# CALIFORNIA GEOLOGY

May 1986

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# SELENIUM

**Understanding California's Geology - Our Resources - Our Hazards**

# CALIFORNIA GEOLOGY

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





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## In This Issue



**Cover photo: Areal view of a portion of the Kesterson National Wildlife Refuge on the left and the San Luis Drain on the right. Kesterson National Wildlife Refuge in the western San Joaquin basin contains 1,280 acres of shallow ponds used to store and evaporate waste agricultural drainage water. In 1983 scientists discovered toxic amounts of the element selenium in the water and wildfowl at the refuge. Steps have been taken to close Kesterson. Selenium in low concentrations is required in the diet of animals; in high concentrations it is one of the most toxic elements in the environment. An article about selenium starts on page 99. *Photo by J.C. Dahlig, courtesy of the U.S. Bureau of Reclamation.***

## STAMPMILL DEMONSTRATION

The Trinity County Historical Society has scheduled a series of demonstrations of the restored Paymaster mine stampmill. Visitors will witness the processing of gold bearing ore by authentic methods using original steam powered milling equipment. This mining relic is in the park adjacent to the J.J. Jackson Memorial Museum at Weaverville, California. The restoration project was described in CALIFORNIA GEOLOGY, October 1985 (p. 232-233).

1986 Demonstration Schedule: 1-4 pm.

Saturday May 24
Memorial Day weekend

Friday-Saturday July 4-5
Independence Day weekend

Saturday August 30
Labor Day weekend

Saturday October 11
Columbus Day weekend

Demonstrations can be arranged (May through November) for tour groups (30 days advance notice) by contacting:

Trinity County Historical Society
P.O. Box 333
Weaverville, CA 96093
(916) 623-5211

## UCLA GEOLOGY FIELD TRIPS

The University of California, Los Angeles (UCLA) extension is offering two geology courses and a natural history course: (1) Geology of the Southern California Coastal Region from Santa Barbara to San Clemente, June 24-July 16, 1986; (2) Treasures of Yosemite, August 5-24, 1986, and (3) the Natural History of Santa Cruz Island, May 16-18, 1986. For further details call the UCLA Extension at (213) 825-7093 or write P.O. Box 24901, Los Angeles, CA 90024.

## NATIONAL AWG FIELD TRIP LOWER SALMON RIVER CANYONS WEST CENTRAL IDAHO

The Association for Women Geoscientists will sponsor a three day trip to be held on the Salmon River of west central Idaho on July 4-6, 1986. The lower canyons of the Salmon River cut through some of the most spectacular country anywhere in the United States. Participants will study the local outcrops of Tertiary and Cretaceous rocks exposed in the canyon and the regional geology and tectonic setting of the area.

For information contact: Association for Women Geoscientists, National Field Trip, Box 1005, Menlo Park, California 94024.

# SELENIUM

By

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Recent media attention directed towards contamination problems and wildlife deformities at Kesterson Reservoir in the western San Joaquin Valley has focused interest on the possible toxic effects of selenium in food and water. This article examines basic background information on the occurrence, properties, uses, and biogeochemistry of selenium, and looks briefly at the larger picture of salinity buildup in irrigated arid lands of the west...*editor.*

## INTRODUCTION

Despite the recent flurry of attention it has received, selenium is hardly a new discovery; not only has it long had many beneficial uses and applications, but even its potentially toxic effects have been known or suspected for many years. As early as 1842 its toxicity was documented (Japha, 1842). Selenium's connection to western rangeland food chains through soil, water, and plants has been known for decades by stockmen and scientists familiar with alkali disease, or the "blind staggers", as it is sometimes called (Moxon and Rhian, 1943). Centuries earlier, Marco Polo noted symptoms of what is now recognized as selenium poisoning in his horses while he was traveling on China's Silk Road. No doubt the Chinese residents of Xinjiang Province were already familiar with the disease, if not its cause, before Marco described it to the European community. On the other hand, a more recently described disease is Keshan disease, which is attributed in humans to selenium deficiency. Keshan disease has also been reported from China (Burau, 1985). Much, however, remains to be learned about selenium's role in animal, human, and plant metabolism, and about its behavior in biogeochemical cycles.

Selenium was discovered in 1817 by Berzelius and Gahn, chemists who were studying the reddish residue from sulfuric acid production at a pyrite mining operation at Fahlun, Sweden (Weast, 1970). The name selenium was taken from the Greek word for moon (*selene*) because of its chemical similarity with the element tellurium which was derived from the Latin word for earth (*tellus*).

Northwestward aerial view of a portion of the 102 mile long San Luis Drain, Dos Amigos pumping plant and switchyard in the foreground, a few miles northwest of Los Banos. Interstate 5 is seen on the left. *Photos by J.C Dahilig, courtesy of the U.S. Bureau of Reclamation.*

## PHYSICAL AND CHEMICAL PROPERTIES

Selenium belongs to the oxygen-sulfur family of elements and is chemically similar to sulfur and tellurium. Selenium combines directly with oxygen, hydrogen, nitrogen, the halides, and most of the common metals. Like sulfur, elemental selenium occurs in several crystal and amorphous forms or allotropes. Amorphous or non-crystalline selenium occurs as a red powder, a black mass, or as a colloid. Monoclinic crystalline selenium is a deep red; the hexagonal variety, the most common, is metallic gray to black. All of these forms are insoluble in water.

Selenium's current notoriety scarcely reflects its abundance: it is one of the less common elements, falling between mercury and gold in abundance, and averages about 0.05 parts per million (ppm) in the earth's crust. Elemental or native selenium ($Se^{\circ}$) is rare, although it does occur in some sediments and is occasionally mixed with native sulfur. More common than the elemental forms are the various chemical combinations of selenium with other cations, mostly metals or metalloids. In these combinations selenium behaves chemically as a nonmetal. There are three common oxidation states of selenium: selenide ($Se^{-2}$), selenite ($Se^{+4}$), and selenate ($Se^{+6}$).

Selenium forms ionic compounds with metals, such as clausthalite (PbSe), naumannite ($Ag_2Se$) and zorgite [$(PbCu Zn)_2$ Se]. With other elements selenium mostly forms covalent compounds, National Academy of Sciences (NAS), 1976. Oxides of selenium occur as selenium dioxide, ($SeO_2$), a white crystalline solid, and selenium trioxide ($SeO_3$), a pale yellow, amorphous, relatively unstable solid. Both oxides react with water to form selenous acid ($H_2SeO_3$), and selenic acid ($H_2SeO_2$).

Depending on its valence state selenium can behave either as a reducing agent or as an oxidizer. In its higher valence states selenium is a strong acid-former. It reacts with hydrogen at temperatures below 250°C to form a very toxic gas, hydrogen selenide ($H_2Se$), which decomposes quickly in the presence of oxygen. This gas also may be prepared by allowing dilute acids to react with metallic selenides such as sodium selenide (NaSe), iron selenide (FeSe), or aluminum selenide ($Al_2Se_3$) (Stone, 1968).

Solubility of selenium compounds varies considerably, from very high (over 40% by weight) for sodium selenate, to very low (0.16 to 0.33 grams per liter) for silver selenate. Heavy metal selenides are insoluble, as is elemental selenium (NAS, 1976). The elemental form is generally rather nonreactive; it also is not readily reduced or oxidized.

In general, the acidity of the environment (pH) affects the types of selenium compounds which form. Alkaline and reducing conditions favor the formation of selenates ($Se^{+6}$), which are resistant to complexing with sesquioxides*. Inorganic selenites ($Se^{+4}$), however, readily form stable complexes with iron and aluminum sesquioxides. Biological processes convert inorganic selenites to organic forms. Under acidic and reducing conditions inorganic selenites are reduced to elemental selenium ($Se^{\circ}$). In its elemental form it is fairly nonreactive and becomes an important repository of selenium in several types of natural geochemical systems (NAS, 1976).

## ECONOMIC GEOLOGY OF SELENIUM

Even in areas where soils are rich in selenium, there has been no attempt to exploit this source of the element. Selenium is commercially produced primarily as a by-product of processing copper ores.

Salt laden farmland near Tranquility, California. Salt and mineral accumulation in irrigated areas has been a historic problem throughout civilization. Salt and mineral accumulation is particularly severe in areas of the western San Joaquin Valley where high water tables prevent the leaching of accumulated salts.

Selenium occurs in copper porphyry ores in massive sulfides, and in stratabound copper and copper-lead-zinc deposits, particularly those of volcanic affinity. Although copper porphyry deposits are more abundant and contain greater reserves of selenium, the other ore types contain higher concentrations per ton of selenium. Major North American sources are the massive copper sulfide deposits in Noranda, Quebec, the copper-zinc deposits of Flin Flon, Manitoba, and the copper-nickel deposits of Sudbury, Ontario (Loebenstein, 1980; Jensen, 1985).

Selenium is also present in sulfur-bearing coals, with the average selenium content of coal estimated to be at least 1.5 ppm. Coal resources in the United States contain a large potential source of selenium (Loebenstein, 1980). In addition, selenium is a minor constituent of sedimentary uranium and phosphatic vanadium deposits in the western United States (200 to 300 ppm), but because of the small quantities concerned, these rocks are unlikely to become economic selenium sources (Loebenstein, 1980).

There are no known economic deposits of selenium ores. In minerals selenium usually occurs as an ionic substitution for sulfur in metallic sulfides. Especially important are chalcopyrite ($CuFeS_2$), bornite ($Cu_5FeS_4$), and pyrite ($FeS_2$), although selenium may also substitute in other sulfides, such as pyrrhotite ($Fe_{1-x}S$). A few selenides occur as minerals: eucairite (CuAgSe), clausthalite (PbSe), naumannite ($Ag_2Se$), crookesite [$(CuAgTi)_2$ Se], and zorgite [$(PbCuZn)_2$Se]. Of these, only clausthalite and naumannite have been reported in California.

Major world reserves of selenium, based on copper reserves, are located in Chile (17,000 metric tons), the United States (12,000 metric tons), Canada (11,000 metric tons), Zambia (7,000 metric tons), and Zaire (6,000 metric tons) (Jensen, 1985). Selenium is produced as a refining by-product in the United States, Canada, Australia, Sweden, Belgium, Japan, Peru, and West Germany. Over half of the world production comes from North America (Stone, 1968).

In Canada, massive metallic sulfide ores and efficient beneficiation methods permit recovery of larger amounts of selenium (0.64 kg per metric ton of mined copper ore) than is common in other countries, where most of the ore is copper porphyry and recovery is about 0.215 kg per metric ton (Jensen, 1985).

*Sesquioxide compounds contain two metallic atoms, primarily iron or aluminum, and three oxygen atoms—for example $Fe_2O_3$ and $Al_2O_3$.

Selenium is usually recovered by processing copper slimes which are a residue in the electrolytic refining of copper. Depending upon the concentration of selenium and the metals, recovery usually consists of roasting the slimes with fluxes. The selenium is then volatilized as an oxide and recovered from the flue gases or incorporated in a calcine, which is later leached.

## USES OF SELENIUM

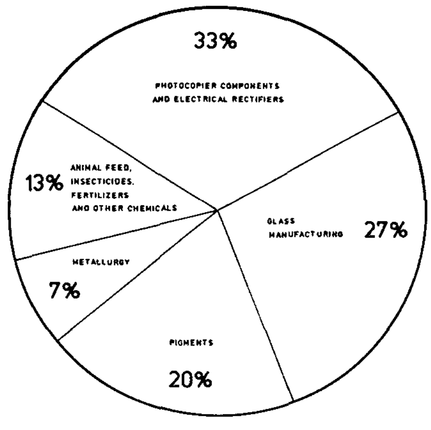
Although selenium was only a laboratory curiosity for about fifty years after its discovery, its versatile properties make it very useful (Figure 1). Among its most useful attributes are its photoelectric properties: photoconductivity, photovoltaic action, and photoreceptivity.

Elemental selenium is an excellent photoconductor: exposure to light causes excitation of electrons, decreasing its electrical resistivity as much as a thousandfold under intense illumination. When the light is withdrawn, its conductivity reverts back to a low value. Selenium has photovoltaic abilities, allowing it to convert light into electricity. It is a semiconductor; its electical conductivity increases with rising temperatures. Because of these properties selenium is widely used in the electronics industries. As a photoreceptor, selenium has a growing use in photocopiers. It is used in photoelectric cells, solar cells, and in calculators. Selenium is still used in rectifiers for converting alternating electric current to direct current, although it is now competing in this area with inexpensive silicon rectifiers.

Selenium is widely used in glass manufacturing. It is combined with cobalt and iron oxides to make energy-conserving architectural glass with reduced glare and solar heat transfer. The oldest use of selenium was adding it to glass to reduce the green tint from iron impurities. Large amounts of selenium are used to impart a ruby red color to glass.

Selenium is used to manufacture stainless steel, as a catalyst in chemical reactions, in antidandruff shampoo, and as a curing agent for natural and synthetic rubbers. Sodium selenite and sodium selenate are added to poultry feed as dietary supplements, except for laying hens.

Demand for selenium in the United States is expected to be 2.2 million pounds per year by the year 2000. Canada will probably become an increasingly important source of selenium for United States markets (Loebenstein 1980). Alternative substances can be found for most uses of selenium. Thus, the United States no longer stockpiles it.




ELECTRICAL AND OPTICAL USES
The electrical conductivity of selenium is low in the dark but increases by about three orders of magnitude on exposure to light.

Photovoltaic Cells:
Photovoltaic cells made with selenium consist of an iron or brass plate on which is deposited a 100 micrometer-thick layer of polycrystalline selenium and then a 1 micrometer-thick layer of cadmium.

Rectifier:
A selenium rectifier consists of a metallic disk, usually steel or aluminum, which is sandblasted or etched, then coated with a 60 micrometer-thick layer of selenium and sprayed with a cadmium alloy. Selenium rectifiers withstand nuclear radiation damage and voltage overloads better than other types of rectifiers.

Xerography:
Xerography is the primary application of the photoconductive properties of selenium. The photoreceptor is made with a 50 micrometer-thick film of selenium on an aluminum substrate.

METALLURGICAL USES

Ferrous Metals:
Selenium is used in small concentrations to decrease the surface tension of molten steel. It retards nitrogen absorption and improves the impact resistance of steel.

Copper and Copper Alloys:
Additions of selenium to molten copper improves the machinability and decreases the ductility and conductivity.

Lead and Antimony:
Selenium increases the recrystalization temperatures of antimony alloys and improves their casting and mechanical properties. Antimony-lead alloys with selenium are less susceptible to gas evolution in automotive, lead storage batteries.

GLASS AND CERAMICS
Selenium is used to decolorize table, lighting, industrial, and container glass. In flat plate glass, selenium is used to produce smoky, ruby red, or bronze colors. In office building plate glass selenium is used to block heat transmission. Selenium produces a variety of colors in glass and ceramics when mixed with other additives.

PIGMENTS
Selenium is used in paints and plastics to produce a variety of colors with other additives. It is used to improve resistance by corrosion from seawater.

RUBBER
Metallic selenium is used with natural rubber to increase the rate of vulcanization and to improve the aging and mechanical properties. Selenium compounds are used in antioxidants and to improve the adhesion of polyester fibers to rubber.

LUBRICANTS
Selenium is added to lubricating oils and greases for extreme pressure service. Some dry powder lubricants contain selenium for use at elevated temperatures in an ultrahigh vacuum. Under such conditions these selenium lubricants possess lower coefficients of friction and have higher stability than graphite.

MEDICINE AND NUTRITION
Selenium is used to treat dermatitis of the scalp, pruritus, and mange in dogs. In conjunction with vitamin E selenium helps prevent muscular dystrophy in animals. Various selenium compounds are used to treat white muscle disease in sheep, infertility in ewes, pneumonia in lambs, premature and stillborn calves, muscular inflamation in horses, control high blood pressure in poultry, improve the healing of burned tissue and to combat memory loss.

From: *Kirk-Othmer Encyclopedia of chemical technology, 1982, Third Edition, John Wiley & Sons, Inc., New York, N.Y., v. 20, p. 593-598.*

Figure 1. Some uses of selenium. *From Kirk-Othmer Encyclopedia of chemical technology, 1982.* Diagram shows percentages of major uses of selenium in the United States. *After Jensen, 1985).*

## SELENIUM IN THE DIET

Selenium's role in human and animal diets is extremely complex and poorly understood (Figures 2 and 3). As is the case with most trace elements in the diet, selenium's effects differ significantly according to the quantities consumed. A minor amount (just how much is unknown) of selenium is necessary in the diet of humans and animals. Its importance in plant metabolism is still incompletely understood.

In California selenium deficiency in livestock is common. Worldwide, problems and losses of livestock due to selenium deficiency historically have been greater than those due to selenium excess (Lakin, 1973). A considerable world body of literature exists which describes symptoms of dietary deficiency and excess of selenium in horses, pigs, sheep, cattle, and chickens. The symptoms of selenium poisoning have been known for some time: softening and loss of hooves, loss of hair, uncontrolled appetite (which includes eating inappropriate items), staggering, listlessness, immobility, and finally, painful death (Moxon and Rhian, 1943). Deficiency is likely if selenium concentration in food is less than 50 parts per billion (ppb). Toxicity probably occurs between 3,000 to 5,000 ppb, and selenium balance likely is achieved between 100 to 1,000 ppb.

Domestic animals generally will avoid selenium-rich waters and vegetation unless they are starving; fences effectively keep them away from selenium-rich areas. Little is known about the effect of selenium on wild animals, fish and fowl. A fairly recent summary of the present state of knowledge of selenium's effects is found in the ambient water quality report for selenium by the U.S. Environmental Protection Agency (USEPA,1980).

Effects of selenium toxicity on humans are less well known than the effects on animals. Selenium toxicity in humans is relatively rare, in part because of modern food distribution techniques, which bring to the diet items from many different regions. A study in China cited by Burau (1985) recorded symptoms of selenium toxicity in a population of peasants who, forced by drought to rely more heavily than usual on vegetables grown locally in selenium-rich soils, began to show such symptoms of selenium poisoning as loss of nails and hair and skin lesions. In the Chinese study no toxic symptoms were noted in individuals consuming less than 750 micrograms (0.00075 grams) per day of selenium, but one or more symptoms of chronic selenium toxicity appeared in persons consuming 5,000 micrograms or more per day.

In the United States, the recommended adult dietary allowance of selenium is 50-200 micrograms per day. For drinking water, the standard used by the National Academy of Sciences (NAS) and the Environmental Protection Agency (USEPA, 1980) is 10 micrograms per liter of selenium. Average U.S. consumption of selenium is approximately 170 micrograms per day from all sources (Burau, 1985). A diet which contains approximately 1,000 to 5,000 micrograms per day would produce chronic selenium toxicity (selenosis), with loss of hair and fingernails, skin lesions, and digestive disorders. More advanced symptoms of selenosis are generalized numbness, paralysis, convulsions, and death. The effects can be alleviated by adopting a low-selenium diet (Hartshorn, 1985).

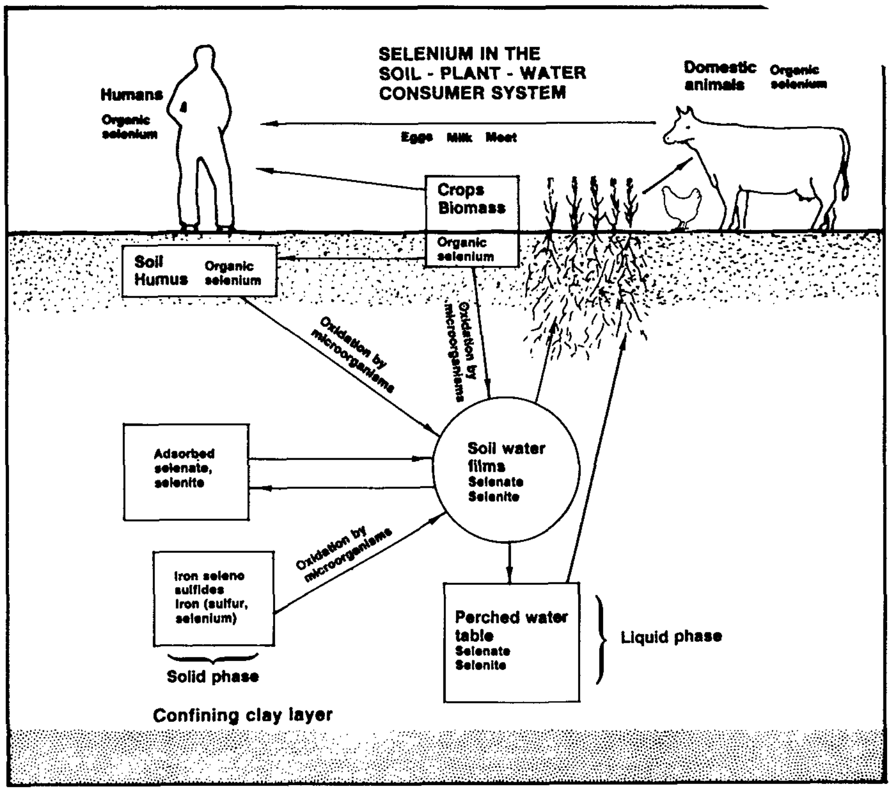



Figure 2. Plant roots take up selenate ($Se^{+6}$) or selenite ($Se^{+4}$) forms of selenium from the soil water. The selenium concentration in solution depends on the solubility of the forms of selenium present and the biological transformation of organic forms. *By Burau (1985, p. 18).*

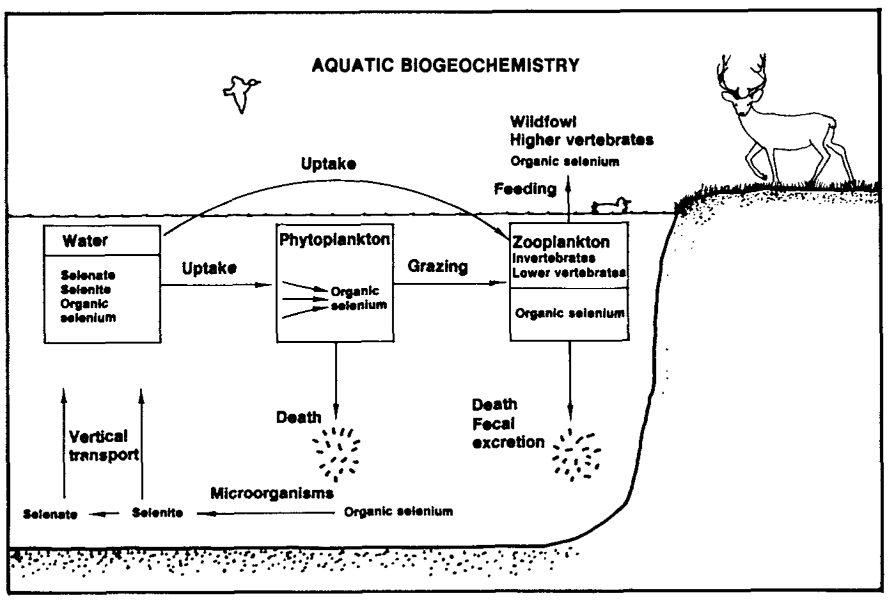



Figure 3. Aquatic organisms such as marsh plants, plankton, and insects take in inorganic selenium and transform it into organic forms. The organic forms of selenium are then more easily taken up by higher life forms such as wildfowl and mammals. *By Burau (1985, p. 18).*

Based on studies of animals the U.S. drinking water standard was set on the basis of concern over selenium's possible role as a carcinogen. However, the evidence is contradictory and inconclusive (USEPA, 1980); there is some indication that non-toxic amounts of selenium salts may inhibit tumor formation.

Experiments with barley, *Drosophila* flies, rabbit kidney tissue cultures, and human white blood cell cultures suggest that at higher dietary levels, selenium may act as a mutagen that causes genetic changes. In addition, a number of studies dating back to the 1950s have implicated selenium as a teratogen that causes defects in the developing embryo. Deformities induced by selenium have been recorded in chickens, turkeys, rats, cattle, and other domestic animals (USEPA, 1980; NAS, 1976). Selenium may be a teratogen in humans, also, according to reports cited by the National Academy of Sciences (NAS, 1976).

## SELENIUM IN THE ENVIRONMENT

Selenium is introduced into the earth's surficial systems primarily through volcanic processes. It is estimated that throughout geologic time volcanic activity has released 0.1 grams of selenium for each square centimeter of the earth's surface (Lakin, 1973).

TABLE 1. FACTORS CONTRIBUTING TO SELENIUM ACCUMULATION IN SOILS.
*After Ganze, 1966.*

- Wind-blown materials from seleniferous bedrock.
- Alluvial deposits along valleys or streams if drainage is chiefly from seleniferous bedrock.
- Leaching and subsequent redeposition of soluble selenium in lower soil horizons or formations.
- Seleniferous salt crusts in semi-arid regions appearing as a result of capillary water movement through selenium-bearing soils.
- Deposition of selenium in soils irrigated by water that has become enriched in selenium by passing through selenium-rich shales.
- Selenium released in surfical horizons of soils as selenium-accumulating plants die and decompose.
- Selenium impurities in superphosphate and ammonium sulfate fertilizers. The evidence for this is incomplete.
- Selenium and other minerals entering the soil from insecticides. This possibility has been suggested but not evaluated.

With a boiling point of 694.9°C, selenium is a component of volcanic gases; it is also emitted from volcanoes in particulate forms. In both cases it is removed from the air by rain and is concentrated in volcanic deposits (Keller, 1982). Selenium is also produced by certain industrial emissions and is in acid rain. In fact, industrial emissions and other human activities contribute about 35 metric tons of selenium per year into the environment (USEPA, 1980). The major contribution of selenium into the environment, however, is from the leaching of selenium out of soils and rocks through weathering processes.

Of all rock types, igneous and metamorphic rocks have the lowest selenium content (10 to 50 ppb), while sedimentary rocks are generally higher in selenium content. In particular, marine shales, which may be in part derived from volcanic activity, appear to serve as source rocks for selenium in the environment. Selenium content of marine shales ranges from 500 to 28,000 ppb (Burau, 1985). The selenium in marine shales is probably in reduced form, such as ferric selenosulfide ($FeSeSO_3$).

## SELENIUM IN SOILS: OCCURRENCE AND CHEMISTRY

Selenium is widely distributed in soils. Usually its concentration is low, approximately 200 to 400 ppb in an average soil worldwide. Some soils are selenium-deficient, so much so that cattle fed on those rangelands must be given selenium supplements in their diets. Selenium-poor soils may contain as little as 100 ppb selenium. In California such soils occur on the eastern side of the San Joaquin Valley, where they are derived from the weathering of selenium-poor Sierra Nevada metamorphic rocks.

Arid farmland in the western San Joaquin Valley. Much of this region receives less than 10 inches of annual rainfall. Since the 1930s the western San Joaquin Valley has been profitably farmed by using irrigation water.

The California Central Valley Project, started in 1935, was one of the most ambitious water engineering projects in history. It has so far cost $2.5 billion and includes 16 dams, 8 major canals, 2 tunnels, and 6 generating stations that transfer water from the Sierra Nevada to the Central Valley. Although the project brought wealth it caused two major hydrologic problems; (1) irrigation water dissolved salts and minerals that over a period of time could accumulate to poison crops and (2) a semi-impervious clay layer, which occurs in the western San Joaquin Valley, trapped water applied to the surface—water levels rose and threatened to drown crops. To alleviate these problems construction began in 1970 on the San Luis Drain, which was initially designed as a primary drainage system to carry waste water from the San Joaquin Valley north to the Sacramento River delta where it would eventually empty into the San Francisco Bay. The drain was never completed and today the partially completed San Luis canal drains directly into the Kesterson Reservoir. In 1983 scientists recognized that selenium levels at Kesterson had reached toxic levels. Near Kesterson an even larger refuge and irrigation district known as the Grasslands also contains worrisome levels of selenium and other minerals.

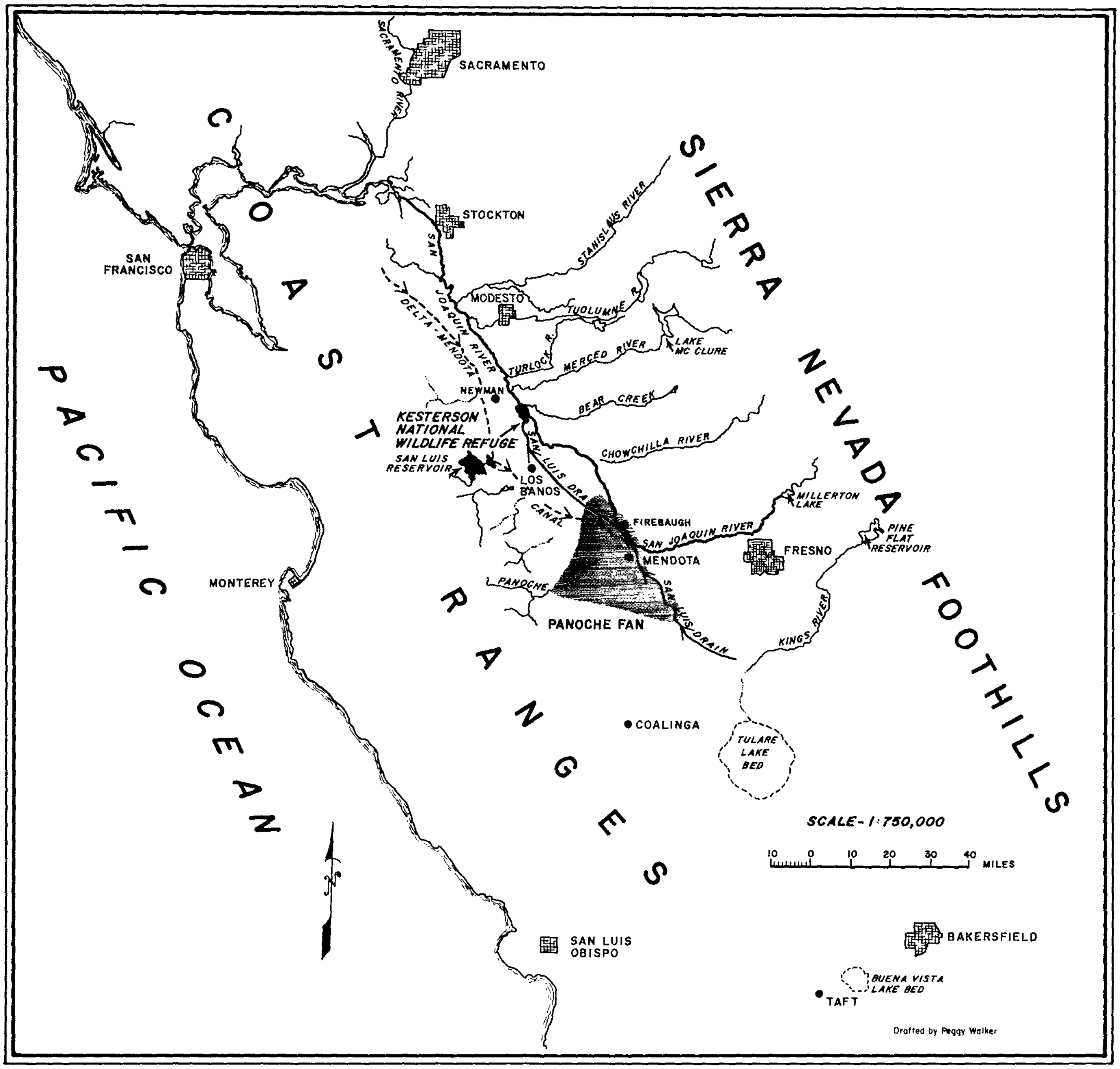


Figure 4. The San Joaquin Valley of California.

Soils derived from the weathering of volcanic rocks may be enriched in selenium. In some Hawaiian soils derived from basalt the selenium content is 6,000 to 15,000 ppb (Lakin, 1973).

Selenium may also be abundant in soils derived from the weathering of sedimentary rocks, particularly marine pyritic shales. Such soils are widely distributed in western North America particularly in areas of dry climate where the parent rock is Cretaceous or Tertiary marine shale. For example, seleniferous soils in Nebraska, South Dakota, Wyoming, Kansas, and Colorado are all developed on the Upper Cretaceous Pierre Shale or on the Upper Cretaceous Niobrara Formation (Moxon and Rhian, 1943). In all of these areas, the soils or occasionally the incompletely weathered shales support vegetation which has concentrated enough selenium to be toxic to grazing animals. Selenium contents as high as 6,000 to 28,000 ppb have been reported in soils developed on the Pierre Shale (Burau, 1985).

Glacial drift in North Dakota and Canada and glacial lake sediments have been suggested as selenium source rocks for soils which support seleniferous plants. There have also been reports of selenium in units older than Cretaceous, including some soils developed on Permian-Triassic rocks in Wyoming and Idaho (Moxon and Rhian, 1943: Ganze, 1966).

In California, selenium-rich soils are found at lower elevations on the west side of the San Joaquin Valley. Selenium-rich soils are especially common in the alluvial fans of Panoche and Little Panoche creeks (Figures 4-6). Although little is actually known about the distribution of selenium in the Coast Ranges, selenium in the Panoche Fan area may have come from Cretaceous and Tertiary pyritic shale units such as the Moreno Formation in the Diablo Range (Lakin and Byers, 1941; U.S. Bureau of Reclamation, 1984; Sylvester, 1985).

While a number of conditions may lead to the production of seleniferous soils (Table 1), not all selenium-rich soils are associated with diseases of selenium toxicity. In North America, seleniferous soils producing toxic vegetation belong to the pedocal category, and are confined to regions with a mean annual rainfall of less than twenty inches (Ganze, 1966). In contrast, seleniferous pedalfer soils, such as those in Hawaii, do not support toxic vegetation.

The key to the problem of soil toxicity is the chemical state of the selenium which is present. Selenium may occur in soils as elemental selenium, as selenide, selenite, selenate, or as organic selenium. Of these, common selenium salts are ferric selenite [$Fe_2(OH) + SeO_3$] and calcium selenate ($CaSeO_4$); elemental selenium is quite rare in soils. Where soils have supported selenium-accumulating vegetation, up to 40 percent of the soil's selenium content may occur in the surficial humic layers, contributed as organic selenium by decayed vegetation. However, studies have shown that the principal source of selenium for plants is in the lower portions of the soil profile, where, in alkaline soils of dry climates, the water-soluble selenates accumulate. In acidic moist-climate soils, selenium accumulates as low-solubility selenites, which are unavailable to plants (Moxon and Rhian, 1943).

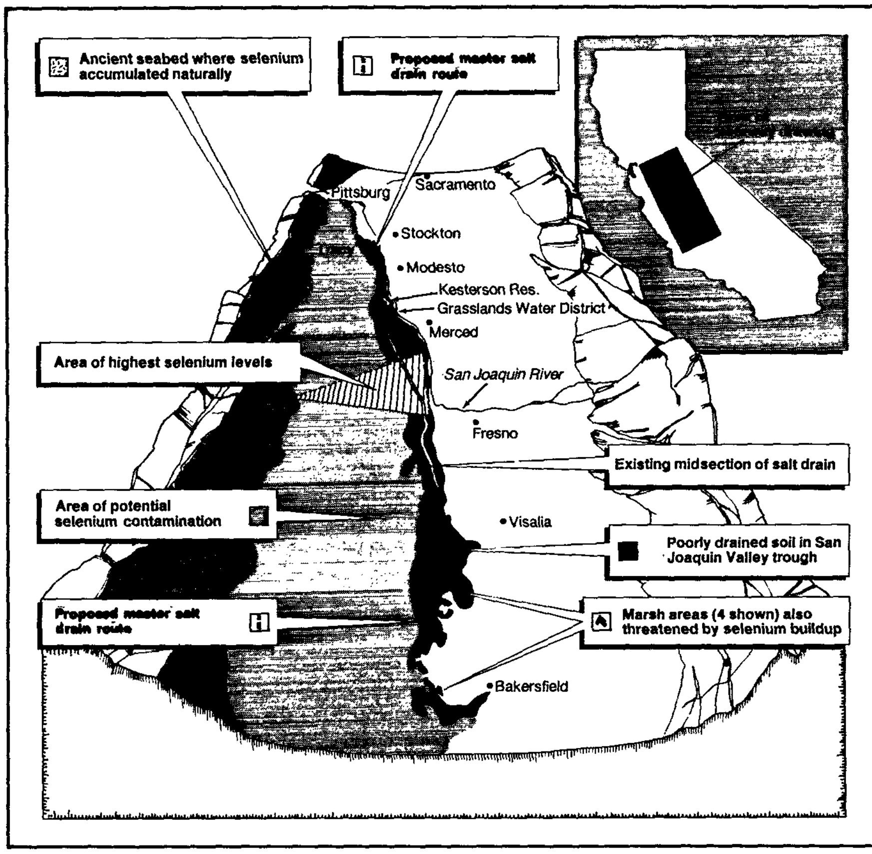



Figure 5. Areas of selenium buildup in the San Joaquin Valley. *Figure by Jim Chaffee, courtesy of The Sacramento Bee.*

## CHEMISTRY OF SELENIUM IN GROUND AND SURFACE WATERS

Commonly, fresh water is slightly acidic and associated selenium usually occurs as selenite ($Se^{+4}$) (Brooks, 1984). Under a combination of acidic and reducing conditions, selenite is reduced to relatively insoluble elemental selenium (Deveral and others, 1984), which accumulates in the sedimentary substrate (NAS, 1976). However in alkaline water, such as found in the San Luis Drain area in the west side of California's San Joaquin Valley, selenate ($Se^{+6}$) is the most common form. This is the most stable form of soluble selenium and, in water as in soil, it is the form most available to plants. Algae incorporate the inorganic selenium into amino acids and proteins, thus permitting the element to enter the animal food chain (Brooks, 1984).

Selenium levels in fresh and marine waters worldwide average approximately 0.2 ppb and 0.1 ppb respectively. Levels may be three or more orders of magnitude greater in seepage water in areas of seleniferous soils. In California, selenium content of water in the east side of the San Joaquin Valley is in the low to average range of values (less than 10 ppb) but in the west side of the valley in the area of Kesterson Reservoir, San Luis Drain and the Panoche fan some selenium levels have been found to be as high as 4,000 ppb (Figure 4) (Burau, 1985). Selenium levels of algal mats and salt crusts from ponds on the San Luis Drain contain up to 20,000 ppb selenium (Deverel and others, 1984; Presser and Barnes, 1984; 1985).

The U.S. Geological Survey, the U.S. Bureau of Reclamation, and the California Regional Water Quality Control Board have been conducting continuing studies on the distribution of selenium in surface waters, shallow wells, and groundwater in the areas around Kesterson Reservoir, Grasslands Water District, and Westlands Water District.

The processes by which selenium has become concentrated in the irrigation drainage waters and other waters of the Kesterson area are not well understood (Deverel and others, 1984). One hypothesis suggests that the selenium, originally derived by weathering and oxidation of sedimentary selenosulfides ($SeSO_3^{-2}$) in marine shales of the Coast Ranges, is released as selenite ($Se^{+4}$) and selenate ($Se^{+6}$) salts, while the sulfides go into solution as sulfates ($SO_4^{-2}$). These materials are then deposited in the alluvial fans on the valley floor, where they are concentrated by evaporation. Later, the oxidized selenium, which probably is highly soluble under alkaline conditions in the area,

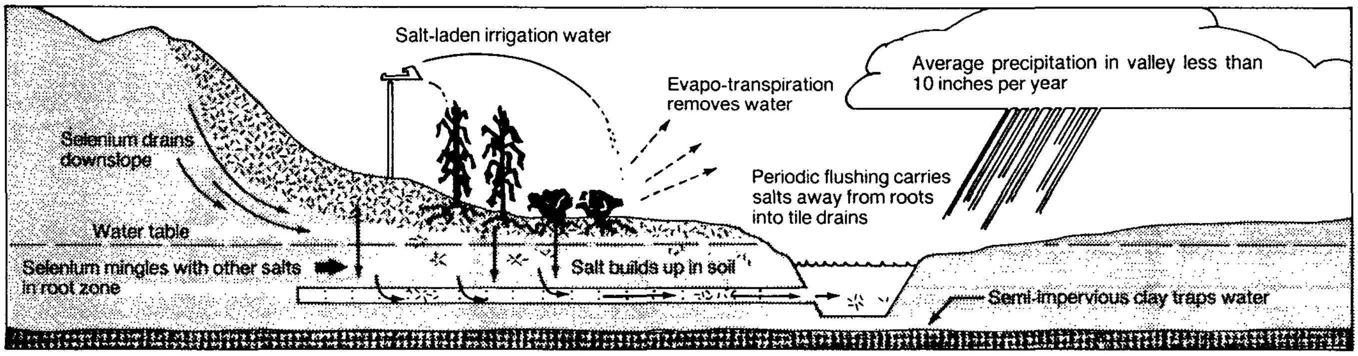



Figure 6. Salt-laden irrigation water is used to grow crops on the west side of the San Joaquin Valley where a thick semi-impervious layer of clay beneath the surface traps the irrigation water which must be drained. Through evaporation, transpiration, and drainage water is removed leaving salts and minerals which accumulate over time. Periodic flushing of the soil carries these salts and minerals out of the root zone into tile drains. Tile drains are placed at an average depth of eight feet and remove the waste water from the soil by transporting it into a collector drainage system. *Figure by Jim Chaffee, courtesy of The Sacramento Bee.*

is taken into solution by infiltrating irrigation water and/or shallow ground water (Presser and Barnes, 1984). Further evaporative concentration would occur during the irrigation process. Evaporation of shallow ground water would likely cause concentrations of selenium in some soils, particularly the saline soils in the rim area of the San Joaquin Valley basin.

Dissolved selenium carried by deeper ground water flow from the Coast Ranges to low lying discharge areas near the San Joaquin River has been suggested as a possible long-term process (Deverel and others, 1984). Such a process may have occurred over geologic time, and may still be occurring in the western side of the San Joaquin Valley. The rate and amount of selenium transport would probably vary with long-term or even short-term variations in precipitation and recharge. In historical times, changing patterns of human use of surface and ground water had an impact on rates and patterns of selenium transport.

## CONCLUSION

Selenium salts are only one contemporary expression of a problem that is nearly as old as civilization. The character of dry-climate soils — their relatively high content of soluble, nutrient mineral salts — which makes them attractive to agriculture also is a principal factor leading to soil degradation under heavy irrigation.

Imported water, carrying salts leached from soils and rocks en route, stands in the fields and evaporates, leaving mineral salt deposits. Some of the standing water percolates downward, carrying salts into the soil profile. The water table is gradually raised, and water, drawn upward by capillary action toward the surface, carries dissolved salts with it, which remain after the water evaporates. Not only are the saline waters taken up by the plants, sometimes resulting in stunted growth and leaf burn, but the raised water table may itself become a problem if plant roots become waterlogged. Addition of irrigation waters adds more salts to soils which often are already saline. The problem intensifies as long as water is allowed to accumulate or pond in the fields.

One solution to this problem is to use large volumes of water to "flush" the soils out. Another is to install subsurface drainage systems, consisting of buried pipes, called "tiles", in the fields. In both cases there must be some provision for the waste drainage water. In the case of the subsurface tile systems, the drainage waters may be fairly saline. However taking these saline waters via tiles to another place transfers the salinity problems elsewhere.

In the San Joaquin Valley of California, irrigated agriculture has been practiced since the 1870s. As early as the 1890s, some soils began to become noticeably degraded from salinity buildup. Today, the problem is most severe in the west side of the San Joaquin Valley where geologic conditions are a contributing factor because shallow, perched groundwater zones slow the downward migration of saline waters. According to the U.S. Bureau of Reclamation, approximately half a million acres in the valley are threatened by salt buildup. The solution that was proposed for the San Joaquin Valley was the San Luis Drain, a concrete-lined canal that was to carry agricultural drainage waters out of the valley into the Sacramento-San Joaquin Delta. Enviromental opposition was raised on the grounds that addition of salty, pesticide-laced water might degrade the quality of the water in the delta. The drain was never completed, and its northern terminus is the Kesterson National Wildlife Refuge. Kesterson comprises 1,280 acres of shallow ponds that serve as wetlands for migratory fowl, and that collect, store, and serve as evaporation basins for drainage water. But Kesterson has proven to be only a temporary solution. The water there is now very saline and unsuitable for use by wildlife; selenium content has reached toxic levels.

The long-term solutions will involve difficult economic and political decisions.

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# ASBESTOS MINING

The Calaveras Asbestos, Ltd., quarry located near Copperopolis, Calaveras County, in the Sierra Nevada foothills is the nation's largest asbestos producer. There are only two other active asbestos mines in the United States.

Asbestos is used to manufacture brake linings, concrete pipe, and insulation materials. Asbestos from the Copperopolis quarry is used in cement products. Asbestos fibers are nonflammable and are heat resistant to about 260°C.

Rock must be carefully removed and milled to avoid potential asbestos contamination of the air and water in the mine area. Asbestos mining also requires careful mined land reclamation procedures to insure long-term environmental safety. Calaveras Asbestos, Ltd. has made numerous design changes in their mine and mill over the past five years in an effort to increase production efficiency and minimize environmental impacts related to the operation. Original quarry benches have been modified to make asbestos ore more accessible, to improve haulage routes, and to provide a safer working environment.

*...John S. Rapp, DMG.*

Asbestos quarry, Calaveras Asbestos, Ltd., Calaveras County, California. The pneumatic rock drill (foreground of photo) is used to drill blast holes during quarry production. *Photo by John S. Rapp, October 1985.*



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## LITHOLOGIC AND STRUCTURAL VARIATIONS IN

# Cretaceous Amphibole-Rich Gabbros

## IN THE SIERRA NEVADA FOOTHILLS NEAR FRESNO

Fresno County

By

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The authors have been investigating Cretaceous intrusions in the Sierra Nevada foothills east of Fresno, California for more than a decade. Results of some of their earlier work was published in a 1979 Geological Society of America Bulletin. This article is a report on the progress of the study since that time.

The current study indicates an exciting mineralogy and interesting structural relationships in these rock units. A striking similarity has been found between gabbros in the Sierra Nevada foothills and gabbros of the Peninsular Ranges in southern California. Apparently both areas were strongly influenced by an explosive calc-alkaline volcanic chain in Early Cretaceous time...*editor.*

### INTRODUCTION

Amphibole-rich gabbroic complexes in the Sierra Nevada foothills near Fresno are the oldest rocks in a sequence of Cretaceous plutons that were injected into Jurassic volcanic arc deposits and their underlying ophiolitic basement along the western margin of the Sierra Nevada batholith. Brief geologic summaries of three gabbroic complexes are given to illustrate their marked lithologic and structural diversity. The unusual mineral assemblage of amphibole linked with anorthite-rich plagioclase and olivine in the complexes indicates that the gabbros had crystallized from hydrous mafic magma containing 2 to 3 percent by weight water. Comparison with liquidus mineralogy in gabbros of the Peninsular Ranges in southern California demonstrates that much of the western margin of the North American Cordillera was probably surmounted by an explosive calc-alkaline volcanic chain in Early Cretaceous time.

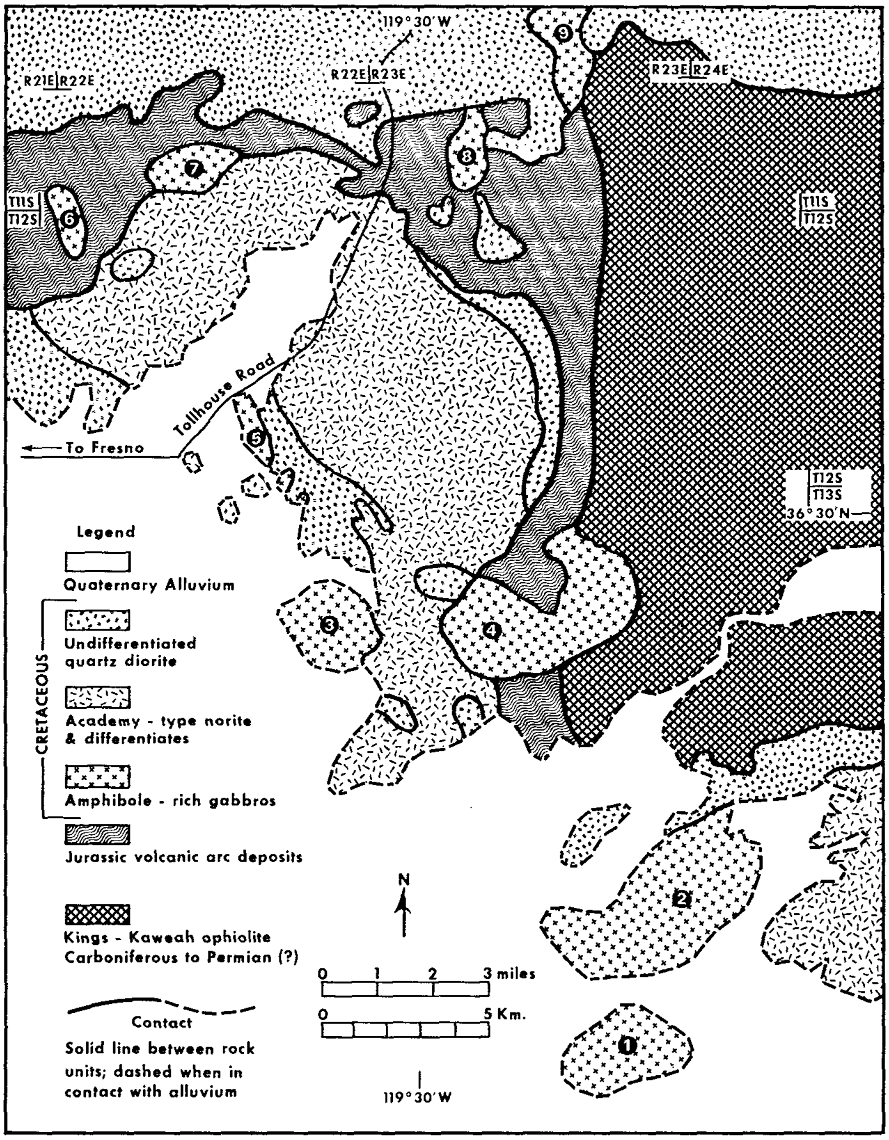


Figure 1. General geologic map of the western Sierra Nevada foothills study area east of Fresno. There are nine distinct intrusive bodies that were emplaced at different times: (1) Campbell Mountain, (2) Jesse Morrow Mountain, (3) Round Mountain, (4) Coyote Ridge, (5) Shepherd Hill, (6) Owens Mountain SW, (7) Owens Mountain, (8) Humphreys Station SW, and (9) Humphreys Station.

Three principal Cretaceous plutonic rock units are present in the western Sierra Nevada foothills near Fresno (Figures 1-4). These are from oldest to youngest,

(1) an amphibole-rich gabbro suite, (2) Academy pluton-type norite and related derivatives (Mack and others, 1979), and (3) biotite-hornblende quartz diorite and tonalite suite. Relative age relationships have been established throughout the area. Academy pluton-type norite cuts amphibole-rich gabbro at a number of localities in the study area. The quartz diorite-tonalite suite is intrusive into the Academy pluton in a 13 km-long arcuate segment along its eastern margin (Figure 1), and north of Round Mountain it extends into the Academy pluton as a narrow intrusive apophysis. The tonalite east of the Academy pluton has been age dated at 114 million years (my) (Saleeby and Sharp, 1980), and Academy pluton norite has been age dated in two localities at approximately 120 my (Mack and others, 1979; Saleeby and Sharp, 1980). Data indicate that the amphibole-rich gabbros were injected only slightly earlier than Academy pluton type rocks (perhaps no more than several hundred thousand years) based upon geological relationships exhibited at Owens Mountain (Figure 4). In the Owens Mountain intrusion, Academy pluton type norite is clearly the youngest injected phase. If the norite had been injected considerably later than the gabbroids, there would be little reason for it to be confined to the older, essentially healed magmatic conduit since substantially more pliable metavolcanic rocks surround the gabbroic complex all along its northern margin. The close spatial relationship of Academy pluton type norite, and earlier gabbroids thus probably points to a relatively close time frame between the intrusion of the gabbroids and the Academy pluton norite.

## AMPHIBOLE-RICH GABBRO SUITE

The amphibole-rich gabbros comprise nine distinct intrusive bodies in the map area (Figure 1). The gabbroid masses are complexes of numerous small bodies emplaced at different times. Their lithology is diverse not only from intrusion to intrusion, but also within specific bodies. Two mineral phases, amphibole and plagioclase, are dominant within the gabbroids. Amphibole, classified as ferro-pargasite (Saleeby and Sharp, 1980) in a related gabbroic complex immediately south of the study area, is generally a prominent constituent except in anorthositic varieties. Plagioclase is highly calcic, averaging about 90 percent anorthite. Common hornblende and intermediate plagioclase are equivalent phases in Academy pluton-type norite and related rocks (Mack and others, 1979).

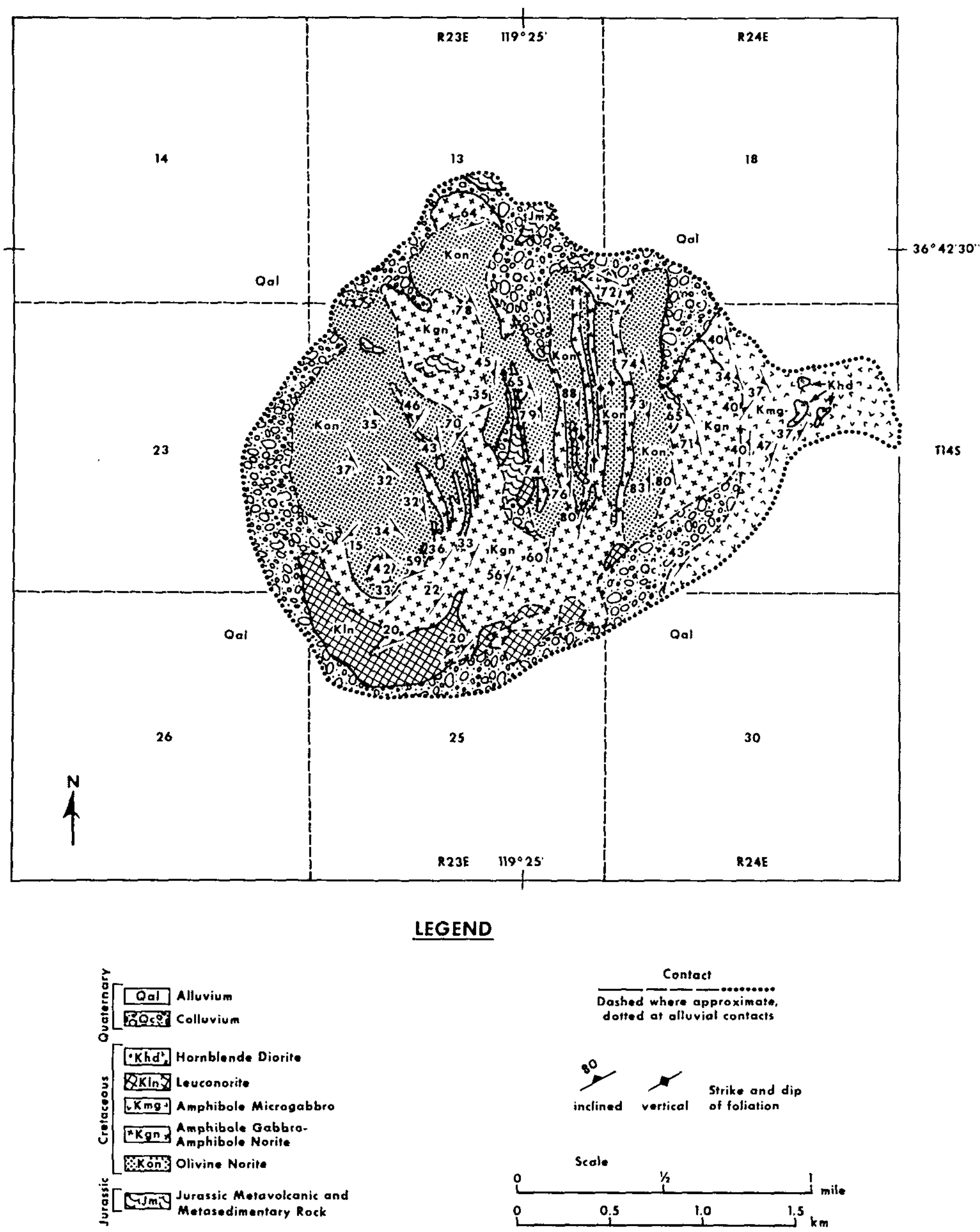


Figure 2. Geologic map of the Campbell Mountain pluton.

Many of the gabbroic rocks can be regarded as accumulates inasmuch as they are layered and banded, and contain euhedral to subhedral unzoned plagioclase, olivine, clinopyroxene, and orthopyroxene. The origin of such rocks is in doubt (McBirney and Noyes, 1979) but the cumulus terminology* of Wager and others (1960) remains useful for descriptive purposes.

Following are brief geologic summaries of several western foothill gabbros near Fresno which illustrate marked lithological and structural diversity.

### Campbell Mountain Pluton

The Campbell Mountain pluton (Figure 2) is composed of a sequence of mafic fractionated units which from oldest to youngest range in composition from (1)

*Cumulus is the accumulation of crystals that precipitated from a magma without having been modified by later crystallization olivine norite, (2) amphibole gabbro and amphibole norite, (3) amphibole microgabbro, (4) leuconorite, to (5) hornblende diorite (Russell, 1982). The geologic map reveals a series of interfingering, roughly linear belts of gabbroic rock. Rock units generally strike north-northwest to south-southeast and dip moderately to steeply westward, subparallel to the alignment of mafic intrusives in the southern Sierra Nevada foothills.

The most obvious geologic feature of the pluton is that the dominant olivine norite unit is intricately dissected by numerous dike-like streamers of amphibole gabbro and amphibole norite which extend generally northward from a massive east-northeast trending segment near the southern margin of the pluton. The amphibole gabbro-amphibole norite unit is clearly younger than the olivine norite, and the curving, intertonguing trend of the injections may indicate that intrusion of the dikes occurred while the norite was still somewhat fluid. Amphibole microgabbro is a fine-grained uniformly dark-gray rock intrusive into the amphibole gabbro-amphibole norite unit along the eastern margin of Campbell Mountain. The youngest injections into the pluton are dikes and pods of leuconorite and hornblende diorite which are probably correlative with rocks of the Academy pluton (Figure 1).

Modal analyses of samples collected from the various units comprising the Campbell Mountain pluton are listed in Table 1. Plagioclase composition ranges from anorthite in the earlier phases to intermediate values in the leuconorite and hornblende diorite. Olivine is present only in the olivine norite unit and optical parameters of mafic minerals indicate a progressive increase in the ratio of ferrous iron ($Fe^{+2}$) to magnesium ($Mg^{+2}$) that is sympathetic with an increase in sodium content of plagioclase.

## Round Mountain Gabbroic Complex

From a distance, the Round Mountain gabbroic complex (Figure 3) appears to be rhythmically layered, with an alternating sequence of light and dark layers. On close inspection, it is apparent that light-colored anorthositic gabbro layers have been injected as thin, gently-dipping dikes into a matrix of dark gray amphibole gabbro (Photo 1 and inset).

Figure 3. Geologic map of the Round Mountain gabbroic complex. ▶

TABLE 1. AVERAGE MODAL ANALYSES OF CAMPBELL MOUNTAIN INTRUSIVE UNITS.

| Units | Number of Samples | Plagioclase | Olivine | Orthopyroxene | Clinopyroxene | Amphibole | Opaques | Spinel | Biotite |
|---|---|---|---|---|---|---|---|---|---|
| Olivine norite | 32 | 62.4% An88-93 Ave=An90 | 8.5% Fo69-83 Ave=Fo76 | 9.5% En72-81 Ave=En76 | ---- | 16.5% Ave $2V_x$=88° | 2.4% | 0.7% | ---- |
| Amphibole gabbro-amphibole norite | 22 | 46.9% An88-90 Ave=An89 | ---- | 4.7% En68-74 Ave=En72 | ---- | 43.0% Ave $2V_x$=79° | 5.4% | ---- ---- | ---- ---- |
| Amphibole microgabbro | 5 | 39.5% An89-91 Ave=An90 | ---- | ---- | ---- | 52.6% Ave $2V_x$=79° | 7.9% | ---- | ---- |
| Leuconorite (Academy type) | 10 | 71.4% An48-53 Ave=An51 | ---- | 19.0% En52-62 Ave=En56 | ---- | 6.8% Ave $2V_x$=73° | 2.8% | ---- | ---- |
| Hornblende diorite (Academy type) | 2 | 60.3% An44-46 Ave=An45 | ---- | 4.5% | 1.5% | 20.2% Ave $2V_x$=72° | 4.9% | ---- | 8.7% |

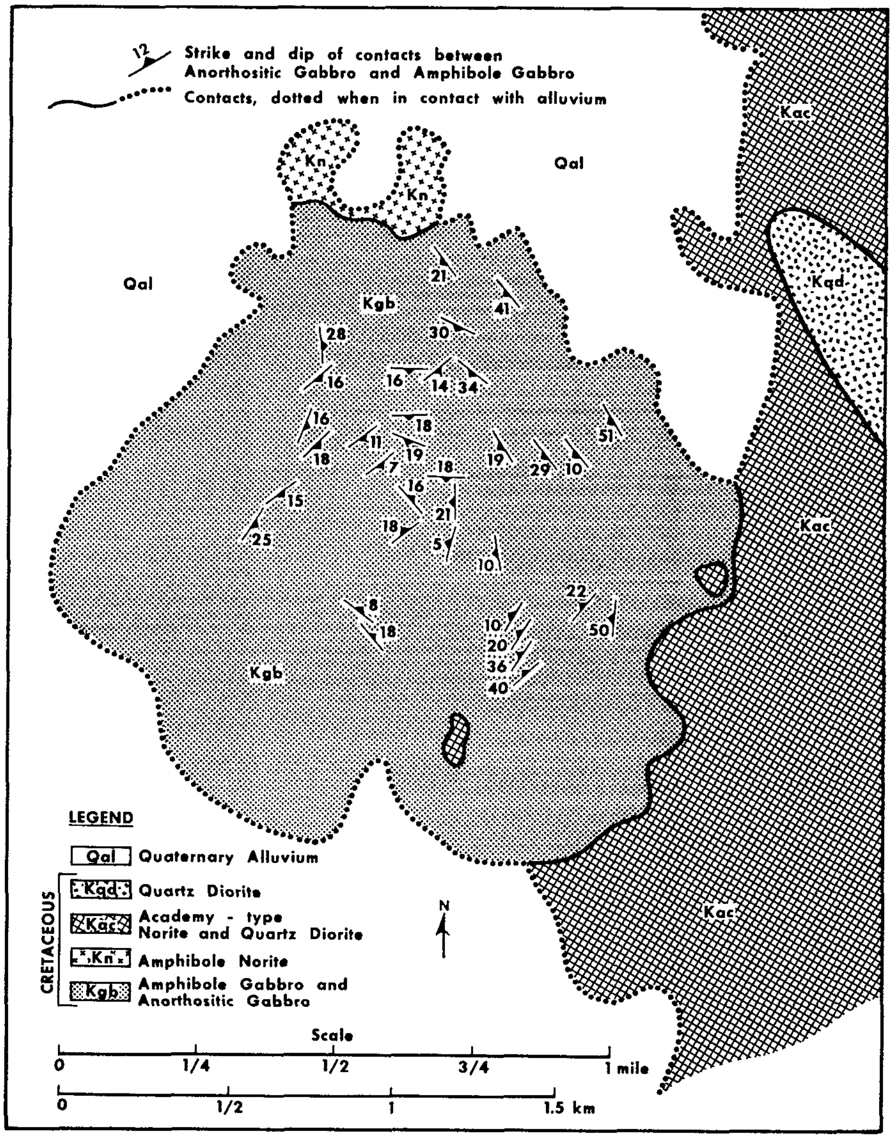

Photo 1. Anorthositic dikes injected into amphibole-rich gabbro, Round Mountain, Sierra Nevada foothill area east of Fresno.

Inset: Closeup of anorthosite dikes cutting amphibole gabbro.

The amphibole gabbro host consists of two varieties possessing similar mineralogy but having different textural habits. These are (1) a medium-grained amphibole gabbro with dominantly poikilitic amphibole and (2) a fine to medium-grained amphibole gabbro with prismatic amphibole. The most extensive type is the poikilitic variety (Sholes, 1982). The dominant mineralogy in both types is anorthitic plagioclase and amphibole. In the poikilitic variety, amphibole is often interstitial to plagioclase and is frequently poikilitic containing numerous subhedral to euhedral plagioclase grains. Clinopyroxene and orthopyroxene are primary minerals, but they have been largely replaced by uralite. In the prismatic variety, textures indicate that plagioclase generally crystallized prior to amphibole, but early simultaneous crystallization of plagioclase and amphibole is also indicated.

Prismatic-type amphibole gabbros occur primarily as irregular dikes and masses within the poikilitic host rock. They have also been injected as numerous thin, gently-dipping dikes which parallel the later injected anorthositic gabbro component. The attitude of these amphibole gabbro dikes and the anorthositic layers define a foliation pattern that resembles a set of stacked saucer-like sheets dipping inward toward the center of Round Mountain (Figure 3). The basin-like structure might have evolved as a consequence of the intrusion of amphibole gabbro from a very shallow magma chamber immediately underlying Round Mountain. It is visualized that the magma formed an essentially dome-like pulse at the exposed level, and that the entire structure ultimately sagged into the evacuated magma chamber, thereby forming a series of saucer-like tensional fractures in the gabbro. Later injection by prismatic amphibole gabbro and especially anorthositic gabbro into these fractures is presumed to have produced the observed geologic configuration.

The anorthositic rocks generally occur as 20 to 50 cm thick layers within amphibole gabbro and also project as numerous intrusive apophyses into the host rock. Anorthositic gabbro is a medium-grained rock with a plagioclase content averaging slightly less than 90 percent of the modal constituents. The plagioclase content is approximately 90 percent anorthite. Amphibole usually occurs as web-like interstitial patches or poikilitic grains. Epidote and chlorite are common alteration products of amphibole, an indication that the magma was probably enriched in water.

Amphibole norite occurs as a small intrusive segment into amphibole gabbro along the northern margin of Round Mountain. It is a medium-grained rock with hypidiomorphic-granular texture. Dominant minerals include plagioclase, amphibole, and orthopyroxene. The anorthite content of plagioclase in two samples averages about 78 percent. Optical parameters indicate that orthopyroxene has a composition of 60 percent enstatite, which indicates substantial iron enrichment compared to the amphibole norite of Campbell Mountain.

Two small pods of Academy pluton-type rocks occur along the eastern and southern margins of Round Mountain. Modal analyses of these and other units comprising the Round Mountain gabbroids are listed in Table 2.

## Owens Mountain Gabbroic Complex

The Owens Mountain gabbroic complex (Figure 4), an oval-shaped area 3 km long by 1.5 km wide, is aligned in an east-west direction. On the west and north, the gabbro is surrounded by dark, fine-grained Jurassic metavolcanic rock which is foliated essentially parallel to the gabbroic contact; it would appear that intrusion of the gabbro had shouldered aside the pliable country rock. Along its southern border and around its eastern end, the gabbro is bounded by the outermost zone of the Academy pluton. Here the Academy rocks are composed of biotite-hornblende quartz diorite which are considered to be the hydrothermally-altered border zone of the pluton (Mack and others, 1979). Flow structure in the biotite-hornblende quartz diorite parallels the gabbroic contact and indicates that this phase of the Academy pluton was injected into the Jurassic country rock somewhat later than the Owens Mountain gabbro.

The Owens Mountain gabbro is composed of three principal lithologic units. From oldest to youngest these are (1) olivine gabbro, (2) gabbronorite, and (3) norite. Bishop (1979) reports that the distribution of outcrops over the area is reasonally good, but massive, clean exposures that would allow examination of gross structural and textural features are lacking. Age relationships are therefore based upon degree of magmatic evolution of mineral phases, and the extent of protoclastic deformation. Presumably, the earliest phase, olivine gabbro, would have met relatively light resistance as a consequence of forcing apart relatively pliable metavolcanics, and later phases would have encountered progressively stiffer resistance as they were injected into the magmatic conduit. Norite, apparently the youngest component of the complex, shows widespread deformation of plagioclase which is generally expressed as bent or cracked crystals, and recrystallized, fine-grained polygonal aggregates.

Olivine gabbro is a medium-grained dark gray rock, ranging from 1 to 3 mm in average grain size, with a hypidiomorphic-granular texture. It is found as a 1.5 km-wide patch along the southern margin of the complex, and as a smaller segment along the northwest margin. Optical parameters indicate that the southernmost segment has a higher ratio of ferrous iron ($Fe^{+2}$) to magnesium ($Mg^{+2}$) in mafic phases (Table 3), and it is presumed to be the older of the two segments.

TABLE 2. AVERAGE MODAL ANALYSES OF ROUND MOUNTAIN INTRUSIVE UNITS.

| Unit | Number of Samples | Plagioclase | Orthopyroxene | Clinopyroxene | Amphibole | Quartz | Opaques | Uralite | Epidote | Chlorite |
|---|---|---|---|---|---|---|---|---|---|---|
| Amphibole gabbro (poikilitic) | 4 | 63.0% Ave=An92 | ---- | ---- | 27.5% 2Vx=80° | ---- | 1.0% | 3.0% | 2.4% | 4.1% |
| Amphibole gabbro (prismatic) | 5 | 44.7% Ave=An91 | ---- | ---- | 45.3% 2Vx=79° | ---- | 5.2% | ---- | 2.0% | 2.8% |
| Anorthositic gabbro | 4 | 87.2% Ave=An90 | ---- | ---- | 8.0% 2Vx=80° | ---- | 1.2% | ---- | 1.8% | 1.8% |
| Amphibole norite | 2 | 49.5% Ave=An78 | 18.0% Ave=En60 | ---- | 25.2% 2Vx=78° | ---- | 6.5% | 0.8% | ---- | ---- |
| Norite (Academy type) | 1 | 59.2% An55 | 19.8% En55 | ---- | 17.9% 2Vx=73° | ---- | 3.1% | ---- | ---- | ---- |
| Pyroxene Quartz diorite (Academy-type) | 1 | 15.5% An40 | ---- | 33.5% | 37.8% 2Vx=72° | 13.2% | ---- | ---- | ---- | ---- |

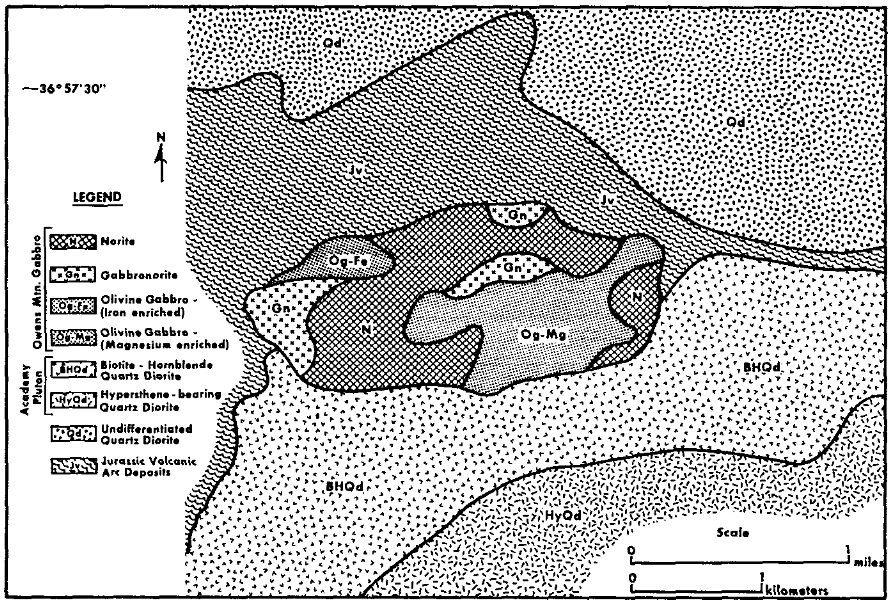


Figure 4. Geologic map of the Owens Mountain gabbro and Academy pluton.

Fine to medium-grained gabbronorite occupies three small sectors comprising about one-eighth the areal extent of the gabbroic complex. Plagioclase is unzoned and has an average composition of 91 percent anorthite, similar to that found in the olivine gabbro (Bishop, 1979). Deformation of plagioclase is generally slight, and it is observed as occasional bent and cracked crystals. Olivine is present sparingly. Clinopyroxene is slightly more abundant than orthopyroxene; by contrast in the olivine gabbro, clinopyroxene averages about six times the modal abundance of orthopyroxene.

The norite unit is intrusive into olivine gabbro and gabbronorite, and comprises about 60 percent of the Owens Mountain complex. It is a gray medium-grained rock which very strongly resembles rock from the nearby quartz norite unit of the Academy pluton. Plagioclase is commonly zoned, producing variations in anorthite content from core to rim, ranging up to 10 percent. Plagioclase is also considerably less calcic than in rocks from the older units, with an average composition of 54 percent anorthite. Olivine is absent. Pyroxene forms about 25 percent of the rock, with orthopyroxene substantially more abundant than clinopyroxene.



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Average modal analyses from the various units comprising the Owens Mountain gabbroic complex are listed on Table 3.

TABLE 3. AVERAGE MODAL ANALYSES OF OWENS MOUNTAIN INTRUSIVE UNITS.

| Unit | Number of Samples | Plagioclase | Olivine | Orthopyroxene | Clinopyroxene | Amphibole | Opaques |
|---|---|---|---|---|---|---|---|
| Olivine gabbro (Mg-phase) | 6 | 49.7% Range An88-94 Ave = An 92 | 19.4% Range Fo70-85 Ave = Fo80 | 2.9% Range En78-83 Ave = En80 | 17.4% Ave $2V_z$=53° | 10.6% Ave $2V_x$=87° | ---- |
| Olivine gabbro (Fe - phase) | 3 | 51.6% Range An89-93 Ave = An 91 | 16.5% Range Fo65-70 Ave = Fo 68 | 1.1% Range=En70-79 Ave = En 74 | 12.4% Ave $2V_z$=56° | 17.1% Ave $2V_x$=88° | 1.3% |
| Amphibole gabbronorite | 5 | 58.5% Range An88-93 Ave = An 91 | 4.1% | 7.0% Range=En68-79 Ave = En 75 | 9.1% Ave $2V_z$=56° | 19.9% Ave $2V_x$ = 83° | 1.4% |
| Norite | 8 | 65.8% Range An47-57 Ave = An 54 | ---- | 21.7% Range=En53-59 Ave = En 56 | 4.3% | 5.5% Ave $2V_x$=74° | 2.7% |

## CONCLUSION

Voluminous magmatism in the western Sierra Nevada commenced at 130 to 125 million years ago (Saleeby and Sharp, 1980), producing the gabbroic suite and related more felsic differentiates in the Fresno foothills. These melts migrated upward through ophiolitic basement and thus do not show isotopic evidence of sialic participation in their evolution (Mack and others, 1979). Subsequent arc-type magmatism migrated eastward through the Cretaceous Period and produced a number of plutons. These later plutons are representative of the greater part of the Sierra Nevada batholith which rose through the continental lithosphere bounded on the west by ophiolitic basement. Thus, the Cretaceous Period batholith formed across a suture between oceanic and continental lithosphere, and the western batholithic rocks owe their oceanic affinity solely to the nature of their structural position (Saleeby and Sharp, 1980). The western margin of the batholith in effect welded Jurassic and younger ensimatic geosynclinal rocks of the California Great Valley and Coast Ranges to the North American continental plate (Mack and others, 1979).

The observed crystallization sequence of the gabbroids is similar to the liquidus mineralogy of high aluminum basalts for pressures less than 5 kilobars (Kushiro and Thompson, 1972; Walawender and Smith, 1980). Anorthitic plagioclase coexisting with olivine and amphibole indicates that the gabbros were formed from hydrous mafic magmas of presumably strong explosive potential. Holloway and Sykes (1979) state that the presence of amphibole in mafic rocks indicates crystallization from a magma containing 2 to 3 percent weight of water in the melt.

Analogous spatial, temporal, and mineralogical relationships exist between the gabbroids of the western margin of the Sierra Nevada and those of the Peninsular Ranges batholith in southern and Baja California. Plutonic rocks within the Peninsular Ranges batholith range in composition from peridotite to granite, but gabbroic plutons are essentially restricted to a western gabbro sub-belt (Gastil, 1975). Both gabbroic terranes contain the unusual mineral assemblage of amphibole linked with anorthite-rich plagioclase and olivine, an indication that much of the western margin of the North American Cordillera was probably surmounted by an explosive calc-alkaline volcanic chain in Early Cretaceous time.

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## CALIFORNIA GEOLOGY

## TRIVIA

1. What is a miner's inch?
2. Where and when did hydraulic gold mining begin in California?
3. What was the largest land mammal ever to have walked the earth?

### ANSWERS

1. A miner's inch was a unit of measurement used in California around 1900 for measuring water flow in hydraulic mining. In California a miner's inch is a stream of water capable of discharging 1 cubic foot per second or 60 cubic feet of water per minute.
2. Hydraulic mining began at American Hill just north of Nevada City, Nevada County and at Yankee Jims, Placer County in 1852.
3. *Indrichotherium* (formerly *Baluchitherium*), a member of the titanotheres group, was an Oligocene giant which belonged to the rhinoceros family. It stood about 18 feet at the shoulder. This is the height at the top of the head of a good-sized modern giraffe.



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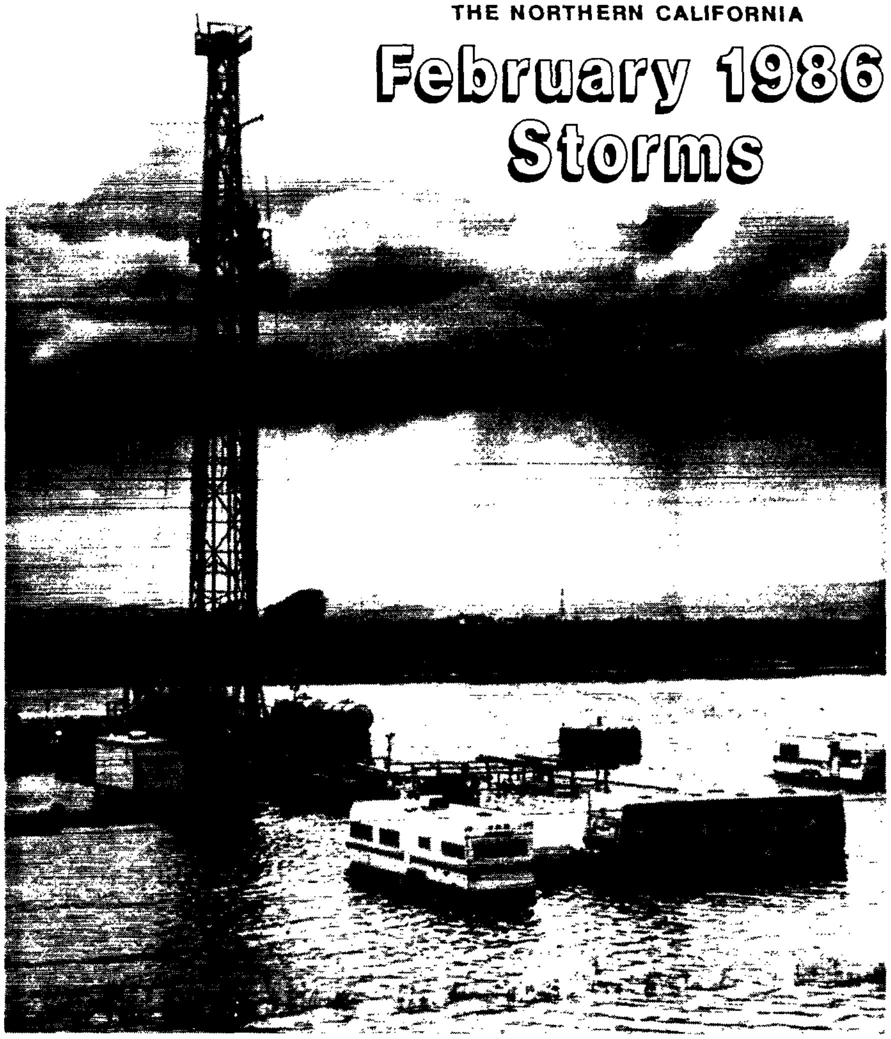
THE NORTHERN CALIFORNIA

# February 1986 Storms



Atlantic rig # 12, Liberty Island, on the deep water channel, Sacramento River. Drilling crews on the rig were drilling a gas well for Amerada Hess Corporation in the Liberty Island Gas Field, about 20 miles southwest of Sacramento, when periods of heavy rainfall in February 1986 caused serious flooding here and throughout northern California. In this instance, drilling had to be abandoned until flood waters subsided. *Photo by Mike Cummings, courtesy of the Division of Oil and Gas.*

Record amounts of rain fell in central California and the southern portion of northern California from February 11 to February 21, 1986. Serious flooding resulted. The rains were caused by a succession of warm subtropical storms that formed in the Pacific Ocean near Hawaii and were reinforced by a jet stream of over 200 miles per hour. The first storms began on Tuesday, February 11, and the last showers fell on Friday, February 21.

The 10-day storm period peaked on February 16 and 17. For about 36 hours beginning on Sunday afternoon, February 16, nearly continuous heavy rain fell throughout northern California. During this 36 hour period up to 27 inches fell in the region north of the San Francisco Bay and in the northern and central Sierra Nevada. The high snowfall in the Sierra Nevada was as much as 17 feet and warm temperatures of the rains raised the snow levels to 7,500 feet, which greatly increased the rate of runoff in the foothills during the 10-day storm period.

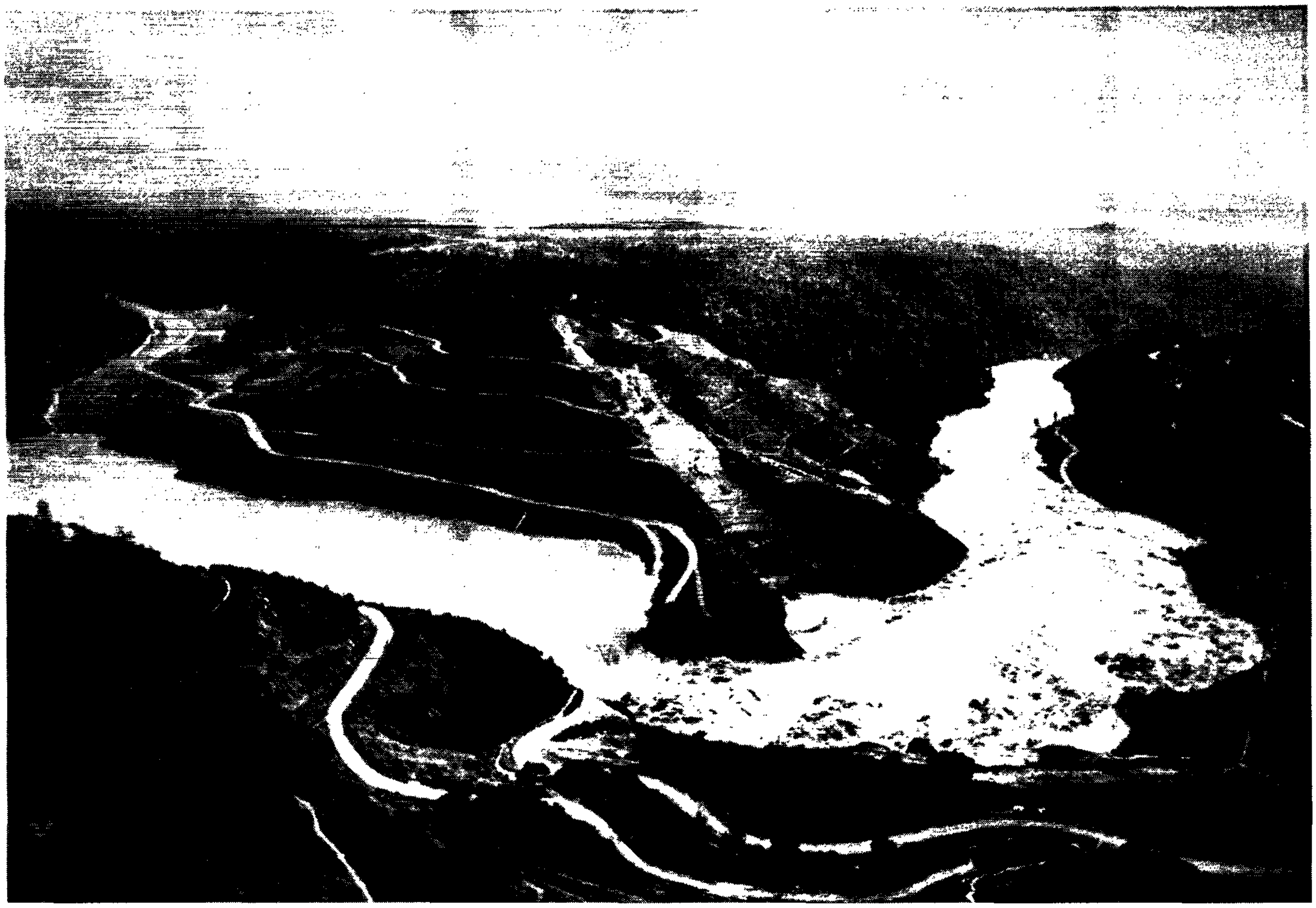
The greatest orographic effect of moisture-laden air encountering the Sierra Nevada was in the Feather River Basin between 5,000 and 6,000 feet. The town of Bucks Lake, located 35 miles east of Chico in the Feather River Basin, recorded a 10-day storm total of 55.72 inches, the most rain recorded from the storm.

The 10-day storm period totaled over 50 percent of the average annual precipitation at many locations impacted by the storms.

## HIGHLIGHTS OF FEBRUARY 1986 STORMS

- Many areas received over half of their normal annual precipitation during the 10-day storm which ended on February 21. Bucks Lake in the Feather River Basin received 4.6 feet of rainfall during the 10 days.
- All time record stream flows were measured on the Russian, Napa, lower Sacramento, American, Cosumnes, and Mokelumne rivers. The Russian River at Guerneville rose 17 feet above flood stage.
- On February 20, the Sacramento River system moved 1.3 million acre feet of water past the latitude of Sacramento, the greatest volume ever measured. That amount could fill an empty Folsom Lake in less than 19 hours.
- Folsom, Black Butte, Pardee, and Camanche reservoirs were filled completely and became surcharged, storing more water than their designed capacity.
- The tide stage at Rio Vista Bridge rose to 12.5 feet, 1.7 feet higher than previously recorded. The daily low tide remained above 11 feet for almost two days.
- 30,000 acres flooded in the Sacramento-San Joaquin Delta.
- On February 20, a Yuba River levee broke flooding nearly 10,000 acres, jeopardizing 26,000 people.
- 1,000 California Conservation Corps and California Department of Forestry floodfighters as well as hundreds of Department of Water Resources and Reclamation District workers were needed to patch and patrol 3,000 miles of threatened levees.
- The U.S. Corps of Engineers engaged in major floodfights to prevent levee failures in the Sutter Bypass and Andrus Island. They also closed the Mokelumne River levee breach which flooded Thornton and the Yuba River breach which flooded West Linda.
- Major highway systems were closed from flooding, slides, and snowfall in an unprecedented scale.
- Twenty-eight California counties were declared Disaster Areas or approved for Disaster Assistance.

. . . . . . .

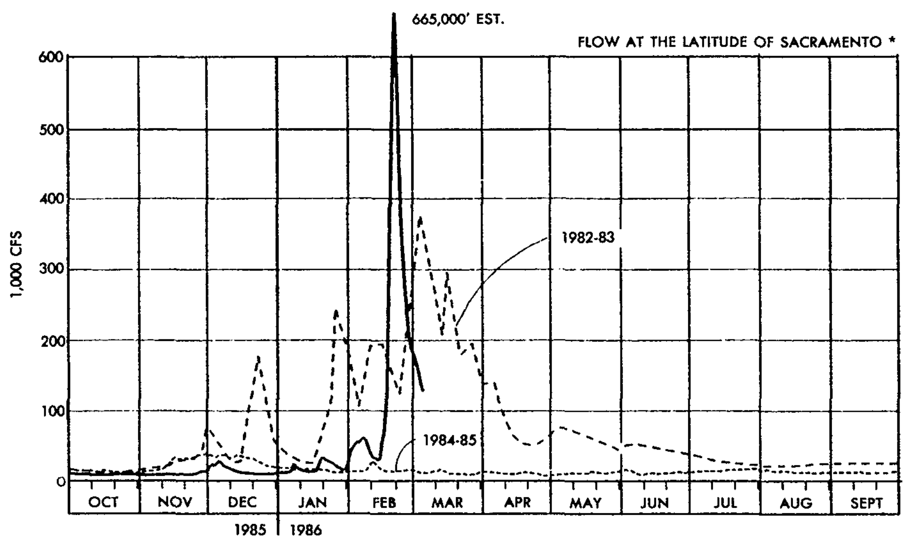


On February 18, 1986 this cofferdam near Auburn burst. A torrent of water sped down the American River into Folsom Lake. The February 1986 flooding caused loss of life and serious damage throughout northern California. Eleven people died and 67 had flood related injuries. Estimated total damages amounted to $374 million dollars. Nearly 50,000 people became temporarily homeless; 1,379 homes were lost and another 12,137 homes were damaged. Flooding caused massive destruction to agricultural equipment, crops, livestock, and commercial businesses; 185 businesses were lost and another 855 were damaged. *Photo by Morgan Ong, courtesy of The Sacramento Bee.*

- Peak inflows to the flood control reservoirs above Sacramento (Shasta, Black Butte, Oroville, Bullards Bar, and Folsom), totaled 789,000 cubic feet per second (cfs). The maximum releases from these reservoirs totaled 425,000 cfs. Without these flood control reservoirs, about one million cfs would have been directed at Sacramento and into a levee and bypass system designed to contain 590,000 cfs. Massive flooding would have resulted.

*....Department of Water Resources releases.*

SACRAMENTO RIVER HYDROGRAPH




* The river flow at "Latitude of Sacramento" is the sum of the mean daily flows in the Sacramento River and the Yolo Bypass

On February 20, 1986, 665,000 cubic feet of water per second surged through the Sacramento River and Yolo Bypass near Sacramento—the highest recorded flow rate at this area. The high tide stage near Rio Vista on February 20 was recorded to be 12.4 feet, it exceeded the previous record of 10.8 feet.



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A PHOTOGRAPHIC ESSAY

# 1985 MIDSUMMER VIEW OF THE MOUNT DANA AREA

Mono County, California

By

ERNEST S. CARTER, Photographer
Mountain View, California

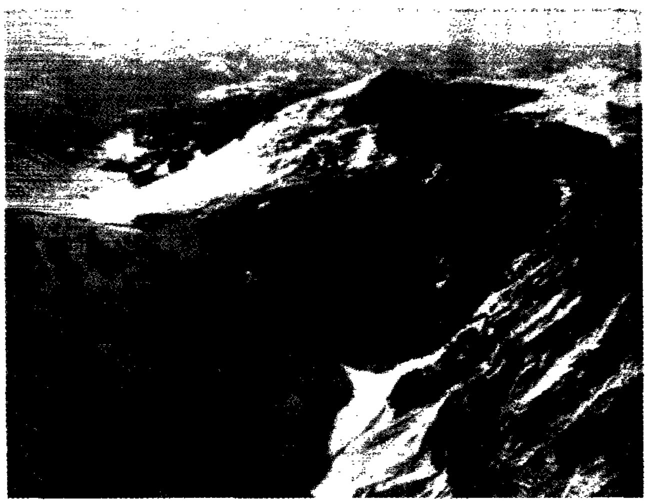
*Photos by Ernest S. Carter.*

Mount Dana was named in 1863 by J.D. Whitney, W.H. Brewer, and Charles F. Hoffman, members of the California State Geological Survey in honor of James Dwight Dana, professor of geology at Yale University. Dana was considered to be the most eminent American geologist of that time. Dana Glacier is near the mountain summit. *...editor*

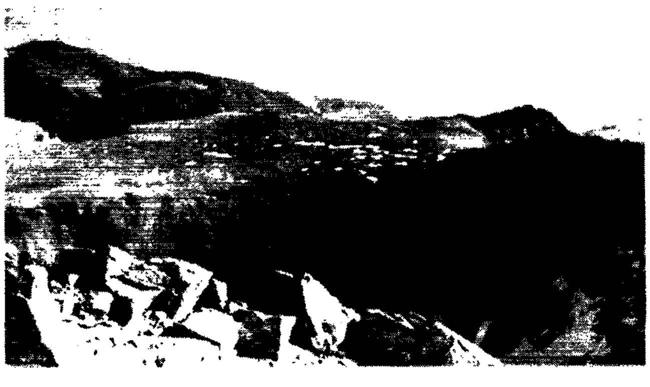
The Tioga Pass area (9,941 feet) and Tuolumne Meadows above Yosemite Valley are well known for spectacular vistas. Mount Dana is a high peak on the eastern Sierra Nevada crest south of Highway 120. During the summer of 1985 Dana Glacier on Mount Dana retreated and the snow fields were reduced to mere patches. All of the snow fields on the summit melted. Viewing the surrounding mountains from Mount Dana (13,058 feet above sea level), it was apparent that most of the snow fields on Mount Conness and Mount Lyell also lacked snow cover in late June 1985.

In Owens Valley to the east, the band of shoreline seen around Mono Lake has widened due to evaporation of water and the low inflow.

Dana Glacier and cirque wall, June 1985. The narrow ice shoot on the right is all that remains of the glacier connection to the plateau and east ridge. The glacier is retreating from the ridge. The three ice patches on the cirque wall were part of the upper glacier five years ago. Mono Lake can be seen in the distance in the valley.



Mount Dana as it looked in the early 1960s



View from the summit of Mount Dana (13,058 feet) across the Dana plateau toward Mono Lake, June 1985. The shoreline of Mono Lake is wider and the dry land area of the islands has increased.

# BOOK REVIEWS

Books reviewed in this section are on file in the DMG library, 367 Civic Drive, Pleasant Hill. The books are NOT available for purchase from DMG.

## Australian Quarterly Journal

BMR JOURNAL OF AUSTRALIAN GEOLOGY & GEOPHYSICS. I.M. Hodgson, Editor. Quarterly journal. Available from Australian Government Publishing Service, GPO Box 84, Canberra, A.C.T. 2601, Australia. $27 (Australian), annual subscription; individual issues, $8.60.

The BMR Journal of Australian Geology & Geophysics, published quarterly, presents papers on research and related activities. Contributions are from officers of the Bureau of Mineral Resources (BMR), from BMR officers working in collaboration with others, or requested work sponsored by the BMR. The Journal also includes short notes and discussion of papers published in it.

The March 1984 issue contained seven papers, including articles on the age of diamond-bearing pipes of the West Kimberley region, peralkaline intrusives of the Alligator Rivers region, and petrology and geochemistry of Proterozoic dolerites from the Mount Isa Inlier in northwest Queensland.

## Correlation Studies

QUANTITATIVE STRATIGRAPHIC CORRELATION. Edited by J.M. Cubitt and R.A. Reyment. 1982. A Wiley-Interscience Publication: a division of John Wiley & Sons, 605 Third Avenue, New York, NY 10016. 301 p.

This collection of 15 papers (by 22 researchers) reviews the current state-of-the-art of quantitative stratigraphic correlation. Until recently correlation in stratigraphy has been made on qualitative rather than quantitative grounds. New insights in statistical theory and evolution have made it possible to solve old problems, such as the correlation of offshore sedimentary sequences. This is the first book to give a thorough presentation of quantitative methods in stratigraphical correlation.

The book is divided into three main sections. The first section deals with theoretical aspects of qualitative stratigraphy, including the mathematical formalization of stratigraphic terms. The next section concentrates on biostratigraphy and the third section is on lithostratigraphy.

Most of the papers in this work were presented at the International Geological Congress in July 1980, as part of the International Geological Correlation Programme, Project 148. The collection will be of interest to stratigraphers, paleontologists, petroleum geologists, coal explorationists, and scientists in related professions.

## Disaster Planning

SAN FRANCISCO CORPORATE DISASTER PLANNING GUIDE. Second Edition. Prepared by Business, Government, and Red Cross Disaster Committee. 1986. Red Cross Resource Center, Golden Gate Chapter, American Red Cross, 1550 Sutter Street, San Francisco, CA 94109. 118 p. $20.00, loose-leaf, binder format.

A recurrence of a magnitude 8.3 earthquake in the San Francisco Bay area, according to earth scientists, would block the freeways to the south, make the bridges to the north and east inaccessible, and therefore isolate San Francisco. If the earthquake occurred during working hours, it would create special problems for the 360,000 workers who commute into San Francisco every day and make it virtually impossible for them to return home.

In the late 1970s, corporations and industries in San Francisco began to consider their responsibilities to employees, both in preparing them for disaster hazards and in providing for their well-being following a catastrophe. The American Red Cross and the Mayor's Office of Emergency Services received many requests for assistance in the development of disaster plans. These agencies cosponsored the development of a comprehensive program with the assistance of representatives from corporations, businesses, and industries that had formulated plans.

The participants produced this disaster planning guide, designed to assist corporate executives in developing plans for corporate preparedness and survival in a major disaster.

The planning guide gives step by step procedures in the planning process, suggested plan structure, flow-chart for emergency preparedness activity, checklists, and many other suggestions to be tailored to specific company situations—all oriented toward the basic concept that planning is the "key to earthquake safety and survival". Reference materials and training films are available through the Business Disaster Resource Center, Golden Gate Chapter, American Red Cross.

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______SP86 Foothills mining handbook. 1985 (new) ........ $4.00

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## Field Trip Guide

GUIDEBOOK TO THE NORTHERN SIERRA NEVADA & RENO-LAKE TAHOE AREAS. By R.A. Schweickert and J.R. Firby. 1985. Prepared for National Association of Geology Teachers Far Western Section, Fall Conference, Mackay School of Mines, University of Nevada, Reno. 51 p. $5.00. Available from Robert M. Norris, Historian FWS-NAGT, Department of Geological Sciences, University of California, Santa Barbara, California 93106. Make checks payable to Historian, FWS-NAGT.

One field trip by R.A. Schweickert gives a broad overview of Sierra Nevada geology through five stops in close proximity to U.S. Interstate 80, west of Reno. The westward route encounters Cenozoic volcanic features (3 to 15 million years old) and Pleistocene glacial features—the more youthful aspects of Sierra Nevada history.

The route continues through Cretaceous plutons (about 100 million years old) and Jurassic metavolcanics (200 million years old) to older rocks of the Paleozoic Era (460 million years old). These rocks contain the history of tectonic plate movement along the ancestral western edge of California.

The second field trip by J.R. Firby includes geologic features where teachers can take photographs to illustrate class lectures. The route covers the Lake Tahoe area and an area south of Reno between Highway 80 and 50. Features of interest for photographs include grabens, horst blocks, fault scarps, sag ponds, geothermal sites, and glacial features.

## Fossil Collecting

FOSSILS: HOW TO FIND AND IDENTIFY OVER 300 GENERA. By Richard Moody. 1986. Collier Books, Macmillan Publishing Company, 866 Third Avenue, New York, NY 10022. 192 p. $8.95, paper cover.

This guide is designed for field use and home study. It is illustrated with over 60 color plates, line drawings, and charts. The book includes step by step instructions for collecting and identifying fossils. Each entry is illustrated in color and is cross-referenced to an identification key that allows each fossil to be classified. Accompanying each illustration is a physical description of the fossil, its geological time period, and where it has been found.

An introduction to the science of paleontology is included and explains how fossils are formed and the techniques used in their collection and preservation. This well illustrated book is a practical guide for amateurs as well as more experienced collectors.

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## Resources

ANNUAL REVIEW OF ENERGY, volume 10. Edited by Jack M. Hollander, Harvey Brooks, and David Sternlight. 1985. Annual Reviews, Inc., 4139 El Camino Way, Palo Alto, CA 94306. 711 p. $56.00, USA; $59.00 elsewhere (prepayment required). Hard cover.

This volume contains 21 articles that review the most important recent research projects in the technology, economics, and politics of energy resources, both national and international.

The collection includes discussions of solar energy, (new materials, measured performance), natural gas and petroleum (exploration, use, future supplies), nuclear power plant problems, ethanol fuel (used in Brazil), and renewable fuels (those used in developing countries).

Other contributions describe the management and policy aspects of the Strategic Petroleum Reserve, and the complexities involved in long-range international energy research and development cooperation.

EARTH RESOURCES, Third Edition. By Brian J. Skinner. 1986. Prentice-Hall, Inc., Englewood Cliffs, NJ 07632. 184 p. $15.95, paper cover.

The kinds of resources, the distribution, the quantities, the amounts used, and man's dependence on them are among the topics covered in this book. Most of the resources discussed are nonrenewable mineral resources. Some renewable resources, such as hydroelectric power, solar energy, and water supplies, are also discussed because their use is similar to, and closely allied with, the use of mineral resources.

Mineral resources have become essential ingredients for life—the "...building blocks of society." But are they sufficient to sustain a healthy future, and are they sufficiently accessible to allow easy exploitation? Empires have flourished because they controlled rich and easily exploited mineral resources, but they withered as those riches declined. Are the world's remaining resources so distributed that the historical pattern of power dependence on resource availability is a thing of the past, or is it still the key to the future?

Such controversial questions are raised in this book. All the answers are not found here, but the book does provide the groundwork for discussion concerning future occupancy of the earth.

# DMG RELEASE

SPECIAL PUBLICATION 86

FOOTHILL COUNTIES MINING HANDBOOK. By the Sierra Economic Development District and the Sierra Planning Organization Mining Task Force. 1986. 106 p. $4.00.

The FOOTHILL COUNTIES MINING HANDBOOK (Special Publication 86) is a reference and educational source book for local governments, communities, and the general public. It is primarily designed to provide assistance in resolving controversial mining issues in four Sierra Nevada foothill counties: Nevada, Placer, El Dorado, and Sierra counties.

The current mining controversy in these four counties concerns the mining operators and the neighboring landowners, residents, and local governments. During the 1800s and early 1900s little attention was given to the environmental impacts of mining in these counties. These past mining practices are not allowed today and environmental concerns must be addressed throughout the mining process from the planning stages to the reclamation phase. Since the 1940s the Sierra Nevada foothills have experienced an influx of people from urban areas of the state. The livelihoods of these people did not directly involve mining and the recent resurgence of large-scale mining in their communities is currently viewed with aversion.

In response to public concern, in November 1984, the voters of El Dorado County passed Measure A, which imposes severe restriction on mining operations in the county. Measure A requires open-pit and strip mine operators to establish a 10,000 foot (1.89 mile) buffer zone around a mine site. Mining companies affected by this measure feel it is far too restrictive.

The consumption of mineral resources continues to increase and the development of new mineral deposits is necessary to support the growth and well-being of the economy. Mining cannot be accomplished without affecting some aspect of the local environment. The development of mineral resources and the associated environmental concerns can be at least partially resolved by careful prior planning. Undoubtedly a thorough approach to mining is required to resolve the various issues.

The handbook presents a concise and educational overview of the mining process from exploration to extraction and reclamation. It describes the permitting process, briefly outlines laws and regulations governing mining, and describes procedures designed to protect the environment and communities impacted by mining operations. The appendices include technical information on various mining activities as well as a reference list of governmental agencies that oversee the mining industry in California.

The FOOTHILL COUNTIES MINING HANDBOOK is designed as a reference and educational source book to provide assistance in resolving the controversial mining issues in the Sierra Nevada foothills. This handbook can be a valuable source book to address similar mining issues in other areas of the state as well.

## GLOSSARY OF MINING TERMS

ADIT: A horizontal or nearly horizontal underground passage coming to the surface at one end.

BENCH: The surface of an excavated area at some point between the material being mined and the original surface of the ground, on which equipment can move or operate.

DECLINE: A low dipping inclined shaft, developed downward, giving access to, and serving the various levels of a mine. In modern times, a frequently used method of access for mobile diesel equipment.

DEWATERING: The process of pumping accumulated water from mine pits, shafts, and tunnels.

DRIFT: A horizontal or near-horizontal opening, lying in or near the orebody, parallel or nearly parallel to its strike.

FLOOR: (1) The bottom or lowermost horizontal, or near horizontal, surface of a mine or mineral deposit. (2) The bottom surface of an underground excavation.

FOOTWALL: Ore limit or wall rock on the lower side of a dipping orebody. Known as a FLOOR in bedded deposits.

GANGUE: Undesired minerals, mostly nonmetallic, associated with ore.

HANGING WALL: Ore limit or wall-rock on the upper side of a dipping orebody. Known as a ROOF in bedded deposits.

LODE: A veinlike deposit, usually metalliferous. See VEIN.

MINING DEBRIS: Tailings from hydraulic mines. Specifically, the sand, gravel, and cobbles which pass through the sluices in hydraulic (placer) mining.

OPEN PIT: A general term for a mine working or excavation open to the surface.

ORE: A metalliferous mineral, or an aggregate of metalliferous minerals, more or less mixed with gangue, which, from the standpoint of a miner, can be mined at a profit, or, from the standpoint of a metallurgist, can be treated at a profit.

PLACER DEPOSIT: A mass of gravel, sand, or similar material resulting from erosion of solid rocks, and containing particles of gold, platinum, tin, or other valuable minerals.

PORTAL: The surface entrance to a drift, tunnel, adit, or decline.

RAISE: A shaft or winze excavated upward, as for connecting adjacent levels. Terms WINZE and RAISE are used interchangeably to describe a completed opening.

RAMP: An inclined underground opening, usually driven downwards, connecting levels or production areas, with inclination allowing passage of motorized vehicles.

SHAFT: A vertical or steeply inclined opening, giving access to and serving the various levels of a mine. An inside or interior shaft is one which does not open to the surface.

STOPE: An underground excavation resulting from actual mining of ore, as distinguished from other excavations in ore such as drifts, crosscuts, raises, or winzes. The verb "to stope" is used loosely, but usually denotes the general plan and work of breaking ground in stopes.

STRIP MINE: Also known as an open-pit or surface mine. Strip mining is employed when the ore lies close to the surface.

SUBLEVEL: A system of horizontal underground workings, normally within stoping areas only, required for ore production.

TAILINGS: The gangue and other refuse material resulting from the washing, concentration, or treatment of ground ore.

VEIN: A tabular shaped deposit of non-sedimentary origin, usually dipping at high angles. See LODE.

WINZE: An opening like a small shaft, sunk from an interior point in the mine . . . . . . . .

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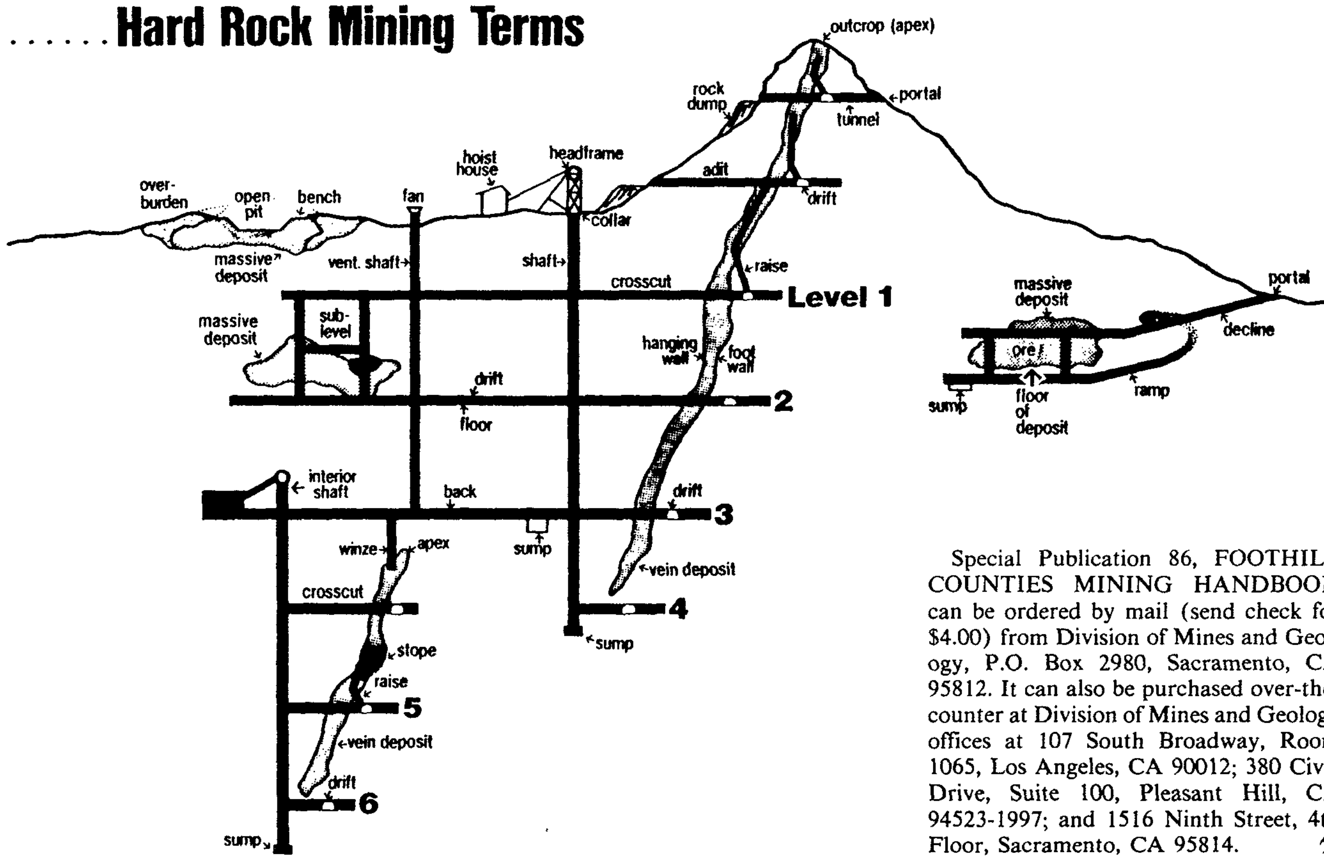
# .......Hard Rock Mining Terms

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