CALIFORNIA GEOLOGY

July 1986

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Singing and Booming Sand Dunes

Understanding California's Geology - Our Resources - Our Hazards

GORDON K. VAN VLECK, Secretary
THE RESOURCES AGENCY

GEORGE DEUKMEJIAN, Governor
STATE OF CALIFORNIA

RANDALL M. WARD, Director
DEPARTMENT OF CONSERVATION

CALIFORNIA GEOLOGY

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In This Issue

Cover photo: The Death Valley sand dunes are a popular tourist attraction and have provided the desert setting for several motion pictures. Some sand dunes in California and Nevada have the unusual feature of producing sound. These dunes are described as barking, booming, or singing dunes and produce low-pitched noises when the sand is disturbed. An article describing the curious acoustical phenomenon of the sand dunes begins on page 147.

AEG CONFERENCE

The Association of Engineering Geologists will hold its 29th annual meeting in San Francisco, California on October 5-9, 1986. The theme of the meeting is "Better Living Through Engineering Geology". The technical program will include symposiums on landslides (investigation and mitigation), and ground water contamination. Technical short courses and field trips will be included in the activities.

For more information contact: Alan D. Tryhorn, Chairman, GeoResource Consultants, Inc., 851 Harrison Street, San Francisco, CA 94107 (415) 777-3177. ⚒

REGISTRATION EXAMINATIONS

State Board of Registration for Geologists and Geophysicists examinations are scheduled as follows:

Geologist and Geophysicist:
November 14, 1986

Engineering Geologist:
November 15, 1986

Final filing date for November examinations is August 15, 1986

For application forms contact Board office, 1021 O Street, Room A-190, Sacramento, CA 95814. Phone (916) 445-1920. ⚒

Singing and Booming Sand Dunes of California and Nevada

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HISTORICAL BACKGROUND

A characteristic of some desert dune sands is an ability to emit acoustical energy when disturbed. This phenomenon has been reported from the Middle East for more than 1500 years and in Chinese literature from as early as the ninth century (Stein, 1912). Many people are familiar with the squeaking sounds typically produced when one walks across wetted beach sands. However, sounds produced by desert sand dunes have been variously described as roaring, booming, squeaking, singing, and musical. For the latter description, the results have been compared to such musical instruments as a kettle drum, zither, tambourine, bass violin, and a trumpet (Curzon, 1923). Other more recent observations liken the sounds to a foghorn or low-flying, propellor-driven aircraft (Humphries, 1966).

The production of sound in desert dunes is not as common as the squeaking of beach sands. In 1976 it was reported that only 27 areas in the world were known to exhibit the booming sound phenomenon and only three sites in the United States were known to produce booming or barking sounds: (1) Kelso Dunes, California; (2) Sand Mountain, Nevada; and (3) Barking Sands at Mana, Kauai, Hawaiian Islands (Lindsay and others, 1976).

Sand Mountain, Nevada.

Subsequently, four additional sites in California and Nevada that exhibit the booming sounds in the field have been identified (Melhorn and Trexler, 1977 and Haff, 1979). These sites are Eureka Dunes and Panamint Dunes in California and Crescent Dunes and Big Dune in Nevada (Figure 1).

Factors Necessary for Sound Production

All sound-producing desert dune sands are medium grained, and very well sorted to well sorted, but so are many non-musical desert sands (Figure 2). The sand must be dry, because as little as 0.1% moisture makes a marked difference in sound producing capability, and 1% moisture permits only feeble sound production (Fairbridge, 1968).

Another factor which affects the ability of sands of the proper size to produce audible acoustic energy is contamination by fine-grained material such as dust or chalk powder. Probably one of the most significant controls discovered (Lindsay, 1976) is that sound producing sand grains are highly spherical, moderately well-rounded, and have highly polished (frosted) surfaces. The smoothness of a grain surface can, however, be discerned by electron microscopy, and thus infers that variability of surface roughness is important at the micron scale.

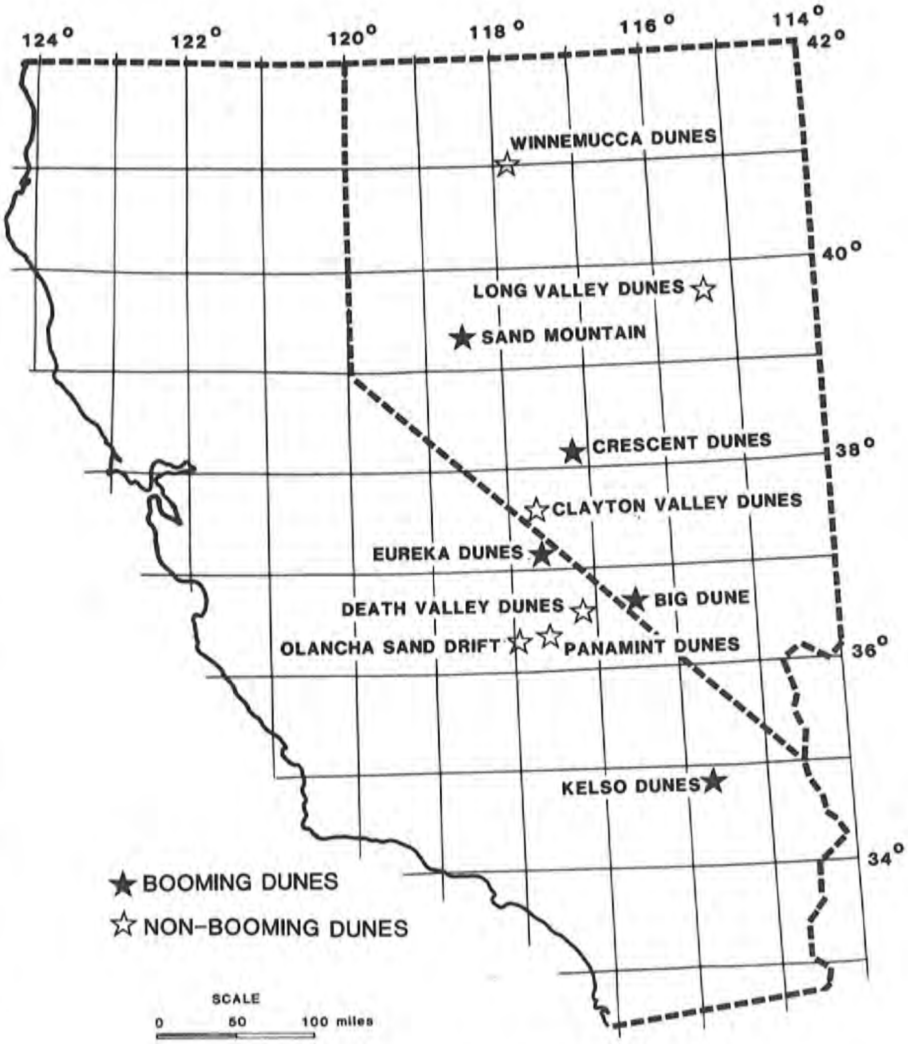

Figure 1. Location map of sand dunes described in this report.

The relative rarity of booming desert sands throughout the world indicates that they form or exist under special and limited conditions. Probably the foremost requirement for the production of sound by desert sands is an ability for the wind, through reworking of sand grains over long reaches of transport (multiple generations of sand movement), to produce well-rounded, extremely smooth, frosted sand grains.

Kelso Dunes, California.

Sound Production

Until recently the mechanism which produces the audible sounds was only conjecture. An early hypothesis (Bagnold, 1954) suggested that the sound is produced by a piezo-electric effect—the production of electrical currents by quartz grains under mechanical stress. More recently it has been shown that a booming sound is produced by the internal shearing of sand grains during avalanche down a dune slope (Bagnold, 1966). The overriding of superjacent layers of sand grains provides the energy of sound production. Bagnold's theory was

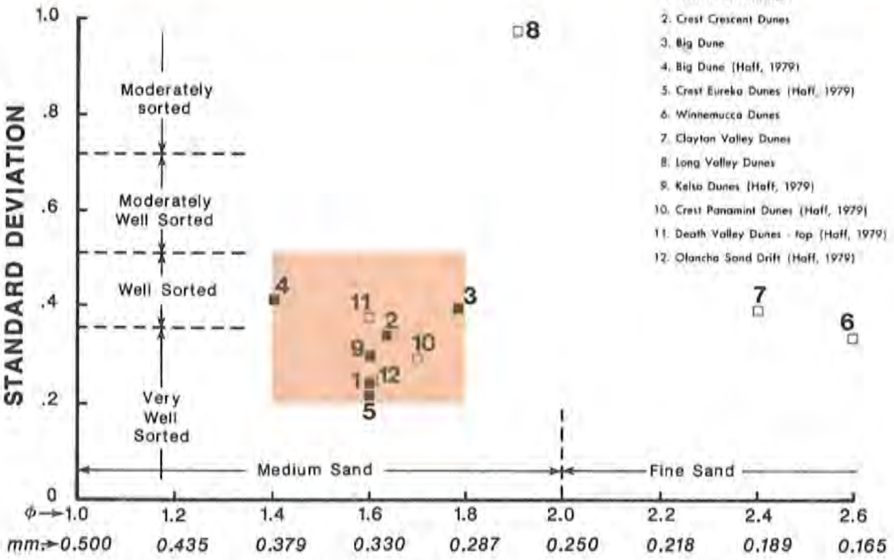

Figure 2. Inclusive graphic mean grain size versus inclusive standard deviation for some California and Nevada sand dunes showing region in which booming sounds would be expected. Size classification after Udden-Wentworth. Solid symbols ■ indicate booming sound in field, open symbols ☐ indicate no sounds. Shaded area indicates grain size and degree of sorting where acoustic phenomena should occur.

discounted in part by Lindsay and others (1976) who state, "that two independent mechanisms must be at work...squeaking sand suggests a simple mechanical explanation of sound production...in both wet and dry sand. Sound production of booming sand appears to be related to mechanical coupling between grains". Whatever internal mechanisms exist, if sand of an appropriate grain-size and smoothness is naturally or artificially put into motion, sound will emanate and will in some instances provide an observer with vibrations which can be felt through the body.

Characteristics of the Acoustic and Seismic Signals

The sound produced by desert dunes initially has only a single frequency, but after two or three seconds a much lower beat frequency is established. The vibration within the sand is enhanced at the aural sensation level as the low frequency wave components intensify by reinforcement. Lindsay (1976) measured the acoustic and seismic energy emitted from Sand Mountain, Nevada, and determined that booming sand produces seismic signals composed of one or more narrow frequency peaks limited to the 50 to 80 Hz (cycles per second) range, as well as appreciable broad-band output below 20 Hz. Acoustic emissions overlay, but are broader than, the seismic peaks in the 50 to 80 Hz range. First-order harmonic peaks also occur between 100 and 180 Hz.

A recording of the sound produced from Kelso Dunes in California (Figure 3) was analyzed into Fourier coefficients (Haff, 1979). The peak energy output is at 92.8 Hz, and has a full width at half maximum of approximately 4 Hz.

Acoustic emissions from Crescent Dunes (Nevada) in July 1976 were so loud and realistic that the authors' field assistant was searching the skies for a turboprop aircraft. A recording was made recently at Sand Mountain which, after the first several seconds of sound emission, can best be characterized as resembling the flight sound of a B-29 aircraft.

LOCATION AND SITE CHARACTERISTICS OF BOOMING DUNES

Kelso Dunes, California

Kelso Dunes are located in the Devil's Playground area, 28 miles (45 km) south of Baker, California (Flynn and Kerens 15-minute quadrangles, Lat. 34°48'N, Long. 115°43'W) near Kelso along the Union Pacific Railroad tracks. The dunes are accessible by a well-graded gravel road (Kelbaker Road) which connects Interstate 15 with Interstate 40 on the south.

The highest part of the dune area is 656 feet (200 m) above the surrounding terrain. Acoustical events were generated on the highest dune. Haff (1979) reports that "the most spectacular and enduring vibrations were produced by the movement of large quantities of sand. This could be initiated by vigorous kicking at the sharp dune crest in order to dislodge a metastable surface layer on the lee slopes". The frequency spectra of such an event are presented in Figure 3.

Sharp (1966) has shown that sand which has traveled farthest in any dune field should provide the best sand for

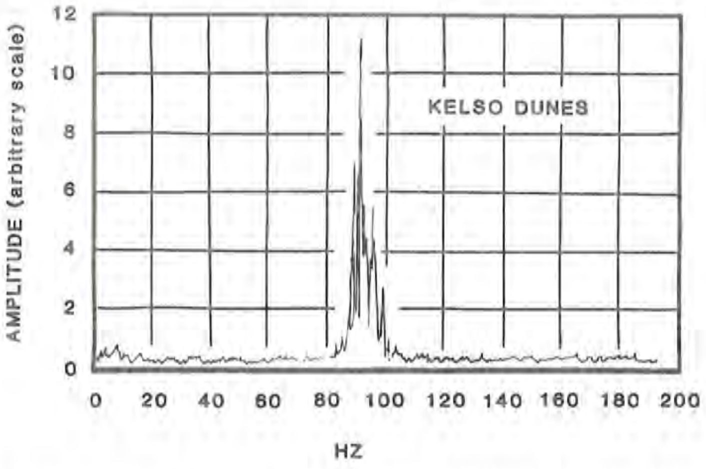

Figure 3. Fourier components of induced booming event at Kelso Dunes near Baker, California (from Haff, 1979).

Eureka Dunes, California. *Photo by R. Rust.*

sound production. Sand at the Kelso Dunes traveled 35 miles (56 km) from the delta area of the Mojave River where it emptied into the Pleistocene lake basin now occupied by Soda Dry Lake east of Afton Canyon, the terminus of the Mojave River.

The sample collected by Haff (1979) from the Kelso Dunes was a medium-grained sand (1.6 ϕ, 0.33 mm) and was very well-sorted.

Eureka Dunes, California

Eureka Dunes are located in Eureka Valley, north of Death Valley, along the western edge of the Last Chance Range (Last Chance 15-minute quadrangle, Lat. 37°6′N, Long. 117°40′W). The dune is accessible via a sign-marked dirt road leading off the main Eureka Valley road.

Eureka Dunes form a singularly massive dune complex, without a large present-day sand supply area. It reaches an elevation of 680 feet (207 m), is 3.3 miles (5.3 km) long, 1.5 miles (2.4 km) wide (anonymous, 1984), and is undoubtedly the highest dune in California. In 1984, the dune area was designated a National Natural Landmark by the U.S. Department of the Interior.

Sand collected by Haff (1979) at this dune was medium-grained (1.6 ϕ, 0.33 mm) and very well-sorted. Haff reports that the dune "demonstrated all the booming properties observed at Kelso Dunes, although the acoustic intensity did not appear to be as great".

Panamint Dunes, California

This dune complex is located at the north end of Panamint Valley (Panamint Butte 15-minute quadrangle, Lat. 36°28′N, Long. 117°27′W). The dunes are accessible by an indistinct dirt road leading north from California Route 190. These dunes are considerably lower than Kelso Dunes and occupy a rather small area (Haff, 1979). Abundant vegetation covers the southern portion of the dune complex.

The dune crests exhibit moderate acoustic activity. Sand avalanches were easily initiated on the steepest slopes. No significant booming sounds were apparent. Forced displacement initiated by walking on steep leeward slopes or by moving one's hands through the sand did elicit audible vibrations.

Sand Mountain, Nevada

Sand Mountain is a terminal, seif dune complex located at the margin of Four Mile Flat playa approximately 3 miles (5 km) east of U.S. Highway 50, 18 miles (25 km) southeast of Fallon, Nevada (Four Mile Flat 7½-minute quadrangle, Lat. 39°19′N, Long. 118°24′W). Some of the sand forming the dune at Sand Mountain has traveled more than 36 miles (40 km) northeastward from the source area in Campbell Valley, the delta of the Walker River where it was debouched (transported by streams) into ancient Lake Lahontan more than 20,000 years ago. The dune is nearly 400 feet higher than the surrounding terrain, and is 4 miles (6 km) long and more than 1 mile (1.6 km) wide.

Criswell and others (1975) and Lindsay and others (1976) investigated the acoustic and seismic signals of the dune in 1973. During our initial visit to the dune in 1975, we were unable to elicit the booming sounds described previously by other investigators, although local inhabitants of the area assured us that the booming sounds were very prevalent (Margaret Wheat, personal communication, 1975). The sand appeared to be dry. However, as already mentioned, less than 0.1 percent moisture can adversely affect the ability of the sand to produce sound.

In August of 1985, booming sounds were produced at Sand Mountain by initiating an avalanche by moving down the lee slope of the dune. The sound at first was a basal beat frequency, but after several seconds the sound resembled the overflight of a squadron of propellor-driven aircraft.

Crescent Dunes, Nevada

This dune complex is in western Nye County on the east side of Big Smoky Valley, approximately 10 miles (16 km) northeast of Tonopah (Lone Mountain, Nevada, 15-minute quadrangle). The area of active dunes is easily accessible by car over well-maintained roads. From Tonopah, one proceeds west on U.S. Highway 50 and 95 approximately 2.1 miles (3.3 km) to a paved county road to Anaconda's Molybdenum mine; turn right (north) and go 10 miles (16 km). The dune is visible on the right and a sign denotes the turn off.

The dunes rise only 230 feet (70 m) above the surrounding terrain. The sand which currently comprises these dunes at the western toe slope of the San Antonio Mountains has been derived by deflation from the now dry bed of prehistoric Lake Tonopah, which occupied the lowest portions of southern Big Smoky Valley during the late Pleistocene. The sand at the dune crest has a mean grain-size of 1.63ϕ (0.32 mm) and is very well-sorted. A sample analyzed under a microscope contained 80 percent quartz, 15 percent

Winnemucca Dunes, Nevada.

accessory minerals, and 5 percent rock fragments. Approximately one-half of the sample is comprised of grains with a well-rounded appearance, and one-quarter of these grains are frosted. The remaining 50 percent of the grains are subrounded to subangular.

The highest dune in the Crescent Dunes complex provided the best acoustic characteristics of all dunes visited by the authors. The sounds produced by this dune may not be as sonorous as one might expect, but were easily produced on two occasions during the summer months of 1975 and 1977. The sounds that have been produced resemble that of a low-flying turboprop aircraft.

Big Dune, Nevada

Big Dune is located in the Amargosa Desert, 10 miles (16 km) south of the town of Beatty in southeastern Nevada, 5.5 miles (9 km) northeast of the California-Nevada state line (Big Dune 15-minute quadrangle, Lat. 36°30'N, Long. 116°35'W). The dune area is easily accessible by paved and dirt roads. Turn off U.S. Highway 95 at the Amargosa Farm area sign approximately 10 miles (16 km) south of Beatty, and proceed approximately 2.5 miles (4 km) to the turn-off (dirt road) into the dune area.

Big Dune has been misnamed. The elevation of the dune crest above surrounding terrain is approximately 300 feet, which is considerably lower than Sand Mountain, Nevada, and Eureka and Kelso dunes in California.

Material collected during a 1977 visit, from a location two-thirds up the dune, has a mean grain-size of 1.4ϕ (0.38 mm) and an inclusive graphic standard deviation of 0.43ϕ (well-sorted). At the time of our visit, the dune did not emit acoustical energy upon initiation of avalanches. Haff (1979) reported that acoustical energy was released during man-made avalanches. Dr. Richard Rust (personal communication, 1984) also was able to elicit sound from the dune while performing research on the Guiliani's Dune Scarab Beetle for the U.S. Fish and Wildlife Service.

NON-BOOMING DUNES

Dunes and sand fields which did not emit the booming sounds characteristic of other well-developed terminal dunes have been visited by the authors and by Haff (1979).

Death Valley Dunes, California

Death Valley Dunes are several miles southeast of Stovepipe Wells (Stovepipe Wells 15-minute quadrangle, Lat. 36°37'N, Long. 117°07'W). These dunes are easily accessible by foot from California Route 190.

Haff (1979) reported that this was the only site of dunes of great height for which no acoustical activity could be generated in the field. He also stated that the dunes are extensively vegetated, which possibly may indicate high moisture content and preclude the ability of the sand to generate acoustical energy.

Olancha Sand Drift, California

Located at the southern end of the Owens Lake Valley near the town of Olancha, these dunes are accessible from California Route 190 near the turn off to Dirty Socks Hot Mineral Springs (Keeler 15-minute quadrangle).

Haff (1979) apparently did not investigate the well-developed dunes located several miles farther south, instead collecting a sample from a small (1 m) high east-west trending sheet sand drift near Highway 190. He reported that no sounds could be produced from this site. This is not surprising due to the fact that free movement of the sand over some distance on a steep slope under optimum moisture conditions would be necessary to provide optimum sound producing conditions. Since the sand sample collected by Haff (1979) falls within the realm of sound producing sands (Figure 2, no. 12), the potential for the highest dunes in the field to produce booming sounds would not be surprising.

Winnemucca Dunes, Nevada

This is the largest dune field in Nevada and is located approximately 10 miles (16 km) north and northeast of Winnemucca, Nevada. The eastern extent of the 40 mile (60 km) long dune field is located in the Bliss 15-minute quadrangle (approximately Lat. 41°07'N, Long. 117°45'W). The dunes do not reach heights of more than 100 feet (30 m), and mostly are stabilized by vegetation near the periphery of the dune field. Active migration, however, is occurring where the dunes cross U.S. Highway 95. The Nevada Department of Transportation removes sand drifts from the highway several times a year.

The sand from the distal end of the field is very fine-grained ($2.6\ \phi$, 0.17 mm) and well-sorted. During visits to the area in 1979, booming sounds could not be elicited from several of the highest dunes in the eastern part of the dune field.

Clayton Valley Dunes, Nevada

This complex dune field is located in the southern part of Clayton Valley, 7 miles (11 km) south of Silver Peak, Nevada (Lida Wash 15-minute quadrangle, Lat. 37°40'N, Long. 117°37'W), and is easily accessible via gravel road. The highest dune rises 280 feet above the valley floor.

The dune sand is of local origin, derived from local deflation of a playa-alluvial fan covered valley only 120 mi^2 (310 km^2) in area. A sample collected from the north end of the dune complex consisted of fine-grained sand (2.4ϕ, 0.19 mm) and was well-sorted. Abundant vegetation is present in the interdune areas and on the slopes of the tallest dune. The current trend toward stabilization of the dune was confirmed by the abundance of numerous animal burrows and tracks, even on dune crests.

This dune did not emit acoustical energy during our 1977 visit and would not be expected to do so because of the fine-grained size of the sand.

Long Valley Dunes, Nevada

The dunes in Long Valley are a very localized phenomenon, generated by a blow-out of playa deposits derived from the carbonate bedrock which bounds the valley on both east and west. The dune is located in the Sunshine 7 ½-minute quadrangle (Lat. 39°37'N, Long. 115°23'W) in eastern Nevada (Figure 1). A sample collected from the highest dune was a moderately well-sorted, medium-grained sand (1.9ϕ, 0.28 mm).

Sound could not be produced from this location during July 1977 by any means of forced displacement.

OBSERVATIONS AND CONCLUSIONS

To hear the sounds produced by booming dunes in the desert environment is a unique and fascinating experience. Some specific observations, apparent from our casual investigations and those of Haff (1979), are:

(1) Sands that have traveled the farthest in a particular dune field have the greatest potential to produce acoustical energy.

(2) High dunes with steep, quasi-stable slip faces that are easily put in motion produce the best sounds.

(3) Dunes that contain medium-sized sand grains which are very well-sorted to well-sorted are the best prospects for production of acoustical energy.

(4) The sands must be very dry and meteorological conditions must provide low-humidity.

(5) Well-rounded, frosted sand grains derived from long-distance transport, or multiple generations of sand movement resulting from variable azimuth wind direction appear best suited to the production of booming sounds.

(6) Vehicular traffic on dune surfaces tends to degrade the ability of the sands to produce sounds under natural conditions.

ACKNOWLEDGMENTS

We thank George Ghusn, Jr., who assisted us during the 1977 field session and performed the size analyses on samples collected during that time. Also, Thomas Flynn, of the University of Nevada, Las Vegas, persevered in 1985 at Sand Mountain, Nevada, and produced the booming sounds after unsuccessful attempts at Crescent Dunes.

The support provided by the Nevada Bureau of Mines and Geology during the early phases of the study also is appreciated.

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CALIFORNIA GEOLOGY
TRIVIA

1. What is the single greatest scientific work ever produced?
2. When and what was the first state park established in California?

Answer

1. *Principia Mathematica* (or more correctly *Philosophiae Naturalis Principia Mathematica*) published in 1687 by Isaac Newton. It presents the laws of motion and of gravitation and shows how his principle of universal gravitation explains both the motion of the planets and of falling bodies on earth. It also includes a discussion of fluid mechanics and the phenomena of tides. Newton is considered to be one of the greatest scientists ever to have lived.
2. In 1864 President Abraham Lincoln signed into law an act of Congress whereby the area including Yosemite Valley and the Mariposa Grove of Giant Sequoias was acquired by California. This was the first state park in California and the nation.

Earthquake Planning Scenario for

A MAGNITUDE 7.5 EARTHQUAKE ON THE HAYWARD FAULT, SAN FRANCISCO BAY AREA

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A major earthquake within the densely populated San Francisco Bay area, such as the event postulated in this planning scenario or an equivalent event in the urban Los Angeles area, would constitute one of the most devastating natural disasters that could conceivably strike this nation. The damage caused by such an event could well exceed that of a larger earthquake (M ~ 8) in lesser populated regions along the San Andreas Fault.

This article is adapted from Special Publication 78, *Earthquake planning scenario for a magnitude 7.5 earthquake on the Hayward fault in the San Francisco Bay area*, Division of Mines and Geology, 220 p., 10 plates, in press.

The scenario provides a perspective on many of the plausible consequences of a major earthquake on the Hayward Fault, focusing on the impact to transportation and utility lifelines and critical structures such as hospitals and schools. The scenario will increase public awareness of the threat and the need for coordinated emergency preparedness and response planning to cope with this eventuality....*editor.*

INTRODUCTION

Following the devastating eruption of Mount St. Helens in 1980, the President requested the National Security Council to consider the implications of the occurrence of a large damaging earthquake in California. One of the major conclusions of that analysis was that although there is a general capability to respond to moderate-size earthquakes, it is unlikely that the collective emergency response capabilities of all levels of government and the private sector would be adequate to cope with the consequences of a major destructive earthquake near a metropolitan area.

The Governor's Emergency Task Force on Earthquake Preparedness was established in February 1981. Working with the Task Force, the Division of Mines and Geology developed two earthquake planning scenarios (Davis and others, 1982a, 1982b). These scenarios were based upon a repeat of the 1906 San Francisco earthquake (M ~ 8) on the northern San Andreas fault and a repeat of the 1857 Fort Tejon earthquake (M ~ 8) on the southern San Andreas fault.

While these two planning scenarios for great earthquakes on the northern and southern San Andreas fault are basic for emergency planning efforts, it was apparent that similar analyses were needed for other faults in metropolitan areas that are capable of producing earthquakes of equivalent or even greater destruction. Paramount among these were consideration of a M 7.0 earthquake on the Newport-Inglewood fault in southern California and a M 7.5 earthquake on the Hayward fault.

Funded in part by the Earthquake Hazards Reduction Program of the U.S. Geological Survey, the Division of Mines and Geology in collaboration with structural engineer Karl V. Steinbrugge developed a planning scenario for the Hayward fault. Similar scenarios for a M 7.0 earthquake on the Newport-Inglewood fault and for a damaging earthquake in the San Diego-Tijuana area are in progress.

While no scenario will prove accurate in detail, this effort provides planners with a regional pattern of the damage and types of problems that will confront emergency response personnel. These scenarios give a more complete understanding of earthquake hazards and provide a basis to develop response plans to cope with them.

HAYWARD FAULT

The Hayward fault is a seismically active major element of the San Andreas fault system, one of several northwest-trending strike-slip faults associated with right-lateral tectonic movement between the North American and Pacific plates. The Hayward fault is the southern segment of an extensive fracture zone consisting of the Hayward, Rodgers Creek, Healdsburg, and Maacama fault segments. The zone extends northwest to Mendocino County (Slemmons and Chung, 1982), a total distance of 280 km (175 miles). The 100 km (62 mile) long Hayward segment extends from San Pablo Bay to an obscure convergence with the Calaveras fault near Mount Misery east of San Jose.

The Hayward earthquake of October 21, 1868 of Richter magnitude about 7 (M ~ 7) was one of the largest earthquakes to occur in this area causing widespread damage throughout the then sparsely populated Bay area. An event of similar destructive magnitude in 1836 also occurred on the Hayward fault. Future earthquakes of comparable magnitude (M 6.5-7.5) are a reasonable expectation and could occur at any time.

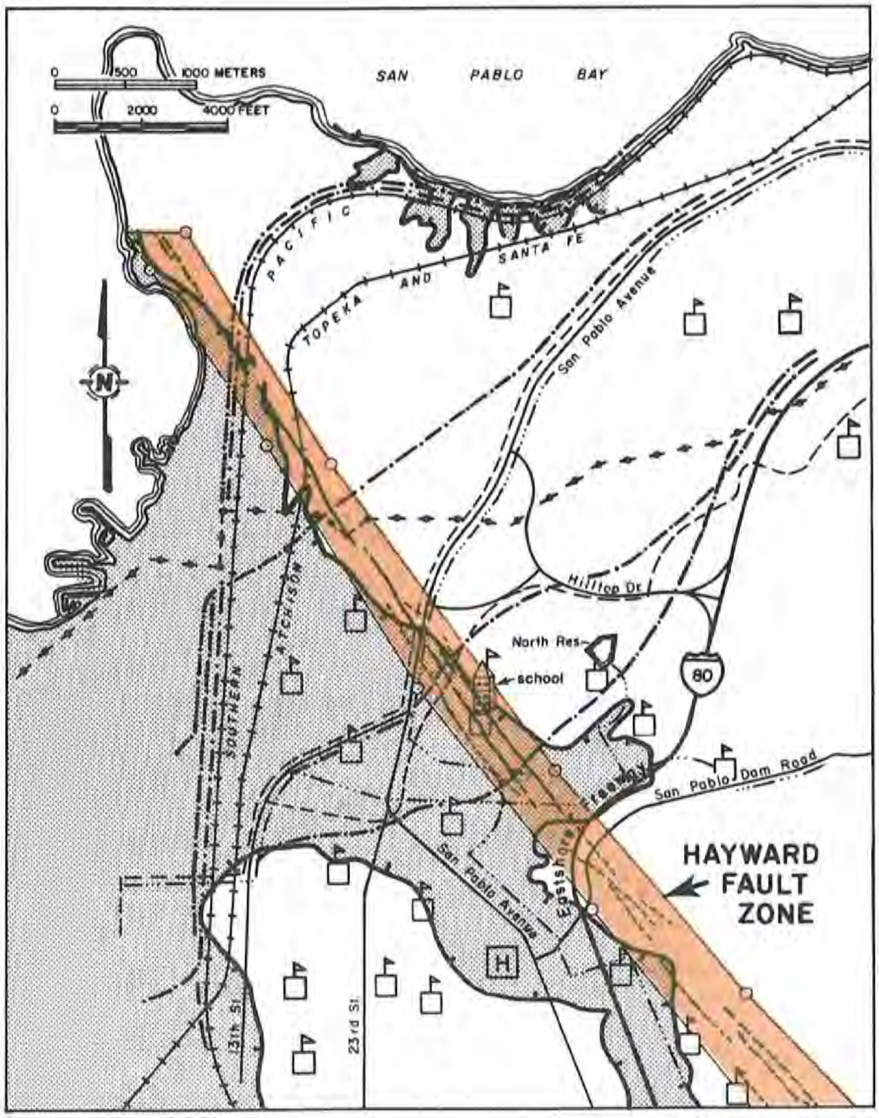

Figure 1. Major lifelines and other critical structures near the Hayward fault in the San Pablo corridor. Pipelines shown are only representative and are neither necessarily complete nor accurately located.

A large earthquake on either the Hayward or the San Andreas fault poses a major threat to the *entire* Bay area. While the effects of these earthquakes may differ from place to place, a major earthquake on the Hayward fault is not an exclusive East Bay concern and a San Andreas event is not an exclusive San Francisco concern. The threat to San Francisco from the Hayward fault was recognized by A.C. Lawson in 1908 in *Report of the State Earthquake Commission, The California earthquake of April 18, 1906,* p. 447: "The foot of Market Street, San Francisco, is about midway between the San Andreas rift and the fault scarp upon which movement occurred in 1868. The city has, therefore, to reckon with the latter as well as the former in its future career, and, consequently, should be doubly prudent in the location and structure of its important buildings".

SCENARIO EARTHQUAKE

Description

This planning scenario is based on the maximum credible earthquake that could occur on the Hayward fault. The assumed characteristics of this earthquake are (1) a Richter magnitude of 7.5 (M 7.5) that results from rupture of the entire length of the Hayward fault from San Pablo Bay to east of San Jose, (2) surface faulting that produces horizontal offsets of up to 10 feet, (3) potentially damaging shaking that continues for 30-40 seconds within 25 km (16 miles) of the fault, and (4) frequent aftershocks that continue for many weeks, including events of M 6 or larger.

While this planning scenario is based upon a maximum credible event for the Hayward fault, damage patterns would in many respects be similar for an event of smaller magnitude. A magnitude 6.5 to 7.0 event similar to the 1868 earthquake, for example, would most probably result from rupture along only one-half the length of the fault and would produce up to about 3 feet of surface offset. The resulting damage to lifelines, critical facilities, and local utility distribution systems, while not as severe, would affect most of the same facilities along the ruptured segment of the fault. Shaking near the rupture zone would be as severe, but presumably, not as prolonged. Ground failures would occur in the same general areas.

Predicted Effects

Fault rupture

Horizontal fault offset of up to 10 feet along the 62-mile length of the fault would cause major damage to structures located on active fault traces. Throughout most of its length the fault traverses residential and commercial areas, posing the threat of widespread damage to buildings, utility lifelines and distribution systems, and transportation routes.

Shaking intensity

The area subject to shaking of Modified Mercalli intensity VIII (strong enough to cause considerable damage in ordinary substantial buildings; great damage in poorly built structures) extends from near Petaluma and Napa in the north San Francisco Bay to south of San Jose. The region encompasses most of the populated areas of eastern Contra Costa County and Livermore Valley on the east, most of the heavily populated greater San Jose area, the communities north along the San Francisco Peninsula to and including much of San Francisco, and the low-lying urban areas of bayside Marin County.

Predicted shaking of Modified Mercalli intensity IX (strong enough to cause considerable damage in specially designed structures; great damage in substantial buildings with partial collapse; buildings shifted off foundations) encompasses an area of some 5 miles in width lying generally west of the Hayward fault, an area that includes virtually all the developed urban area of the East Bay from San Pablo southeast to and including the eastern half of San Jose.

Intensities greater than IX will most commonly occur along the zone of surface rupture and in those areas having a high potential for ground failure, notably around the Bay margins.

Ground failures

Secondary ground failures, notably differential settlements and shifting of the land surface due to liquefaction will be common, particularly on filled ground around the Bay margins. These movements will damage various major structures and lifeline facilities, notably highways, railroads, airport runways, port facilities, and some utility pipelines. Seismically induced landslides pose an additional threat, particularly in the East Bay hills, with the probability of failure being highest in the rainy season.

EARTHQUAKE IMPACT

Deaths and Injuries

Deaths resulting from this scenario earthquake are estimated to range from 1,500 to 4,500 depending upon the time and day of occurrence. Hospitalized casualties are estimated to be three times the number of deaths; significant non-hospitalized casualties are estimated at 30 times the number of deaths.

Courthouse at San Leandro after the Hayward earthquake of October 21, 1868.

Hospitals near Fault

Eight of the 26 general acute care hospitals (99 beds or more) in Alameda and Contra Costa counties are located within one mile of the Hayward fault. This represents a bed capacity of 2,300 (about 35 percent) of a total of 6,200 beds available in these major facilities. Almost all buildings at these eight sites were constructed prior to adoption of more stringent hospital building requirements in 1972. Direct damage, restricted access, prolonged loss of public utility services and reduced public confidence in structures near the fault, may necessitate closure of some of these facilities. Thus, one or more hospitals could become an added post-earthquake burden.

Public Schools

Earthquake resistant public school buildings are generally well distributed throughout populated areas and are normally in a safe condition following earthquakes. These structures provide a major resource for mass shelter and feeding. Some substantial damage to several schools can be anticipated, however, because of close proximity to the fault. Also, schools located in the hills east of the fault will be functionally impaired due to disrupted utility services. The Hayward fault traverses the University of California campus where about 20 percent of the floor space is in buildings classified as seismically poor or very poor, some of which can be expected to partially or totally collapse.

Transportation Lifelines

Trans-bay bridges

The trans-bay bridges will be temporarily closed due to ground and structural failures at the bridge approaches. Roadway clearance, emergency repairs, detours, and bridge inspections will preclude or severely restrict use of these structures during the initial post-earthquake hours. The Oakland Bay Bridge will be effectively closed due to major damage at the east approach interchange and northward along Interstate 80/Route 17; the Richmond-San Rafael, San Mateo, and Dumbarton crossings should be available to limited emergency traffic in less than 36 hours. The Golden Gate Bridge will remain open, but traffic will be severely limited by damage at the southerly bridge approaches.

Major freeway routes

All of the major freeway routes to the East Bay from the east and south either cross the fault or are otherwise vulnerable to damage by strong shaking and ground failures. Major routes subject to surface fault offset (up to 10 feet) include Interstate 80 at San Pablo, Interstate 580 in East Oakland, Interstate 680 at Fremont and south to Milpitas, Route 24 west of the Caldecott Tunnel and most of Route 13 (Warren Freeway). Ground failures due to liquefaction and strong ground shaking may cause major damage along Route 17 from Richmond to San Jose.

Virtually all older freeway bridges in the area have been refitted to increase their resistance to shaking. Nevertheless, damage to and collapse of some of these structures is to be expected. Access to and travel within the East Bay will be difficult and limited to emergency traffic. Most principal routes on the San Francisco and Marin peninsulas and western portion of the greater San Jose area will be open subject to major delays and detours.

Airports

Runways at the major Bay area airports are generally constructed of fill placed over Bay mud of varying depths. Their performance when subjected to prolonged shaking is questionable, and liquefaction and differential settlement may render all or portions of many runways unusable by larger aircraft. For planning purposes, San Jose Municipal Airport is assumed to be available for larger transport aircraft. San Francisco and Oakland International, Hayward Municipal, and other secondary Bay area airports should be available for limited use by small aircraft and helicopters. Alameda Naval Air Station will be closed.

BART

BART will be shut down due to the lack of electrical power and the need to assess and repair damage. Principal damage will be to the Berkeley Hills tunnels which will be closed indefinitely as a result of fault rupture. Damage to a few elevated spans is postulated in the East Bay. The trans-bay tube and the subway systems are expected to survive with no major damage.

Railroads

Rail service to the Bay area from the east and south will be curtailed due to fault rupture, ground failures at various locations around the Bay perimeter, and structural damage to numerous bridges. Rail service via the coast route from southern California to San Francisco will be restored rapidly but all other lines to and from the Bay area will be blocked for at least the initial 72-hour post-earthquake period.

The Bay Bridge east approach interchange (I–80/580), main line railroads, and EBMUD's Special District Number 1 waste water treatment plant.

Port facilities

Most of the docks in the Bay area are pile supported and are not expected to be greatly affected. Port facilities at San Francisco are, therefore, expected to generally remain functional, though initially the loss of power and impaired access to the area will curtail operations.

In the East Bay, the major Port of Oakland and other smaller commercial port facilities at Richmond and in the Carquinez Straits will generally be nonfunctional as a result of prolonged power loss and damage to truck and rail access routes. Within the port areas filled land will settle disrupting both rails and streets. Damage to oil pipeline and storage facilities at the Richmond and Carquinez facilities poses a threat of contamination and fire.

Utility Lifelines

Communications

Telephone communications will be overloaded by post-earthquake calls within the area and from the outside. This situation will be further complicated by physical damage to equipment due to ground shaking and loss of electrical power. Moreover, not all of the systems in the region are set up to process emergency calls automatically on a previously established priority basis. Thus, overloading of equipment still in service could be very significant.

The East Bay and San Jose areas have a substantial number of telephone facilities located in areas subject to severe shaking and high probability of ground failure.

Access for repairs will be a major problem.

The lack of emergency power has been the primary cause of communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate. The presumed scarcity of propane and gasoline after a major earthquake will strictly limit the viability of surviving communications sites.

Electrical power

During some portion of the first 72-hour period following the earthquake, all portions of the planning area will experience some loss of power. It is reasonable to consider about one-third of the service connections in the area to be without power for 24 hours. In the urban sections of Oakland and other East Bay cities, the power outage should be considered at 100% for the first 24 hours and 75% for an additional 24 hours. This means that 75% of customers will have *no* power and 25% will have only limited service. The power outage for San Francisco should be considered at 50% for the initial 24 hours and at 25% for an additional 24 hours.

Electrical power facilities in the East Bay are particularly vulnerable to damage from the scenario earthquake, and the time required to restore full power will be prolonged. While the resources may be available to rapidly deal with repairs to the system, the general confusion and damage to other lifelines such as communications and highways will complicate restoration efforts. Realistically, power is unlikely to be restored to many areas for several days or longer. Those concerned with emergency planning for power-dependent systems such as communications, water supply, fire fighting, and waste treatment should be cognizant of this likelihood.

Water supply

Water supply systems in the East Bay will be severely crippled in this scenario earthquake. Displacement along the Hayward fault will heavily damage all major tunnels, aqueducts and the many distribution systems that cross the fault. The flow of water crossing the fault will be reduced to 10% for the first 24 hours. The public will need to conserve available supplies (as an example, water in hot water heaters) and to take safety measures against contamination.

Restoration of water service to all areas east of the fault in the East Bay hills will be greatly delayed. In the Alquist-Priolo zone, temporary pipelines, similar to those provided to many residences after the 1971 San Fernando earthquake may be used. Restoration of full service could take months.

Within the past 10 years the East Bay Municipal Utility District (EBMUD) has rebuilt the older, weaker dams in their system to improved seismic standards. Consequently, a major dam failure is not considered a credible element in this scenario.

Waste water

Waste water pipelines from the hillside areas that cross the Hayward fault will be sheared and unable to carry sewage. Open trenches may be necessary to carry sewage for short distances. Alternatively, planners will have to provide for emergency housing or temporary sanitation facilities.

Treatment plants will shut down due to lack of power. EBMUD's electric power system which uses methane gas from its treatment plant will be unable to support full plant function. It may be necessary for emergency treated raw sewage to be discharged into the Bay for up to one month.

Natural gas

Horizontal displacement of up to 10 feet across the fault zone will cause hundreds of breaks in mains, valves, and service connections. Secondary ground failures resulting from high intensity shaking will result in many additional breaks in the system in the proximity of the fault zone. Some fires will occur in streets due to broken gas mains;structural fires will occur as a result of broken service connections.

Fault rupture will also cause damage to the larger diameter transmission pipelines where they cross the fault at San Pablo and Fremont. As a result of damage to these transmission facilities, natural gas will be unavailable to all of the East Bay from San Pablo on the north to Milpitas on the south.

While gas supplies to most of the East Bay will be restored rapidly, some areas in the hills immediately east of the fault could be without gas for several weeks.

Damage to facilities serving the south Bay and San Francisco Peninsula should be minimal. Where poor ground conditions result in substantial damage to distribution systems, restoration of service will be prolonged. Throughout the north Bay, only minimal damage to isolated segments of the distribution system is anticipated.

Petroleum refineries and products

The six major refineries in the San Francisco Bay area are all subject to shaking and damage from ground failure. Refineries may also suffer damage by fire and operations will be curtailed by loss of utility services. Pipelines and storage facilities located on unstable and landslide sensitive ground along the Bay margin are vulnerable to damage, particularly those at marine terminals. All major pipelines transporting petroleum fuels to the Bay area (including the south Bay) cross the Hayward fault either at San Pablo or Fremont. They all are vulnerable to damage by surface fault rupture.

Lifeline Corridors

The major transportation corridors that serve the East Bay area, such as the routes through San Pablo and Fremont, are commonly shared by various other lifeline facilities, all of which are vulnerable to major damage where they cross the fault. Multiple failures of several major lifelines within these restricted corridors have the potential to complicate emergency response efforts. These corridors warrant special attention by emergency planners.

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Geologic Hazard Abatement Districts

By

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Geologic Hazard Abatement Districts (GHAD) enabled by the Beverly Act of 1979 (SB 1195), are potentially useful financial mechanisms for reducing hillslope hazards (Kockelman, 1986). The enabling statute, (Division 17 of the Public Resources Code, Sections 26500 - 26654) provides for the formation of local assessment districts for the purpose of prevention, mitigation, abatement, or control of geologic hazards. The Act broadly defines "geologic hazard" as "an actual or threatened landslide, land subsidence, soil erosion, earthquake, or any other natural or unnatural movement of land or earth."

A GHAD may be proposed by one of two means:

(1) a petition signed by owners of at least 10 percent of the real property in the district, or

(2) by resolution of a local legislative body.

Abalone Cove landslide, Rancho Palos Verdes, Los Angeles County. The toe of the landslide is at the shoreline. The Abalone Cove Landslide Abatement District was formed in January 1981, and was the first district formed after the Beverly Act of 1979. *Photo by Martin L. Stout.*

PLAN OF CONTROL

A proposal for a GHAD must be accompanied by a "plan of control", prepared by a certified engineering geologist, "which describes in detail a geologic hazard, its location and the area affected thereby, and a plan for the prevention, mitigation, abatement, or control thereof" (Section 26509). The land within a district need not be contiguous; the only requirement is that lands within a GHAD be specially benefitted by the proposed construction and that formation of a district is required to ensure the health, safety, and welfare of the residents.

LOCAL DISTRICT ORGANIZATION

The Act requires public hearings prior to district formation. If owners of more than 50 percent of the assessed valuation of the proposed district object to the formation, the legislative body must abandon the proceedings. If there are few objections, the legislative body may form the district, initially appointing five property owners to the board of directors. Thereafter, the district becomes an independent entity with an elected board of directors. A GHAD may issue bonds, purchase and dispose of property, acquire property by eminent domain, levy and collect assessments, sue and be sued, and construct and maintain improvements.

First GHAD

The Beverly Act was originally drafted to allow for the formation of the Abalone Cove Landslide Abatement District in Rancho Palos Verdes, Los Angeles County. The 600-acre Abalone Cove landslide, which began moving in 1978, threatened over 100 homes upon and adjacent to it. It is located immediately west of the well-known Portugese Bend landslide, and probably has a similar mechanism (movement along seaward-dipping bentonitic tuff beds) (Ehlig, 1979).

The district was formed in January 1981 and has financed continued geologic investigation of the slide and installation of mine dewatering wells (Heffler, 1981), which appear to have successfully reduced lateral movement. The Beverly Act provided a mechanism for the Abalone Cove home owners to jointly finance abatement measures. A significant point is that it allowed them to treat the landslide as a single physical entity, irrespective of property boundaries. A companion bill by Senator Beverly provided for liability exemption of local district for actions taken to abate gradual earth movements.

Other Districts

In the six years since enactment of the Beverly Act, not many Geologic Hazard Abatement Districts have formed, though a few have been proposed. A Plan of Control was prepared for a proposed GHAD at Mount Washington (City of Los Angeles) in 1981 (Lung, 1981), but the District was never formed because affected homeowners felt that they could not afford the remedial measures.

In 1982 a second GHAD was formed in Rancho Palos Verdes, encompassing the Klondike Canyon landslide, located immediately to the east of the Portugese Bend slide (Ehlig, 1982). As with Abalone Cove, this GHAD was formed in order to finance continued investigation, monitoring, and dewatering measures.

Since 1984 the Blakemont Property Owners' Association in Kensington (western Contra Costa County) has been working on formation of a GHAD to include approximately 135 parcels covering 35 to 40 acres. This GHAD would cover an earthflow complex that has been periodically active over the years. During the 1960s an attempt was made to form a drainage improvement district, but this attempt failed. The present effort is in response to damage from January 1982. An engineering geologist is currently preparing a Plan of Control for the GHAD, jointly financed by the Association, public agencies, and a utility district.

The most recent GHAD was formed in June 1985 at Canyon Lakes, a subdivision of over 1000 acres near Danville in Contra Costa County. This District is different because it was formed prior to occupancy of the subdivision and there has not yet been active landsliding. The purpose of the District is to establish a mechanism to pay for regular maintenance of drainage systems, routine reconnaissance, and timely repairs of any slope failures. The subdivision will have several thousand owners when fully developed. The Plan of Control (Proctor, 1985) is a general document, describing the types of activities that the District might perform.

The Canyon Lakes GHAD initially appears to go beyond the original intent of the Beverly Act, which was designed to abate an immediate, existing hazard. However, the Act is ambiguous on this point. According to an informal opinion by the staff consultant to the State Senate Committee on Local Government (Detwiler, 1985) it is indeed possible, under the enabling legislation, to create a one-landowner district in which the "threatened landslide" is an event which has a small, but finite, probability of occurring. Thus, it appears that a GHAD may serve a maintenance and prevention function as well as an abatement function. The Act is still unclear, however, regarding how detailed a Plan of Control for a maintenance-oriented district needs to be, and what the legal responsibilities of the initial owner-developer would be to future home owners. Clear guidance is still needed on how to equitably and effectively operate a *prevention*-oriented GHAD.

SUMMARY

The Geologic Hazard Abatement District is a potentially useful tool to effectively abate a landslide hazard that crosses property boundaries. It is a mechanism that responds to the physical realities of landslides, and allows property owners to cooperate in solving a common problem. It removes much of the stigma of legal liabilities among adjacent landowners and allows them to cooperate rather than litigate. It also provides for a cost-effective solution, requiring only one geotechnical engineering firm and one plan to solve the problems of several landowners. In short, as local communities become aware of the existence of this statute, it is likely that the GHAD, be it for repair of an existing landslide or prevention of an impending one, will become more commonly used throughout the state.

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GYPSUM MINING

California is one of the leading producers of gypsum in the United States. In 1984, U.S. production was 1,346,000 tons. Nearly all the gypsum mined in California is used to manfacture wallboard. Wallboard (also called sheet rock or gypsum board) is an inexpensive fire-proof building material.

Gypsum most commonly occurs in dry lakebed deposits, where it has gradually precipitated from saturated saline marine brines. It normally is associated with clays and bedded evaporite minerals. Most of California's gypsum is mined in the eastern Mojave Desert, Imperial County, and in the southern San Joaquin Valley.

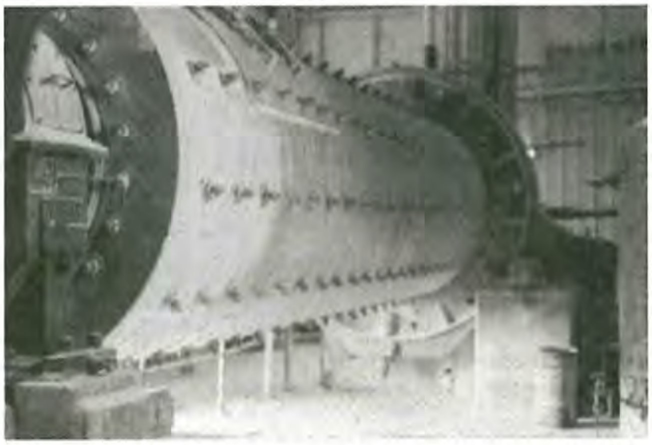
Pit run gypsum is crushed, heated or calcined, and mixed with water to form the slurried mix that is the primary ingredient for making wallboard. Calcining dehydrates gypsum ($CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 + 2H_2O\uparrow$); when mixed with water, it rehydrates to form plaster.

....John S. Rapp, DMG.

These photos were taken at Centrex American Gypsum Company, Albuquerque, New Mexico. U.S. Gypsum Company has a similar, though larger, gypsum processing plant at the north end of Fish Creek Mountains, Imperial County, California. *Photos by John S. Rapp, October 1985.*

Manufacture of wallboard. The freshly made gypsum mud, which has the consistency of toothpaste, is measured and placed between two continuously moving sheets of heavy gray paper. The four-foot wide gray belt of gypsum mud and paper is swaged to precisely $\frac{1}{2}$ inch or $\frac{5}{8}$ inch in thickness, and the paper edges are folded over. The workers are making sure that gypsum mud flows uniformly between the continuous rolls of paper sheets.

Gypsum mining, Centrex American Gypsum Company, Albuquerque, New Mexico. Gypsum is mined and stockpiled (on right) with earthmoving equipment such as this front loader. Pit run material from the stockpile will be transported by truck to a gypsum manufacturing plant.



Rotary mill, Centrex American Gypsum Company, Albuquerque, New Mexico. Gypsum is commonly pulverized and then blended in rotary mills.

Gypsum wallboard on continuous belt (left foreground) is moving away from viewer. As it moves along the conveyor belt, the gypsum mud hardens; at far end of the factory it is firm enough to be mechanically cut and flipped. Board is cut into 8 or 12-foot lengths. Conveyor (right) is pulling sized and cured wallboard towards the viewer from large gas dryers. Finished gypsum wallboard is checked for quality and size, and shipped to construction sites and warehouses. ⚒

Historic Earthquakes Recalled

The year 1986 marks milestone anniversaries for three of the more destructive earthquakes to occur in the United States in historic times.

Here are capsule summaries of the three earthquakes and their locations:

* SAN FRANCISCO — The earthquake began at 5:13 a.m., April 18, 1906 (80 years ago), with a sudden movement along a 270-mile segment of the northern San Andreas fault from San Juan Bautista north to near Cape Mendocino. Although the earthquake was felt throughout California and part of Nevada, it is usually referred to as the San Francisco earthquake because of the extensive destruction in the city. Fires that started in overturned stoves and ruptured gas lines raged out of control for several days because broken water mains left firemen helpless to control the blazes.

The western side of the San Andreas fault moved northward relative to the eastern side, as much as 22 feet. That meant that San Francisco (east of the fault) and Los Angeles (west of the fault) moved closer together. The offsets of roads, fences, buildings, lines of trees, water pipes and gas mains were vivid evidence of the horizontal movement.

The amount of energy released by the magnitude 8.3 earthquake in 1906 is estimated to have been about 27,000 times more than released by the recent magnitude 5.3 earthquake that occurred near Fremont on the east side of San Francisco Bay, March 31, 1986. More than 800 deaths in the earthquake and fires were reported, and property losses were estimated at billions of dollars in today's prices.

* CHARLESTON — The earthquake occurred near Charleston about 9:50 p.m., August 31, 1886 (100 years ago), and lasted less than a minute. The earthquake caused 60 deaths and extensive damage in Charleston. It was felt as far away as Chicago, New York, and Boston. The earthquake was followed by a series of aftershocks that occurred during the next several decades. Some scientists say that the earthquakes that still occur in the Charleston area today could be aftershocks of the 1886 earthquake.

The source of the Charleston earthquake and its aftershocks remains poorly understood. No fault has been identified as the likely source of the earthquakes. Charleston, unlike California, is not situated near a boundary between two crustal plates. The U.S. Geological Survey (USGS) and other agencies are conducting research in the area in an effort to determine why earthquakes occur in the Charleston area, as well as in other regions in the eastern United States.

* NEW MADRID — The trio of shocks, beginning with an earthquake December 16, 1811 (175 years ago), strongly shook southeast Missouri, northeast Arkansas, and western Tennessee and Kentucky. The three earthquakes each probably had magnitudes greater than 7.5. The Mississippi River was reported to have flowed backward and Reelfoot Lake in Tennessee reportedly was enlarged. There was extensive landsliding of banks on the Mississippi River and other streams. The town of New Madrid, Missouri, sustained almost total damage. The earthquakes were felt over most of the eastern United States. Damage and casualities were relatively light because the area was sparsely settled.

The initial shock was followed by two equally strong earthquakes January 23, 1812, and February 7, 1812. These were followed by hundreds of aftershocks during the next dozen years or so. The New Madrid region continues to experience earthquakes.

Recent research by the USGS and scientists from other organizations, however, indicates that earthquakes in the New Madrid area may be related to recently identified deeply buried crustal rift and associated faults.

...*U.S. Geological Survey News Release* ⚒

Careers in Geology

The American Geological Institute has given CALIFORNIA GEOLOGY magazine permission to reprint a series of descriptions about the different geosciences and what training and skills are needed by the geoscientists.

ENGINEERING GEOLOGY

Every man-made structure depends on the earth beneath it for its stability and safety. Thus, the success and economy of an engineering project eventually depends upon the degree to which it is adapted to the geological environment in which it is placed. Sir Francis Bacon put it better. "Nature, to be commanded, must be obeyed."

The application of the science of geology to the art and practice of civil engineering is the special field of the engineering geologist. Today, few major civil engineering projects are undertaken without extensive preliminary investigations by geologists and other geotechnical experts. These investigations are carried out for large buildings, bridges, dams, levees, tunnels, underground installations, canals, and many other projects.

The engineering geologist uses a wide variety of tools. His basic information is gathered from the published literature, by field observation, and by various types of exploratory drilling. In addition to this information, the engineering geologist may make use of geophysical studies, groundwater studies, and various forms of instrumentation (special adaptations of stress and strain instruments). Because he never has all of the data concerning what lies in the earth, he must also use his experience in reaching a decision concerning the physical characteristics of a particular site. In addition to expertise, this requires a large measure of common sense. Finally, because the information must be used by engineers, he must be able to transmit it to them in concise, understandable terms which they can use in the design of the proposed project or structure.

To prepare for a career in engineering geology, one must be firmly grounded in the basic concepts of geology and have a working knowledge of the techniques and principles of civil engineering. An undergraduate degree in geology with additional emphasis on mathematics and basic engineering provides a firm educational foundation which may later be strengthened by graduate study in rock and soil mechanics, hydrology, geochemistry, or other specialty fields. Practical experience is an important and necessary part of every engineering geologist's training.

Engineering geologists are employed by engineering and/or architectural consulting firms; local, state, and federal design and construction agencies, environmental control agencies, and water resource agencies; private exploration firms; large construction companies; mining companies; universities; and many others.

This description has been prepared by the Association of Engineering Geologists, a member society of the American Geological Institute. ⚒

REVIEWS

Marine Geomorphology

MAP OF THE OCEAN FLOOR and GUIDE AND TOURBOOK TO THE MAP. By Earl Bateman. 1985. Available from Celestial Arts, Dept. DM, P.O. Box 7327, Berkeley, CA 94707. Poster (36"x36") and 28-page booklet, $12.55 (California residents); $11.95 (all others).

The Map of the Ocean Floor displays how the major topographic features of the Earth's sea floor look. The accompanying pamphlet, Guide and Tourbook to the Map, briefly describes the origin of these major topographic sea floor features. The map and pamphlet are designed as learning aids to understand ocean floor terrain. These materials are current products of data recently acquired by the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and the National Aeronautical and Space Administration (NASA).

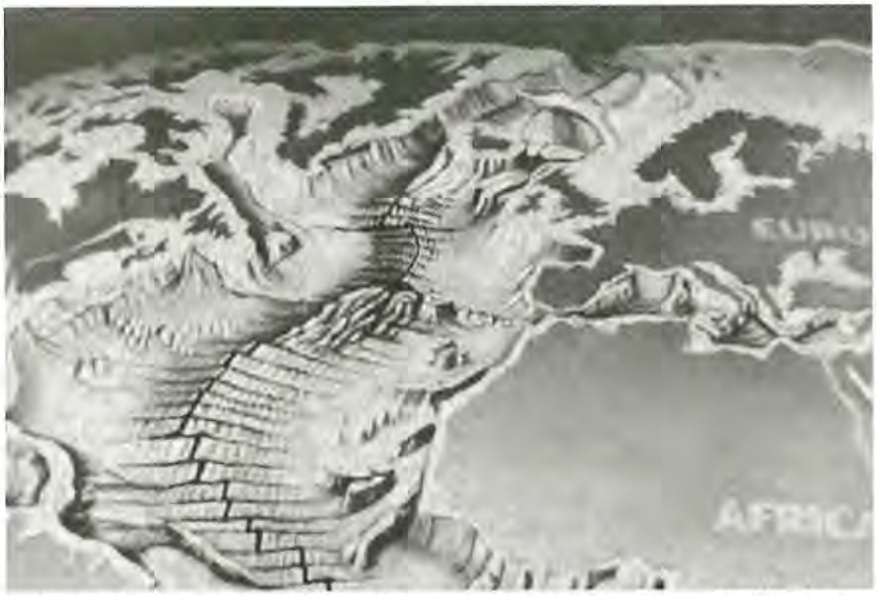
The map is a diagrammatic projection of the ocean floor showing its unusual topographic features. Scientists have only recently developed a wide variety of creative remote sensing methods to determine the sea floor topography shown on the map.

The ocean floor map is divided into two separate maps; in normal light it shows the major topographic features of the sea floor; in the dark, phosphorescent paint glows to reveal the tectonic forces that shape Earth's surface.

Each type of major topographic feature—cordillera, abyssal plain, fracture zone, trench, ridge, fan, seamount, or archipelago—is color-coded to indicate its location. In addition, specific topographic feature names are listed on the map and in the map margin and are coded by numbers as well as by color.

Major tectonic features are revealed in the dark and are listed in the map legend. Each major type of tectonic feature—plate, rift, thrust, hotspot, or volcano—is represented by a phosphorescent symbol on the map. The directions of movement of the plates and active spreading centers also glow in the dark. In normal light the specific tectonic features are shown coded by color and number and are listed on the map and in the margin.

The booklet describes the plate tectonic theory and how continental drift formed the ocean floor shown on the wall map. Separate chapters describe ocean geomorphology and give a brief historical geologic summary of each of the ocean basins. Black and white figures show the surface expression of the tectonic forces that shape each ocean basin. These figures include the topographic place names of canyons, banks, fracture zones, rises, and other features. Diagrammatic cross sections show the anatomy of spreading centers, subduction zones, and rift systems. In the final chapter, Plate Tectonics: Concepts, Discoveries, and Techniques, an informational outline of the major discoveries of plate tectonics is highlighted. The following excerpts of major discoveries since the mid 1970s were taken from that chapter:



Bathymetric view of the Atlantic Ocean and the tectonically active mid-Atlantic Ridge.The ridge is a slow spreading center that is pushing the Eurasian and North American plates apart at a rate of 2.8 to 5 centimeters per year. Sediments fan out on the ocean basin, burying the basement rock in deposits up to 14 kilometers thick. *Photo courtesy of Celestial Arts.*

SEASAT (launched by NASA, 1978) - Radar altimeter readings measure variations in height of sea surface (gravitational anomalies caused by differences in mass below sea surface). Instruments failed after three months, but Seasat had surveyed oceans between 72°N and 72°S.

Geotectonic Imagery (William Haxby, Lamont-Doherty Geological Observatory, Columbia University) - Maps ocean features based on Seasat radar altimetry readings.

Sonic Techniques - Instruments for measuring high-frequency acoustic pulses perfected, improving resolution at various depths (e.g., side-scanning sonar, deep-towed sonar).

1980s and Beyond - Increased utilization of satellite and laser technologies; continued on-site field work in manned and unmanned submersibles; on-going organization of international research effort.

MAGSAT - Magnetic field research, gravity measurements and laser-ranging to monitor polar motion and wobble, absolute plate motion, earth rotation, and map the earth's magnetic and gravity fields. (NASA Crustal Dynamics Program; Lamont-Doherty Geological Observatory; Jet Propulsion Laboratory; NOAA National Geodetic Survey).

GEOSAT - Launched October 1984 to survey magnetic and gravitational anomalies of Earth's crust. Results to be declassified by late 1986; will provide unprecedented detail of the ocean floor.

Global Positioning System - A network of 17 satellites in permanent geosynchronous orbits expected to become operational in 1987, sponsored by Department of Defense. Will be used by research community to detect discrete crustal motions and determine relative plate position in only a few hours observation.

Seismic Tomography - Incorporated Research Institute of Seismology (IRIS) includes nearly 50 universities worldwide with the objective of modernizing seismological research facilities and coordinating a global array of permanent seismometers to study Earth's interior.

U.S. Space Shuttle will tow geodetic satellites by tethers at low altitudes to collect data at better resolution.

Surveys of Exclusive Economic Zone - On-going survey and mapping of the U.S. continental margin using the DSRV Alvin manned submersible, GLORIA long-range sidescan, SeaBeam and Sea-Marc II deep-towed sidescan sonars. (U.S. Geological Survey and the Woods Hole Oceanographic Institute).

Deep Hole Drilling Projects - Nine countries (Russia, United States, Canada, Japan, Germany, France, Belgium, Britain, Iceland) now drilling into continents. First penetration of mantle expected in Cyprus, where mantle is close to the surface.

U.S. Continental Scientific Drilling Program to drill holes up to nine miles deep. First project is to drill six miles under the Appalachians into the "Overthrust Belt" to test theory that Africa and North America were once attached, drifted apart and then rammed together again. ⚒

REVIEWS

MINERAL TECHNOLOGY

MINERAL COMMODITY SUMMARIES 1986, An Up-To-Date Summary of 87 Nonfuel Mineral Commodities, by the staff of the Bureau of Mines, United States Department of the Interior, is available from Albert E. Schreck, Chief, Division of Publications, U.S. Bureau of Mines, 4900 La Salle Road, Avondale, MD 20782-3393. The report is free on request.

MINERAL COMMODITY SUMMARIES 1986 is the earliest U.S. government publication to furnish estimates covering 1985 nonfuel mineral industry data. Most of the estimates are based on nine months data acquired in 1985. These data sheets contain information on the domestic industry structure, government programs, tariffs, and five-year salient statistics for 87 individual minerals and metals. World resource data appearing in the statements have been provided by the U.S. Geological Survey.

The significant results of research in mineral commodities and economics are summarized under topic headings: role of nonfuel minerals in the U.S. economy; net import reliance, selected mineral materials, 1985; significant events, nonfuel mineral industry, 1985; and commodities (aluminum through zirconium).Resource reserve definitions, units of measure and definitions, and other publications are also included.

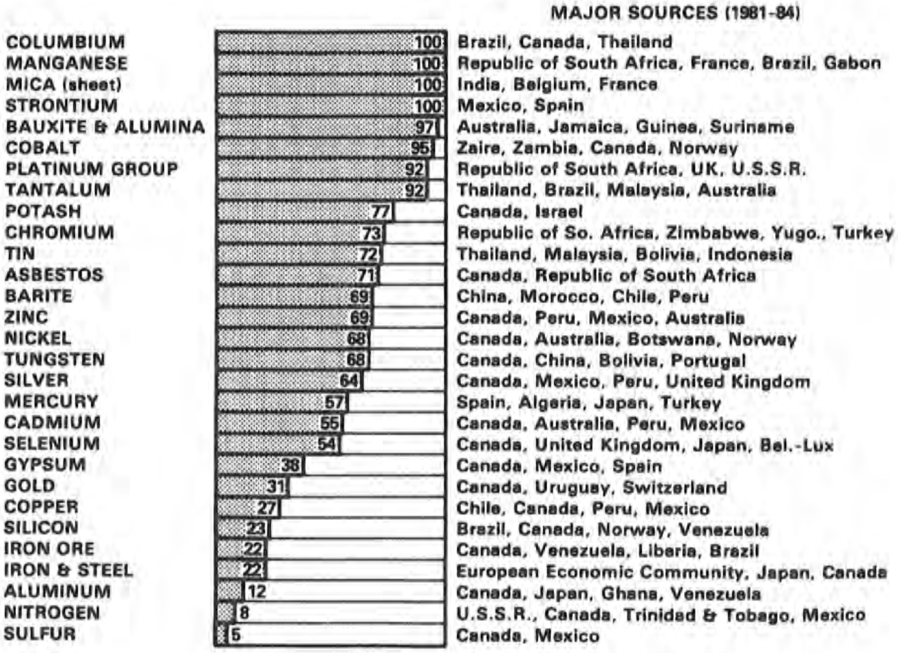
Periodic reappraisal of U.S. and world nonfuel mineral information is vital for the government to formulate and implement mineral policies and programs. The U.S. Bureau of Mines has the responsibility of assessing the nonfuel mineral resources of the United States and assuring that their development is in the best interests of our citizens.

Like fossil-fuels, nonfuel mineral resources are not limitless. Nonfuel minerals include metallic minerals such as iron, copper, and silver as well as nonmetallic minerals such as mica, asbestos, and sulfur. Although the term *nonfuel minerals* is commonly used, some so-called minerals included in this group such as nitrogen, aggregate, and cement are not true minerals.

The White House announced on July 8, 1985, that the President had approved National Security Council (NSC) recommendations for modernizing the strategic and critical materials stockpile. Under the NSC proposal, the stockpile would be structured into two tiers, Tier I and Tier II. Tier I would contain materials required by military, industrial, and essential civilian users during a military conflict that would not be available from domestic or reliable foreign sources. Tier II would contain a supplemental reserve of materials already possessed by the government. The updated program provides for a Tier I stockpile of materials with goals valued at $700 million and a Tier II supplemental reserve of materials valued at $6.0 billion, based on market prices of May 31, 1985. The proposal is now before Congress, where the basis for the new stockpile goals will be examined. All of the materials recommended for stockpiling in Tiers I and II—with the sole exception of natural rubber (for aircraft tires)—are materials under the primary jurisdiction of the Department of the Interior. In proposing the new stockpile goals, the NSC emphasized the need for studies to identify new high-technology materials that may be required for future weapons systems.

1985 NET IMPORT RELIANCE [e][1] OF SELECTED NONFUEL MINERAL MATERIALS AS A PERCENT OF APPARENT CONSUMPTION[2]

U.S.A.



[e] Estimated.

[1] Net import reliance = imports − exports + adjustments for Government and industry stock changes.

[2] Apparent consumption = U.S. primary + secondary production + net import reliance.

REVIEWS

Physical Geology Text

EARTH, Fourth edition. By Frank Press and Raymond Siever. 1986. W.H. Freeman and Company, 41 Madison Ave., New York, NY 10010. 656 p. $32.95, hard cover.

This book is written primarily for beginning earth science students who have not had previous college science courses and who may not intend to specialize in geology. The emphasis is on concepts and examples of scientific study. Through the use of analogies to familiar processes ("kitchen physics" and "kitchen chemistry") and diagrammatic illustrations, Press and Siever show the evidential bases of geologic theories and the strong dependence of geology on the basic scientific disciplines of physics and chemistry.

The book is divided into three parts. Part I groups topics relating to the Earth as an evolving planet. Part II covers aspects of the Earth dominated by processes that result from the Sun's radiant energy impinging on the surface of the planet, on the atmosphere, and oceans. Erosion, transportation, and deposition of chemically altered and physically fragmented rocks, and the resulting sculpture of the surface, are discussed in relation to tectonics and the dynamics of the atmosphere and oceans.

Part III explores the consequences of the internal heat machine of the Earth and how it drives major movements of the interior and determines the structure of the whole planet. Internal heat, volcanism, and the kinds of igneous and metamorphic rocks that are produced by thermal processes are the subjects of the first group of chapters. The structure of the interior as deduced from seismology, gravity, and magnetism is then explored, in preparation for a detailed systematic explanation of plate tectonics. The deformational patterns of the continents and their mountain chains are treated in the context of the large-scale motions of the lithospheric plates. The book concludes with a chapter on Earth materials as resources, including an extended treatment of energy reserves and the central importance of energy costs in the recovery of all other resources.

This edition of EARTH incorporates the classical elements of geology with new findings in geoscience, such as satellite sensing, climate change, acid rain, and recent discoveries in astronomy.

✱ Volcanoes that have short-term eruption periodicities (100-200 years or less), or have erupted in the past 200-300 years, or both;

Cascades

1 Mount St. Helens
2 Mono-Inyo craters
3 Lassen Peak
4 Mount Shasta
5 Mount Rainier
6 Mount Baker
7 Mount Hood

Hawaii

8 Kilauea
9 Mauna Loa
10 Hualalai
11 Haleakala

Alaska

12 Augustine volcano
13 Redoubt volcano
14 Mount Spurr
15 Illimna volcano
16 Katmai volcano
17 Aleutian volcanoes

● Volcanoes that appear to have eruption periodicities of 1000 years or greater and last erupted 1000 years or more ago:

Cascades

A Three Sisters
B Newberry volcano
C Medicine Lake volcano
D Crater Lake (Mount Mazama)
E Glacier Peak
F Mount Adams
G Mount Jefferson
H Mount McLoughlin

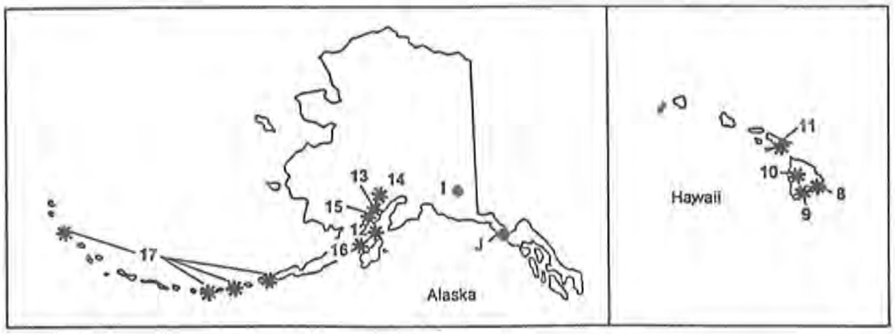
Alaska

I Mount Wrangell
J Mount Edgecumbe

✳ Volcanoes that last erupted more than 10,000 years ago, but beneath which exist large, shallow bodies of magma that are capable of producing exceedingly destructive eruptions:

AA Yellowstone caldera
BB Long Valley caldera
CC Clear Lake volcanoes
DD Coso volcanoes
EE San Francisco Peak
FF Socorro

This Figure is found on page 428



Location of potentially hazardous volcanoes in the United States. Within each group, volcanoes are listed in general order of decreasing probable cause for concern, subject to revision as studies progress. After R.A. Bailey, P.R. Beauchemin, F.P. Kapinos, and D.W. Klick, U.S. Geological Survey, 1983.

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.

Child's Book

MAPS & GLOBES. By Jack Knowlton. Pictures by Harriett Barton. 1985. Thomas Y. Crowell Junior Books, 10 East 53rd Street, New York, NY 10022. 42 p. $9.95, hard cover.

An engaging introduction to geography, this colorful, large-format picture book will be welcome both in the home and in the classroom. In clear, easy-to-understand language the author gives a brief history of map making and world exploration. He then explains to young readers about the differences between maps and globes, and gives basic map-reading pointers—information about directions, imaginary divisional lines, distance, and scale. Examples of a variety of different kinds of maps—physical maps, political maps, maps indicating land elevation—are shown.

The illustrations by Harriett Barton make up a distinctive and integral part of the book. The colorful pictures of maps and of children studying the maps and globes are both beautiful and accurate.

Geology of Oregon

TIME TRAVEL IN OREGON, a geology scrapbook. By John Eliot Allen. 1985. Available from John Eliot Allen, Emeritus Professor of Geology, Department of Geology, Portland State University, P.O. Box 751, Portland, OR 97207. 96 p. Paper cover.

This geology scrapbook consists of two years of weekly columns published in *The Oregonian* newspaper from November 1983-October 1985. At 77, this eminent earth scientist is busier than ever writing books, articles, memoirs, and a weekly column for *The Oregonian's* science section. Urged on by friends and colleagues, Professor Allen has compiled the articles from his earth science column.

Currently, Dr. Allen is completing "Cataclysms on the Columbia—a Layman's Guide to the Effects of the Catastrophic Bretz Floods in the Pacific Northwest." This follows Allen's first book on the same subject "The Magnificent Gateway—a Layman's Guide to the Geology of the Columbia River Gorge." This project detailed the formation of Columbia River Gorge, on which Allen is considered an authority. The gorge and many other features of Oregon's geology are included in this interesting collection.

Geology Textbook

GEOLOGY: Principles and Methods. By Jean Dercourt and Jacques Paquet. 1985. Gulf Publishing Company—Book Division, Box 2608, Houston, TX 77001. 384 p. $38.00 (plus $2.00 for handling), hard cover.

This undergraduate text presents a perspective on the principles, scientific methods, and techniques of geology, as well as the current theoretical concepts that emerge from them. To present an overview of geology basics, this richly illustrated translation from the French contains many examples of geological processes from around the world. The profusion of illustrations adds to the book, making points which both reinforce the text and make complete statements in themselves.

The authors point out that geology is a recent science that has progressed quickly. During the past 150 years, geological facts were established on three decisive levels: (1) the past landscapes of the earth, (2) the evolution and succession of the flora and fauna that inhabited earth, and (3) the determination by experiment of the conditions for rock formation.

Geology is truly an international and interdisciplinary subject. The dynamic nature of the earth is revealed here through examples that are interesting because of their foreign locale—the channel coast of France, Brittany, the Paris basin, the Jura Mountains, and the Massif Central.

Map Interpretation

AN INTRODUCTION TO GEOLOGICAL STRUCTURES AND MAPS. Fourth Edition. By G.M. Bennison. 1985. Edward Arnold, 3 East Read Street, Baltimore, MD 21202. 65 p. $8.95, paper cover.

This concise text leads the student by easy stages from the simplest ideas on geological structures through a first course on geological mapping. The author adopts an approach designed to help students working with minimum supervision or no supervision. Each new topic is explained in simple terms and is illustrated by text and exercises shown on succeeding maps. If students are unable to complete the problems they can read on to obtain more specific instructions on how the theory may be used to solve the problem in question. In addition, the structural problems presented in the text are shown on British Geological Survey maps (BGS) at the end of most chapters.

In this new edition, besides updating the terminology, three main changes have been made:

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the topic of isopachs (points of equal thickness), of wide application in economic geology, is introduced; more emphasis is placed on subsurface problems than in previous editions; and solutions based on broad interpretations of mapped outcrop patterns are then constructed.

The BGS maps provide an overview of structural features found throughout England.

Mineral Statistics

ARIZONA MINERAL INVENTORY LIST SYSTEM (MILS). By Dietz and Associates. For information write to Dietz and Associates, 4706 North 31st Drive, Phoenix, AZ 85017.

The Arizona MILS data base lists all the currently known mineral locations within the state. Data bases are available in three forms (bibliographies, indexes, and maps listed by individual counties). A total of 78 different commodities are listed including gold (3,100 occurrences) and silver (2,800 occurrences). The data base provides quick reference to users involved in mineral exploration in Arizona.

The information has been compiled using dBASE software, and may be ordered in either a dBASE II or dBASE III format for use with IBM PC's and Compatibles. All information contained within the data bases can be manipulated and extracted by the purchaser using standard dBASE commands or custom user programs.

Oregon Resources Map

MINERAL RESOURCES MAP OF OREGON (GMS-36). By Mark L. Ferns and Donald F. Huber. 1985. Scale 1:500,000. Six-color map, 42 x 59 inches. $8.00.

MINERAL RESOURCES MAP, OFFSHORE OREGON (GMS-37). By Jerry J. Gray and LaVerne D. Kulm. 1985. Scale 1:500,000. Four-color map, 42 x 59 inches. $8.00.

Both maps available from Oregon Department of Geology and Mineral Industries, State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201.

Mineral Resources Map of Oregon (GMS-36) covers the entire state of Oregon and provides mineral information from Oregon's east border to 131° west longitude in the Pacific Ocean. Past mineral production, current mineral exploration/production activities (as of 1983), and areas of potential resources are listed on the map.

This nontechnical map is intended for use by federal, state, and local authorities in assessing the impact of land use planning for mineral exploration and development, by private industry as a guide to identify areas favorable for discovery of new mineral deposits, and by the interested public.

Offshore Oregon Mineral Resources Map (GMS-37) covers the newly established Exclusive Economic Zone (EEZ) which extends 200 nautical miles offshore contiguous to the continental United States, its territories and possessions. The EEZ offshore Oregon is approximately equal in size to the state. EEZ covers the Gorda Ridge (currently being explored for minerals) and the Juan de Fuca Ridge, where hot springs and accompanying mineralization were discovered a few years ago. The bathymetry of the map enables the user to see the features that have been described in many recent newspaper and magazine articles.

The map is a nontechnical publication intended for use by the general public. It graphically depicts known mineral resources from the crest of the Coast Range to about 200 nautical miles beyond Oregon's coast line. It is also intended to aid federal, state, and local authorities in assessing the impact of possible future mineral exploration and development and to serve as a guide to private industry in identifying areas favorable for discovery of new mineral deposits.

Prospecting

THE ROCKHOUND AND PROSPECTOR'S BIBLE, a reference and study guide to rocks, minerals, gemstones, and prospecting. By L.J. Ettinger. 1985. Available from L.J. Ettinger, 16170 Rhyolite Circle, Reno, NV 89511. 136 p. $10.00 plus $2.00 postage, paper cover.

This book started as lecture outlines for adult community college classes in rocks, minerals, and prospecting. The author noted that many persons interested in rockhounding do not have access to college classes and that few publications were available for the person who wants to learn the basics of rocks and minerals at home.

Numerous tables and figures are included in this reference and study guide. Rocks and minerals are described in relation to the geologic environments in which they occur.

This is a useful ready reference for prospectors, miners, rockhounds, and others interested in learning more about rocks, minerals, gemstones, and prospecting. ⚒

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. . . AVAILABLE PUBLICATIONS . . .

LAND CONSERVATION UNIT PUBLICATIONS

The California Department of Conservation includes the Land Conservation Unit (Williamson Act Program and Soil Conservation Advisory Committee), and the Farmland Mapping and Monitoring Program.

The following publications are available (price includes postage and handling):

Advisory Guidelines for the Farmland Mapping and Monitoring Program (FM-84-01), April 1984, $2.00.
California Soils: An Assessment (Draft), April 1979, $12.50.
California Soil Conservation Report (Report of Independent Select Committee), July 1983, free.
Erosion and Sediment Control Handbook, May 1981, $3.75.
Farmland Mapping and Monitoring Program: Status Report 1985 (SP88), 1986, free.
Fifty Years of Soil Conservation, In cooperation with the California Association of Resource Conservation Districts 1985, free.
Index to Soil Surveys in California, December 1982, free.
(soon to be updated)
Recommendations for a California Soil Conservation Plan, Draft March, 1986, free.
Soil Conservation Advisory Committee: First Year Report, 1985, free.
Windbreaks for Conservation: An Annotated Bibliography (WB-84-01), April 1984, $4.00.

Order these publications from: Division of Mines and Geology, Information office, 1516 Ninth Street, Fourth Floor, Sacramento, CA 95814.

In addition the following publication is also available:

Erosion and Sedimentation Study of a Portion of The Geysers-Calistoga KGRA, prepared under contract to the California Energy Commission (P700-82-011), November 1982, $2.50.

Order this publication from: California Energy Commission, Publications Section, 1516 Ninth Street,First Floor,Sacramento, CA 95814. ⚒

GSA GUIDEBOOKS

The Cordilleran Section of the Geological Society of America has a limited number of guidebooks available from the March 25-28, 1986, 82nd annual meeting at Los Angeles. The guidebooks are:

Vol. 1, Landslides and landslide mitigation in southern California, 201 pages, $15.00.

Vol. 2, Neotectonics and faulting in southern California, 208 pages, $15.00.

Vol. 3, Hydrogeology of southern California, 148 pages, $13.00.

Vol. 4, Cenozoic stratigraphy, structure and mineralization in the Mojave Desert, 144 pages, $13.00.

Vol. 5, Mesozoic and Cenozoic structural evolution of selected areas, east-central California, 94 pages, $10.00.

Vol. 6, Mojave Desert xenolith suites; Peninsular Ranges batholith; and Geology and hydrology of Catalina Island, 36 pages (3 papers), $4.00.

If ordering the entire set of six volumes, the price is $60.00, discounted from $70.00. For each volume ordered, please add $1.50 shipping and handling. For three or more volumes, or if the entire set is ordered, please add $4.00 for shipping and handling. Be sure to include your name and address for shipping.

Make checks payable to: Cordilleran Section, GSA, and send orders to: GSACS Guidebooks, Martin L. Stout, Department of Geology, California State University, Los Angeles, CA 90032. ⚒

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OFR 86-3 SF

SUMMARY REPORT — FAULT EVALUATION PROGRAM, 1984-1985, SOUTHERN COAST RANGES REGION AND OTHER AREAS. By E.W. Hart, W.A. Bryant, M.W. Manson, and J.E. Kahle. March 1986. One plate (1:500,000 scale), 2 figures, 1 table, 8-page text. $5.00.

The report summarizes the results for the seventh of ten regions to be evaluated under the statewide Fault Evaluation Program. (The first six regions evaluated are in coastal and central California and are summarized by Open File Reports 77-8 SF, 78-10 SF, 79-10 SF, 81-3 SF, 83-10 SF, and 84-52 SF). This summary includes the Coast Ranges south of Monterey and Hollister, as well as selected areas in Ventura, Los Angeles, and Orange counties. During 1984-1985, numerous potentially active faults were evaluated relative to the hazard of surface fault rupture. Those faults judged to be Holocene-active and well-defined surface features were recommended for zoning under the Alquist-Priolo Special Studies Zones Act. Data on the recency of faulting and recommendations for zoning are summarized on Plate 1 and Table 1 of the report.

Thirty-two new and revised Special Studies Zones maps were issued for Preliminary Review on January 1, 1986, as a result of this work. The proposed zones encompass segments of the San Andreas, Calaveras, Paicines, San Simeon, San Cayetano, Newport-Inglewood, and other faults.

OFR 86-3 SF can be obtained from the Bay Area Regional Office, Information Section, 380 Civic Drive, Suite 100, Pleasant Hill, California 94523-1997, telephone (415) 671-4920, and the Public Information Office, 1516 Ninth Street, Fourth Floor, Sacramento, California 95814, telephone (916) 445-5716. ⚒

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SPECIAL PUBLICATION 87

PLACER GOLD RECOVERY METHODS. By Michael Silva. 1986. 32 p. $2.50.

This publication is designed for those interested in the various aspects of placer gold recovery. There are many different types of efficient placer gold recovery systems available today. Factors considered in the design of a placer gold recovery operation at a particular site must include: initial and operating costs versus recovery, ore grade and volume, gold size distribution, and processing capacity. Special Publication 87 is well illustrated with figures, tables, photos, and detailed explanations that describe the placer gold recovery equipment and methods that are commonly used. Particular emphasis is placed on descriptions of modern gold recovery technologies such as rotating spirals, shaking and rotating tables, tilting frames, bowl concentrators, dry washers, and jigs.

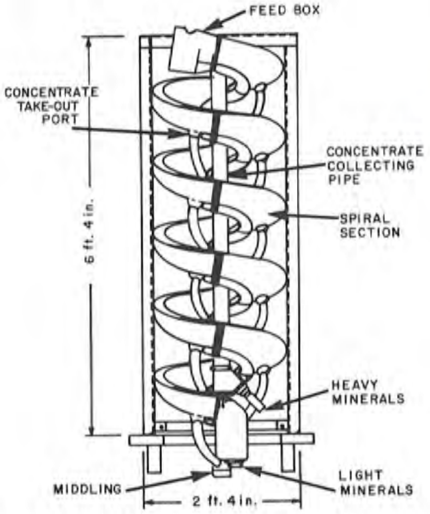

Diagram of a modern Humphreys spiral concentrator. This gold concentrating device exploits differential densities of placer materials by a combination of sluicing and centrifugal action.

A long tom in use near Auburn, California, early 1850s. The long tom is a trough for washing gold-bearing placer and is longer than a rocker. *Photo courtesy of Wells Fargo Bank History Room.*

Chapter 3—Small Scale Recovery Equipment—includes information on the traditional time-tested gold pans, rockers, sluices, and shaking tables as well as information on modern portable processors such as the Denver Gold Saver. A brief discussion of the amalgamation process is also included in this section.

Most high-capacity gold mining equipment has been heavily modified and modernized since the 1800s. In addition, new more efficient equipment and methods have been introduced. Today gold may be profitably recovered from ores containing only 5 parts per million of the metal. The chapter on Modern Recovery Equipment gives a straight-forward, understandable explanation of how these various gold recovery machines and methods are used. Results of gold recovery test runs are included where available to show the effectiveness of the different designs.

The final chapter—Operating Mines—explores the gold recovery equipment and techniques used at four operating mines in California: (1) the Yuba-Placer dredge operation in the Hammonton dredge field on the Yuba River, (2) Hansen Brothers Sand and Gravel operation on the Bear River, (3) Hansen Brothers Greenhorn Creek operation, and (4) the TRI-R Engineering operation north of Nevada City. ⚒