CHAPTER 47
SULPHUR AND PYRITES
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The forms in which sulphur is commonly found—native sulphur, sulphides of many metals and sulphates—are widely distributed throughout the world. The two first mentioned are the principal sources of sulphur. Substantial amounts of sulphur in some form are recovered from gases from industrial plants and from gases from smelters treating other minerals. In recent years, plants have been installed in the United States to recover sulphur in elemental form from sour gases. The amount of sulphur so produced is small at the present time but undoubtedly will increase in the future. The recovery of sulphur from gases is not covered in this chapter, which is confined to: (1) native sulphur deposits of Texas and Louisiana; (2) those of Italy; (3) other scattered deposits of native sulphur; and (4) pyrites deposits found in many countries of the world.

Sulphur, a nonmetallic element, occurs normally in well developed bipyramidal or tabular crystals of the orthorhombic system, as well as in stalactitic and earthy masses. The mineral has a distinctive yellow color, which may be dark and discolored by impurities; the streak is white; the luster is resinous; and the fracture is conchoidal to uneven. Sulphur is translucent to opaque; has a hardness of 1.5 to 2.5, a specific gravity of 2.05, and an atomic weight of 32.06.16 The molecular weight of the solid is expressed by the symbol \( S_8 \) and that of the liquid and vapor ranges from \( S_2 \) to \( S_6 \), depending on the temperature. Sulphur melts at a temperature between 234° and 248°F, depending on its crystalline state, to a liquid of dark amber color, the boiling point of which is 832°F. The viscosity near the melting point is about that of water and increases to 50,000 times that of water at a temperature of 380°F, subsequently falling rapidly to a low figure at the boiling point. Crystallization changes slowly from rhombic to monoclinic above 205°F and in cooling the transformation is reversed. The mineral is a very poor conductor of heat and electricity; it is insoluble in water and nearly all acids and is soluble in cold carbon bisulphide and carbon tetrachloride. It ignites in air at a temperature of 478°F, burning with a distinctive blue flame with evolution of sulphur dioxide.17

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SALT-DOME SULPHUR DEPOSITS

The sulphur deposits within the area bordering the Gulf of Mexico in Texas and Louisiana are of primary economic importance because of their known and potential reserves, their productive capacity, the ability to market this basic commodity at a reasonable price, and the unequaled purity of the product as mined. These are the commonly called salt-dome type deposits. The structures with which sulphur is associated may be described as submerged islands of rock lying at irregular intervals in a sea of unconsolidated sediments of great areal extent and unknown depth.

Sediments—The territory in which these domes are found is uniformly low-lying and flat, with little topographical relief other than occasional mounds, which evidently are the result of salt-dome intrusion. The areas contiguous to the Gulf of Mexico, and extending irregular distances inland, are composed largely of sea marshes with numerous shallow bays, lagoons, lakes, and bayous. The surface farther inland rises very gently by a series of inconspicuous terraces, probably former shore lines, and finally merges at its interior border into a low, rolling terrain. Drilling has not reached depths much greater than 15,000 ft but it is generally assumed that sedimentary formations are not less than 20,000 ft thick, as illustrated in Fig 1. The formations dip and thicken in a southerly direction toward the Gulf of Mexico and they have a slight pitch in an easterly direction. It is evident that the sediments were deposited when and where the larger streams met encroaching waters of the Gulf of Mexico. Geologists are now able to describe this process in great detail and apparently to reach logical conclusions on the age of formations and methods of deposition as a result of intensive drilling for the past 30 years.

Salt—The salt, which is the basic formation of all domes of the Gulf Coast, is an essentially dry, compact, and coarsely crystalline halite. Anhydrite is the principal accessory mineral and, occurring as scattered grains and small crystals of sand size, averages from 5 to 10 pct of the salt mass. The top of the salt on some domes is rather flat, while others exhibit a domal or anticlinal shape. Salt domes usually have a circular outline with steeply dipping flanks but some show an elliptical tendency in configuration. In a few instances, salt lies within 100 ft of the surface and in contact with unconsolidated sediments, but usually it is immediately overlain with cap rock. Available evidence indicates that salt has intruded the sediments at great depths from mother beds of unknown geologic age. Weight of the sediments upon the salt evidently is the force that caused the intrusion. A factor that has been suggested

* Publications of the American Association of Petroleum Geologists contain numerous papers on Gulf Coast stratigraphy and salt-dome geology.
as contributing to the present position is subsidence of sedimentary formations resulting from settlement of the basement series.\textsuperscript{6,17,50}

\textit{Cap Rock—}Cap-rock formations,\textsuperscript{10,24,73} consisting of limestone, gypsum and anhydrite and underlain by salt, differ materially in features such as size, depth, thickness, and configuration, as well as in the relative proportions of principal and accessory constituents.\textsuperscript{27} Typical cross sections of sulphur-bearing cap rock are illustrated by Fig 2. The mineralogical basis of this series of formations is a hard and dark gray

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Theoretical cross section of part of Louisiana Gulf Coast. Showing estimated depths to older formations not reached in drilling, “mother salt beds” and basement complex, and the relationship of different types of salt plugs to the sediments. Adapted from Storm\textsuperscript{74} and others.}
\end{figure}

anhydrite superimposed on and lying in contact with salt. Gypsum, when present, may be a dense gray variety or a porous white material containing lenses, nodules, and well developed crystals of selenite. Limestone strata are relatively large in comparison with gypsum and anhydrite. Limestone may be present as a single stratum, as a series of lenticular beds covering only a portion of gypsum and anhydrite, or in disseminated lenses and nodules included in the upper portion of the series. The limestone is typically a fine-grained gray carbonate inter-spersed with vugs, seams, fissures and cavities, which may be partly or wholly filled with calcite. Siliceous solutions have frequently indu-rated the limestone in the upper portions, where it is usually barren of
sulphur. Domes exhibit variations in thicknesses of cap rock from less than 50 ft to more than 1000 ft. A universal constituent of cap rock is water highly charged with hydrogen sulphide, polysulphides, sodium chloride, and other salts, and having a temperature of approximately 100°F.

Current publications discuss two principal processes, with minor modifications, explaining the origin of cap rock, and both of these assume
Fig 2—Typical cross sections of sulphur-bearing cap rock on some salt domes.
the intrusive origin of the salt structure. One theory is that anhydrite was an original formation with and overlying the salt beds before inception of the movement and that it has been lifted to its present position with the salt. The other theory is based on the assumption that circulating waters dissolved vast quantities of salt during its upward movement. Its anhydrite content was thus concentrated as an insoluble residue on top of salt. Anhydrite was subsequently compacted and recrystallized by the same forces causing the salt intrusion, into the hard and dense cap rock that lies as a mantle on nearly all salt domes.

Both theories assume that gypsum was formed by hydration of anhydrite. Structural and petrographic studies indicate that limestone, at least in part, is an alteration product of these formations. The amount of coarsely crystalline calcite present is very suggestive of the important part played by circulating waters.

Sulphur Formations—Sulphur of mineralogic interest is quite persistent in many cap-rock formations but deposits of sufficient size to warrant development have been found on a small percentage only of the known domes. The principal deposits usually are confined to the lower parts of the limestone and in some places substantial amounts extend into the gypsum. Sulphur occurs as well-developed crystal aggregates in the seams and cavities of the porous limestone and also in a semicrystalline or massive state as a filling in the openings of formations. The thickness of the barren cap rock varies from a minimum of 5 or 10 ft to a maximum of 200 ft. The thickness of the sulphur horizon is seldom less than 25 ft and may reach 300 ft as a maximum, the average for bodies of economic size approximating 100 ft. For a few feet, sulphur may be in practically pure state, but the average content of formations for the various deposits ranges from 20 to 40 pct. These deposits differ markedly in reserves, as illustrated by mines that have been depleted. Sulphur, Louisiana, with a cap-rock area of 75 acres, produced 9,412,165 tons; Bryamround, Texas, with a cap-rock area of 800 acres, produced 5,001,068 tons; Palangana, Texas, with a cap-rock area of 1800 acres, produced 236,662 tons; Gulf, Texas, with a cap-rock area of 300 acres, produced 12,000,000 tons; Jefferson Island, Louisiana, with a cap-rock area of 400 acres, produced 438,811 tons. The average porosity of the sulphur-bearing formations is generally assumed to be between 15 and 25 pct.

Distribution of Salt Domes

The area in which coastal salt domes are found extends from slightly east of the Mississippi River to the vicinity of Corpus Christi, Texas, and inland from the Gulf of Mexico for approximately 75 miles. The presence of 119 domes has been definitely established by drilling within this territory, comprising nearly 45,000 square miles. Many other
deeper structures have been indicated by geophysical surveys. Most of the proven structures have been prospected for sulphur, some more thoroughly than others. Production of importance has been secured from 12 domes, which include Sulphur, Louisiana, by the Union Sulphur Co.; Bryan mound, Hoskins Mound, Texas, and Grande Ecaillle, Louisiana, by Freeport Sulphur Co.; Gulf, Newgulf (located on Boling dome), Long Point, and Moss Bluff, Texas, by Texas Gulf Sulphur Co.; Palangana, Boling (on Boling dome), and Orchard, Texas, by Duval Texas Sulphur Co.; and Jefferson Island, Louisiana, Clemens, and Long Point, Texas, by Jefferson Lake Sulphur Co.

There are known salt domes or similar structures in regions other than the Gulf Coast of Texas and Louisiana but none of them has reserves worthy of development. Those best known include interior domes of Texas; interior domes of Louisiana; Rumanian salt domes; German salt domes; salt domes of the Isthmus of Tehuantepec; Persian salt domes; the Emba region of USSR; and salt structures in Colorado and Utah.

The discovery of a salt dome in Mississippi in 1937 established the presence of a new salt-dome basin, which was found to extend into Louisiana and Alabama by subsequent drilling. Additional domes were rapidly discovered and by October 1948 there were 42 proven domes. Although 21 of the shallow domes in the Mississippi basin have been prospected for sulphur, no deposits of importance have been developed. As a result of geophysical surveys started in 1944, six salt domes have been proven in the maritime strip that extends seaward from Louisiana and Texas coasts. It is expected that additional domes will be discovered in this area, which is geologically an extension of the coastal salt-dome basin. The potential value of this maritime strip, from the standpoint of sulphur, is questionable, owing to the great hazards and high costs that can be visualized for mining sulphur at exposed locations in the Gulf of Mexico, where the depth of water ranges from 20 to 50 ft.

**Exploration and Mining of Salt-dome Deposits**

Since 1924, geophysical methods have played an important part in prospecting and locating structures favorable for sulphur deposits. The normal procedure includes seismograph and gravity-meter surveys of large areas. When rock structure is indicated, it is customary to supplement the seismograph or gravity meter with a torsion balance to secure more detailed information on size, depth, and configuration of cap-rock area. A few wells may then be drilled at scattered locations at distances ranging from 500 to 1000 ft or more. When sulphur is encountered, a systematic drilling and sampling program is carried out. Conventional oil-well rotary equipment is used. The accurate sampling of sulphur formations for estimation of reserves is difficult because of the
loss of returns in porous formations and also because of soft, friable nature of sulphur, which may lead to the impoverishment of samples when coring. Bailers and sand pumps are used to recover cuttings and thus improve coring results. The reverse return with air is another method commonly used. An airlift by this method induces a flow of water and cuttings into the drill stem and to the surface equipment for dividing and settling. This method is considered less expensive and more accurate than coring.

The early history of the Frasch process at Sulphur, Louisiana, was recounted with great interest by Herman Frasch in an address upon receipt of the Perkin medal. Since then a number of deposits have been found, developed, and a few abandoned because of depletion. Publications for the past 20 years contain comprehensive descriptions of methods and practices. Typical well equipment and the principles of sulphur mining by the Frasch process are illustrated by Fig 3. The following discussion will be confined to a few specific phases of the subject.

The Frasch process requires water in quantities varying with size of plants from 1,000,000 to 10,000,000 gal per day. The water, being heated from atmospheric temperature to at least 300°F, must be fairly pure originally and must be carefully treated to control corrosion and scale. In comparatively recent years, improvements in water-treating processes and equipment have added materially to the efficiency of power plants. High-pressure boilers, which require water of good quality at all times, contribute to high efficiency and to a favorable heat balance by maximum use of exhaust steam. Sulphur deposits of Texas and Louisiana have been generally fortunate in lying in close proximity to large rivers. The water occasionally becomes high in salt content where mines are situated near the Gulf of Mexico, and large reservoirs are employed to store good water when available. Fuel to heat the water usually constitutes one of the largest items of expense. A reliable supply at reasonable costs is therefore an important factor in production of sulphur by the Frasch process.

In equipping a sulphur property for production, probably the largest single item of cost is the central heating and power plant. The first requisite for the plant is continuity of operations because interruption of hot water to wells would endanger their loss by freezing of sulphur. The principal function of boilers, the largest part of power-plant equipment, is to convert one fourth of the water to steam. The temperature of all the water is then raised by the steam in mixing-type heaters to that required for mining purposes. The plant also furnishes steam for turbine-driven centrifugal pumps to transport water through thousands of feet of insulated pipe lines to wells and underground formations. It also has equipment for compressing air for raising the liquid sulphur to the sur-
FIG 3—TYPICAL WELL EQUIPMENT FOR SULPHUR MINING.
face, as well as electrical equipment to generate power. Electrically operated equipment is now used for many purposes such as drilling, lighting, pumping water and liquid sulphur, loading and transportation of sulphur, and operation of maintenance facilities including machine, blacksmith, carpenter, and electric shops. Waste formation water, about equivalent in volume to that used for mining purposes, can be treated with plant stack gases or aerated to eliminate the sulphide content before disposal. Modern plants for sulphur mining have attained a comparatively high degree of efficiency. From 75 to 80 pct of total heat in the fuel is put into the water by boiler equipment, and, in addition, a substantial part of the heat in stack gases can be utilized.

The Bryanmound sulphur deposit, except for two short suspension periods, was in operation from 1912 to 1935. At one period in its history, Bryanmound, with an installed plant capacity of 23,000 boiler horsepower, delivered daily about 9,000,000 gal of water for mining purposes with a fuel consumption of approximately 4500 bbl of oil. The cap-rock area comprises approximately 800 acres but the major part of production was secured from 296 acres. During the life of Bryanmound, 1897 wells were drilled. The average production was 2635 tons per well.

The maximum depth from which sulphur can be mined by the Frasch process has not been established. Depth limitations probably will be determined by costs rather than by engineering difficulties. Sulphur has been produced profitably from 2300 ft at Hoskins Mound, Texas. Mining from very shallow depths could involve problems in maintenance of necessarily high temperatures and pressures for water.

Formation conditions that are favorable for the Frasch process include a thick and rich deposit of sulphur; absence of overlying barren cap rock, which retards or prevents subsidence of upper sedimentary formations into cavities; impervious strata above and below the sulphur deposit to prevent escape of hot water; and a uniform porosity to assist in an even distribution of hot water. A substitute method for filling the largest voids and channels in the rock structure has been developed because subsidence does not always take place naturally and quickly. The desired effect is a more uniform porosity to increase the efficiency of hot water. Mud is pumped into wells, at locations remote from mining areas, until the pressure reaches 200 or 300 lb. The amount of mud applied varies greatly, ranging from 25,000 to more than 300,000 cu yd per well. Innovations in methods of applying mud to formations offer interesting avenues for improvements in mining sulphur.

Sulphur produced by the Frasch process is exceptionally free from foreign materials and by analyses shows a very small ash content, usually less than 0.01 pct. An explanation for this fortunate condition is the relatively greater wettability of gangue rock compared with sulphur. Thus the fine gangue rock when wet by hot water is either washed away
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from the vicinity of the well or floats on the surface of liquid sulphur and does not contaminate it. Organic impurities, such as petroleum residues, soluble in sulphur, infrequently contaminate and discolor the product. When this occurs quality and color can be improved by distillation or by adsorption.

ITALIAN SULPHUR DEPOSITS

The sulphur deposits of Sicily are among the outstanding mineral deposits of the world, owing to their long history and their known and potential reserves. Unique methods of beneficiation developed under adverse conditions add further interest to the history of these deposits. The Italian sulphur industry has experienced vicissitudes of many kinds. Development of the Frasch process resulted in a severe reduction in its markets and the value of the product. In addition, the recent war caused complete suspension. The resumption of operations has been slow, difficult and expensive, as illustrated by production. In 1939, the production was 350,208 tons; in 1944, it was an estimated 37,000 tons; and in 1947, it was 169,273 tons.

Formations—An ideal section of formations includes yellow, loosely cemented sandstone, argillaceous marls and blue clay, foraminiferous limestone interbedded with clay, and below this series of sediments the gypsum and sulphur-bearing formations. The entire region was subjected to severe faulting and folding which, together with erosion, complicated the regional geology and resulted in a rolling and semimountainous terrain. The sulphur-bearing member of these formations is composed of a series of strata of brownish cellular limestone interbedded with bituminous shales, but the continuity is not equivalent to that of the overlying gypsum. The sulphur-bearing formations lie in isolated basin-like deposits 1 to 5 miles long; the width varies from 1000 to 3000 ft and the thickness may reach a maximum of 200 ft. In the larger deposits, sulphur usually is disseminated through the limestone; it may lie in thin seams parallel to the bedding or may occur as well-developed crystals in the porous phases of the rock. The grade of ore as mined lies between 12 and 50 pct, the estimated average being 26 pct.

Distribution—The region of sulphur deposition in Sicily is confined to the south central part. The deposits are included in an area of approximately 495 square miles, constituting 5 pct of the island. There were 99 mines producing in 1939 and the 13 largest produced 70 pct of the total. Relatively important deposits, similar to the Sicilian, occur on the mainland, and the principal mines are found in the northeastern part of Italy. The mines are usually inferior to those of Sicily; yet the production before World War II reached one third of all sulphur produced by Italy.
Mining—Methods of mining and beneficiation are the most highly developed for any deposits of this type in which the ore is brought to the surface through mine openings such as shafts, tunnels, and drifts. This was brought about by the great number of years the Sicilian mines have been in operation and also by the size and extent of the deposits.\textsuperscript{61,62} The largest mines have installed mechanical equipment for stoping, tramming, and hoisting. Development has been carried to 1400 ft in depth with workings extending great distances from the outcrops. Where beds are flat, the room-and-pillar system is used, and after pillars have been robbed rooms are closed by waste filling or caving of the roof. The longitudinal cut-and-fill method of stoping is commonly employed in the larger mines, especially where the dip is steep. Development work is carried well ahead of extraction, and the mines can thus be worked efficiently and with high recovery. The danger of fires, particularly in the richer deposits, is a serious hazard. Hydrogen sulphide in pockets in the formation is an additional source of danger. Pumping large volumes of water constitutes a considerable item of expense.

Preparation—At one time the Calcaroni method was employed almost universally. This method employs skillfully constructed piles of ore 15 to 100 ft in diameter and 3 to 15 ft deep.\textsuperscript{61} When the ore is ignited, part of the sulphur is burned. The heat of combustion liquefies the remainder and about one half of the sulphur is recovered. The Gill regenerative furnace was developed about 1880 to improve on the efficiency of the Calcaroni and to reduce the quantity of objectionable gases. This furnace consists of a series of masonry kilns, eight being the maximum, which are arranged in circular form and connected in series by flues. The kilns are filled with ore and ignited, and the products of combustion pass successively through the remaining charged kilns before being discharged to the atmosphere. Thus the gases and vapors transfer their heat to the ore; sulphur vapor is recovered by condensation; and relatively cool gases only are wasted. The cycle is continuous and extraction of sulphur lies between 80 and 85 pct. The product, as in the Calcaroni system, is contaminated with fine gangue and analyzes from 90 to 95 pct sulphur. Other methods for beneficiation have been tried, such as concentration by flotation, solvent extraction of sulphur, and application of steam in closed containers.\textsuperscript{75} These methods have not shown sufficient reduction in costs to displace the older systems to any great extent.

**SULPHUR DEPOSITS IN MANY COUNTRIES**

Deposits of sulphur are found in many countries of the world and in the aggregate contain substantial reserves. Some of these deposits are operated profitably and are of economic importance to the countries in which they are located. A considerable number are situated in isolated
regions and at high elevations. The costs for production and transportation in such cases are usually prohibitive. Most of these deposits originate by thermal activity associated with solfataras and thermal springs. The gases and solutions given off, being highly acid, have altered the formations surrounding each vent into masses of bleached, porous rock. Sulphur was deposited subsequently, both in crystalline and massive state, filling the fissures, vugs, and pores. The bleached outcrops of the altered rock indicate the presence of ore, which, because of need for oxygen to effect deposition, is usually found at shallow depths.

**Distribution**—The most important deposits from the standpoint of production are in the Andes Mountains of South America and in Japan. The Andean deposits occur at exceptionally high elevations in a zone about 3000 miles long extending through Peru and Chile. There are more than 100 deposits in this area, with indications that some of them contain substantial tonnages of high-grade ores. For the past 10 years, production has averaged about 30,000 tons annually. In Japan, sulphur is found in a chain of volcanoes extending through the main islands and there are more than 40 known deposits. The principal deposits are situated on northern Honshu and Hokkaido Islands and there 12 important mines have been responsible for most of Japanese production. After World War II, production declined materially, owing to the disrupted economy of the country. This is illustrated by the yearly production figures, which range from 200,000 tons before the war to 21,000 tons in 1946. There are small and scattered deposits in European and Asiatic countries, as well as in the mountain ranges bordering the Pacific Ocean, including the Netherlands East Indies, the Aleutian Islands of Alaska, the Sierra Nevada Mountains of California, and the numerous mountain ranges of Mexico. Other localities in the United States where deposits have been operated include the states of Nevada, Utah, Wyoming, New Mexico, and the western part of Texas.

**Mining and Preparation**—Mining methods consist of simple forms of open-pit, gophering, room-and-pillar, and open stope-and-pillar. Melting of sulphur in autoclaves is one method of beneficiation commonly used, but recovery rarely exceeds 50 pct. Low-grade ores can be concentrated by flotation before additional treatment. Distillation of sulphur is commonly practiced in Japan and Chile by charging the ore into retorts of small capacity, which are heated externally. Usually 6 to 12 retorts comprise a unit, which is equipped with common firebox, flue, and condensation chamber.

**ORIGIN OF SULPHUR**

The principal deposits of the world—the salt-dome type and those of Sicily—have several features in common, which may be indicative
of their origin. In both regions, sulphur is closely associated with limestone, gypsum or anhydrite; carbonaceous matter, in the form of petroleum and petroleum residues, or as bitumen, is a frequent constituent of the sulphur-bearing rock or associated formations; and hydrogen sulphide is present as a gas or in solution in water. These common features led to the hypothesis that the sulphur was formed through reduction of sulphates by carbonaceous matter. As a result of this reaction, calcium carbonate and hydrogen sulphide were first formed, the hydrogen sulphide being subsequently oxidized to sulphur. Laboratory experiments have shown that this reaction requires temperatures in excess of 1100°F, and there are no indications that such temperature existed in either type of deposits. The question arises as to whether time, measured in geologic sense, may at normal temperatures bring about reactions that in the laboratory require high temperatures. Another theory, recently discussed in various publications, does not require unusual temperatures but is based on the power of certain species of anaerobic bacteria to reduce mineral sulphates. These organisms derive energy from carbonaceous matter of their environment and oxygen from molecular oxygen of the sulphate minerals. According to this theory, the first product of reduction is calcium sulphide, which reacts in the presence of water with carbon dioxide, generated in the life process of the organism, to form calcium carbonate and hydrogen sulphide. Extensive experimental work recently conducted has demonstrated the presence of bacteria in oil-field waters in great abundance. These bacteria include sulphate-reducing forms that appear to have been instrumental in the formation of sulphur deposits associated with hydrocarbons. The oxidation of hydrogen sulphide to sulphur can best be explained by the assumption that this reaction took place where deposits were exposed to oxidizing conditions. This assumption has been made for Sicilian deposits, and there is no evidence available or recorded that would prohibit a similar consideration for the salt-dome type.

Volcanic emanations frequently contain sulphur vapors, sulphur dioxide, and hydrogen sulphide. Many deposits that outcrop at the surface have evidently originated from one or more of these gases. Temperatures are prohibitively high at the seat of activities for deposition, but at more remote locations, or during dying stages of volcanism, lower temperatures are more favorable. There are three methods by which sulphur may be deposited from solfataras: the first by condensation of sulphur vapors, the second by reaction between hydrogen sulphide and sulphur dioxide, and the third by oxidation of hydrogen sulphide. Deposits may originate also by deposition of sulphur from thermal springs containing hydrogen sulphide. Other agents of deposition, active in mineral springs, are sulphur bacteria, which have the power of
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oxidizing hydrogen sulphide to sulphuric acid and, in an excess of the gas, of storing sulphur in their cells.

PYRITES

Definition—Pyrites is an inclusive term used to designate metallic sulphides such as iron pyrites (pyrite), magnetic pyrites (pyrrhotite), white iron pyrites (marcasite), copper pyrites (chalcopyrite), and tin pyrites (stannite). The metallurgical treatment of some of these and other sulphide minerals in the copper, lead, and zinc industries frequently results in the recovery of by-product sulphur in some form. The term "pyrites" is here limited principally to sulphide minerals in which sulphur is of primary interest. The minerals of common commercial interest under this definition are pyrite, pyrrhotite, and marcasite.

Properties—Pyrite (FeS₂) when pure contains 53.4 pct S and 46.6 pct Fe. It has a brass-yellow color, metallic luster, greenish or brownish black streak; and crystals of cubic, octahedral, pyritohedral, or other isometric forms are common. The hardness is from 6.0 to 6.5 and the specific gravity 4.9 to 5.2. It has no cleavage, is brittle, and of uneven fracture.¹⁶

Pyrrhotite, varying in chemical composition, is considered to have the formula Fe₁₋₁₋₀₋₁₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁₋₀₋₁

Marcasite has the same chemical composition and hardness as pyrite. The luster is metallic, the color ranges from pale yellow almost to white, and the streak is greenish black. It is sometimes found in tabular crystals of the orthorhombic system, also frequently in radiating fibrous masses, and its multiple twinning often results in jagged outlines. It is brittle, of uneven fracture, and has a specific gravity of 4.85 to 4.90.

Origin—Pyrite and pyrrhotite are very common sulphide minerals and are associated with rocks of all ages and types. A discussion of their origin here is necessarily limited to relatively pure deposits. The origin of such deposits is generally ascribed to their association with igneous rocks.¹⁰ Literature on the subject indicates that the origin is dissimilar in other respects and divides these deposits into two broad groups—those formed at high temperatures and those formed at intermediate temperatures. Associated minerals are used as evidence of the temperature at which deposition took place. Pyrrhotite deposits and those associated with silicates were formed at relatively high temperatures and at great depths. This class includes deposits of magmatic origin, those of the con-
tect-metamorphic type, and those believed by many to have resulted from the injection of sulphide magmas. The second group, those formed at intermediate temperatures, includes deposits associated with minerals such as calcite, barite, and quartz. Deposits of this type may have been formed by hydrothermal replacement at moderate depths, and the origin of deposits in Spain has thus been explained.\textsuperscript{5,57}

\textit{Pyrites Deposits}

\textbf{UNITED STATES}

Deposits are being operated in Tennessee, New York, Virginia, California, Wisconsin, Montana, Illinois, Indiana, and Pennsylvania. The principal production is from the Ducktown region, in the most southeasterly corner of Tennessee, which is currently leading all other states in production. Coal brasses are recovered by concentration in the treatment of certain coals, particularly in Illinois and Indiana.

\textit{Formations}—The Ducktown district lies in the southern Appalachian Mountains. The formations are of Lower Cambrian age, and consist almost wholly of metamorphosed conglomerate sandstone and shale, complexly folded and faulted. For many years, it was assumed that the ore bodies were the result of partial replacement of included beds of limestone and marble.\textsuperscript{19} Later investigation resulted in the theory that the deposits were formed by several stages of mineral deposition, each initiated by fault movements and each associated with a distinct group of minerals. Ore minerals were last in the order of deposition and replaced most of the vein material and portions of the country rock.\textsuperscript{50} The ore bodies are elongated, roughly tabular masses, some of which are curved, folded or lens shaped. In general, the veins strike northeast and dip from 35° to 65°. In length they extend over a distance of about 2000 ft and in width from a few feet to a maximum of 180 ft. The ore consists of massive pyrrhotite, pyrite, and chalcopyrite, with minor amounts of sphalerite and galena. The principal gangue minerals are quartz, actinolite, and tremolite. The ore contains from 25 to 39 pct S, 35 to 45 pct Fe, and 0.8 to 2.5 pct Cu.

\textit{Mining}—The ore is mined by sublevel stoping.\textsuperscript{46,35} Longitudinal stopes are taken out from wall to wall where the ore is not wider than 40 ft. In wider sections, transverse stopes 40 ft wide alternate with pillars of equal thickness. The ore, when broken in stopes, falls to funneled raises and is then worked through grizzlies into cars on the haulage level. After tramming to ore pockets or directly to skips, it is hoisted to the surface through an inclined or vertical shaft generally located in the footwall.

\textit{Preparation}—Copper originally was the principal value in the Ducktown ores. Sulphur subsequently became of increasing importance because of the strategic location. The major part of the ore, usually low
in copper, is floated to produce copper and pyrites concentrates. The latter is roasted in multiple-hearth furnaces and sulphur dioxide is sent to the chamber or contact acid plants for production of sulphuric acid. Calcines from the roaster are sintered and shipped to Birmingham for conversion to pig iron and steel. Zinc is recovered as a 50 pct zinc concentrate and is sold as such.

**CYPRUS**

Deposits of cuprous pyrites on Cyprus were worked for copper in very ancient times. An American company, Cyprus Mines Corporation, began an exploration program in 1914. Two massive sulphide ore bodies were discovered and production started in 1922. It has been continuous since that year, except for the suspension of operation caused by World War II. Shipment of pyrites amounted to 523,574 tons in 1938 and 263,314 tons in 1946. The ore bodies are found in a narrow zone of andesitic lavas that lies as a rim around the island’s principal mountain mass of diabase and serpentine. They occur as irregular lenses and stockworks of massive and disseminated ore. Copper as chalcopyrite and chalcocite is the principal nonferrous metal and small amounts of zinc, gold, and silver also are present. Two large, massive ore bodies are now being mined—the Skouriotissa and the Mavrovouni. The Skouriotissa is a horizontal lens 2000 ft long by 600 ft wide. The thickness ranges from a few feet near the perimeter to 150 ft in the center. The ore averages 2.25 pct Cu, 48.0 pct S and 43 pct Fe. The Mavrovouni ore body is a large, irregularly inclined chimney enclosed in hydrothermally altered lava. The ore averages 4.2 pct Cu, 48 pct Fe, 0.4 pct Zn, 0.025 oz Au and 0.25 oz Ag. A top-slicing system of mining as developed by the company is used where conditions are favorable. Methods of treatment differ for the two ore bodies and are described in detail in recent publications.\(^{11,12}\)

**SPAIN**

Postwar information on deposits of pyrites in European countries is not complete. The following discussion is therefore based primarily on prewar operations. The zone of pyrites deposition that extends through the province of Huelva in southern Spain and into Portugal has furnished the major part of the world’s supply for many years.\(^{33,34,83}\) World War II curtailed production and exports, as shown by recent production figures, which were 792,587 tons in 1946, compared with 2,727,003 tons in 1939.

*Formations*—Formations in the vicinity of the deposits consist of folded slates and graywacke, striking east and west, and probably of Carboniferous age. After being folded, the slates, which dip steeply northward, were intruded by porphyries and diabase. The ore bodies are found in the form of elongated lenses in these formations or at
the contact of intrusive rocks. There are approximately 50 such lenses, the maximum dimensions of which are: length, 6000 ft; width, 800 ft; known depth, 1800 ft. Massive pyrite is frequently found in well-defined contact with the enclosing rock and in some places a transition zone of disseminated pyrite occurs. The ore contains minor amounts of chalcopyrite, sphalerite, and galena. The small amount of gangue consists of quartz with some barite. The total reserves of pyrite ores in Spain have been estimated at approximately 500,000,000 tons.

**Mining**—The two principal producers in this district are the Rio Tinto Co. Ltd. and the Tharsis Sulphur and Copper Co. Ltd. The ore body in the San Dionisio lode, operated by Rio Tinto Co. Ltd., has approximate dimensions of: width, 600 ft; length, 3300 ft; and depth, 1200 ft. The original opencut resulted in a terraced crater of which the rim is about 1350 by 1800 ft and the depth 450 ft. Some mining is still being carried on by glory-hole methods in the open pit. The ore is scraped into winzes, which feed loading pockets on the twenty-third level. Thence it is trammed by compressed-air haulage, hoisted electrically in skips to the sixteenth level, and hauled by electric locomotives through a 3-mile adit to the surface. Underground methods formerly consisted of driving wide drifts and crosscuts on approximately 40-ft centers with 45-ft vertical intervals between the levels. The present underground system, accounting for the major production, consists of mining the entire block of ore between the old filled stopes by driving sublevels 9 ft apart across the ore body. From these sublevels, the ore is broken out in blocks 9 ft square. Timber and lagging are used in all workings, the timbers being subsequently removed and the stopes filled with waste. Good ventilation and removal of all timber are necessary on account of the danger of fire. Ore from underground workings is dropped through passes to the sixteenth level, where it is hauled through the adit to the surface.

**Preparation**—Ore averaging 48 pct S and less than 1.5 pct Cu is marketed with no treatment other than screening. Ore containing more than 1.5 pct Cu is leached for its copper content before shipment. For leaching, the ore is placed in huge piles, which are intermittently sprayed with water for two or more years. The solution is collected and passed through launders containing scrap iron to precipitate the copper. After leaching, the ore analyzes from 48 to 50 pct S and 0.4 pct Cu. Ores containing 3 pct Cu or more are smelted for recovery of copper. Sulphur is produced from ore of this grade by methods similar to the Orkla process in Norway.

**NORWAY**

Pyrites production comprises the major mining industry in Norway and is also the principal source of copper. Production declined from
1,027,776 tons in 1938 to 247,465 tons in 1945. In 1946, the production was 537,916 tons. Important deposits are found in the Hardanger, Trondheim, Grong, and northern districts. The Lokken mine, operated by the Orkla Mining Co., with a smelter at Thamshavn, is the major producer of pyrites.

**Formations**—The Lokken deposits are in the Scandinavian mountain chain and the country rock is described as schistose greenstone with gabbro intrusions on the hanging wall a short distance from ore. The main ore body is lens shaped; it dips at an angle of 45°, has a thickness of 150 ft in the central part and a length of approximately 6000 ft. The principal mineral is medium-grained pyrite and quartz is present in small amounts. The ore averages 42 pct S and 2.5 pct Cu.

**Mining and Preparation**—Shrinkage stoping is the system used for mining. After crushing and screening, the major part of the production is shipped to Scandinavian pulp mills or European acid plants. The calcines are retained by the producer or shipped to others for recovery of copper and utilization of iron. The Orkla process for recovery of sulphur and copper is used with another part of the production. A charge consisting of ore, coke, quartz, and limestone is smelted in a blast furnace. The resulting gases contain, in addition to sulphur vapor, sulphur dioxide, carbon disulphide, and carbon oxysulphide. These gases react in the presence of a catalyst to form more sulphur vapor, which is condensed to a liquid and solidified. Copper matte is converted to blister copper.

**Sweden**

For many years, the Boliden Mining Co. has been the major producer of pyrites in Sweden. Total production for the country in 1947 was 386,000 tons. The ores are complex and contain pyrite, chalcopyrite, arsenic, bismuth, selenium, gold, and silver. Selective mining is employed to produce pyrite ores and ore of high gold content. Treating methods formerly included roasting and smelting with recovery of elemental sulphur from stack gases by an absorption process. Complicated metallurgical processes were used for the recovery of other contained metals. Selective flotation with recent improvements now produces clean pyritic concentrates, which can be sold to pulp mills. These developments have made possible the gradual suspension of unprofitable recovery of sulphur from stack gases. Lower production recently at the Boliden mine has been offset by development of new deposits of pyrites in the vicinity.

Elemental sulphur is recovered as a by-product from oil-shale plants that were installed by the Swedish Government during the recent war. Approximately 15,000 tons of sulphur a year is thus recovered.
FINLAND

Production of cuprous pyrite concentrates by the Government-owned mine, Outokumpu, has reached an annual rate of 177,000 tons since the war. The smelter, formerly operated at Imatra, was moved to western Finland. Outokumpu concentrates are now mixed with nickel-copper concentrates from the Nivala deposit for smelting at the new location. The production of liquid sulphur dioxide at Imatra has been discontinued and sulphur dioxide in stack gases is now converted to sulphuric acid.

OTHER PYRITES DEPOSITS

Japan, normally a large producer of pyrites, uses its entire output in the manufacture of acid. Italy, another main producer, is similar to Japan in that its production is principally for local consumption. Iron in the calcines is an important factor where iron ores are scarce. Other important sources of pyrites are Russia, Germany, Greece, France, Portugal, and Canada. Countries in which minor amounts of pyrites were produced before World War II include Korea, Yugoslavia, Czechoslovakia, Union of South Africa, Algeria, Australia, Poland, Southern Rhodesia, Rumania, and the United Kingdom.

MARKETING AND USES

The largest single use of sulphur is for the production of sulphuric acid. Native sulphur, pyrites, smelter gases, particularly from zinc concentrates, and hydrogen sulphide are all used for this purpose. The manufacturer of sulphuric acid, therefore, has his choice among these raw materials. His selection will be determined by economic factors such as price, availability, and dependability.

Sulphur and sulphuric acid enter into a vast number of industries and a multiplicity of uses, some of which are shown in Fig 4. Washed phosphate rock is treated with sulphuric acid in the preparation of fertilizers. This not only makes the phosphate available to plants but also furnishes sulphur, which is an essential plant food. In petroleum refining, sulphuric acid removes gums and tarry matter, as well as other constituents that would form end products of a corrosive nature. Sulphuric acid in recent years has become increasingly important in synthesizing fuels and chemicals from petroleum. A specific example recently developed is the manufacture of high-octane components for aviation gasoline. Nitrogenous constituents resulting from the coking of coal pass off as ammonia and the gases are scrubbed with sulphuric acid to produce ammonium sulphate. Sulphuric acid is used in the purification of other products of coal distillation, such as benzol and toluol. The iron and steel industry uses sulphuric acid to remove scale formed during the various steps of rolling and annealing. Another
metallurgical operation consuming sulphuric acid is electrolytic production of zinc. A large and increasing use in the paint and pigment industry is for manufacture of titanium dioxide. The ore is dissolved in sulphuric acid and titanium dioxide is then precipitated in a pure form by hydrolysis. Among the explosives, black powder with sulphur as a constituent has been almost entirely replaced by nitroglycerin in the form of dynamite and similar compounds. In the manufacture of nitroglycerin, nitration is carried out with nitric acid in the presence of concentrated sulphuric acid. Propellant explosives for military use contain large amounts of nitrocellulose, which is made by nitrating cellulose in a bath of mixed nitric and sulphuric acids. In the viscose process for making rayon, the viscose solution is precipitated in a sulphuric acid solution. Sulphur is employed in the viscose process in the form of carbon bisulphide, this being used to make cellulose xanthate from caustic soda and cellulose. Large amounts of sulphuric acid are used in the nitrating bath in making nitrocellulose from which motion picture films are produced. The textile industry uses sulphuric acid in the various operations of washing, bleaching, shrinking, and dyeing. Sulphur and sulphur dioxide are used in the production of magnesium ingots and castings to create an inert atmosphere.

As in the manufacture of sulphuric acid, either sulphur or pyrites may be used as a raw material for the production of sulphite pulp. In
this process, a solution containing calcium bisulphite and sulphurous acid is prepared by absorbing sulphur dioxide in a solution of milk of lime, or by a reaction between sulphur dioxide and lime rock in towers. The resulting solution digests the wood chips until most of the noncellulosic materials have been dissolved. In many kraft plants, sulphur is added to the cooking liquor to increase the sulphidity for the production of high-strength paper.

The amount of sulphur used for the manufacture of rubber depends upon the properties desired in the final product. Hard rubber in storage-battery cases usually contains 30 pct while rubber used in tire stock may contain not more than 1.5 pct. Sulphur is essential also in the manufacture of synthetic rubbers, which have more resistance to chemical attack and oil deterioration than natural rubber. Thiokol, one of the special-purpose rubbers, results from the chemical reaction between ethylene dichloride and sodium polysulphide.

Sulphur and sulphuric acid are assets of great and expanding value in agriculture. Work on insecticidal and fungicidal uses of sulphur is currently in progress in experiment stations and research organizations. Sulphur, in the form of dust and also in the form of spray materials, such as lime sulphur solution and wettable sulphurs, is used in control of pests that attack fruit trees as well as field and truck crops. The development of combination contact insecticides in which sulphur is mixed with such materials as DDT, pyrethrum and rotenone, is of particular interest. Sulphur and sulphuric acid are used as soil amendments to neutralize alkalinity and to correct sulphur deficiency. Where soils contain a relatively high concentration of selenium, together with a deficiency in sulphur, selenium may be selectively absorbed by certain forms of plants and cattle may be thus poisoned. When added to such soils, sulphur acts as an inhibitor to absorption of selenium. Sulphur in the form of sulphur dioxide is used in greenhouses and mushroom houses as a fumigant. Carbon bisulphide is used to exterminate insect pests in soils and as a weed killer.

**TESTS AND SPECIFICATIONS**

Specifications for sulphur and pyrites concern three items of principal interest: (1) that the raw material shall contain a guaranteed minimum of sulphur; (2) that it shall contain not more than specified amounts of injurious materials; and (3) that not more than certain amounts of materials that prevent or retard combustion shall be present.

Sulphur produced by the Frasch process frequently averages 99.8 pct. It is guaranteed to contain not less than 99.5 pct S on a dry basis and to be practically free of arsenic and selenium. Impurities consist
of traces of ash and petroleum hydrocarbons. Italian sulphur is sold under several different grades as a result of the varying amounts of inorganic impurities.

Commercial flour sulphur is prepared by grinding and sizing crude sulphur, and the chief specification for this material, in addition to those listed above, relates to particle size. Commercial flour sulphur is used by the rubber industry. In addition to being carefully sized, it should contain not more than 0.01 pct free acid. Flowers of sulphur is a finely divided product manufactured by subliming crude. It contains a variable amount of amorphous (insoluble in carbon bisulphide) sulphur.

Sulphurs as marketed are customarily tested for moisture, ash, sulphur, organic impurities and free acid to ensure proper specifications. Moisture and ash are determined by standard methods. Dry sulphur is extracted by carbon bisulphide and the sulphur content is determined by subtracting the insoluble portion from 100. When amorphous sulphur is present, hot aniline can be used as an additional solvent. Organic material is generally determined by burning a small sample under controlled conditions and comparing the resulting deposit of carbon with a series of standards. Free acid is determined by wetting a ground sample with alcohol and extracting the acid with water, subsequently titrating the extract with standard caustic solution.

Because injurious impurities are commoner in pyrites than in sulphur, specifications are more rigid. Specifications for pyrites are usually determined by agreement under long-term contracts between the producer and consumer, because each mine produces ore peculiar to itself. Physically, pyrites is classed either as lump or fines. Lump ore varies in size from 2 to 10 in. and should contain not more than 10 pct through \( \frac{1}{2} \) or \( \frac{3}{8} \)-in. screen. The undersize, classed as fines, was sold at a discount prior to development of suitable burners. Contracts usually call for a premium or penalty when the sulphur content deviates from a guaranteed percentage. Zinc and lead are objectionable because they cause retention of sulphur in calcines. For the manufacture of sulphuric acid, more than 1 pct of arsenic is objectionable, and the rigidity of this specification depends on the type of equipment available at consumers' plants for removal of arsenic from the gases. Where pyrites is to be used for papermaking, selenium may cause oxidation of the sulphur dioxide to sulphur trioxide in the digester, and is therefore objectionable. The calcines, which may contain other valuable constituents, are disposed of by agreement between producer and consumer.

Test methods employed are the usual standard methods for determination of sulphur, iron, copper, zinc, lead, arsenic, selenium, and moisture.
POLITICAL AND COMMERCIAL CONTROL

The present status of the world sulphur industry can be clarified by a review of major developments during the past 45 years. In the early part of the twentieth century, the Frasch process made rapid strides commercially, supplanting Italian and Japanese sulphur in American markets and exporting small amounts. Subsequent to World War I, with a greatly increased production and with previously scarce shipping facilities then available, American sulphur gained rapidly in all world markets. During the first World War, domestic manufacturers of sulphuric acid had difficulty in obtaining pyrites from foreign sources and many plants were altered to burn sulphur. There has been no subsequent change in the attitude of American consumers, because domestic sulphur offers greater security in supply. After World War I, American producers, in order to develop additional outlets, found it necessary to enter foreign markets more aggressively, and in 1922 the Sulphur Export Corporation was formed to distribute sulphur in world markets.

Many nations of the world have fostered local sources of production by bounties, tariffs, embargoes, and sometimes by complete government control. In 1935, the Italian Government established a fund of 20 million lire to underwrite the price it guaranteed to Italian producers of sulphur. Similar subsidies continued until the outbreak of World War II. Since that time, Italian production has been insufficient to supply appreciable amounts for export and therefore subsidies have not been feasible. In 1948, trade agreements between the French and Italian Governments have made possible the exportation of about 80,000 tons from Italy. Japan protected its industry prior to 1941 by a 20 pct duty on the c.i.f. price of imported sulphur. Japan does not export any sulphur at this time. In 1934, the Spanish Government practically prohibited imports of sulphur into Spain, in order to protect a new plant that was built to produce sulphur from pyrites. The plant was not able to supply all of Spain’s requirements and accordingly some sulphur was imported under governmental control. Through a Government agency known as Mining Credit Institute, Chile is authorized to pay a subsidy of 100 pesos per ton of refined sulphur exported. In Finland, a Government-owned pyrites mine, having a productive capacity of 400,000 tons per year, sells pyrites concentrates to Scandinavian paper mills. In Sweden, a Government-owned shale-oil recovery plant has produced sulphur as a by-product since 1943. In 1947, it sold 14,000 tons in the domestic market. In Portugal, a plant for producing sulphur from pyrite with a capacity approximately equal to Portugal’s consumption is protected by an import tax on sulphur. The British Government controls the purchase and distribution of sulphur and pyrites to manufacturers of sulphuric acid in England and
Fig 5—World consumption of sulphur from crude sulphur and pyrites.

Fig 6—Production and shipments of crude sulphur, United States.

Fig 7—Domestic consumption of pyrites, United States.
thereby effectively directs the supplies into desired channels. The Argentine Government requires importers of sulphur to purchase a percentage of their annual requirements from a domestic producer at prices considerably higher than the cost of imported sulphur. Since sulphur is not produced in Australia, the Government pays a premium of 36 shillings for each ton of sulphur recovered from sulphide ores in the form of sulphuric acid. Other countries have import duties on crude sulphur, not to protect the domestic industry but as a source of revenue.

CONSUMPTION AND PRODUCTION

Statistics and trends of the sulphur industry are illustrated by Figs 5 to 7. The part played by sulphur and pyrites, respectively, in supplying the world requirements for sulphur in all forms is shown in Fig 5. The adjustment of domestic production to shipments since 1935 is illustrated in Fig 6, which also shows the failure of exports to increase comparably with domestic consumption in recent years. Increasing domestic production of pyrites is shown by Fig 7. World trade relations for the two minerals emphasize the fact that, under present economic conditions, the United States relies on crude sulphur and Europe on pyrites as the principal source of sulphur. This situation is essentially true today but the economic dislocations in many foreign countries caused by the war have resulted in a decline in world production of pyrites and an increased demand for American sulphur from other countries.

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