STATE OF CALIFORNIA
GOODWIN J. KNIGHT, Governor
DEPARTMENT OF NATURAL RESOURCES
DeWITT NELSON, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

SAN FRANCISCO | BULLETIN 176 | DECEMBER 1957

MINERAL COMMODITIES OF CALIFORNIA

GEOLOGIC OCCURRENCE, ECONOMIC DEVELOPMENT AND UTILIZATION OF THE STATE'S MINERAL RESOURCES

Revision of Bulletin 156

Prepared Under the Direction of
OLAF P. JENKINS

Edited by
LAUREN A. WRIGHT

Price $7.50

SULFUR AND SULFURIC ACID

By Philip A. Lydon

During 1954, the total sulfur production in California was equivalent to 251,900 tons of 100-percent sulfur. Only 63,300 tons of this came from sulfur deposits; the remainder was recovered from crude oil and gas. This output fell far short of supplying the numerous sulfur-consuming industries of California. Most of the sulfur used by these industries is obtained from deposits in Texas and Louisiana from which sulfur is recovered by the Frasch process. Most of the industrial sulfur consumed in this state is used to manufacture sulfuric acid. In 1954, pyrite estimated to be equivalent to 64,007 short tons of 100-percent sulfur was mined in California for this purpose (see section on pyrite in this bulletin). The markets and uses for sulfur and sulfuric acid are diverse, and include almost all phases of industrial technology.

MINERALOGY AND GEOLOGY

Sulfur normally occurs as well-developed bipyramidal or tabular orthorhombic crystals, and as earthy or disseminated masses. The mineral has a resinous luster, a yellow or gray color, a hardness of 1.5 to 2.5, and a density of 2.05. Sulfur melts in the range 234° to 248° F., and ignites in air at a temperature of 478° F.

Native sulfur occurs in salt-dome caprock, as sedimentary beds, and as deposits associated genetically or spatially with volcanism. Most of the sulfur consumed in the United States is obtained from the Gulf Coast of Texas and Louisiana, where salt domes of various sizes have intruded great thicknesses of sedimentary rock. Many of these domes are capped by limestone, sulfur, anhydrite, and gypsum. The sulfur commonly occurs as a replacement of the limestone. Most of the zones of sulfur-bearing limestone are between 25 and 300 feet thick, and cover salt domes 100 to 2,000 acres in extent. Millions of tons of sulfur are produced annually from these deposits by means of the Frasch process, in which superheated water is injected into the deposit through part of a bore hole while melted sulfur is pumped to the surface through another part.

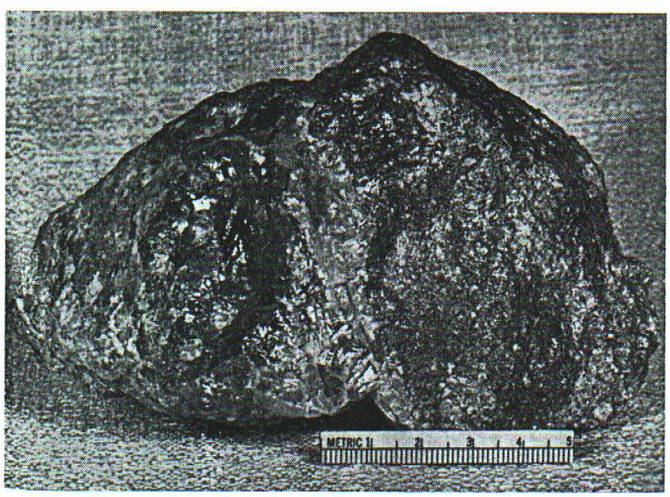

Figure 1. Specimen of sulfur ore from Leviathan mine, Alpine County. Stringer of sulfur (greasy luster) in altered andesite. *Photo by Mary Hill.*

Sulfur deposits of volcanic origin contribute about 3 percent of the total annual world production of sulfur. Japan, with an output of approximately 200,000 tons yearly, has been the principal producer from this type of deposit. Other countries that produce sulfur from volcanic deposits are New Zealand, Formosa, Indonesia, Italy, Spain, Mexico, South American countries along the Andes Mountains, and the United States. Production in this country has come from California, Colorado, Idaho, Nevada, Utah and Wyoming. The largest reserves of native sulfur of volcanic origin are in the Andes Mountains, where an estimated 100 million tons of ore are distributed among more than 100 deposits. Japanese reserves have been estimated at 60 million tons of 30-percent sulfur in 18 deposits (Bonfield, 1955).

Most sulfur of volcanic origin occurs as disseminations, massive replacement bodies, or veins. Disseminated sulfur is characteristic of deposits in which the ore grade is less than 50 percent, although such disseminations commonly form envelopes about richer massive replacement bodies. Large veins usually are found in the lower parts of deposits where the wall-rock is relatively unaltered. Sulfur formed by hot-spring action may be deposited in sediments at the bottoms of warm lakes. Sulfur also forms as liquid flows from volcanic vents, as cement in near-surface alluvium, and as sublimates about sulfurous gas vents.

OCCURRENCES IN CALIFORNIA

Almost all of the native-sulfur deposits in California are associated with volcanic rocks. Production has been reported from Alpine, Colusa, Imperial, Inyo, Kern, Lake, and Shasta Counties. By far the two most productive localities have been the Leviathan mine in Alpine County and an area on the west slope of the Last Chance Range in Inyo County. The entire output of the Leviathan mine is shipped to Yerington, Nevada, where it is converted to sulfuric acid. Some of the material from the Last Chance Range has been concentrated and shipped to Los Angeles for use in the manufacture of sulfuric acid; some also has been trucked to the Bakersfield area for use as soil sulfur.

Alpine County. The Leviathan deposit, 9 miles east of Markleeville, consists of sulfur in equant masses, stringers, and veins, in a gray, altered, porphyritic andesite. It is hourglass-shaped in plan, with the long axis trending northward, and is flat-lying and saucer-shaped in section. The deposit has a maximum thickness of 135 feet, and is successively overlain by an average of 150 feet of kaolinized agglomerate and about 100 feet of tuff that has been silicified at the surface. Thin beds of sulfur interfinger with volcanic breccias and tuffs at points approximately a mile south and a mile west of the present pit, and large dikes of sulfur cross-cutting water-laid tuffs formerly could be seen in old underground workings.[1] The mined ore has averaged

[1] G. H. Curtis, Professor of geology, University of California, personal communication, Oct. 1955.

about 28 percent sulfur and contains a minor amount of pyrite and traces of cinnabar. Early analyses showed that the ore contained only negligible amounts of arsenic, antimony, magnesia, lime, alumina, and mercury. A small amount of selenium is recovered during treatment of the ore.

Because it is more economical and allows better ventilation and fire-control than is possible in underground workings, an open pit is used to work the Leviathan ore body. The pit is 1,500 feet long and 600 feet wide. The large volume of overburden it has been necessary to remove has resulted in an ore to waste ratio of about 1 to 11. The sulfur-bearing rock is mined with 15-foot benches, using 5-foot vertical blasting holes in a 9- by 8-foot pattern. The altered host rock contains scattered blocks of tough, relatively fresh rock that sometimes render drilling and loading of ore difficult. In 1955, one man was operating a 2,300-pound dropball, taking the place of four or five men formerly engaged only in secondary blasting. The mined material is loaded into trucks that take it to a crushing unit west of the pit. Here it passes through a jaw crusher and an $\frac{1}{8}$-inch vibrating screen. Fragments less than an eighth of an inch in diameter average between 12 and 18 percent sulfur, and are rejected in order to improve the ore grade. The crushed ore is trucked to Weed Heights, near Yerington. Here it is crushed again, ground, and roasted exothermically in FluoSolids reactors. The resulting sulfur dioxide gas is cooled in a water-spray chamber and passed through a series of cyclone precipitators to remove most of the dust load. The gas is then scrubbed, passed through Cottrell mist-precipitators, and sent to a contact sulfuric acid plant.

The Leviathan mine was discovered in 1863 and was first worked for copper and gold. It was abandoned shortly afterward and remained inactive until about 1894, when it was reopened and 200 tons of copper ore were mined. Abandoned again, it lay idle until the early 1930's, when the Leviathan Sulphur Company was organized to exploit its sulfur. Development and moderate production marked the period 1933-34, after which no further shipments were made until mid-1953. In March, 1936, the property was leased to Texas Gulf Sulphur Company and was maintained under an assignment of that lease by the Calpine Corporation of Los Angeles. In 1941, Calpine Corp. surrendered its lease to Leviathan Sulphur Co., and in 1945, Siskon Mining Corporation, a subsidiary of Texas Gulf Sulphur Co., purchased the mine. Anaconda Mining Company acquired the property in 1952 as a source of sulfur for the manufacture of sulfuric acid to be used in leaching low-grade copper ore near Yerington, Nevada. Contracts for an access road and overburden stripping were let, and mining of the ore body began in July 1953.

FIGURE 2. Leviathan open-pit mine, Alpine County. Sulfur orebody is overlain by kaolinized agglomerate and tuff. Upper surface of orebody marked by line. View to northeast.

Colusa County. A small amount of sulfur has been produced from the Elgin mine, near Wilbur Springs, in Colusa County. The sulfur deposit at the Elgin mine is in shale and serpentine and lies only a short distance from the margin of a large body of serpentine. Sulfur occurs sparingly in cracks and fissures and forms a cement in the few feet of overlying soil and debris. Hot springs and sulfurous gases issue from a number of points on and near the property.

Unconfirmed reports state that unsuccessful attempts were made to produce sulfur on a commercial basis prior to 1888, and again in 1891, 1909 and 1916 (Bradley, 1918, and Logan, 1929). In 1918, two 12-foot-high steam retorts were installed, and about 3 tons of ore were mined and treated experimentally before a drop in prices after World War I forced the operation to close down. No more sulfur was mined until 1929, when a steam-retort unit and storage tank were constructed. A total of 265 tons of ore were mined before this operation was abandoned in 1932. Some exploration for sulfur was later conducted west of the mine, probably within the last 5 years, but no production has been reported. When visited in October 1955, the mine was idle.

Imperial County. The Full Moon sulfur deposit (Tucker, 1926) is on the southwest slope of the Chocolate Moutains in north-central Imperial County. It is a surficial deposit in which sulfur occurs in disseminations and seams in tufa. It was located in 1928, and subsequently was developed by several open pits, shallow shafts, and short tunnels.

The Coyote Mountain gypsum and sulfur deposit, 7 miles north of Coyote Wells, consists of brown, iron-stained gypsum mixed with 2 to 5 percent elemental sulfur. The sulfur occurs in slightly greater abundance along a northeastward-trending fault zone that cuts granite, schist, and limestone. Development has been by means of pits and an open cut in the hillside. Vesubio Mining Corporation, Ltd., has leased this property since the early 1930's. Soil sulfur and refined dusting sulfur were produced by this company at their plant in Calexico from 1940 to 1942. However, ore for this plant came from the company's mine in Baja California, and not from Imperial County as has been previously reported (Sampson and Tucker, 1942). Equipment at the Baja mine was damaged by fire in 1942, and raw material for the Calexico plant has since been secured from Texas.

Inyo County. The sulfur claims on the west slope of the Last Chance Range, east of Big Pine, yielded almost a third of the native sulfur produced in California be-