths is similar to true clasts but usually the xenoliths have discrete edges and are more rounded. Although in some cases, the edge of the xenolithic core cannot be readily discerned against matrix (Photo 2), making it difficult to recognize the fragment as foreign.

Photo 1. Outcrop surface of Tamarack tuff at Tamarack Lakes exposures. Lightly colored clasts display a variety of shapes and sizes and are aligned in long dimension. The deposit appears bimodal (large clasts in finer-grained matrix) and lacks multiple layering. The map case in the lower right is 12 inches wide. *Photos by authors.*

Xenoliths are usually less than 10 cm (5 in.) in average diameter and generally decrease in size and abundance upward through the lowermost 10 meters (33 feet) of tuff. Xenoliths are rare higher in the unit. In places, xenoliths occur only in the basal few inches. The resulting mixed zone identifies the approximate base of the unit when the contact itself is unexposed.

Shapes of smaller lapilli in the matrix (Photo 2) include a variety of subequant polygons, triangles, ovoids, and ribbon-like forms. Rarely, the larger matrix fragments have sinuous shapes like those of some clasts. Ragged edges similar to those on clasts are common on matrix lapilli. Those ash-sized matrix particles which are visible without a microscope have subequant blocky and ovoid shapes. Overall, the appearance of the matrix is reminiscent of shredded paper clippings and confetti.

The texture of matrix particles is less uniform than that of clasts. Lighter colored areas of matrix fragments look similar to clasts, being smooth and chert-like, but the dark, reddish patches of the matrix have a rough, granular appearance, completely unlike clast surfaces. Lineations are visible in larger grains, and some contain apparent vesicles, filled with chlorite or quartz.

Distribution and Thickness

Based on geographic distribution, internal features, and chemical composition, the exposures of Tamarack tuff between Sierra Buttes and Lakes Basin are thought to represent a single depositional unit. Most gaps in outcrop can be attributed to Pleistocene glacial erosion or cover. However, a 4 km (2 1/2 mi.) hiatus exists west of Upper Salmon and Gold Lakes (Figure 2), where the projected stratigraphic position of the tuff is occupied mostly by **heterolithologic** tuff-breccia and **turbidites**. The tuff-breccia contains large blocks of Tamarack tuff and probably records erosion of the original deposit by later submarine debris flows. Therefore, we think the original distribution of the tuff was continuous for the entire 11 km (7 mi.) of present exposure.

The thickness of the Tamarack tuff has been estimated from the outcrop map because no section could be measured in the field. The outcrop at Tamarack Lakes is more than 100 meters (325 feet) thick. The Deer Lake outcrop, 3 km (2 mi.) north, has a present thickness of at least 150 meters (485 feet). The tuff appears to pinch out 10 km (6 mi.) north of Tamarack Lakes, near Long Lake. Due to compaction and subsequent erosion, the present thickness is probably less than the original thickness.

Features typical of the Tamarack tuff are best seen in two areas. The Tamarack Lakes locality has magnificent displays of clasts and matrix features, upper and lower contacts of the unit, internal stratification, and primary orientation of clasts. The Deer Lake area contains representative examples of sorting, size ranges and shapes of clasts, and provides a vertical section through the deposit.

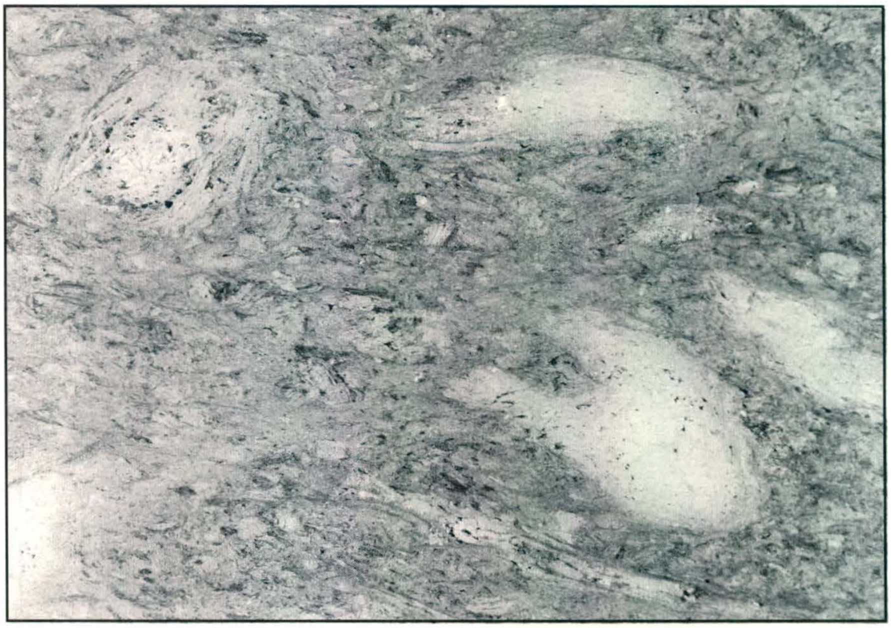

Photo 2. A close-up view of the Tamarack tuff weathered surface. Wispy ends and hazy edges of the clasts with irregular shapes are typical of the deposit. Many of the contrasting darker matrix fragments of various shapes are flow aligned. The "clast" in the upper left is a quartz-porphyry xenolith which has a concentric halo of matrix fragments. Photo width is 10 inches.

Contact Relationships

The lower contact, exposed at the north and south end of the Deer Lake outcrop, west of Long Lake, and at several places north of and east of Tamarack Lakes, is sharply defined. Underlying rocks include massive and brecciated quartz porphyry, chert, and pillowed and massive flows of andesitic lava. Chert and quartz porphyry xenoliths occur in the tuff near the lower contact. Lava-flow xenoliths were not found, but the lava and tuff are similar in appearance and lava fragments may have been overlooked.

The upper contact is not so well exposed as the lower, but is sharp where visible east of Tamarack Lake, southwest of Deer Lake, and west of Long Lake. Overlying rocks include silicic (dacite?) lava, quartz porphyry breccia, other pyroclastic flow deposits, and chert.

Even though the tuff is a submarine deposit, its contact with adjacent rocks is not depositional everywhere. Quartz porphyry apparently was intruded along the lower contact in places. Also, it is possible that some overlying rocks were intruded after deposition of the tuff and other units. Fragments of tuff, that could have been incorporated either by intrusion or by erosion, were found in the quartz porphyry and **felsic** lava which overlie the tuff.

Size Distribution, Stratification, and Alignment of Clasts

The tuff appears superficially to be **bimodal**. We attempted to confirm the grain-size distribution by determining the average dimensions of fragments. Because the finest material is recrystallized, individual matrix particles cannot be discriminated completely. Those fragments which are visible show that the matrix consists of all sizes of dust, ash, and lapilli to 3 cm (1+ in.). The pumice clasts can be measured accurately and mostly range from 3 to 40 cm (1+ to 16 in.) in average diameter. A few individual clasts to 2 meters (6.6 feet) and zones with abundant large (>50 cm or 20 in.) blocks are found in the southern outcrops. The distribution of sizes in clasts indicates the tuff is polymodal, rather than bimodal.

The whitish pumice clasts are found throughout the section in varying abundance, making up from a few percent to 80 percent of the rock by volume. Overall, concentration of clasts approximates 20 percent. Pumice clasts are **inversely graded**, and increase in number upward (Photo 3), except at the northernmost exposures, where clasts are evenly distributed. Xenoliths, conversely, are normally graded and found mostly near the base of the deposit.

The average size, variation in size, and concentration of clasts decrease along strike from south to north. The matrix fragments also decrease in grain size and become better sorted from south to north. The matrix appears to be sorted compositionally; the ratio of pumice grains to **vitric** granules increases in the matrix from south to north and upward in the deposit. The matrix at the northernmost outcrop consists almost entirely of bits of pumice.

Except for two places, the Tamarack tuff is a single, thick bed. At Tamarack Lake, for about 40 meters (130 feet) of lateral extent, the tuff deposit consists of a 75-meter (240-feet) thick inversely-graded bed overlain by a second 2-meter (7-feet) thick inversely-graded layer. Elsewhere at the Tamarack Lake outcrop, the bed is overlain along 50 meters (165 feet) of its upper contact by a fine-grained, clast-free layer averaging 25 cm (10 in.) thick. This thin fine-grained layer appears to be recrystallized vitric ash which may or may not be related to the tuff. The absence of a second layer in other areas is puzzling; it could have been removed by erosion, or the second layer may have been only locally deposited.

Alignment of long axes of both clasts and matrix grains, which appears to be primary orientation, has been preserved in some areas. Sinuous, elongate, and large ovoid clasts are aligned with the bedding plane at the Tamarack Lakes locality (Photos 1 and 3). Alignment of adjacent matrix fragments suggests that the clasts were oriented by laminar flow. Several other outcrop surfaces show alignment of long axes of matrix particles, which is considered the result of turbulent flow because alignment is neither parallel to bedding nor to metamorphic foliation.

Photo 3. A ridge formed by the resistant Tamarack tuff. This outcrop shows flow alignment of large clasts and inverse grading. The tree is about 3 meters (10 feet) high.

PETROGRAPHIC FEATURES

Petrographic studies were conducted by the senior author on 96 thin sections cut from 76 samples of tuff. Microscopic study of the rocks was critical to determine the abundance of glass, pumice, and the paucity of lithic components in the Tamarack tuff. In outcrop, pumice clasts cannot easily be distinguished from chert fragments or small lava pillows present in adjacent breccia deposits, except where phosphate nodules are present in the chert or where chilled margins are found on the pillows. Otherwise, thin sections are necessary to see the mosaic of quartz in the chert, the lesser abundance of vesicles, and greater abundance and size of plagioclase **microlites**. Microlites are found in pillow lava fragments and are distinguished from pumice clasts.

The rocks have been devitrified and metamorphosed to **prehnite-pumpellyite** or low **greenschist facies** mineral assemblages. The present rock is a very fine-grained (less than 0.01 mm diameter), foliated aggregate of albite, quartz, chlorite, epidote, calcite, sphene, pyrite, and sericite, prehnite and pumpellyite, and actinolite (in approximate order of abundance). Pervasive foliation is present locally. Despite recrystallization and orientation of metamorphic minerals, relict primary features are readily discernible.

Primary Textures

Originally, the Tamarack tuff was predominantly glassy and highly vesicular, with little crystallization. Both matrix and clasts generally have less than 1 percent microphenocrysts of quartz, plagioclase, and magnetite, and less than 1 percent of the tuff is made up of lithic fragments.

The conspicuous lightly colored clasts consist of pumice containing spheroidal vesicles less than 0.1 mm in diameter (Photo 4). Vesicles make up at least 50 percent of the pumice clasts, but this figure probably represents the lower limit of vesicularity. Vesicles now are filled with quartz and/or chlorite and those smaller than 0.01 mm cannot be identified reliably within the metamorphic fabric.

The matrix originally consisted primarily of pumice fragments, grains of nonvesicular glass, and interstitial glassy dust (now chlorite). Pumice, which makes up a few percent to nearly all of the matrix, is identical to clast pumice. Glass grains are sagittate or cuneiform splinters and angular, equant granules. Cuspate or Y-shaped glass shards, typically found in subaerial **vitroclastic** deposits, were seen in only two thin sections. The rarity of these classic shapes is probably due to the lack of large vesicles whose broken walls would produce the shards.

Sparse perlitic cracks occur both within individual clasts or matrix grains and continue across grains. Other devitrification features, including **axiolitic** structures, spherulites, and "snowflake texture," (an intergrowth of quartz and feldspar which develops in devitrified collapsed pumice) (Anderson, 1969), are present, but rare.

Several kinds of nonmetamorphic deformation were identified. Collapsed pumice occurs in several samples, indicated by streakiness in the mosaic and by snowflake texture. Some pumice vesicles are flattened parallel to adjacent grain boundaries. Recurved and flattened glass shards and granules molded against other grains are present in two samples taken from near the base of the deposit.

Primary Minerals

Sparsely scattered microcrystals in the Tamarack tuff consist of whole and broken **euhedral** bipyramidal quartz phenocrysts and plagioclase microlites.

Quartz commonly is embayed or fractured. Most quartz crystals are less than 0.5 mm across but range in size to 2.0 mm and are visible in outcrop. Plagioclase microlites are generally between 0.01-0.05 mm in length, but range to 1.5 mm, with the notched terminations and hollow centers that are common in quenched crystals. Quartz and plagioclase are subequally distributed in the rock.

CHEMICAL COMPOSITION

Compositions of 47 whole-rock samples, comprising 13 matrix and clast pairs (collected from the same outcrop), 14 clasts, and seven matrix samples, were determined by x-ray fluorescence analysis (Legler, 1983; Legler and Brooks, 1983; Brooks and Legler, 1989). SiO_2 ranged from 50.5 percent to 67.1 percent and averaged 59.8 percent in matrix samples which are considered the least altered. Silica in clasts ranged from 65.1 percent to 84.9 percent and averaged 71.8 percent. The difference in silica content between clasts and matrix is attributed to silica infilling of abundant vesicles in the clasts and does not necessarily indicate original differences in rock chemistry. Analytical results indicate an andesitic composition for the Tamarack tuff.

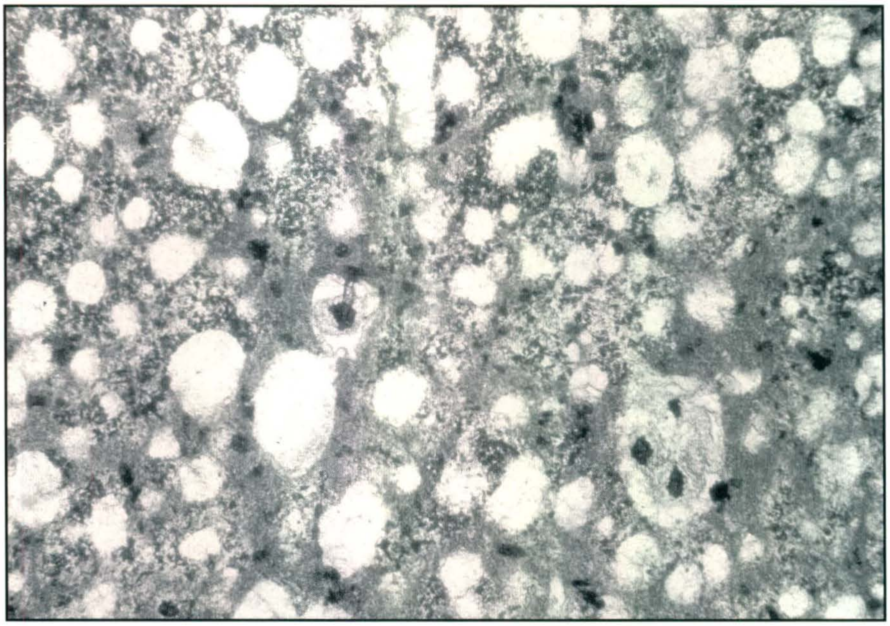

Photo 4. Photomicrograph, plane polarized light, showing the lower limit of vesicularity (about 50 percent) of the pumice fragments. Vesicles average less than 0.1 mm in diameter, are filled mostly with quartz with lesser chlorite and are deformed by metamorphic foliation. The horizontal field of view is 2.5 mm (0.1 in.).

DISCUSSION

Origin by Submarine Pyroclastic Flow

The Tamarack tuff displays a number of characteristics which have been described for both subaerial and subaqueous pyroclastic flow deposits erupted and deposited under various conditions (Ross and Smith, 1961; Francis and Howells, 1973; Sparks and others, 1973; Sparks, 1976; Sheridan, 1979; Fisher and Schmincke, 1984). These include andesitic composition, vitroclastic textures, an abundance of pumice, inverse grading of pumice blocks, normal grading of lithic fragments, conformity with adjacent bedded units, large areal extent, poor sorting, polymodal grain-size distribution, and stratification which comprises a single very thick bed with or without an overlying, much thinner layer.

Combinations of laminar and turbulent flow are typical in pyroclastic flows (Sparks, 1976; Fisher, 1983). Clasts locally are aligned by laminar flow at Tamarack Lakes. Elsewhere at that outcrop and at Deer Lake outcrop, random orientations of elongated clasts and flow lineations record the turbulence which would be expected by rapid ejection and deposition of a mass flow of exploded **tephra**. The irregular lower contact at Tamarack Lakes and the size and number of xenoliths suggest turbulent corrosion of the underlying quartz porphyry. Turbulence in the flow is the probable cause of chaotic incorporation of chert into the base of the tuff at Long Lake and is a likely contributor to the geometry of clasts (see below). Turbulence also occurs during subaqueous sediment flows, but the resulting deposits usually have fining-upward patterns that are lacking in the tuff.

Several lines of evidence infer that the Tamarack tuff originated from a single explosive eruption in a submarine environment. The great variety of shapes of fragments with irregular boundaries and many inflection points indicates brecciation by explosion, rather than by hydro-quenching or other means (Walker and Croasdale, 1972; Honnorez and Kirst, 1976). Also, the sparsity of larger microlites or microphenocrysts in the tuff and the presence of quench crystals are consistent with rapid cooling during explosion. These features are evidence that the tuff did not develop as a **hydrobrecciated** lava flow, such as the adjacent andesitic isolated-pillow breccia that has abundant, large microlites.

The adjacent pillow lavas and little-disrupted chert lenses, which conformably underlie and overlie the tuff in places, attest to submarine deposition of the tuff. Furthermore, small size of vesicles in pumice and near-absence of broken-bubble glass shards, such as in the tuff, are characteristics attributed to suppression of vesicle development under high hydrostatic pressures (Heiken, 1974).

The absence of multiple layers within the deposit suggests that a single episode of eruption and deposition occurred. The two-layer sequence found at Tamarack Lakes is similar to descriptions of other single eruptions, and submarine pyroclastic flow deposits (Fiske and Matsuda, 1964; Niem, 1977). Furthermore, the lack of turbidite sequences in the tuff implies that the erupted material moved not as a water-fluidized current, but as a gas/grain mass flow wherein the gas pressures excluded significant invasion and disintegration by water. The abundance of delicately angular and irregular shapes throughout the deposit indicates that abrasion was not extensive during transport, nor is it likely that the material was reworked after deposition.

Volume of the Deposit

The volume of the Tamarack tuff is within the range for other known pyroclastic flow deposits (Fisher and Schmincke, 1984). The thickness now averages about 100 meters (328 feet), which is less than the original. Assuming that the gap in outcrop west of Salmon Lakes is the result of later disruption, the tuff extended for at least 11 km (7 mi.) in one direction. Present orientation inhibits assessing the width of the deposit, but the broad Deer Lake outcrop provides a lower limit of 650 meters (2,130 feet) of width. The present exposures, therefore, reveal a minimum of 0.7 km^3 (0.2 $mi.^3$) of material in the deposit. Since many pyroclastic flow deposits have equidimensional areal extent (Ross and Smith, 1961; Sheridan, 1979), it is more reasonable to assume that the width was equal to the length, in which case the volume would approximate 12 km^3 (2.9 $mi.^3$).

Possible Vent Location

Thickness and distribution of the deposit, along with sorting and rounding of the fragments, suggest a south-to-north direction of transport of the Tamarack tuff from a vent site south of Tamarack Lakes. A plug south and west of Tamarack Lakes (Figure 2), consisting of rocks similar in composition to the tuff and to the underlying andesitic pillow breccias, is speculated to be the eruptive center. However, talus and glacial debris unfortunately mask any confirming field evidence.

Origin of Unusual Clast Geometry

The unusual shapes of clasts are thought to result from two factors: great plasticity of the pumice (indicated by elongation of vesicles and alignment of plagioclase microlites) and turbulence during eruption and transport of the flow. Pumice often has a lower viscosity and greater plasticity than associated non-vesicular material because of the high gas concentrations in the pumice (Ross and Smith, 1961). Ross and Smith state that viscosity also derives from composition and temperature of the glass, but even slight variations in gas content can lead to rapid changes in viscosity. When pumice collapses under pressure, some of the trapped gases may go back into solution, which decreases viscosity and increases plasticity of the glass.

In a pyroclastic eruption, the blobs of glass which separate from the erupting mass would mold and distort during extrusion. Deformation could continue until cooling and loss of gases froze the blob to a rigid, pumiceous glass. If some re-solution occurred during impacts of tumbling in the turbulent mass, the period of plastic behavior would be extended. Many of the contorted clasts probably formed during turbulent extrusion and shortly thereafter.

Clast shapes suggest that fragments in the tuff remained plastic and were molded additionally during transport and deposition. Flattened vesicles, collapsed pumice, and vesicles deformed against adjacent fragments could develop only while the glass was plastic and these occur at considerable distances from the inferred vent. Delicate protrusions and feathery edges are found on fragments several miles from the implied vent and probably did not form only during eruption. It seems unlikely these features would have survived abrasion during transport over that distance. These fragile features must have formed during transport by tearing of still-plastic blobs or after deposition from compression of the plastic mass.

SUMMARY OF FINDINGS AND THEIR SIGNIFICANCE

The Tamarack tuff is a devitrified and recrystallized andesitic tephra deposit with textural and structural features typical of pyroclastic flow deposits. Petrographic and field evidence indicates submarine eruption and deposition. Textures, fragment morphology, stratification, and orientation of components show that the tuff was ejected explosively and moved by turbulent and laminar flow for at least 11 km (6.6 mi.), producing a deposit over 100 meters (325 feet) thick. This mass flow appears to have originated at a vent near what is now the southern end of the deposit.

Pale, weathered, chert-like clasts, which give the Tamarack tuff its distinctive outcrop appearance, are pumice blocks and lapilli. Extremely fine vesicularity, contorted shapes resulting from plastic deformation during eruption, transport, and deposition, and subsequent silicification have disguised the nature of the peculiar pumice fragments.

Sparse evidence suggests that welding may have occurred at the base of the deposit and possibly stratigraphically higher in those portions of the deposit near the vent. Evidence for welding is inconclusive and still under investigation, but includes some petrographic features associated with subaerially deposited welded tuffs. Weak welding would account for the initial preservation of the Tamarack tuff.

Although explosive submarine eruptions should be common in oceanic volcanic arcs, few submarine pyroclastic flow deposits have been described. Such deposits are often disrupted by currents or subsequent eruptions soon after deposition. Older deposits which survive this vigorous submarine activity may become altered beyond recognition during subsequent tectonic events or destroyed by erosion. Similar modern deposits can be studied only by dredge samples and drill cores which give an incomplete picture of their extent and fabric. The opportunity to study the Tamarack tuff submarine pyroclastic flow deposit is as unique as its outcrop appearance. The documentation of significant criteria for identifying the tuff may aid in the recognition of other such ancient deposits.

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Glossary

axiolitic: A rock texture in which needle-like crystals radiate from a central axis rather than from a point.

bimodal: A grain or fragment size distribution having two sizes occurring with greatest frequency.

euhedral: A mineral grain completely bounded by its own regularly developed crystal faces.

felsic: A term applied to igneous rocks containing abundant light-colored minerals primarily quartz and feldspar.

greenschist facies: Metamorphic mineral assemblage represented by albite + epidote + chlorite + actinolite and characteristic of low-grade regional metamorphism.

heterolithologic: Clastic rocks containing fragments of different rock types.

hydrobrecciated: Broken into fragments by contact with water.

inversely graded: A sedimentary structure in which grain or fragment size increases upwards within a bed.

lapilli: Volcanic fragments that range in size from 2 to 64 mm.

mafic: Dark-colored iron and magnesium bearing minerals or a rock composed primarily of these minerals.

microlite: Minute crystals, usually of tabular or prismatic shape.

prehnite-pumpellyite facies: Similar to greenschist facies but containing the minerals prehnite and pumpellyite.

tephra: A general term for all fragmental volcanic material ejected during an eruption and transported through the air.

turbidite: A sedimentary rock deposited from a sediment-laden current and characterized by graded-bedding, moderate sorting and well-developed layering in a fixed sequence.

vitric: Pyroclastic material containing more than 75 percent glass particles.

vitroclastic: A pyroclastic rock structure characterized by fragmented bits of glass.

volcanic island arc: A generally curved linear belt of volcanic islands located above a subduction zone.

xenolith: A foreign inclusion in an igneous rock. ⚒

Help Your Students Get Excited About Earth Science

Help for planning activities is difficult to find, say many science teachers and volunteers. This source list was compiled to help you stimulate interest in your earth science students.

Earth Science Investigations, edited by Margaret A. Oosterman and Mark T. Schmidt. The American Geological Institute (AGI) published this collection of activities for grades 8-12 in fall 1990. The 26 activities were developed by teachers, reviewed by scientists and tested with students. Each hands-on exercise provides the concepts, vocabulary, and worksheets, plus an answer key when applicable. Order from AGI, 4220 King Street, Alexandria, VA 22302, (703) 379-2480: spiral-bound book, 231 pages, $34.95 plus $4 postage/handling.

Inside Hawaiian Volcanoes, a 25 minute color video, illustrates techniques for monitoring Hawaiian volcanoes. The video, aimed at audiences of all ages, includes spectacular eruption footage. Subsurface features are depicted by cutaway views, models, and computer graphics. Noted volcano cinematographer Maurice Kraft produced the video in collaboration with the U.S. Geological Survey and the Smithsonian Institution. Orders must include check or money order made out to Smithsonian Institution. Send to Richard S. Fiske, Natural History Building 119, Smithsonian Institution, Washington, DC 20560, (202) 357-1384: videotape, VHS format $20.00, PAL format $25.00.

The teacher's guide for **Inside Hawaiian Volcanoes** contains questions and lab exercises. Order from the U.S. Geological Survey (address above): USGS Open File Report 89-685, $3.50 for paper copy, $4.00 for microfiche.

Earth Science Research Activities, by James Scannell. Published in 1988, this book is one of four in the series, Explorations in Science. It contains 50 ready-to-use individual and group enrichment activities for grades 8-12. Each has been tested and includes a teacher's guide and answer key. Order from Alpha Publishing Company, 1910 Hidden Point Road, Annapolis, MD 21401, (301) 757-5404: spiral-bound book, 273 pages, $35 plus $3.50 postage/handling.

Resources for Earth Science Teachers 1991 lists 43 sources of earth science reference and enrichment materials including catalogs, publications lists, teacher packets, books, and journals. To get a copy, contact the American Geological Institute (AGI), National Center for Earth Science Education, 4220 King Street, Alexandria, VA 22302 (703) 379-2480.

Earthquakes: A Teacher's Package for K-6, a six-unit book, was developed by the National Science Teachers Association (NSTA) with a grant from the Federal Emergency Management Agency (FEMA). It is a complete earthquake curriculum containing activities, lesson plans, line masters, and background information. Order from FEMA, Earthquake Program, Marilyn MacCabe, 500 C Street, SW, Washington, DC 20472: one free copy to schools (while supplies last). Order additional copies from NSTA (address below): $15 plus $2.50 postage/handling.

Earth: The Water Planet, a book of readings and activities for middle-grade teachers, resulted from a joint project of Horizon Research, Inc., and AGI. Order from NSTA, 1742 Connecticut Avenue, NW, Washington, DC 20009, (202) 328-5800: $16.50 plus $2.50 postage/handling.

How to Construct a Paper Model Showing the Motion That Occurred on the San Andreas Fault During the Loma Prieta, California, Earthquake of October 17, 1989, is available from the U.S. Geological Survey, Books and Open-File Reports Section, Box 25425, Denver, CA 80225, (303) 236-7476: USGS Open-File Report 89-640A, $1.50 for paper copy, $4.50 for microfiche.

Oceanography for Landlocked Classrooms, for teachers of grades 7-12, contains easy-to-follow lessons and activities written by marine educators from high schools and universities. Order from National Association of Biology Teachers, 11250 Roger Bacon Drive #19, Reston, VA 22090, (703) 471-1134: $15 plus $2 postage/handling.

Water in Your Hands, an imaginative 16-page booklet, uses cartoon characters to help children (grades 4-6) develop awareness of water quality and management problems. The instructor's guide includes activity masters, background information, implementation suggestions, optional activities, and sources of additional information. Order from Soil and Water Conservation Society, 7515 N.E. Ankeny Road, Ankeny, IA 50021-0764, (515) 289-2331 or (800) THE-SOIL: single copies $2, discounts on bulk orders.

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DMG Releases

SPECIAL PUBLICATION 107

MINERAL COMMODITY REPORT—Bentonite and Fuller's Earth. By Michael A. Silva and Daniel T. Eyde. 1990. 37 p. $5.00

Mineral commodity reports describe the availability and demand for industrial minerals in California, the United States, and the world. Part I consists of United States and worldwide mineral statistical information and analysis adopted directly from the U.S. Bureau of Mines "Mineral Commodity Summaries." Part II discusses the geology and production and marketing of industrial minerals in California.

Special Publication 107 describes significant occurrences of bentonite and fuller's earth in California by county. Bentonite is any clay that is composed dominantly of a smectite clay mineral. In turn, smectite is a class or group of clay minerals, formerly called the montmorillonite group, that posses swelling properties and high cation-exchange capacities. Smectite clay minerals include montmorillonite, hectorite, saponite, and nontronite. Fuller's earth is a bentonite that has absorbing, decolorizing, and purifying properties. Fuller's earth is not produced in California at this time. The most productive bentonite deposits in California are in San Benito, Inyo, and San Bernardino counties.

Bentonite is used for a variety of commercial applications in many industries. Sodium bentonite is used in well drilling operations; it functions as a sealant, conditions the drill hole and holds the drill hole open, and aids in bringing up drill-hole cuttings. Bentonite is also used as a impermeable liner for landfills and waste water ponds, and as a binder for foundry molds and iron ore pellets. Calcium bentonite is used as an adsorbent for removing impurities from mineral and vegetable oils. Calcium and sodium bentonites also absorb pet wastes (cat litter) and are used for removing grease and oils from floors and driveways. Bentonite is heated and expanded to produce lightweight aggregate that is commonly used in skyscrapers. Both types are added to animal feed for trace element retention and are used to carry pesticides.

Specially treated bentonite or chemically unique bentonite is used for specialty products. Specialty uses include filtering agents for beer and wine, ingredients in cosmetics, medicines, paints, inks and adhesives, and additions to ceramic and tile mixes to increase flow.

In 1988, according to the U.S. Bureau of Mines, California produced 2,200,000 tons of clay worth over $31,000,000. Bentonite production was reported at 137,000 tons worth $10,000,000 (this production accounts for 6 percent of clay by volume, yet almost one-third of the value of the clay produced in California during 1988). The majority of bentonite mined was non-swelling and is used mainly for pet adsorbents, oil and grease adsorbents, and animal feed additives. Most of the swelling bentonite is used for paint, inks, cosmetics, and other similar high value-added materials.

Although bentonite reserves are large and the United States is self-sufficient in this commodity, environmental issues, conflicting land use, and competition for public lands have adversely affected mining costs. These increased costs have made imported materials, especially from Mexico, more attractive in some market areas.

The Newberry hectorite mine operated by Rheox, Incorporated (formerly N.L. Industries). Hectorite is a colloidal, gel-forming type of bentonite clay used for pharmaceuticals, cosmetics, and clarification of wine. Note the characteristically intense white color of hectorite. *Photo by John Clinkenbeard.*

DMG Releases (continued)

OFR 91-07

OFR 91-07 PRINCIPAL FACTS AND SOURCES FOR 1528 LAND GRAVITY STATIONS ON THE SAN FRANCISCO 1° BY 2° QUADRANGLE, CALIFORNIA. By Rodger Chapman.

Gravity data are frequently used in studies of local and regional geology. For example, these data can be used to investigate geologic structures such as subsurface folds, faults, and possible sources of groundwater or mineral resources. Many multi-purpose geologic studies that include gravity measurements have been made in the San Francisco area. These earlier data were used to produce maps of the area showing contoured gravity values. Additional work has either been done or is currently underway in the area. These new data will be combined with the older data to make new, more detailed maps of the area. OFR 91-07 combines and documents the older data to provide investigators with the information in a convenient form. It is intended that this report will enable investigators to readily find the sources of data they need so that they can ascertain data accuracy and usefulness.

OFR 91-07 has ten tables of gravity data arranged by sources, information on the reduction processes used, the base stations used, and the sources of the data. Maps showing the location of most of the gravity stations are included. Copies of OFR 91-07 may be purchased by check or money order for $8.00.

Make check or money order payable to the Division of Mines and Geology.

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Inland Geological Society Call for Papers

The Inland Geological Society invites technical papers for its newest volume entitled "Quaternary Faulting and Related Phenomena in the Inland and Desert Areas of Southern California" to be published in June 1992. This geographically large and varied region consists of most of southern California with the exception of the coastal areas. Only high quality, original papers will be considered. This publication will be similar to the Society's previous volume entitled "Landslides in a Semi-Arid Environment." Any topic related to faulting is encouraged.

Abstract deadline: December 1, 1991

Manuscript deadline: March 1, 1992

For more information, contact:

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Book Reviews

Books reviewed in this section are not available for purchase from DMG.

Astronomy

THE CELESTIAL PLANISPHERE, Poster of the Universe as it appears in the Northern and Southern hemispheres. Compiled and designed by Tomas Filsinger. 1990. Available from: Celestial Arts, P.O. Box 7327, Berkeley, CA 94707. Poster is 24 inches x 36 inches. A 28-page manual is included. $14.95 (add $2.25 for postage and handling for 1 to 10 posters).

This planisphere projection of the Universe during the year 2000 includes a polar projection from the Northern Hemisphere connected to a polar projection from the Southern Hemisphere. It shows galaxies, galactic clusters, quasars, constellations, planetary nebulae, meteor showers, planets in our solar system (other than Earth), black holes, and stars; pulsars, supergiants, red giants, neutron stars, white dwarfs, and supernovas. This poster is coated with a phosphorescent paint that allows the stars, galaxies, and other represented bodies in the cosmos to glow in the dark after being illuminated by a light source; the Milky Way galaxy, containing 40 billion stars, is a prominent feature. The accompanying manual includes descriptive information on how to understand and interpret the poster. Also included are astronomical tables, a brief history of celestial astronomy, and definitions of astronomical terms such as pulsars and nebulae.

As we gaze at the celestial bodies in the night sky, we see into the past. The nearest stars to Earth other than the Sun are more than four light-years away. Light from the Magellanic Clouds—or galaxy cluster—can be seen with the naked eye in the Southern Hemisphere and takes 150,000 years to reach Earth. Scientists using the latest technologies can hear the echo of the big bang and are seeing the far reaches of the Universe as it looked more than 12 billion years ago. The opportunity to be so easily informed about the immenseness of the Universe is a tribute to the science of astronomy.

The constellations, such as the 12 familiar constellations of the Zodiac, are imaginary figures superimposed on the patterns of stars we see at night. Many constellations were invented thousands of years ago. The invention of the constellations probably results from symbolic representations of prominent figures of mythology and is not due to their imagined resemblance; instead, areas of the sky were dedicated in honor of mythical figures and the familiar pictures of these figures were then fitted to the patterns of bright stars more than 2000 years ago. The patterns of stars we see today may not necessarily be what the ancients saw. The designation of constellations to specific areas of the night sky helps account for the lack of obvious resemblance between star patterns and the mythical figures they represent.

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Energy

ALTERNATIVE ENERGY SOURCEBOOK. 1991. Available from: Real Goods Trading Corporation. 966 Mazzoni Street, Ukiah, CA 95482. 398 p., $14.00, paper cover.

The 1991 edition of this sourcebook and catalogue focuses on energy education and contains a comprehensive collection of energy-sensible technologies. With this book readers can plan independently powered homes that maintain their accustomed comfort levels. It demystifies solar, wind, and hydro-electric technologies, deals practically with energy conservation, and features complete step-by-step instructions for installing power generating systems, power storage and management, and conservation and purification systems.

This is not only a how-to guide, but a catalogue as well. The 1991 edition contains over 2,000 environmentally conscience, energy-efficient products such as an electric refrigerator which uses one tenth the power of an ordinary refrigerator, and compact fluorescent lights that produce four times the light of incandescent lighting and last twenty times as long. This catalogue is a blend of renewable energy supply options and illustrates efficient ways to use the energy. *Reviewed by Max Flanery.*

Geochemistry

OXIDE ZONE GEOCHEMISTRY. By Peter A. Williams. 1990. Available from: Prentice Hall, Prentice Hall Building, Englewood Cliffs, NJ 07632. 286 p. $109.95, hard cover. Price does not include sales tax, postage, and handling.

Oxide zones form by the weathering of sulfide minerals near the surface of the Earth. Sulfide minerals in turn form from silicate melts or by precipitation from geothermal water from silicate melts. Oxidized mineral zones are an important source of metallic ores and have been mined for many centuries. These metallic oxide zones are the primary source of base metals such as copper, lead, and zinc. Other important metallic ore deposits in these zones include tin, iron, and tungsten. Most of the spectacular museum specimens come from these oxide zones.

This book combines much of the knowledge and recent research about the complex geochemistry and mineralogy in oxide zones. Oxygen dissolved in groundwater is a powerful oxidizing agent, particularly when heated. The oxygen/water solution reacts with many common minerals to produce strong solvents, such as carbonic acid, hydrochloric acid, and sulfuric acid. Over geologic time, such chemical reactions have produced significant metallic oxide zones peripherally to the original sulfide deposits. This book is designed for geochemists, mineralogists, environmental chemists, and researchers in groundwater or soil contamination by heavy metals. An extensive bibliography is included and is listed by topic at the end of each chapter.

Gold Mining

STAKE YOUR CLAIM! How to Find Gold and Stake a Mining Claim. By Mark G. Silva. 1990. Available from: High-Grade Publications, Box 995, Aptos, CA 95001. 105 p. $14.95 (California residents add 6 3/4% sales tax) plus $2.00 shipping, paper cover.

. . . . . more Books

Over 10 million ounces of gold are expected to be produced in 1990 from 47 states. Mineral exploration and mining are possible on over 440 million acres of public land. Beginning gold hunters will find most of their basic questions answered in this step-by-step guide to locating potential gold deposits and filing a legal claim to the property. The book also includes standard claim forms, lists of pertinent State and Federal agencies, sources of government information and gold prospecting clubs, magazines, videos, and organizations.

History

HISTORIC SPOTS IN CALIFORNIA. Fourth Edition. Revised by Douglas E. Kyle. 1990. Available from: Stanford University Press, Stanford, CA 94305-2235. 617 p. $49.50, hard cover; $19.95, paper cover.

This book guides the reader or traveler on a county-by-county tour of historical California landmarks. Mileage and specific locations are given. Each county's chapter proceeds in a chronological vein, beginning with geography, continuing with Indian life, early Spanish settlements, and moving on through history into the twentieth century. Not intended as a history book per se, it does highlight historic landmarks and gives a chronicle of each. Mining landmarks can be located quickly by consulting the index under "Mines" and "Mining Camps." Counties impacted by the late 1800s gold rush receive detailed attention and include buildings and other landmarks from this era.

Igneous Geology

MAGMA TRANSPORT AND STORAGE. Edited by Michael P. Ryan. 1990. John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158, 420 p., $310.00, hard cover.

Over recent decades geologists became increasingly aware of the need to understand how magma (molten rock charged with gases) moves and behaves at depth and at the surface. Geologists interested in igneous processes also wanted to determine actual causes of the structural features seen in volcanic and plutonic rocks in the field. The working hypothesis is that knowledge of these structural features can be combined with mineral, textural, trace element contents, and isotope ratios of specific elements to yield information about the temperatures and pressures at which magma forms, how magma forms, how the magma gets to the surface or is emplaced at depth, and the nature of the conduits from magma chambers to centers of eruption. One of the many reasons the knowledge of magma transport and storage is important to geologists is that it leads to an understanding of the behavior of volcanoes and volcanic eruptions.

This book is a collection of articles by specialists in the fields of continuum mechanics, fluid dynamics, computational fluid dynamics, heat transfer, experimental high-pressure geophysics, seismology, seismic tomography, volcanology, geodesy, field geology, and structural geology. These specialists discuss theoretical approaches to basic geologic questions about magma movement and storage. They then compare their theoretical work with actual field evidence to see how well the theory explains what is observed in the field. They also compare their theoretical work with indirect observations. For example, magma bodies can frequently be detected by analyzing; (1) bulging of the Earth's surface, (2) clustering of small earthquakes, (3) attenuation of seismic signals through magma chambers, and (4) differences in seismic velocity along specific paths around and through magma chambers (a system known as seismic tomography).

While this is an advanced text, the discussions include interesting and productive treatment of some of the Earth's most fascinating phenomena. The concepts presented in this book advance our understanding of many parameters controlling magma movement and storage. *Reviewed by Dale Stickney.*

Mother Lode Geology

YOSEMITE AND THE MOTHER LODE GOLD BELT: Geology, Tectonics, and the Evolution of Hydrothermal Fluids in the Sierra Nevada of California. Edited by Leslie A. Landefeld and Geoffrey G. Stone. 1990. Available from: Publications Committee, Pacific Section AAPG, P.O. Box 631, Ventura, CA 93002. 200 p. $21.50 (including shipping and handling), paper cover. Make check payable to: Publications Pacific Section AAPG.

The discovery of gold in 1848 forever changed the landscape and history of California. Placer mining, hydraulic mining, hard rock mining, and dredge mining served to remove millions of ounces of gold from the Sierra Nevada. The quest for gold has not stopped. Mother Lode mining activity has returned after a 30-year hiatus following World War II. More than 230,000 ounces of gold have been mined since 1985. Today, geologists continue to study the structural, stratigraphic, and chemical processes that formed the Mother Lode in order to locate additional gold ore deposits. Additionally, geologic investigations and mining operations are carried out within a framework of local government and public concerns as well as State and Federal permitting requirements.

This field guide is adapted from the annual meeting of the American Association of Petroleum Geologists (held in San Francisco in June 1990) and is organized into two parts. Part 1 contains three road logs that sample the geologic and mining history of the Mother Lode from Yosemite to Coloma. The road log stops describe the tectonic and structural forces that formed the gold deposits within the Mother Lode. Part 2 contains articles covering the geology, mineral land classification, and mine permitting procedures within the Foothills Metamorphic Belt. Part 2 also includes descriptions of six mines; Pine Tree-Josephine, Harvard, Royal-Mountain King, Carson Hill, Gold Cliff, and Lincoln.

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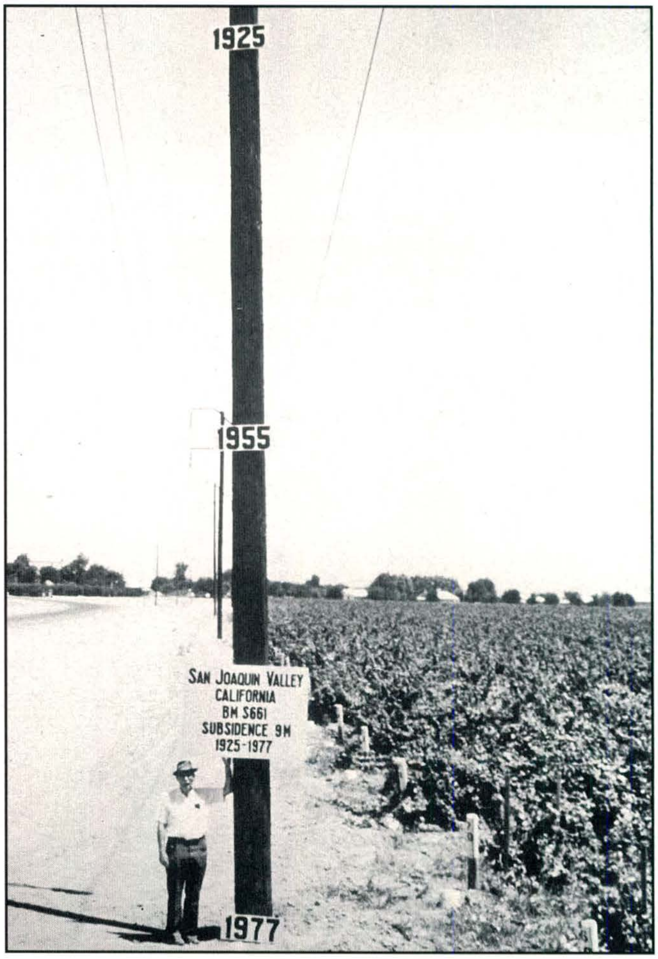
MEMORIAL
Joseph F. Poland
1908-1991

Joseph Fairfield Poland, an internationally recognized authority of land subsidence, died June 4, 1991 at the age of 83. Poland earned his bachelor's degree in geology from Harvard University in 1929 and his master's degree from Stanford University in 1935. His friends point out that he had one of the longest graduate careers on record. Although he completed his doctoral studies and oral examinations at Stanford in the late 1930s, Poland lacked a written dissertation when he joined the U.S. Geological Survey in 1940. It was not until 1981, when his former co-workers at the Survey submitted 40 years of research papers and reports, did Poland receive his doctorate from Stanford University.

While at Stanford, Poland became interested in groundwater. In 1940 he joined the U.S. Geological Survey's Ground Water Branch in Long Beach and later transferred to the Survey's Sacramento office where he directed a research program on land subsidence caused by groundwater withdrawal.

After retiring from the Survey in 1974, Poland continued working as a groundwater consultant. One of his many accomplishments was the explanation of why Venice, Italy was sinking; he became known to the Italians as the "healer" and "savior" of the city. Over several years of observation, Poland determined that the Santa Clara Valley was sinking at an average rate of 4 inches per year due to extensive groundwater pumping. He also made many contributions from his investigations of sea water intrusion into coastal aquifers of California, investigations of subsidence in the San Joaquin Valley, and investigations of subsidence in the Wilmington-Long Beach harbor area. ⚒



Dr. Poland standing at the approximate point of maximum ground subsidence in the San Joaquin Valley. Subsidence of approximately 30 feet occurred from 1925 to 1977 due to aquifer compaction caused by groundwater pumping. Signs indicate the former elevations of the land surface in 1925, 1955, and 1977. Photo taken in December 1977. *Photo by Richard Ireland, courtesy of the U.S. Geological Survey.*