THE SULPHUR MINING INDUSTRY OF THE UNITED STATES

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PREFACE

Sulphur, the first chemical element found and used by the cave man, penetrates many industries. Its adaptability, cheapness, and stable qualities enhances the mineral's varied industrial uses. Few Americans are aware of the importance of sulphur and a far lesser number understand the modern extraction methods and related problems. Perhaps no other mineral is more widely used and less recognized than sulphur, which today is almost wholly supplied by a limited number of mines in the Gulf Coastal Plain.

The purpose of this study has been to trace the development of sulphur mining from ancient crude methods to the modern Frasch Process, and the industry's relation to climatic, physiographic and cultural factors.

Government documents and professional publications supplied the writer with the greatest portion of research material. Personal observation, correspondence and personal interviews carried on by the writer supplements research material.

The writer became interested in sulphur and methods of obtaining the mineral, while visiting the Hoskins Mound sulphur mine in 1938. While serving with the United States Army, in Sicily and Italy, during World War II his interest became further stimulated when observing sulphur mining methods in those regions. During 1946 - 1947 he personally visited each operating sulphur mine on the Gulf Coastal Plain, in addition to each exhausted mine. Information gathered during these visits made possible a better understanding of the industry and provided a valuable collection of material, part of which entered this study.

The writer sincerely credits the Management of Texas Gulf Sulphur Company, Freeport Sulphur Company, Jefferson Lake Sulphur Company, and

Duval-Texas Sulphur Company for information provided and the courtesy extended while visiting their mining operations.

The libraries of Oklahoma University, Texas University, Louisiana State University and Texas Agricultural and Mechanical College have been most generous in providing research material. To Miss Marguerite Smith, Documents Librarian, Oklahoma Agricultural and Mechanical College, is due the credit for locating available documentary material.

The assistance rendered by Doctor Edward E. Keso, Head of the Geography Department of Oklahoma Agricultural and Mechanical College and members of his staff, especially Professor George S. Corfield who aided in arrangement of this study, is greatly appreciated.

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John I. Stroup

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THE ORIGIN AND OCCURRENCE OF SULPHUR

Historical Background

Mankind has known sulphur since ancient times. Mention is made of sulphur in the Bible and in the Homeric poems, being sometimes referred to as brimstone.[1] The Romans evidently obtained it in the same way as now, by melting it out of its mixture of marls, gypsum, and limestone. The Greeks named it theion; the Romans sulfur. In early times it was used for medicinal purposes, fumigation, bleaching of linen by the Egyptians, cleaning wine-casks, for destroying fungus growths in vineyards and orchards, preparing torches, for cementing glass, and for work on metals.[2]

During the time of the Caesars sulphur was used in the preparation of incendiary materials for warfare. History records that the Chinese, during the time of the great philosopher, Confucius, compounded sulphur with other substances in the preparation of gunpowder. When the Roman Empire was at its height, about 50 A. D., Pliny wrote that there were four kinds of sulphur and stated also that fourteen medicinal uses were being made of this strange substance.[3] Pliny recognized and distinguished the four different kinds of sulphur, evidently differing in purity, by the uses to which they were put. (a) "Live" sulphur, used in medicine; (b) fuller's sulphur employed in the preparation of cloth; (c) egula, used in fumigating wool; and (d) that used

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[1] George Lunge, Sulphuric Acid and Alkali, Volume 1, (2nd ed. rev.), London: Gurney & Jackson, (1891), p. 156. Revelations. 19:20, 21:8.

[2] Karl Blumner, Translated by W. C. Phalen, "The Phlogiston Theory." Treatise, University of Zurich, (1887), p. 23.

[3] Luigi Delabretoigne, L'industria Mineraria, Solfifera Siciliana, Torino, (1925), p. 429.

in preparing lamp-wicks for easy kindling.[4] Dioscorides, according to his Materia Medica, knew of the dermatological value of sulphur when applied to ointments. It remained, however for Gay-Lussac and Thenard to demonstrate that sulphur is an elemental substance.[5]

The alchemists of ancient ages worked with the so called "yellow magic". Both Geber and Abu - Bekr - Alrhases divide the credit as the first to discover that acid produced from sulphur was a great solvent.[6]

In 1804 Theodore de' Saussaure found sulphur present in plants, listing it as essential to plant growth. Sachs confirmed the belief that sulphur was essential as a food in culture solutions.[7]

The mountainous island of Sicily, off the toe of Italy, produced, early in the 15th century, the first commercial sulphur of modern times. Not until 1735, however, did nations of the world begin to vie for control of the element. The cause of this struggle resulted from finding a method of preparing sulphuric acid from elemental sulphur. A quack Doctor, named Ward, first carried out experiments, near London, and upon successful results produced the much desired acid in large quantities.[8] Soon after the Ward process became a commercial success, numerous sulphuric acid plants were established in England, France and Germany. Roebuck, of Birmingham, in 1746, introduced the lead-chamber process, an extremely improved method.[9] In

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4 Ibid., p. 430

5 W. L. Powers and W. T. McGeorge, Use of Sulphur in Soils, Oregon State College, Corvallis, (1939), p. 4.

6 Lunge, op. cit., p. 7.

7 McGeorge & Powers, op. cit., p. 4

8 Lunge, Loc. cit., p. 8.

9 O. Guttman, Journal Society Chemical Industry, (London: 1901), p. 5.

Germany the sulphuric acid industry was late in getting a foothold. This did not create a great demand for raw sulphur in that country.[10] The first sulphuric acid works in Germany were established, near Dresden, in 1820.[11] In 1827, Gay-Lussac's condensing apparatus was erected.[12] The new method of preparing sulphuric acid created a great demand for native raw sulphur. It was then that the sulphur industry had its real birth.

Origin of Sulphur

Sulphur is an element whose atomic weight is 32.06 (oxygen = 16). It is very brittle; its hardness varies from 1.5 to 2.5 of the ordinary minerological scale. Its specific gravity is 2.0454. In most occurrences, it is semi-transparent at the edges and of the well known bright yellow color, which darkens with an increase in temperature.[13] At -50° C. (-58° F.) sulphur is nearly devoid of color.[14] It melts at 111° to 120° C. (234° to 248° F.), it does not conduct electricity, but becomes electric by friction; it is therefore difficult to powder finely, as it adheres to the mortar or pestle. At 250° to 260° C. (482° to 500°F.) molten sulphur is nearly black in color and so viscid that it does not run or flow when the vessel is upset. At a still higher temperature it again becomes thinner, keeping a brown color and at

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[10] H. A. Smith, Sulphuric Acid Manufacture, (London: Gurney & Jackson, 1894), p. 96.

[11] Lunge, op. cit., p. 11.

[12] Ibid., p. 1.

[13] Frank H. Thorpe, Outlines of Industrial Chemistry, The Macmillan Company, (1917), p. 58.

[14] Lunge, Loc. cit., p. 14.

446° C. (802.8° F.) it boils, forming a brownish-red vapor.[15] Many theories occur concerning the origin of sulphur. It is generally agreed that of the two commercial types of formations, worked today, volcanic and deposition types constitute the ones in which geologists and companies interest themselves most.

The action of oxygen on hydrogen sulphide causes sulphur to be liberated and deposited. ($H_2S + O = H_2O + S$). In regions of volcanic activity or where volcanic activity has recently ceased, occurrence of sulphur incrustations are commonly observed.[16] G. F. Baker who studied the phoenomena of sulphur formations at Sulphur Bank, California states that sulphur is formed by the action of water vapor on hydrogen sulphide.[17]

Native sulphur is a frequent companion of gypsum, and this too may be produced in several ways. It is known as a volcanic sublimate and is a product of reaction between sulphur dioxide (SO_2) and hydrogen sulphide (H_2S). It is also formed by the incomplete combustion of hydrogen sulphide, probably in accordance with the equation: $2H_2S + O_2 = 2H_2O + 2S$.[18]

Where oxygen is in excess, as at the surface, hydrogen sulphide is completely oxidized, and sulphuric acid is formed. A short distance below

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15 Ibid., p. 14.

16 O. Stutzer, Translated by W. C. Phalen, "Origin of Sulphur Deposits," Economic Geology, Volume 7, (December 1912), p. 732.

17 G. F. Baker, Monograph, United States Geological Survey, Volume 13, (1888), p. 254.

18 U.S.G.S. Bulletin 770, Data of Geo-chemistry, 5th edition, (1924), p. 586.

the surface oxygen is deficient, and then sulphur is liberated. The actual conditions are probably more complex. At all events sulphuric acid and free sulphur both occur at Sulphur Bank, California, and in accordance with the conditions imposed by the experiments and theory. The deposition of sulphur at the abandoned Rabbit Hole Mine, Nevada is ascribed to solfataric activity.[19]

At Cove Creek, Utah sulphur occurs in great quantities as an impregnation in rhyolitic tuff.[20] It is derived from hydrogen sulphide of volcanic origin and is also accompanied by strongly acid water. So far as the sedimentary rocks are concerned, in this region, the association of limestone, gypsum, sulphur, and hydrogen sulphide seems to be quite general.

The sulphur deposits of Sicily are of the sulphate type, which is mixed with, or in the vicinity of bituminous gypsum, which in turn is associated with other sedimentary rock. It is usually assumed that the bitumunious matter of gypsum causes a reduction of sulphate of calcium to the sulphide with the production of carbon dioxide and water.[21] The resulting sulphide is then decomposed by carbon dioxide, water and oxygen, yielding calcium carbonate and sulphur. Sulphates are known to be very stable compounds and their reduction at ordinary temperature by lifeless organic material is seriously questioned. On the other hand bacteriologists have known for quite

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[19] G. I. Adams, Bulletin U.S.G.S., No. 225, (1904), p. 495

[20] W. T. Lee, Bulletin, U.S.G.S., No. 315, (1907), p. 485

[21] C. Palmer, Bulletin, U.S.G.S., No. 340, (1908), p. 455.

some time that certain living micro-organisms, under favorable conditions, are capable of reducing sulphates in solution with the liberation of hydrogen sulphide. This important biochemical reaction has been alluded to in geological literature.[22]

Occurrence of Sulphur

The sulphur deposits of Louisiana and Texas have been formed by sedimentation from brackish water during a previous Geologic Age. These sedimentary deposits have been covered to their present depth, and the domes that are observed have been formed by intrusion.[23] Both salt and sulphur occur in these domes. The cap rock contains the sulphur. In horizontal section the domes are elliptical in shape. Overlying and surrounding the domes are clay, sand and "gumbo." The upper portion of the dome consists of a porous cap rock which is largely limestone and calcite, with traces of carbonates and sulphates of other alkaline earths. The sulphur occurs in the porous limestone in the form of rhombic crystals.[24]

Commercial sulphur is found scattered widely over the world. The most noteworthy deposits appear in the following countries, in addition to those of the United States and Sicily already noted.

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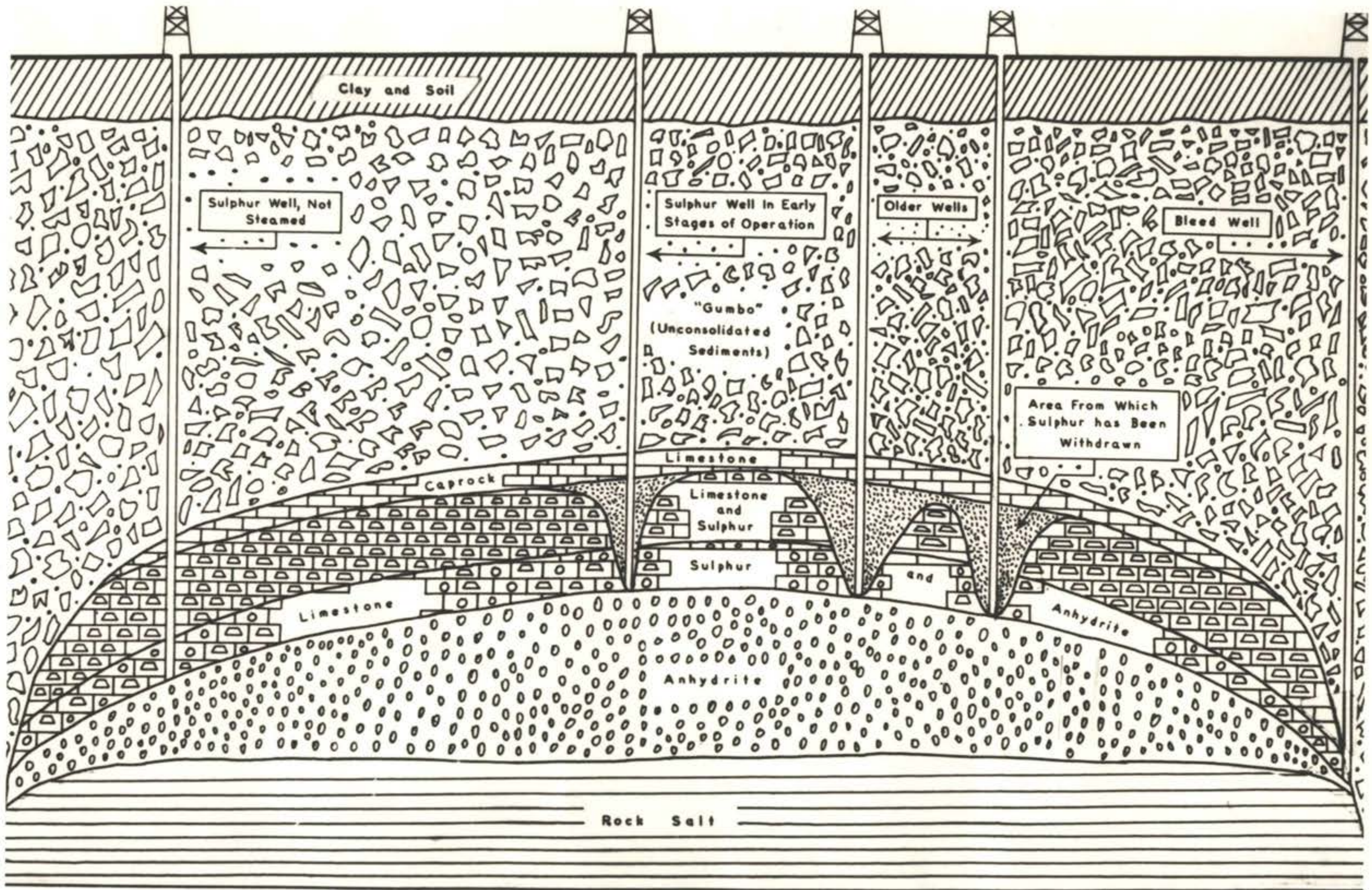
[22] O. Stutzer, Translated by W. G. Phalen, op. cit., p. 733.

[23] Raymond C. Moore, editor, Bulletin American Association of Petroleum Geologists. "Geology of Salt Dome Oil Fields." E. L. DeGoyler, "Origin of North American Salt Domes." pp. 1-44; Francis E. Vaughan. "The Five Islands, Louisiana." pp. 452-469. Houston, (1926). Donald C. Barton. Bulletin American Association of Petroleum Geologists. Volume 17, Tulsa, (1933), pp 1025-1083. G. S. Rodgers, "Intrusive Origin of the Gulf Coast Domes." Economic Geology, Volume 13, (1918), p. 468. A. F. Lucas, "The Avery Island Salt Mine and The Joseph Jefferson Salt Deposit, Louisiana." Engineering and Mining Journal, Volume 62, (1896), pp. 463-464.

[24] Modern Sulphur Mining. Texas Gulf Sulphur Company, (New York, 1941), pp. 11-13.



IDEAL SECTION, SHOWING SULPHUR-SALT DOME IN VARIOUS STAGES OF OPERATION | after DeGolyer (modified)

Plate I.

Japan:[25] Sulphur deposits of the country are associated with volcanoes. The volcanic zones in which the sulphur deposits occur, stretch from Formosa to the Kurile Islands. The most important mines in Formosa are in the vicinity of Mount Daiton. In Kyushu a few mines lie near the volcanoe Kirishima, among which are those known as Sulphur Island and Kujusan. In the northern part of Honshu several occurrences are known along the Japan Sea, the most important producing mines in this locality being Numajiri, Tsurugizan, and Ugisuzawa. The most important mines operating now in Hokkaido includes Oshimo, Kobui, Iwaonupuri, Kumadomari, and Shikabe. Several producing localities are known also in the Kurile Islands.

The greater part of the sulphur is directly traceable to solfataric action. The Asada and Kobui mines, in Hokkaido, yield deposits of clayey sulphur formerly deposited in an old crater lake.

Chile:[26] The principal mines reported cluster around Mount Tacora in Arica and Antofagasta Province, several miles inland, near the Bolivian Border. The problems in Chilean sulphur mining, include barren terrain and high altitudes, 13,000 to 19,000 feet above sea level. The fuel used comes from resinous moss. The altitude affects workers, and greatly hinders full capacity of potential work.

Bolivia: [27] Principal mines lie near Concepcion and San Pablo de Napa.

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25 Mineral Resources of the United States, U.S.G.S., Part 2, (1910), p. 793.

26 Fernando Benitez, "Chile." Engineering and Mining Journal, Volume 143, Number 8, (1942), p. 18.

27 Engineering and Mining Journal, Volume 143, Number 7, (July 1943), p. 100.

Argentina:[28] Mines located south of Socompa, produce about 30,000 tons annually.

Mexico:[29] Shallow deposits occur in the State of Vera Cruz. Extraction plans consider the use of the Frasch Process, in obtaining sulphur from these deposits. Discovery in 1931 of a surface deposit of sulphur near the Rio Grande opposite Candelaria, Texas, about fifty miles south of Marfa, Texas, created new interests, in the sulphur industry in Mexico.[30] The deposit rises above the surface to a height of ten to fifteen feet. Exploitation would require extensive road or railroad building.

The following countries produce minor quantities of sulphur.[31]

Europe: Russia, Austria, Greece, France, Germany, and Spain.

Asia: Baluchistan, Palestine, Persia, Philippines, and Siberia.

Africa: Algeria, Kameroon, and Morocco.

Oceania: New Hebrides.

South America: Peru.

Exploitation of sulphur deposits afford profitable returns providing they contain twenty-five percent of sulphur or more.[32] Deposits are worked that yield upwards of fifty-five percent sulphur, however adverse working conditions generally hamper miners' ability for full work capacity, therefore

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28 Minerals Yearbook, United States Department of Interior, Bureau of Mines, (1944), p. 1367.

29 Ibid., p. 1367.

30 Engineering and Mining Journal, Volume 132, (July 13, 1931), p. 35.

31 Phalen, op. cit., p. 793.

32 Statement by H. W. Swem, Personal Interview, (Newgulf, Texas, September 8, 1947).

lowering output, as has been noted in Chile. Some Sicilian deposits have yielded as high as 70 percent sulphur, which is 98.5 percent pure.[33] Sicilian mines have been worked, bearing eight percent, or less of mineral, only to be abandoned after a short period.[34]

Sulphur content of Japanese deposits vary from seventeen percent to thirty-six percent, those containing the richest ore are worked extensively. Low wages and home consumption, coupled with lower living standards in Japan justify operations of sulphur beds bearing less percent of mineral than in the United States.[35]

American Mining Companies concern themselves with sulphur bearing strata showing twenty-five percent or more. Modern sulphur mining methods practiced by American Companies, are so technically perfected as to render sulphur having a purity of 99.5 to 100 percent, when brought to the surface.[36]

The Frasch Process practiced in modern sulphur mining, along the Gulf Coast of the United States, is based on two peculiar properties of the mineral:

1. Sulphur has a low melting point, approximately 240° F. Superheated water —— water heated under pressure above its normal boiling point —— pumped down to the deposit easily melts sulphur.
2. Sulphur is about twice as heavy as water. The mineral melted by superheated water sinks to the bottom of the deposit forming a pool.

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[33] Williams Haynes, The Stone That Burns, p. 72.

[34] G. Aichino, Mineral Industry, Volume 8, (1899), p. 592.

[35] Letter from Major George Henning, G-4 Section, Headquarters, Supreme Commander for the Allied Powers, Tokio, Japan. (August 13, 1947).

[36] H. A. Swem, Personal Interview, op. cit.

Sub-surface sulphur deposits similiar to those of Louisiana and Texas require utmost engineering skills and techniques for exploitation. This fact brought about development of the modern methods for sulphur extraction — The Frasch Process.[37]

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[37] Journal of Industrial and Engineering Chemistry, Volume 4, (February 1912), pp. 138; Engineering and Mining Journal, Volume 8, (September 28, 1869), pp. 196-197.

CHAPTER II

PRODUCTION OF SULPHUR

Italy and Sicily

Sulphur ranks as one of the leading mineral products of Italy. With a normal annual output of about 350,000 gross tons, it becomes the most important sulphur-producing country of Europe. Italy, including Sicily, ranks second to the United States in world sulphur production. Four districts of Italy supply sulphur, namely; Sicily, Romagna and Marches, Campania and Calabria, and Siena.[1] Main offices of mines operating in the respective areas are included in the following table, for the years 1908 and 1909.[2]

Main Office	Year	No. of Mines	Tonnage	Value
Caltanissetta, Sicily	1908	408	2,633,924	$5,581,964
	1909	380	2,616,000	5,671,890
Bologna, Romagna & Marches	1908	11	142,700	411,189
	1909	10	132,500	376,427
Naples, Campania & Calabria	1908	10	69,019	198,522
	1909	10	75,851	221,347
Florence, Siena	1908	1	2,300	2,663
	1909	1	3,091	5,966
TOTAL	1908	426	2,847,943	$6,194,338
	1909	401	2,827,455	6,275,630

Sicilian sulphur mining methods are very simple. The ore is mined by the shaft and strip methods. Few mines have modern machinery and transportation facilities, but many use hand tools, and haul the ore from the mine to the

[1] "Mineral Resources of the United States." Translated by W. C. Phalen. United States Geological Survey, (1910), p. 785.

[2] O. Stutzer, Translated by W. C. Phalen, The More Important Deposits of Non-Metallic Minerals. (Berlin: Borntraeger Brothers, 1911), p. 474.

refinery either in hand-carts or by mules and burros. Heat is applied to the crude ore, the sulphur melts, runs off and is collected. Two methods of heating or smelting the ore are employed: (1) by burning part of the sulphur in the so-called calcaroni and beehive ovens and (2) by superheated steam. Greater use is made of the beehive oven method.

The years 1908 and 1909 have been used as examples for the Sicilian Sulphur Industry, because these years mark the beginning of the steady decline of the industry in Sicily.

For over 150 years Sicily had a virtual monopoly on world sulphur supplies. Her greatest problem in the industry has always been the difficulty and expense of bringing the sulphur from the mine to the ports.[3] The two principal export points, Port Empedocle and Licata have very poor harbors. Vessels, forced to lie offshore, exposed to strong winds, were loaded from lighters. Only during the last century has a more economical means replaced this method.

In earlier days the principal sulphur exports went to Lisbon, Barcelona and Marseilles. The French Mediterranean port prospered when it established sulphur refineries and large sulphuric acid and alkali plants.[4] After 1823, British chemical manufacturers became Sicily's best customers. In that year the heavy tax on salt, a law of the Napoleonic Wars, was repealed and Muspratt immediately began the manufacture of soda alkali near Liverpool.[5]

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[3] Williams Haynes, <u>The Stone That Burns</u>, (1942), p. 77

[4] Phalen, <u>op. cit.</u>, pp. 785-786.

[5] J. F. Allen, <u>Some Founders of the Chemical Industry</u>, (1933), p. 81.

The sulphur trade was arrested during the Napoleonic Wars, but it had, in 1823, shown a gradual growth. The chief uses, at this time, included the making of sulphuric acid and gunpowder with smaller quantities going into bleaching, fumigation and medicines.

Organization of the Sicilian Industry

Poor organization characterizes the early sulphur industry. Each mine operated independently and sold its output to the agents of commercial organizations, chiefly British trading firms, which had their own representatives in Sicily. Trained to be very shrewd these buyers lost no time in playing off one mine against the other in order to lower prices. Sulphur output came at that time, from about 200 mines, and was sold according to the foreign matter visible to the naked eye. The marketing system worked at a disadvantage to the producer.

After 1824, the chemical industry throughout the world expanded rapidly and sulphuric acid plants appeared in Austria, Germany, Italy, Belgium, Holland and the United States. With this expansion in sulphuric acid manufacture, sulphur demands soon outgrew Sicilian production. This demand naturally caused prices to advance and with added efforts to produce, Sicilian exports rose to over 44,000 short tons by 1831.[6] The price had risen to slightly above $70.00 per ton. This plunged the Sicilians into a speculative condition which Delabretoigne described, as similiar to the California gold rush.[7] Within a year the output reached almost 80,000 tons and the price rose

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[6] Haynes, op. cit., p. 79.

[7] Luigi Delabretoigne, L'industria Mineraria Solfifera Siciliana. Torino, (1925), p. 319.

to $30.00 per ton. Price increases caused the English and French importers to cover their needs in advance, but the Sicilians exporting less than one-half of their output that year attempted to further price increases. In 1833 a reversal of conditions suddenly occurred when the price dropped to $16.00 per ton.

This sudden price drop threw sulphur producers into a panic. They appealed to the government for help. Some consideration was given to nationalizing the companies. Sicilian merchants proposed to buy all the sulphur and to market it in an orderly manner, but the producers could not agree to any plan. The matter became worse and in 1838, the Bourbon Government, under King Ferdinand II attempted to correct the condition.

The motive, behind the monopoly which Ferdinand created to solve the problems of the Sicilian sulphur producers, did not reach any wide agreement. At this time Ferdinand, a gay young man of twenty-six, lived most of the time in Paris while his Kingdom of the Two Sicilies and Naples together provided little income for his taste of champagne. Two shrewd Frenchmen, Aime Taix and Arsene Aycard, took advantage of this fact by proposing that all Sicilian sulphur sales be placed exclusively in the hands of their company, Taix, Aycard & Cie, for a period of five years. In this proposal Ferdinand and the Duchess de Berry became silent partners.[8] The proposal was accepted; organization of the company set up at once with a capital of $1,050,000. Under the contract all Sicilian sulpher should be marketed through Taix, under threat of penalties imposed on the producers.

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[8] Haynes, Op. cit., p. 20.

This was the first attempt at valorization of sulphur in Sicily. Taix proved to be reasonable and fair in its objectives and terms, provided an orderly sale for sulphur, reduced the output, established a sulphuric acid and alkali plant in Sicily, and gave the Bourbon state a revenue tax of $360,000 annually. Failure resulted when the price leaped from $20.00 to $70.00 per ton.

The exhorbitant price of raw sulphur caused the acid and alkali industries to search for other sources of raw material. By 1880, all acid industries with the exception of those in the United States had begun to use iron pyrites as a source of sulphur supplies.[9]

Two new developments aided in keeping the Sicilian sulphur trade at a steady upward trend after 1845, namely the manufacture of fertilizer from sulphuric acid and the use of sulphur in controling a disease on grape-vines which appeared in 1845 near the mouth of the Thames River.

In 1867, rich deposits of rock phosphate were discovered in South Carolina.[10] This discovery caused the fertilizer business to increase rapidly. The number of fertilizer manufacturing establishments grew from 47 in 1860, to 278 in 1880 and the value of their output during the same period increased from $1,000,000 to $20,000,000. By 1890 the total fertilizer production in the United States had reached 1,898,000 tons, and throughout the southern states, where fertilizer consumption was greatest, sulphuric acid plants had increased proportionately.[11]

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[9] Oscar Guttman, "Early Manufacture of Sulphuric and Nitric Acids." Journal Society of Chemical Industry, Volume 20, (1901), pp. 5-8.

[10] C. A. Moses, "The Phosphate Deposits of South Carolina." Mineral Resources, (1882) pp. 504-531; Carol D. Wright, "The Phosphate Industry of United States", 6th Special Report, U. S. Labor Bureau (1890), pp. 23-69.

[11] Theodore J. Kreps, The Economics of the Sulphuric Acid Industry, (Stanford University Press, 1938), pp. 19-23.

Immediately following the expansion of the fertilizer business, another important use of sulphur appeared. The petroleum industry began using sulphuric acid to refine first, kerosene and later gasoline.

Two additional technical developments opened up new markets for sulphur. Charles Goodyear discovered a method of rubber vulcanization in 1839 and C. D. Elkman, a Swedish engineer perfected a process, in 1873, using a compound of sulphur to obtain chemical wood pulp, used in the paper industry.[12]

These new uses became highly significant in the United States, because at that time the Frasch Process came into operation in Louisiana.[13]

American Sulphur, Sicily's Competitor

Herman Frasch, son of Johannes Frasch, burgomaster of Gaildorf, Wurtembury, Germany was born in that town on Christmas Day, 1851. When nineteen years old he came to America, settled in Philadelphia where he became chief laboratory assistant to Professor Maisch in Philadelphia College of Pharmacy.[14] Frasch became interested in petroleum and chemical engineering and realized the prominent position each would maintain in the enormous economic expansion in the United States. After specialization in petroleum refining and contributing several outstanding improvements and securing patents on these, he purchased, in 1885, the Empire Oil Company which had wells and a small refinery near Petrolia, Ontario. Here he perfected a method of removing sulphur, from the oil, which had previously caused an undesirable odor and sooting when burned. Standard Oil Company purchased

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[12] Haynes, op. cit., p. 87.

[13] C. F. Chandler, "Perkin Medal Presentation Address," Journal of Industrial and Engineering Chemistry, Volume 4, (February 1912), pp. 134-140.

[14] Haynes, op. cit., p. 18.

his patents, his Canadian Company and engaged him as chief of their research department. The company paid him in stock in the company, selling then at $168.00 per share, plus seven percent dividends. After his processes were installed shares rose to $820.00 each; dividends advanced to 40 percent. At this point Frasch sold half his stock. As a result of his discoveries, conceived and executed on enormous scales, billions of dollars have been added to our national wealth.[15]

Briefly the Frasch Process functions as follows: A hole is bored to the lower layer of caprock. Four concentric pipes are placed in the hole. The outer pipe, ten inches in diameter is a protective casing. The next pipe, eight inches in diameter, is sunk through the caprock, to the bottom of the sulphur deposit. The lower end is perforated with small holes extending up the pipe from five to twenty feet. A four-inch pipe is lowered to within a short distance from the bottom. The innermost pipe, one and a quarter inches in diameter, is placed last and reachs to within two hundred feet of the bottom.[16]

Superheated water raised to about 330 degrees Fahrenheit by intense heat and pressure, is forced down the space between the eight-inch and four-inch pipes and flows out the holes into the sulphur deposit. The sulphur melts and sinks to the bottom of the well, where it is displaced by water and rises in the four-inch pipe. Compressed air forced down the smallest central pipe lifts the sulphur to the surface.

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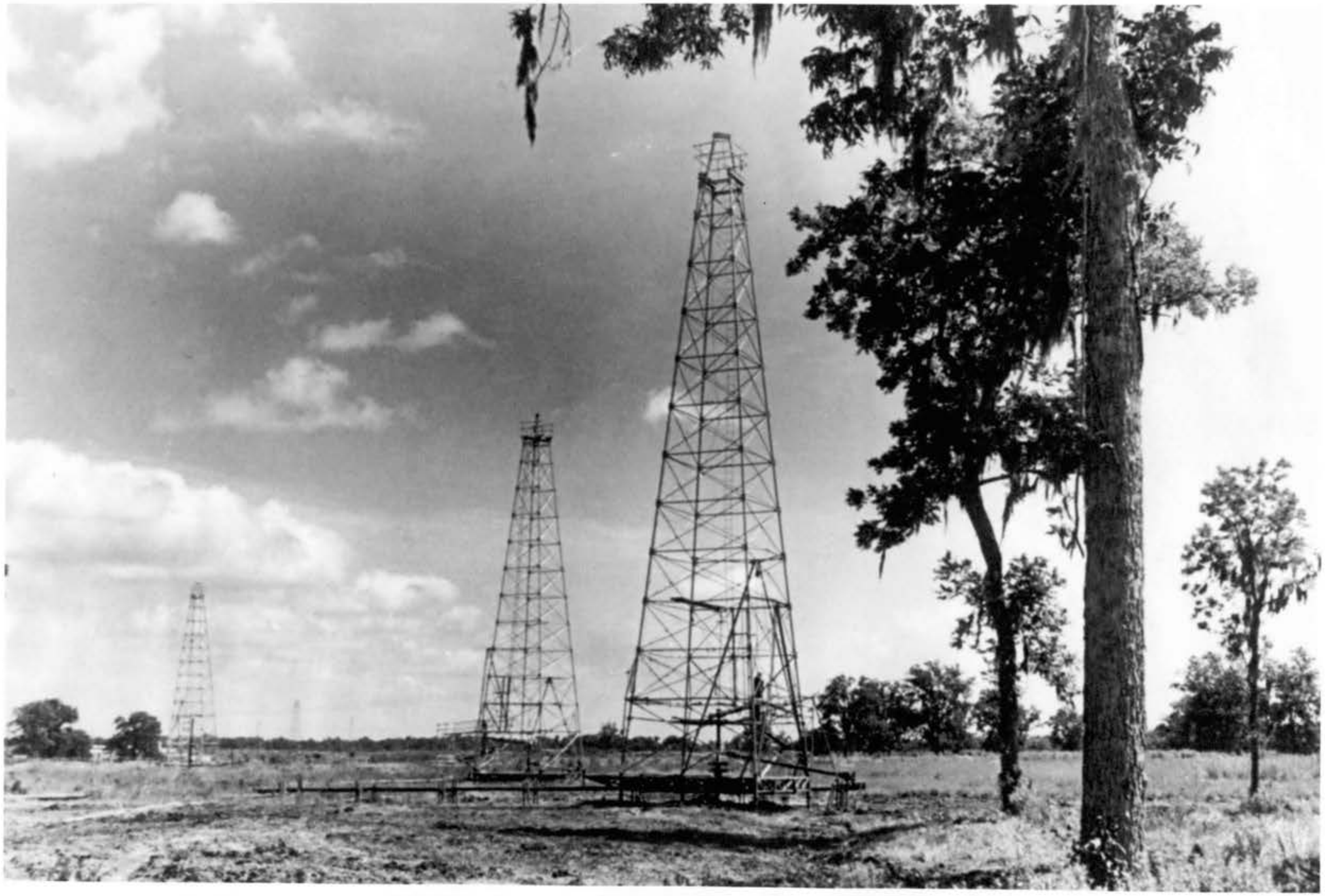
[15] Chandler, op. cit., pp. 136-137.

[16] United States Patent Office, Patent Number 461,429, Mining Sulphur, Herman Frasch, Cleveland, Ohio, Filed October 23, 1890: Serial Number 369,072 (no model). Patent Number 461,430, Filed December 26, 1890: Serial Number 375,799. Patent Number 461,431, Filed December 26, 1890: Serial Number 375,800. p. 284.



Sulphur Wells

Figure 1. (Courtesy, Texas Gulf Sulphur Company)

From their beginning in 1792, sulphuric acid industries used native sulphur as raw material.[17] In the decade from 1820 to 1830, English and French sulphuric acid industries began using pyrites as a source of sulphur, due largely to exhorbitant prices of the raw sulphur. Continued use of pyrites prevails in European countries today. Currently American supplies of sulphur, coupled with efficient transportation and low costs cause a steady decline in the use of European pyrites.

Prior to 1903 Sicily held a virtual monopoly on raw sulphur, and as our chemical activities expanded, our imports of Sicilian sulphur gradually increased. The following figures indicate this trend.[18]

Year	Metric Tons
1892	88,966
1893	88,434
1894	110,067
1895	100,722
1896	132,438
1897	123,341
1898	142,553
1899	134,238
1900	165,813
1901	149,710
1902	176,845

Production, by the Frasch Process, passed 23,000 tons in 1903 and imports from Sicily dropped to 157,259 tons. The following year imports declined to 105,606 tons. Thereafter they dwindled to practically nothing, as noted by the following figures.[19]

Year	Metric Tons
1906	7,235
1907	14,474
1908	13,967
1909	13,929
1910	7,580

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17 Williams Haynes, Chemical Economics, pp. 166-169

18 Delabretoigne, op. cit., p. 429.

19 Ibid., p. 430.

Year (Continued)	Metric Tons
1911	7,125
1912	1,792
1913	970
1914	2,060
1915	886

Sicilian sulphur producers paid little attention to the news of Louisiana production by the Frasch Process. They had heard before of prospective rivals; Japan, Chile, the Rabbit Hole Mine of Nevada, and small quantities being extracted in California and Utah.[20] Self-confidence of their ancient monopoly, made them skeptical of the tale of the enormous American deposits. Fantastic, was the word applied to the Frasch Process of extraction! They simply ignored possibilities of American competition. Confronted with a serious sulphur crisis in 1895 - 1896, Sicilians concerned themselves with reorganization of their industry.[21] Taxes, ownership of property and mineral rights, disorganized markets, high priced imported fuels, and lack of large capital investments in mines operated contributed to this crisis. Studies were conducted concerning the situation in Sicily, both by private concerns and Governmental agencies. A group of chemical makers finally effected a market stablization. This group included Englishmen , who desired, above all, to secure sufficient supplies to control marketing by means of centralized selling. Practically all capital for the Anglo-Sicilian Company came from England, however the Sicilians managed to contract for 66 percent of its output, and persuaded the government by decree of July 27, 1896,

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[20] Mineral Industry, (1892), p. 425.

[21] Williams Haynes, The Stone That Burns, p. 91.

to abolish all taxes except by lump sum levy of one lira (four cents) on every ton of sulphur leaving Sicily.[22] The terms of the contract were almost identical with the old Taix agreement. The force of the contract extended for five years.

At the end of the second period, however, the situation became quite different. Stocks amounting to 150,000 tons more than shipments, had accumulated. Direct competition from American sulphur appeared for the first time on the European market. The Union Sulphur Company's output in 1905 totaled 218,950 tons as compared with 3,000 tons in 1901. Sicilians still doubted the new competition, but better informed directors of the Anglo-Sicilian Company realized their precarious position and sold and delivered 20,000 tons to the United States, at a cost far below prices quoted and only slightly above actual costs.[23] Desiring to receive everything possible for his sulphur, Frasch met with the Directors of the Anglo-Sicilian Company, in London, to establish price agreements. Receiving him cooly, Frasch was told his plan was unsound and the parties could not agree.

Frasch returned to the United States, managed to secure additional American business and delivered several thousand tons to European markets, the following year at a cost of one-fifth less than Sicilian production costs. Briefly, Frasch's action gave extreme alarm to the Anglo-Sicilian Companies; therefore its third five-year contract was not renewed.

Since 1905 the Union Sulphur Company rose to world importance and outputs increased steadily.

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[22] Haynes, op. cit., p. 96.

[23] Herman Frasch, "Perkin Medal Speech," Chemical and Metallurgical Engineering, Volume 10, (February 1912), pp. 79-80

The following are their production figures from 1905 to 1913 inclusive.[24]

Year	Long Tons
1905	220,000
1906	295,123
1907	188,878
1908	364,444
1909	273,369
1910	247,060
1911	205,056
1912	787,735
1913	491,080

During the same period their exports were as follows:[25]

Year	Long Tons
1905	11,522
1906	14,437
1907	35,925
1908	27,894
1909	37,142
1910	30,742
1911	28,103
1912	57,736
1913	89,221

Frasch's pricing policies revealed his appreciation of the advantages to the consumer, of a steady, open price, quoted the same to all. He held firm convictions that reasonably priced sulphur would extend its use, and as early as 1898 he advocated research aimed to broaden the market.

Accordingly Frasch built a refinery in Brooklyn, New York. Francis H. Pough, took charge of this refinery. His task was to increase use of sulphur in the agricultural field. Much was accomplished at the refinery; new methods of refining sulphur were discovered, sales methods broadened and Cornell University established fellowships for sulphur research.

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[24] Robert H. Ridgeway, "Sulphur," United States Bureau of Mines, Information Circular Number 6329, (reprinted May 1934), p. 22.

[25] Ibid., p. 48

In 1912, Frasch decided to build a sulphur refining plant at Marseilles, France. Placed in charge of the plant was, Herman Hoeckel, a German. Hoeckel was instructed to make an impressive demonstration. Instructions were thoroughly executed. The plant's foundation and walls were so solidly constructed, that several years later, during World War I, Hoeckel was accused of erecting a fortress for the benefit of the Germans. It was a pure and simple spy story, but Hoeckel, thoroughly alarmed, slipped away, and vanished completely, as far as the sulphur industry was concerned.[26]

Southwestern Louisiana, about half way between Lake Charles and the Texas state line, is credited with being the operational site of America's first modern sulphur mine. Surrounding a small hilly dome, some fifty acres in area, are the marshes of Bayou Choupique: The dome is simply an open, dry clearing in the midst of these marshes; a subtropical jungle of cypress and pine, festooned with Spanish moss. This conspicious mark attracted early attention. In 1884, thirty-five years before it was named Sulphur Mine, oil seepages were observed trickling, off the domed structure, into the marshes.

In 1860, one year after oil was discovered in Pennsylvania, an attempt to drill a test well on the knoll, was made by use of the Canadian pole. This method consisted of a long, strong tree trunk mounted on a swivel. Engaged in the enterprise were Eli and William Perkins with the aid of Dr. Kirkman, the local physican. The Perkins', a prominent family of Calcasieu Parish, owned part of the knoll, it being located in the Parish. The Doctor was interested, since petroleum was widely advertised as "rock oil",

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26 Haynes, op. cit., p. 113.

a cure for several chronic ailments.[27] The Civil War interrupted this drilling attempt, however a showing of oil was made.

Organization of the Louisiana Petroleum & Coal Oil Company, was in 1867 by General Jules Brady of New Orleans, and with a driller named Mudd a boring was made at the knoll or sulphur Mine as it was later named.[28] Penetration was 1230 feet. Strata of clay and gravel were encountered before entering quicksand, where a heavy flow of sulphurous water was struck. Beneath the quicksand a thick bed of limestone was struck, and under that about 100 feet, a porous limestone impregnated with pure sulphur. Below the sulphur-bearing deposit, gypsum was found and after drilling over 600 feet without leaving the gypsum and not finding oil, drilling was halted.

Discouraged at not finding oil and perplexed by geological formations unlike those accustomed to elsewhere, the company invited Professor Eugene Hilgard, of the University of Mississippi, to examine its findings. Professor Hilgard at that time (May 1869) was making an oil and mineral reconnaissance of Louisiana. Carefully this trained geologist and trained driller checked corings and drilling logs. Appraisal, by Hilgard, was unfavorable for oil but sulphur possibilities were favorable.[29] Professor Hilgard pointed out, in his written report to General Brady, that oil bearing strata about 340 feet below the surface, was unlikely to furnish a large, or at least, a lasting supply of petroleum. Regarding sulphur he wrote, "The sulphur-bearing formation consists of superior stratum of friable, crystalline, semi-transparent native sulphur."

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[27] Walter W. Jennings, <u>History of the Economic and Social Progress of the American People</u>, pp. 482-483.

[28] <u>U.S.G.S. Annual Report</u>, Volume 3, (1883), p. 509.

[29] Eugene W. Hilgard, "The Petroleum and Sulphur of Calcasieu," <u>Engineering and Mining Journal</u>, Volume 8, (September 28, 1869), pp. 196-197.

Hilgard's report concluded with the suggestion that a shaft be sunk 450 feet below the surface to the upper portion of the sulphur bed. He noted probabilities of encountering difficulties and recommended adequate financial support, should the endeavour be undertaken. He believed a competent engineer with sufficient means, could make the project practical.

Upon reaching the sulphur deposit he believed that, "the working of the mine would be easy and in the highest degree remunerative --- capable, in view of the difficulty under which the production of Sicilian sulphur labors, of controling the sulphur market of the world, and adding to the prosperity of the whole country by cheapening the production and improving the quality of that great fundamental agent, 'sulphuric acid', the preparation of which from impure pyrites is so often a source of annoyance and loss to all kinds of manufacturers."[30]

Hilgard's report described with accuracy the various strata underlying the Calcasieu dome. It recognized the great sulphur potentialities of the property, when Sicily was the world's only commercial source of sulphur. Furthermore, the report forecast breaking the sulphur monoply maintained by Sicily. The Calcasieu Sulphur and Mining Company was organized, replacing the Louisiana Petroleum and Coal Oil Company, as a result of the report being unfavorable to oil and favorable to sulphur production.

Organization of this corporation was in New Orleans, in 1870, where close commercial and social connections were maintained with France. Belief is held that considerable French capital was behind the enterprise.[31] Several directors of the organization were recommended by the French Government.

An exploratory well was made. Careful examination of the quicksands and limestone overlying the sulphur deposits, caused a conclusion to be

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30 Ibid., p. 197.

31 Williams Haynes, The Stone That Burns, (1942), p. 9.

reached that the limestone strata, twenty-five feet in thickness, lying directly over the sulphur, protects it from the contact of sulphurous water.

This conclusion was the basis of the methods proposed to reach the sulphur deposit by a shaft. Herman Frasch's process was based on this assumption. Furthermore it identified the caprock that overlies all Gulf Coast salt domes.

Boilers from France and cast-iron rings from Belgium were purchased, and a shaft was sunk to the quicksand. The cast-iron rings, ten feet in diameter and five feet high, were used to case the shaft. There seems to be no record of the time spent at this operation, but it was abandoned and all equipment was sold in 1879, to the newly organized Louisiana Sulphur Company.[32]

During the next ten years several attempts were made to reach the sulphur bed, but all failed. Frasch wrote, "The deposit seemed to bring misfortune to everyone connected with it, and I have heard many stories and met many people who have told me of having lost money in the various schemes that marked the progress of the sulphur mine. Progress there seemed to mean failure. An Austrian company, a French company and numerous American companies, failed and not a ton of sulphur was produced." 33

In 1890 five men working in a shaft, in which the same Belgian rings were being used again, were overcome by a burst of water and hydrogen sulphide. This tragic happening marked the end of the shaft method, the use of the iron rings and thirty years of successive sulphur mining failures.

Herman Frasch drilled four exploratory wells within two miles of Sulphur Mine, in 1891. Sulphur, limestone, gypsum and petroleum showings were negative, Frasch, therefore, concluded that all the sulphur in that region must lie beneath the fifty-acre dome owned, at the time, by the American Sulphur Company.

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[32] <u>Mineral Resources</u>, 1883-1884, p. 864.

[33] Frasch, <u>op</u>. <u>cit</u>., p. 79

To secure rights to drill on the dome was Frasch's next problem. After several months of negiotiating, Frasch's patent rights and the property rights of the American Sulphur Company were pooled, forming the Union Sulphur Company. Union was the first company to use modern sulphur mining methods.

CHAPTER III

SULPHUR PRODUCTION IN THE UNITED STATES (1894 - 1919)

Frasch secured patent rights on his process for sulphur extraction in 1891, but not until 1894, in late December, did he produce any sulphur. Enduring difficulties were ever present. Fuel for firing the boilers had consisted of slabs of lumber from nearby sawmills, and when depleted, coal was imported from Alabama, at a cost of $4.05 per ton. The enormous amount of heat required for one well consumed about fifty tons of coal per day and at that time the operation was still in the laboratory or experimental stage.

An adequate supply of water, free of minerals, is necessary to allow operation of the Frasch Process of sulphur mining. Water for the early operations was taken from creeks, marshes, bayous and drain ditches, without removing impurities. As pointed out the first operations were experimental and it was not until later that it was found practical to remove mineral matter from the water used, because pipes through which water passes becomes coated with foreign matter.

The first two wells pumped yielded 912 tons of sulphur.[1] A third well yielded about 50 tons before the ten inch casing broke in the quicksand formation which necessitated the abandoning of operations.

Discovered during these early operations that an excessive waste of hot water occurred, Frasch pumped mud and cut rice straw to seal the fissures of the limestone formation to remedy the problem. These methods gave the desired results.

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[1] Union Sulphur Company vs Freeport Texas Company, Record on Appeal, United States, Circuit Court of Appeals for the Third Circuit. Plaintiffs' Exhibit No. 54, III, p. 378.

Progress was being made but an examination of the financial condition of the Union Sulphur Company, in September 1897, revealed total investments and indebtedness of $319,305.90, while the company received from its sulphur sales $38,906.69.[2] Faced with a financial crisis Union Sulphur Company shut down operations in Louisiana and attempted mining sulphur in Sicily in 1898. Failure to reach sulphur in two borings, this endeavour too was abandoned.

Frasch drew criticism from men of repute, due to the abandonment of his operations. Edward W. Parker, of the United States Geological Survey, wrote that the Frasch Process seemed of no commercial value.[3] Rothwell, editor of Engineering and Mining Journal, wrote in his statistical supplement, Mineral Industry 1898, that Frasch's method conceded complete commercial failure.[4]

On January 23, 1896 the Union Sulphur Company was incorporated in the State of New Jersey, to secure land title and mineral rights at Sulphur Mine and also to secure the Frasch patents. Capital stock was $200,000 shareholders included, in addition to the American Sulphur Company, Frasch, Rockefeller, and several other financiers. Although heretofore failure resulted to some degree, these men determined to salvage the loss, if possible, of such an investment. After long and cautious studies and deliberations on the possibilities of future production, the management of Union Sulphur company decided to resume operation of its shut-down mine.

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[2] Union Sulphur Company vs. Freeport Texas Company, op. cit., Testimony of C. A. Snider, I, p. 339.

[3] Edward W. Parker, "Sulphur and Pyrite", United States Geological Survey, Annual Report, Volume 6, (1896-1899), p. 641.

[4] Mineral Industry, Volume 7, (1898), p. 643.

Accordingly one well was steamed, in 1899-1900 and yielded only thirty-six tons of sulphur,[5] while during 1901 production from two additional wells amounted to 3,078 tons.[6]

A discovery wholly unrelated to sulphur mining solved the Frasch problem. On January 10, 1901 an oil well was "brought in" at Spindletop, Texas, near Beaumont.[7] This "gusher" began to flow at 70,000 barrels per day, one of the greatest in petroleum history. Thus only sixty miles from Sulphur Mine, this ample supply of cheap fuel became available for the Union Sulphur Company's operations.

Spindletop's gusher not only solved the problem of fuel supply but had far reaching effects on further sulphur operations. Every dome-shaped formation on the Gulf Coast has been drilled or cored for oil as a result of the "gusher." One hundred six true salt domes have been found by these explorations. Forty-seven of these domes bore no traces of sulphur; forty-seven had showings of appreciable amounts, one of which was steamed but never produced commercially. Eleven domes have produced sulphur in large quantities, five of which operate at present. Union Sulphur Company, the pioneer in sulphur mining, no longer operates.

Sulphur mining entails much drilling in locating a deposit. Drilling and coring is necessary to arrive at satisfactory estimates of sulphur contained in the deposit. Contours of sulphur bearing strata, generally irregular, lie at varying depths in the dome. Clean cut cores are necessary

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5 Haynes, <u>op. cit.</u>, p. 47.

6 Haynes, <u>Loc. cit.</u>, p. 49.

7 "Mineral Resources of the United States," <u>U.S.G.S.</u> (1904), p. 712.

for a complete cross-section of strata underlying the caprock. Cost of exploration and proving a sulphur deposit run unusually high.[8]

Bryanmound and Freeport Sulphur Company

Near the mouth of the Brazos, the largest of Texas rivers, lies a conspicious historic landmark, covering several hundred acres in area. The ancient Spanish city of Quintana had stood between the Gulf of Mexico and the mound, west of the river.[9] This once flourishing port was wiped out by a hurricane and tidal wave in 1900, the same being so destructive to the city of Galveston. On the east bank of the Brazos, a mile from its mouth, stood the town of Valesco, named it is said for a Spanish Count. The first free port of entry in Texas was established at this site and here in 1823 Stephen F. Austin made his first headquarters. For services rendered as an impresario, the Mexican Government granted Austin a tract of 177 acres within the dome area.[10]

Austin no doubt selected this mound as his choice of land, because it rises boldly about twenty feet above the level, treeless plain, punctured with great anthills, streaked with marshy swamps, the habitant of enormous grey herons, and the wild range of the famed longhorned Texas cattle. This rise of land in such a landscape, like the sulphur mound in Calcasieu swamp, was an oasis.

Due to keen interest in oil, scant attention was paid to any indications of sulphur in earlier tests of the mound. True and typical during oil

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[8] A. F. Zemanek, Personal Interview, Newgulf, Texas, (September 8, 1947).

[9] Haynes, op. cit., p. 118.

[10] Abstract prepared by Brazoria County Abstract Company, (certified September 16, 1920), in the Depletion File of Freeport Sulphur Company's Bryanmound Deposit.

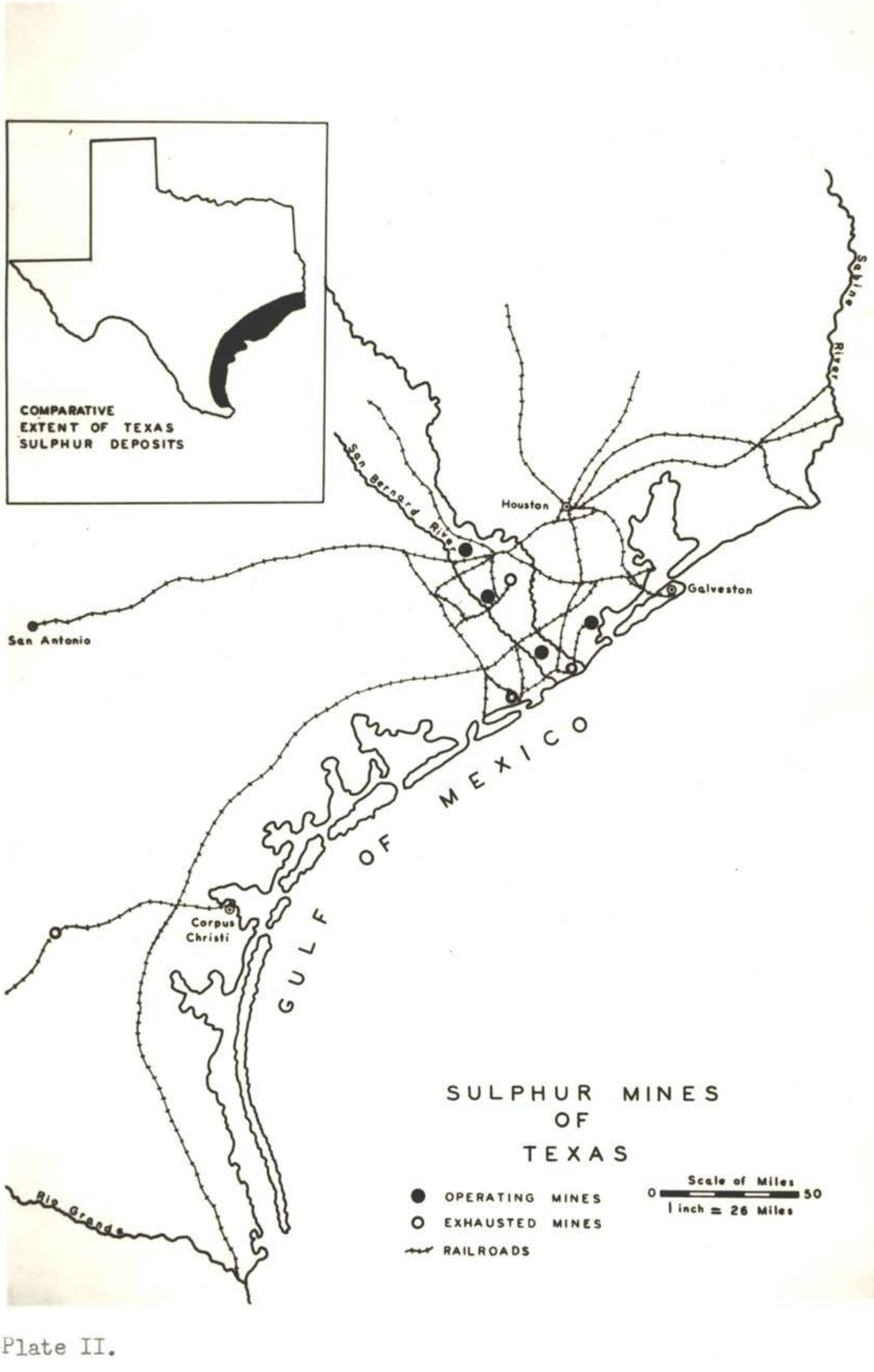
COMPARATIVE
EXTENT OF TEXAS
SULPHUR DEPOSITS
Sabine River
San Bernard River
Houston
Galveston
San Antonio
GULF OF MEXICO
Corpus Christi
Rio Grande
SULPHUR MINES
OF
TEXAS
OPERATING MINES
EXHAUSTED MINES
RAILROADS
Scale of Miles
0
50
1 inch = 26 Miles

Plate II.

speculation in a given locality land titles change often, the mound had several owners, finally the Bryan family acquired title to the greater part, hence it was named Bryanmound.

Local tradition credits an oil exploratory well drilled in 1904, by a Doctor Reed, as the first indication of sulphur. After 1904, oil prospecting, found that twenty-seven tests wells bore sulphur in greater or lesser quantities.

The Bryanmound formation provided an impressive demonstration of the difficulty in obtaining satisfactory sulphur cores. Its limestone horizon was so fissured and cleaved that usually in previous drilling no cutting at all had been obtained, although sometimes an artesian flow carried out remnants containing sulphur. Development of a reverse flow system enabled the prospectors to determine the sulphur content of the mound fairly accurately.[11] In 1910 and 1911, eleven such test wells were drilled on Bryanmound, and the report bore the fact that the deposit was fairly good but spotty.

The Freeport Sulphur Company was incorporated in Texas, on July 12, 1912. At the same time, the Freeport Townsite Company, acquired title to most of the land of the dome area. Accordingly the city of Freeport was established on the west bank of the Brazos River.

The greatest problems at Bryanmound included labor and transportation. Every piece of construction material had to be brought to the storm-torn town of Valesco, on the east bank of the Brazos. This was accomplished either by use of a makeshift railroad or the old barge canal from Galveston,

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[11] This is a method of removing the water and cuttings from the drill pipe.

which had been used in early days for transporting rice and sugar. Ascribable to poor transportation, shipments of material were irregular and much delayed. It was necessary then to ferry every bit of material to the west bank of the river, and finally mules hauled and dragged material to the mine site, through the sticky gumbo mud.

Good construction men, after vast expenditures of capital and hardships of drilling, hauling, building and all other necessary work, produced the first sulphur, at Bryanmound, on November 12, 1912. As a monument to the achievements of ten years work at Bryanmound, a dump cart load of the first Texas sulphur produced, placed in front of the Tarpon Inn, at Freeport, Texas, remained there for several months.

Bryanmound did not produce copious quantities smoothly. Numerous adjustments became necessary, including a second power plant, additional boilers and an ample supply of mineral-free water. The following production figures evidence changes in operation methods: 1912, 636 tons; 1913, 10,504 tons; 1914, 41,872 tons.[12]

Sulphur's Position in World War I

Modern war profoundly affects all chemical activity. Generally, usual sources of raw material are not available. International chemical trade channels are disrupted. War necessitates and demands enormous quantities of chemicals, frequently those for which only a moderate peace time market exists. Research —— especially research for substitutes and processes —— is abnormally stimulated. Certain chemical progress always evolves from

[12] Statistical Department, Files Freeport Sulphur Company, p. 61.

wartime activities. From chemical research during World War I the United States secured giant coal-tar, plastics, lacquer and other industries. During this period the American sulphuric acid industry switched from pyrites to native sulphur as its principal source of raw material. This change, remaining after the war, revolutionized the American sulphur industry.

American sulphuric acid manufacturers relied chiefly upon imported Spanish pyrites, prior to World War I. During the first two years of war, manufacturers suffered little inconvenience for raw material. In 1917, pyrites imports dropped from 1,200,000 tons for the year previous, to about 750,000 tons.[13] The following year saw a further drop to about 270,000 tons. During the same period, domestic production of pyrites expanded from 439,132 to 464,494 tons.[14] The official tonnage figures which follow; reveal the sulphur situation.

Year	Marketed Production	Imports	Exports	Total Consumption
1914	341,895	26,135	98,153	369,967
1915	293,803	24,647	37,271	281,179
1916	766,835	21,289	128,755	659,369
1917	1,120,378	973	152,763	968,588
1918	1,266,709	55	131,092	1,135,672
1919	678,257	77	224,712	453,622

From the above figures, one observes a situation appearing hopelessly confused. It was clear that a shortage of sulphur-bearing raw materials was impending. Solution of this problem was not at all clear.

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13 A. E. Wells and D. E. Fogg, "The Manufacture of Sulphuric Acid in the United States", United States Bureau of Mines, Bulletin 184, (1918), pp. 41-42.

14 All figures from annual statistics of Mineral Resources.

Obviously enough, little relief was expected from imported pyrites. Pressure upon available shipping was certain to increase. Moreover greater demands for sulphuric acid, vitally essential in industry and explosives, came from war industries. Possibilities of increasing American pyrites production were ruled out. Accordingly the Bureau of Mines made a survey of the supply of all sulphur-bearing materials and the country's acid plant capacity.[15]

In order to insure that no sulphur-bearing materials were wasted and in order to facilitate sulphuric acid outputs the Council of National Defense also instructed chemical industries to use all available stocks of pyrites before changing to raw sulphur. The result of all necessary changes, was much crosshauling among various plants, at a time when there was a serious shortage of rail cars. To alleviate this condition arrangements were made with the Army and Navy to ship acid from the nearest manufacturing point, with clearance settlements from time to time. This simple plan provided a better regional distribution of acid and an increased tank car efficiency.

Arrangements were made with sulphur producers in Louisiana and Texas, in 1918, to ship sulphur in solid trainloads to distributing points in the North and East. From these points the cars were distributed to individual consuming plants, thereby saving much invaluable time.[16]

During October, 1917, a committee of engineers detailed by the Bureau of Mines, surveyed the sulphur situation. Properties of the Freeport and Union Companies were closely examined to determine the available supply of sulphur and possibilities of increasing production. Stocks of both companies

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15 Wells and Fogg, <u>op. cit.</u>, p. 8.

16 Bernard M. Baruch, <u>Report of the War Industries Board</u>, (1921), pp. 162-163.

were determined at 1,440,000 long tons. The survey estimated that in the next five years the two mines could produce 6,200,000 tons of sulphur —— 2,000,000 from Freeport and 4,200,000 from Union. For the succeeding year 1,400,000 tons could be brought to the surface —— 500,000 tons by Freeport, 900,000 tons by Union, also increasing the output for 1919-1920 by increasing the size and number of steaming plants. Such an increase should tend to rapidly exhaust the deposits, resulting in a marked decrease in the two succeeding years. Already both mines were equipped sufficiently to exhaust the deposits; the installation of additional equipment was not recommended.

The engineers report pointed out that each sulphur company used approximately 4,000 barrels of fuel oil per day; Freeport's supply came from Mexico by boat, while Union's supply came from Mexico and the fields of Louisiana and Texas.

Such a report showed plainly the important role of sulphur in national defense. Recognizing the vital character of the sulphur deposits, the indomitable, General John J. Pershing, authorized, in May 1917, military protection for the Freeport plant situated on the Gulf of Mexico at the mouth of the Brazos River, a site exposed to attack from the sea.

Bryanmound's production increased steadily beginning in 1914, and lasted through the war period. Operating technique gradually overcame extraction difficulties from this peculiarly porous formation. Applied experience, accumulated in drilling and steaming wells, increased the average output per well. Increased efficiency and economy of the entire operation followed.

During the war a railway spur three and one-half miles in length was laid from the city of Freeport, to the mine site. This spur, built by the Southern Pacific Railway Company increased loading facilities of Freeport Sulphur Company.

Sufficient distance from the sea, of the Union mine in Louisiana precluded dangers of attack from German raiders, but the operation offered other difficulties. In 1911 the sulphur flow stopped. The staff worked upon the problem for about six months without success and finally called upon Doctor Frasch, a seriously ill man, to help solve the problem. Frasch determined the difficulty arose from excessive quantities of cold ground water in the sulphur horizon. Installation of bleed pumps, capable of withdrawing in excess of 9,000,000 gallons of cold water per day, succeeded in removing enough of this to permit pumping of hot water down to do its desired work. Thus overcoming another obstacle in sulphur mining, operators practice this method today to attain maximum production efficiency.

Subsidence in the Union mine became quite serious. In 1914, many places within the mine area had sunk as much as twenty feet, and periodic lowering of the ground, necessitated filling to sustain the foundations of the boilerhouses.[17]

Outstanding among events at Sulphur Mine, Louisiana during the war period included the cyclone that struck the area in August 1918.[18] Destruction and damage necessitated suspension of operations. Temporary stoppage of production fortunately preceeded two months of extremely heavy production so that ample stockpiles permitted the shipping of sulphur regularly from this supply.

The strategic role of sulphur during the war prompted projects to mine sulphur from known deposits in Western United States. Mines located in

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[17] A. E. Wells, "Report on Supply of Raw Materials for Manufacturers of Sulphuric Acid," War Industries Board, (March 14, 1918).

[18] Times-Picayune, New Orleans, Louisiana, (August 12, 1918), p. 1.

Colorado, Nevada, Utah, Idaho, Wyoming and one in the gypsum beds in Western Texas reached production status. All were worked by the white steam process, but produced comparatively little sulphur. Transportation difficulties, inaccessible location and lack of machinery discouraged continued production, following a few months venture by enterprising miners at these points. Efforts were concentrated on the mines of the Gulf Coast salt domes. As a result of such concentration the organization of the Gulf Sulphur Company developed a new dome called Big Hill in Matagorda County, Texas. No sulphur was produced during the war, at Big Hill, but it was destined to furnish vast quantities of sulphur soon, therefore erased all fears of a sulphur shortage, in the United States.

Developments of new techniques in mining, efficiency in transportation and marketing, adequate supplies of fuel oil and plain hard work were each equally responsible for supplying all war and domestic demands for sulphur during the war. Emerging from this period in a respectable position as an essential industry to a war-time as well as a domestic economy, sulphur mining and the sulphur industry continued upward.

CHAPTER IV

EXPANSION OF SULPHUR MINING IN THE UNITED STATES: THE NEWGULF, TEXAS OPERATION

During 1920 and 1921, inevitable exhaustion of Union Sulphur Company's operation at Sulphur Mine, Louisiana became plainly evident. Union's management began prospecting for additional deposits. Four domes prospected indicated inadequate amounts of sulphur for economic production, prior to the summer of 1922 when the Texas Exploration Company optioned to Union the sulphur rights at Damon Mound. Here they checked the considerable sulphur-testing which the Exploration Company previously carried on in 1918 and 1919.[1]

Damon Mound is located in Northwestern Brazoria County, Texas, near the Fort Bend County line. It is thirty-eight miles southwest of Houston, nine miles south of Big Creek and ten miles northwest of the West Columbia oil field.

This mound was a famous camp site and stronghold of the Karanawa Indians. They recognized the strategic defensive advantages afforded by this natural elevation and established a settlement on its higher portions. Arrowheads, burial grounds, pottery and stone implements evidence this early village.[2] On the west side of the mound the Indians found a bluish-black substance within and around a depression or crater-like formation. Unlike the surrounding soil the substance, possessed a sour, acid taste, being always moist. The Indians discovered curative properties in this substance, by drinking water that collected in the crater. The substance referred

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[1] George M. Bevier, "The Damon Mound Oil Field, Texas," in Raymond C. Moore, editor, "Geology of Salt Dome Oil Fields," American Association of Petroleum Geologists, Houston, Texas (1926), pp. 613-643.

[2] *Ibid.*, p. 615.

to is commonly known as "sour dirt", currently sold as medicine, and its presence in soil is an indication of a salt dome formation.

Damon Mound named after Samuel Damon, a blacksmith who settled there in 1830, bore crystals of pure sulphur exposed along the sides of gullies on the northern part of the hill. This sulphur is of secondary origin, having been deposited in the crevices and porous formations by ascending vapors or solutions.

The sour dirt was reported by tests, to indicate small amounts of radioactive material; however tests by the Radium Chemical Company of Pittsburgh produced a negative reaction. A general analysis by Dr. E. H. S. Bailey, of the University of Kansas, showed the following components:

Silica	59.33 percent
Ferric oxide.	22.40 percent
Sulphur anhydrid.	3.07 percent
Sulphur	16.13 percent
Water	1.85 percent[3]

Union Sulphur Company drilled 52 test wells at Damon Mound and set up a small plant in 1923, but it was never operated. Exploration crews moved to Big Creek, for further prospecting. This area had also been prospected for oil, with sulphur appearing in several wells. During 1925 and 1926 Union steamed and produced 1070 tons of sulphur from six wells, and extensively explored several additional wells. Operations at Sulphur Mine, Louisiana ceased in 1924 and with no satisfactory holdings Union Sulphur Company dissolved.

The plight of Union Sulphur Company set forth the need for adequate reserves. This fact prompted detailed explorations of every salt dome known during the early 1920's.

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[3] Ibid., pp. 614-615

Exploration Methods

Introduction of geophysical methods of exploration in the Gulf Coast area, in 1922 and successful practice of this method in 1924, enabled locating domes which gave no surface indication of their presence. Further benefiting the sulphur miner, geophysical exploration accurately determines the depth of the dome. This feature is extremely important because physical and economic limitations of the Frasch Process of extraction prohibit mining sulphur at great depths.

Geophysical exploration methods enabled definite location of vast sulphur resources at Newgulf, in 1927. No mound gave surface evidence of this salt-sulphur dome, which proved to be the largest sulphur deposit discovered and exploited to date.

Location

The location of Newgulf has been an important factor in its development. Lying near producing oil and gas fields, adequate cheap fuel supplies assure its economical operation. Water, removed from the nearby San Bernard River, supplemented with shallow wells, insures the operation against construction of extensive water supply lines. Transportation facilities, furnished by rail and the Gulf of Mexico, are excellent and expedient. Low cost water transportation from the Galveston ship-loading dock compensates in some degree for overcoming distance to receivers of sulphur along the Atlantic seaboard and around the Great Lakes. Moreover, nearby petroleum refineries consume large shipments of sulphur.

Physiographic and Climatic Features

Newgulf lies about three miles from the San Bernard River, forty-seven miles southwest of Houston and forty miles from the Gulf of Mexico. No outstanding topographic features exist locally. The surface presents an unbroken pattern, except for small streams and bayous. Elevations range from fifty to seventy feet above sea level, with drainage trending seaward and into the San Bernard River.

Average summer temperatures range from 80 to 95 degrees, while in winter temperatures range from 50 to 60 degrees.[4] Such a mild climate enhances working conditions and economic housing facilities. First frosts appear about November 21, with the last frost occuring about March 1.[5] This allows an average growing season of approximately 300 days, during which time, cotton, corn, grain sorghums, vegetables and fruits are produced in the surrounding area. The Southern Prairie soils, although highly alkaline, support natural vegetation consisting of short and tall grasses, scrub oak, native elm, willow, scrub pine, and other sub-tropical plants.[6] This area was formerly a semi-tropical jungle except for scattered small clearings. Poor dirt roads, insects, snakes, and other pests hampered early operations.

Early Prospecting at Newgulf

Several years before the salt dome was actually located, seepage of hydrogen sulphide gas on the banks of the San Bernard River, a few miles distant, gave hint of mineral in the area.[7]

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4 United States Department of Agriculture, Atlas of American Agriculture, (1935), Part II, Section I, Plate 2 and pp. 7-8.

5 United States Department of Agriculture, Atlas of American Agriculture, (1936), pp. 30-31 and 34-35.

6 United States Department of Agriculture, Atlas of American Agriculture, (1924), Part I, pp. 4-5.

7 James W. Schwab, MS, "History of Texas Sulphur Company's Mining Operations", (January 27, 1941), Company Files, Texas Gulf Sulphur Company, Newgulf, Texas.

Shortly after the hydrogen sulphide gas seepage discovery, Gulf Production Company secured a block of oil leases in the area. Texas, Humble and other oil companies became interested. The first well drilled in August, 1923 produced oil and during the following three years the area was an active producer. Occassional signs of sulphur appeared while the oil-drilling activity progressed. Completion of Gulf Production's wells, Chase numbers three and four, in March and April of 1927, revealed outstanding quantities of sulphur. Immediately sulphur companies sought what appeared to be an exceedingly promising mine location. The Texas Gulf Sulphur Company acquired the sulphur rights for $3,000,000 cash plus half the profits with costs of equipment, including prospecting, reservoirs and townsite being deducted. In this agreement an option went to Texas Gulf Sulphur Company on all sulphur deposits discovered and controlled by the Gulf Production Company.

Sulphur Prospecting

Practically all the sulphur deposits at Newgulf lie beneath land granted to Stephen F. Austin. Before oil drilling in the area, this same grant was subdivided by the Missouri Land Company which sold eighty-eight tracts to various individuals.

Sulphur rights, acquired by the Texas Gulf Sulphur Company, called for drilling within a five-year period beginning in 1922, otherwise the leases would expire. Twenty-five rigs drilled in excess of two hundred development wells during the early part of the five-year lease period. This action maintained the leases in force and enabled a detailed study of each coring.[8] Each

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[8] Statement by H. A. Swem, Assistant General Manager, Texas Gulf Sulphur Company, Newgulf, Texas, (August 27, 1947).

core was carefully assayed for sulphur and inspected for grade and porosity. This careful survey indicated a sulphur formation upwards of fifteen hundred acres lying in the shape of a crescent around the east and south slopes of the dome. Sulphur grades of the formation were as high as 50 percent and thickness varied from a few inches to over two hundred feet. Sulphur estimates of the deposit totaled over forty-six million long tons.

Mining sulphur under leases involves more expenditures of capital than operating a property which the company owns. Ideal mining conditions cannot be attained by forced, scattered operations. Most efficient operation of the Frasch Process requires close grouping of wells with drilling operations starting at the highest point of the sulphur-bearing area. From this point work proceeds down the side of the dome toward its periphery. This allows even subsidence to close in the space from which the sulphur has been removed. Such operational methods require land ownership, or the pooling of leases covering the entire sulphur-bearing area. Operations taking place on individual leases entails the additional cost of constructing pipe lines for hot water, sulphur stations, sulphur sumps, and other necessary facilities. Economic efficiency becomes less when operating from individual leases.

Efforts to secure large units of area on which to operate resulted in about half the leases being pooled. The royalties paid on the leases were agreed to by both parties on estimates by impartial engineers.[9] The remaining unpooled leases required simultaneous operations throughout the area forcing the company to mine on an individual basis on each unpooled lease.

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[9] Statement by A. F. Zemanek, Field Manager, Texas Gulf Sulphur Company, Newgulf, Texas, (September 3, 1947).

Operating Equipment at Newgulf.

Simultaneous operations at Newgulf, required enormous quantities of superheated water. Plans adopted required the use of eight million gallons every twenty-four hours. Most of this water comes from the San Bernard River, supplemented by water obtained from shallow wells. A reservoir containing two hundred sixty-two acres with a water capacity of one billion gallons constructed some distance from the sulphur area insures adequate water supplies.

Pumps, with a forty thousand gallon per minute capacity, installed at the San Bernard River raise its waters to the reservoir. Water taken from the river during flood time or at high flow contains less mineral, therefore it requires less softening and is most desirable. Water from such sources is seldom suitable for use in boilers and mine water heaters because of the presence of natural salts in solution. If not softened certain salts, when heated, precipitate from solution and coat the boiler tubes and other piping with a hard scale. This scale hampers production by being difficult to remove and seriously curtails plant efficiency and capacity.[10] At Newgulf almost all of the scale-forming and corrosive substances are removed from the water before going to the boilers or heaters. The Cochrane hot process lime-soda softening plant at Newgulf, being the largest of its kind in the world, successfully treats thirty thousand tons of water in twenty-four hours.

The power plant at Newgulf consists of ten water-tube boilers. They at present operate on natural gas obtained from a producing field about ten miles

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[10] Statement by C. L. Orr, Power House Manager, Texas Gulf Sulphur Company, Newgulf, Texas, (September 2, 1947).

distant from the plant. Equipment stands in readiness to permit operation with fuel oil if for any reason gas supplies are interrupted. This change can be effected in the space of a few minutes. Economizers make effective use of heat from the stack gases. The arrangement of the power plant will allow, should gas or fuel oil not be available, the installment of necessary equipment for burning powdered lignite. The major portion of the steam is used for heating water for mining; the remainder being used for operation of machinery and maintaining the sulphur in a molten condition when being transported to storage vats.

Pipe varying in diameter from one and one-quarter inch to sixteen inches, traverses the entire area. Pipes conduct superheated water from the powerhouse to the mining zone and into each well that is steamed. Other pipes return molten sulphur to storage vats, where it cools.[11]

Other operational equipment includes several large air compressors, electric generators, recording thermometers, pressure gauges, meters and various other units for regulating operations of machinery.

Waste water, called "bleedwater", from the mines is purified before returning it to the San Bernard River, at a point below tidewater. This practice eliminates dangers of poisoning wild life, human life and domestic animals along with destroying foul odors.

A power plant sufficiently large and capable of producing tremendous amounts of work is absolutely essential in modern sulphur mining. The hot water, furnished by the power plant, enables continuous operation, thus

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11 A. F. Zemanek, "personal interview," op. cit.

Figure 2. Sulphur Pipe Lines (Courtesy, Texas Gulf Sulphur Company)

preventing the molten sulphur from conjealing in wells and pipes. A shut down of operations for less than one hour, would require months of tedious, painstaking labor to remove the solid sulphur from wells and conduits.[12]

Field Operations

All sulphur deposits mined by the Frasch Process occur in the caprock of the salt domes.[13] In horizontal section, the domes are circular to elliptical in shape. Surrounding and overlying the domes are clay, "gumbo", and sand. The upper portion of the dome consists of a porous caprock composed largely of limestone and calcite, with an occasional trace of carbonates and sulphates of other alkaline earths. The sulphur occurs in the porous limestone in crystalline form. Below the limestone lies a stratum of heavy anhydrite which in turn overlies the rock-salt core of the dome. General agreement prevails that these salt-sulphur domes are the result of intrusion during the Cretaceous Epoch.[14] Wells drilled with a modern rotary oil drilling rig penetrate the formation extending some distance into the anhydrite. Hot water is introduced and molten sulphur is removed from the same well.

Pumping stations are erected at carefully chosen locations within the sulphur area. From each station a group of wells operate. The station equipment consists of steam heated collecting sumps, control valves, meters and gauges which permit proper operation of the wells. Pipes from the power house lead to these stations and provide for distribution of water, steam and air to the individual wells.

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[12] C. L. Orr, "personal interview", op. cit.

[13] To the geologist and oil man "caprock" means all formations from the top to the bottom of the anhydrite immediately above the salt, while to the sulphur miner, "caprock", refers to only the limestone stratum.

[14] Raymond C. Moore, editor, Bulletin American Association of Petroleum Geologists, E. DeGoyler, "Origin of North American Salt Domes," pp. 1-44 and Hans Stille, "The Upthrust of Salt Masses of Germany," pp. 142-164, Houston, Texas, (1926).

Well location is influenced by existing local characteristics at any point considered. Underground physical features of the sulphur deposit and the effective reach of the hot water outward from the well in horizontal and vertical directions determine well location. Favorably located wells pump continuously over long periods, becoming increasingly intermittent as old age advances. Some wells last a year or more, sometimes producing as much as one hundred thousand long tons. Others cease to produce in a few weeks, due to destruction of the well equipment by ground movement, or to density of the "gangue", which prevents circulation of hot water and molten sulphur. As sulphur extraction proceeds the integrity of the rock structure is weakened, resulting in a general downward creep of the overlying formations. This inequality of movement in which different strata are involved brings about bending or breaking of the well pipe thereby forcing the well out of service. Abandoned wells are immediately sealed to prevent water from escaping.[15]

Subsidence is a disadvantage in mining in so far as it causes the loss of producing wells and equipment failure. Sometimes this disadvantage is more than offset by the relatively impervious character of the crushed exhausted sulphur formation. Since water circulates through this caved formation with difficulty, the incoming hot water is confined to the porous unexhausted parts of the deposit. The conditions of subsidence as a factor in the actual mining operation does not prevail at all sulphur deposits. In some cases the barren rock above the sulphur bearing stratum may be so thick and of such character as to preclude subsidence. Production costs in mining such deposits are greater than in those were subsidence readily occurs.

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15 A. F. Zemanek, "personal interview", op. cit.

In the most successful type of deposit, the "gumbo" and shale, which overlies and surrounds the dome are relatively impervious to water. Since no natural outlet exists for the considerable volume of water which is pumped into the deposit, the water is removed at practically the same rate at which it enters, by means of "bleed" wells. Such wells located some distance from the active steaming zone tap the deposit at lower levels than the producing wells. This method removes the water which cools in its downward progress through the porous rock formation. The incoming hot water displaces the water from which the useful heat has been removed, the latter being progressively discharged to waste through the bleed wells. In this process a certain degree of dilution occurs with the original ground water.

The permanent equipment of a sulphur well consists of the underground piping and the necessary surface connections. These include hot water and sulphur lines, both insulated, and compressed air lines with the necessary control valves. A one and one-quarter inch steam line placed inside the sulphur discharge line prevents the sulphur from solidifying. All lines conveying sulphur are equipped with the smaller steam lines. Ordinary piping is used in the transmission of sulphur since that material is not corrosive unless water is prevalent. Pipe movements due to temperature changes are offset by expansion joints.

The drilling rig utilized at Newgulf is the modern oil drilling rotary rig. All drilling equipment operated at Newgulf today is owned outright by the Texas Gulf Sulphur Company. Prior to this practice the company contracted with other drilling concerns for all wells sunk. The cost of sinking a well totals approximately $10,000.[16]

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[16] H. A. Swem, "personal interview", op. cit.

Upon completion of a producing well, the drilling equipment is removed, leaving the steel derrick and equipment to raise pipe as part of the permanent surface equipment. This practice enables removal of portions of the pipe for repairs or replacement. When wells are discontinued equipment is salvaged if possible.

The collecting sump dimensions depend upon operating conditions and the number of wells supplying sulphur. The sumps, lined with cast iron, require steam heat by coils at the sides and on the bottom, to maintain the sulphur in a liquid state.

When the sumps become reasonably full, motor driven centrifugal pumps force the liquid sulphur through sulphur pipe lines to the storage vats. The pumps are especially designed, with all moving parts either submerged in liquid sulphur or equipped with steam jackets. Ideal operating conditions are determined in all instances by experiment, enabling easy control by a single attendant at each station.[17]

Production at Newgulf

Initial production at Newgulf began March 20, 1929. During the remainder of the year, efforts for improving operation techniques, installing equipment, and extending construction took precedence over actual production. The apparent exhausting of the other principal source of supply spurred plans for concentration on the Newgulf operation.

The slow but consistent increase of production at Newgulf indicates the exercising of considerable care in location of wells, installation of equipment, and the marketing of the product.

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17 A. F. Zemanek, "personal interview," <u>op. cit</u>.

The following yearly production figures of the Newgulf deposit, lend an idea of the magnitude of the operation.[18]

Year	Production (in long tons)
1929	337,625
1930	705,806
1931	663,092
1932	414,515
1933	597,236
1934	794,674
1935	879,695
1936	1,181,229
1937	1,698,807
1938	1,204,328
1939	818,322
1940	1,428,206
1941	1,839,391
1942	2,173,381
1943	1,186,881
1944	1,842,107
1945	2,203,416
1946	2,090,974
1947	2,737,255
1948	3,065,601
Grand Total	27,853,541

This amount of sulphur extracted from the deposit represents approximately 60 percent of the world's annual output. Since operations began, taxes collected on sulphur removed from the Newgulf deposit, total $31,373,997.07. This figure is far greater than the total tax collected on oil, gas and related enterprises within Wharton county. The gross tax derived from oil and related industries in the entire State of Texas generally amounts to approximately eighteen times that derived from sulphur mining. The oil industry spreads over the entire state, while sulphur mining is

[18] "Official Figures." Office of Comptroller, State of Texas, Austin, Texas, (February 18, 1949).

limited to Brazoria, Fort Bend, and Wharton counties. According to Texas law, sulphur severance tax is 14.2 percent of value while oil tax is 4 1/8 percent of value.[19]

Storage and Shipment

Sulphur from the pumping stations reaches the storage vats through insulated pipe lines, each carrying internally a small pipe in which live steam constantly flows. This constant flow of live steam maintains the sulphur in a liquid state, allows an even flow, and reduces friction. These lines discharge directly on the vats. Sulphur vats are formed by the solidification of liquid sulphur in a sheet metal bin. The sulphur discharges into the bin at a rate which increases the height a few inches each day. Gradually a large solid block of sulphur accumulates as the liquid sulphur solidifies. The sheet metal vat-walls are fastened to the sulphur by means of wooden spikes, and the walls are kept only a few inches higher than the surface of the sulphur. Under this practice two four foot strips of sheet metal suffice as a vat wall. Upon completion of the vat, the walls are removed leaving only the solid block of sulphur, which is then ready for shipment. This block of sulphur will stand indefinitely without support.

Spacing and location of sulphur vats present a problem. It is important when selecting the site to consider areas of possible subsidence. Since the vats are generally 1200 feet long, 160 to 200 feet wide and 50 feet high, the tonnage contained in a single vat reaches about five hundred thousand long tons. Under ordinary conditions, this mass would be susceptible to some degree of settling. The Newgulf operation's vats are located some distance

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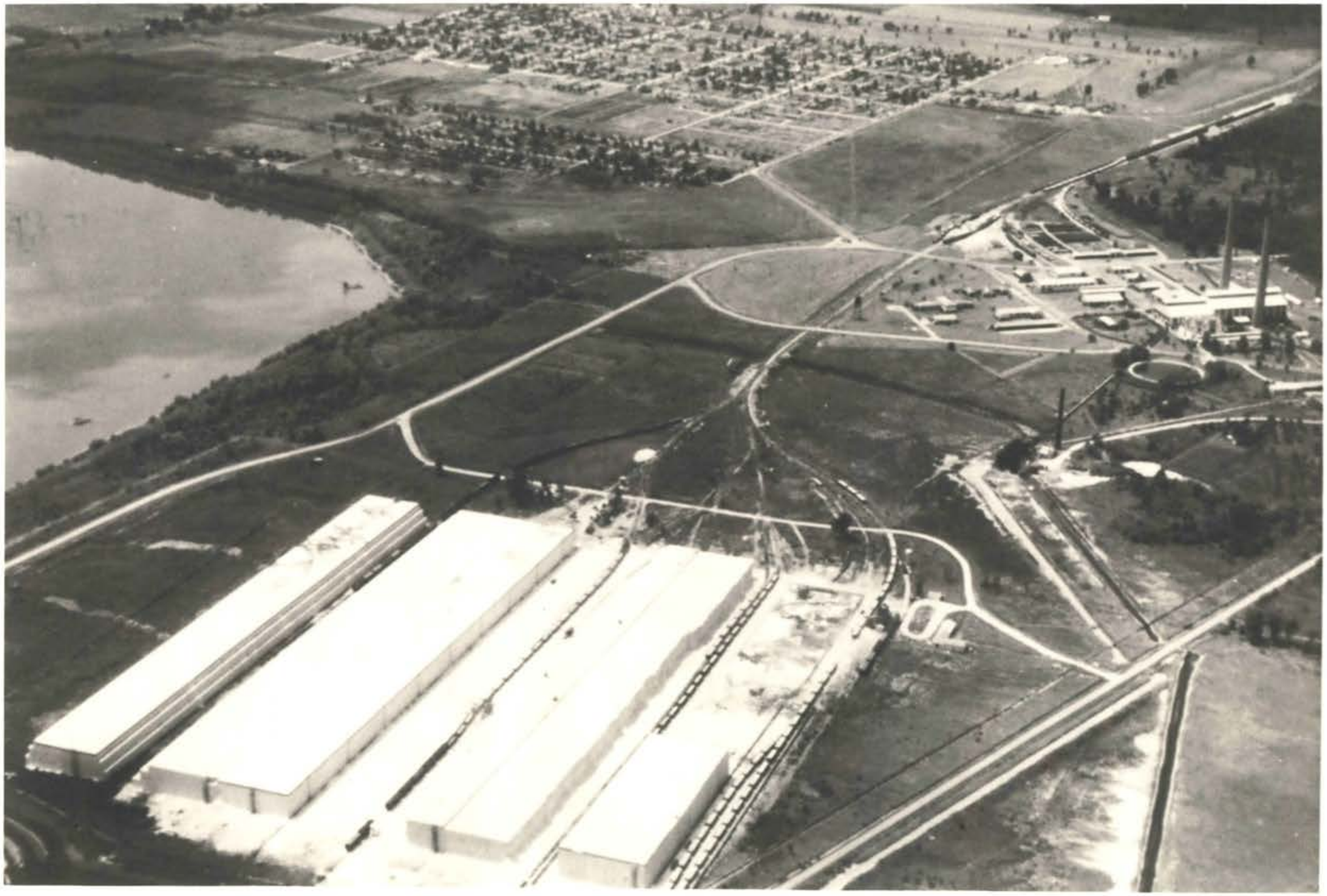
[19] Gross Receipts Tax Laws, State of Texas, Article 7047 Section 40b -- Sulphur Producers, Austin, Texas, (May 1943).

from the sulphur-bearing underling strata, which reduces the probability of severe settling. Space between each vat allows the building of rail spurs for loading purposes. In relation to the power plant, vats at Newgulf lie about one mile distant, between the power plant and water reservoir, where the sub-strata offers the greatest resistance in the mine area. Although some subsidence has occurred, the amount offers no serious problem.

The double track, five mile rail spur owned by the Texas Gulf Sulphur Company, enables direct rail shipment to the Southern Pacific main line, over which the loaded sulphur cars enter various trade channels. Locomotive cranes equipped with two-yard clamshell buckets, load the sulphur into rail cars. These loaders are set on railway running gear, enabling rapid handling.

Sulphur for shipment is blasted from the face of the vats as required. Vertical blocks twelve to twenty feet thick are removed at a time. Light explosive charges generally spring the desired blocks of sulphur from the vat, enabling rapid and efficient handling. At Newgulf, permanently placed vats are built up and broken down in rotation. Current shipments of sulphur has probably been in storage for one to two years. The management believes it wise to maintain large stockpiles to avoid curtailing shipments should a temporary shut-down become necessary.

Connected with the mining operations at Newgulf is the Galveston ship loading plant. Sulphur for water shipment reaches the docks by rail, where it may be unloaded for storage or be transferred directly to ships from railway cars. The sulphur loading plant at Galveston, provides storage space for thirty-five thousand long tons. Equipment at this plant removes sulphur from the storage piles or directly from railway cars to the vessel's hold at the rate of five hundred long tons per hour. Cranes with three-ton capacity



View of Newgulf, showing sulphur storage vats, water supply sump, city, power house, railroads and motor roads.

Figure 3. (Courtesy, Texas Gulf Sulphur Company)

clamshell buckets remove the sulphur from cars or bins to hoppers which automatically feed a conveyor belt leading to the ship's hold. While being conveyed to the vessel the sulphur is weighed when in motion. In addition to export shipments, great quantities of sulphur move by water transport to numerous points on the Atlantic and Pacific Coasts. Sulphuric acid plants in Maryland, New York and the Great Lakes area cause numerous shipments to reach Baltimore and New York City, in addition to other points. San Pedro, Los Angeles, and San Francisco are the leading North American Pacific Ports receiving large orders of sulphur.

Exported sulphur finds a ready market in Europe. England, France, Germany, Norway, Sweden and the Low Countries receive most of the European shipments. Italy, although producing some sulphur at present receives American sulphur, coming through the European aid program.

Labor Relations

The personnel at the Newgulf operation comprises for the greater part highly skilled engineers and technicians. Mexicans compose most of the laboring group, although this force remains very small in number. Normally some 785 employees at Newgulf produce over two and one half million long tons of sulphur annually, compared with the 200,000 Italian workers, who produced one hundred forty-five thousand long tons in 1947.

Employer and employee relationships are such that no labor unions exist. This is extremely important inasmuch as no shut down of operations, resulting from labor relations, has curtailed production.

Housing Facilities at Newgulf

While Newgulf was being equipped and operated more and more efficiently, bringing to the surface for industrial use the vast sulphur reserves buried deep underground, the former hog pasture occupying the surface area became transformed into the attractive model town of Newgulf. This social development is as important as the industrial development alongside. There now stands a town of modern homes owned by the company and leased, at low rental, to its employees. The community is served by grocery stores, pharmacies, barber and tailor shops, theatres, garages, and department stores all of which were erected by the proprietors and are held by them on thirty-day leases. This thriving center with a population of approximately three thousand competes with surrounding towns and cities.

The company provides a modern hospital, library, school, water and milk supplies, golf course, guest hotel, swimming pool and other recreational facilities. Insurance provided by the company, covers accidents and death of all employees.

Concentrated in a relatively small area, less than eight hundred skilled engineers operate a mine which normally supplies about seventy-two percent of the Texas sulphur output, and sixty percent of the world's production. Favored by raw material, fuel, transportation and adequate water supplies, Newgulf will maintain its world position in sulphur production until its vast reserves become exhausted.

The beneficial social results of this large scale industry in the midst of the typical Texas farming and ranching section is not limited to Newgulf. The entire county provides schools, libraries, roads, hospitals and other public facilities of excellent quality. These practical benefits are further stimulated by the expenditures of employees at Newgulf where the annual payroll is over $1,500,000.

CHAPTER V

THE LATEST DEVELOPMENT: GRANDE ECAILLE, LOUISIANA

Increased petroleum explorations in the Gulf Coastal Plain during 1928-1929 aided the sulphur mining industry. Underground physical characteristics of the area provide petroleum pools in several distinct strata. Salt-sulphur domes generally contain oil reserves, a fact which prompts extensive prospecting. Spurred by oil explorations, geophysical methods enabled discovery of the Grande Ecaille deposit, lying beneath the east fringes of Lake Grande Ecaille in the Mississippi Delta area.

The Deposit

Detailed surveys revealed the caprock lying beneath the surface at a general depth of 1250 feet, with the caprock averaging about 250 feet in thickness. Overlying the caprock is sand, gravel, gumbo, sandy shale, and scattered boulders. The anhydrite, beneath the sulphur bearing caprock and overlying the salt plug, is fairly impervious, which allows the molten sulphur to settle in a sump at the well's bottom, below the sulphur bearing horizon. Located beneath an oily marsh the Grande Ecaille deposit presented the usual problems encountered in modern sulphur mining, plus that of overcoming adverse working conditions.

Topographic Features

Characteristic of the delta region, the terrain comprises a low, monotonous uninhabited area of marsh land containing numerous shallow lagoons and bayous. Salt grasses supply the only vegetation and presents, in all directions an unobstructed path to the erratic winds. The general character of this district can be easily visualized from the process of its formation.

Johnson points out that offshore bars formed enclosing long narrow lagoons between the bar and the shorelines.[1] The lagoons maintained an outlet to the sea by means of tidal inlets. The quiet waters of the lagoons favored the deposition of fine debris composed of sand brought into the lagoons by wave action, tides and river sediments, from the interior. The finer material carried in by tidal currents was widely distributed over the shallow bottom, while the coarser materials were added to the bar or dropped near the inlet to form the tidal delta.

Rivers, bringing in sediments from the land surface, deposited heavier materials near the inner shoreline forming deltas, while the current delivered lighter materials in the lagoon, covering a wider are of distribution.

Onshore winds blew sands off the beach and sand dunes of the bar receded into the lagoon. Generally heavier materials dropped into the water near the lagoon shore while lighter materials blew over the water surface dropping and coming to rest on the submarine floor.

As the material accumulated, the bottom of the lagoon rose toward the surface. Eventually marsh grass began to grow. Deposition was sped up by these grasses because the current was checked. Increased deposition gave rise to increased grass growth and decay which formed the present day expanse of soft slippery mire existing in the area.

Salt and Sulphur Dome Characteristics

Numerous studies made of practically all salt domes within the Gulf Coastal Plain agree that the domes have been formed by intrusion of salt

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[1] Douglas W. Johnson, Shore Processes and Shoreline Development, (1919), pp. 374-383.

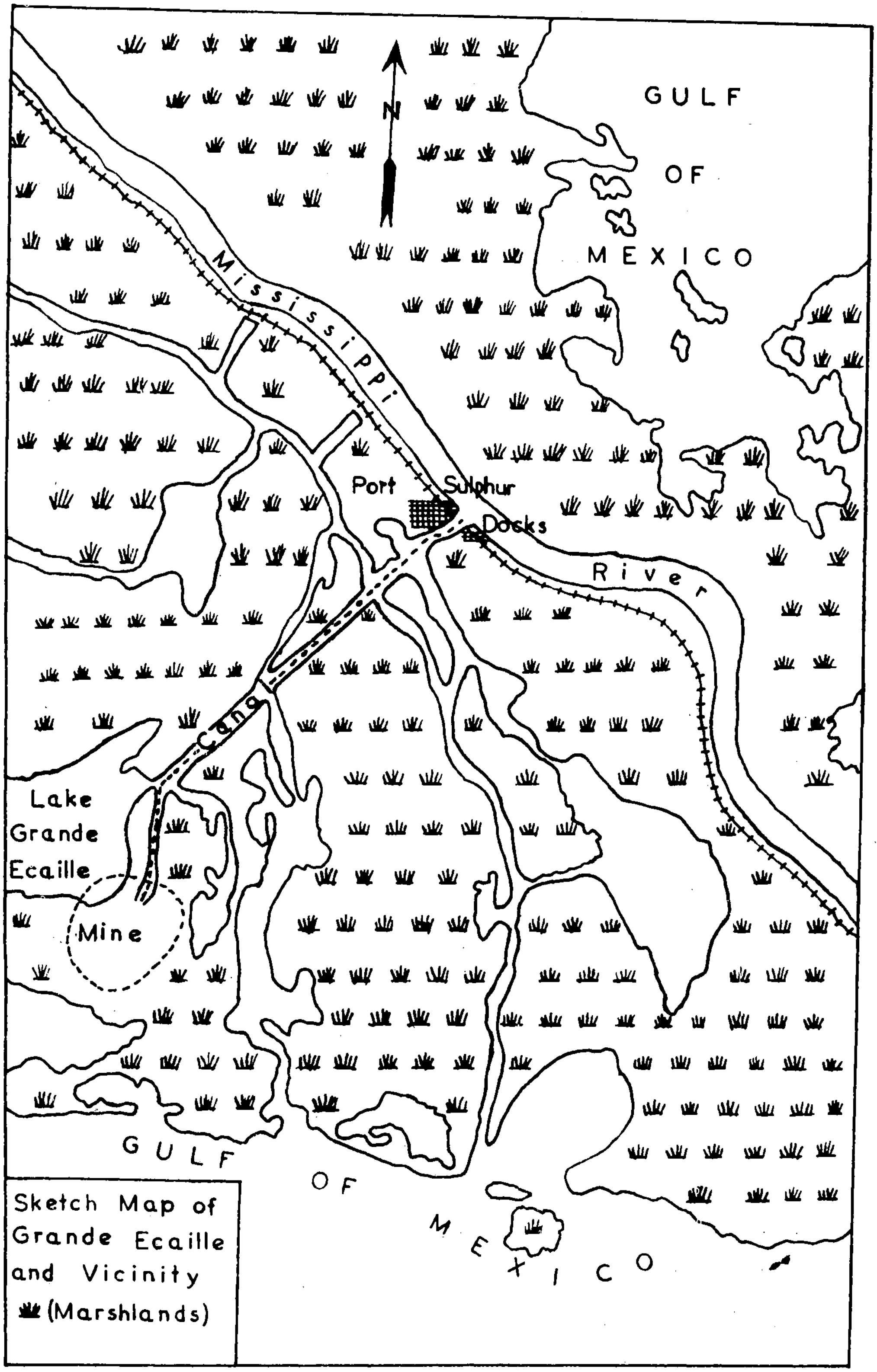
N
GULF
OF
MEXICO
Mississippi
River
Port Sulphur
Docks
Canal
Lake
Grande
Ecaille
Mine
GULF
OF
MEXICO
Sketch Map of
Grande Ecaille
and Vicinity
(Marshlands)

Plate III.

into the overlying sediments. Different pressures force the salt upwards. Deeply buried salt beds flow under certain conditions. The conclusive evidence of the plastic flow of sedimentary salt can be observed in the salt domes of Germany. In Persia salt domes rise to an elevation of 2600 feet above the surface. Salt is reported to be flowing from the base of some larger Persian domes at present, forming salt glaciers in the adjacent valleys. Studies reveal the similarity of the Gulf Coast domes to the above named, and to those in the Isthmus of Tehuantepec, Mexico, Colorado and Utah. Geologists ascribe such like domes to a similiar origin. Fossils found in the Louisiana and Texas domes strengthen the conclusions that their formation occurred from sedimentary salt beds during the Cretaceous Period.

During the upward thrust of the domes, the salt mass passes through sand, clay, "gumbo", limestone and sometimes gravel. The domes are steep pillars generally having straight sides, but in some cases overhanging sides exist. General agreement prevails that pressure upward from beneath and pressure from the weight of overlying materials causes the flow.[2] Usually, directly above the salt core, anhydrite occurs. Above this may be found a mixture of limestone and sulphur, which underlies a layer of porous caprock. Overlying the caprock is gumbo, unconsolidated material and sand while at the surface clay and soil exist.

The Grande Ecaille dome explorations revealed the caprock lying beneath the surface at a general depth of some 1250 feet. The caprock averages about 250 feet in thickness. Overlying the caprock is sand, gumbo, sandy shale and scattered boulders. The anhydrite, beneath the sulphur bearing caprock and

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2 Raymond C. Moore, editor, Bulletin American Association of Petroleum Geologists, Everette DeGolyer, "Origin of North American Salt Domes," pp. 1-44 and Hans Stille, "The Upthrust of Salt Masses of Germany", pp. 142-164, Houston, (1926).

overlying the salt plug, is fairly impervious. This allows the molten sulphur to settle in a sump at the well's bottom, below the sulphur bearing horizon.

Initial Prospecting

Oil possibilities prompted prospecting of the Grande Ecaille Dome in July, 1929.[3] These operations gave rise to sulphur indications. Humble Oil Company, Gulf Refining Company and the Shell Petroleum Corporation held mineral rights, jointly, in the area. Prospecting, delegated to the Humble Oil Company, proceeded accordingly. All accessory equipment to oil prospecting came to the dome from Harvey, Louisiana by means of barges. The circuitous route followed by the barges, through canals and across lakes, covered a distance of approximately 70 miles. This being the only practicable means of communication between the dome and the Mississippi River, expenditures for transportation were great and the task proved hazardous.

Large wooden mats placed on the marsh, with drilling rigs mounted on them formed a support for the Humble Oil Company's first two exploratory wells. Results from this arrangement proved unsatisfactory, because the mats settled unevenly. Drilling became difficult even for shallow wells. Subsequent operations found derricks set on piling with operating power derived from a diesel electric plant, installed on a barge of special design, measuring 28 by 90 feet.

Mosquitoes added greatly to the discomfort of the employees operating the rigs. To remedy this menace, blowers, consisting of airplane propellers attached with Model T. Ford motors, drove the pests away.

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[3] Wilson T. Lundy., "Development of the Grande Ecaille Sulphur Deposit", The American Institute of Mining and Metallurgical Engineers, Technical Publication, Number 533, (February 1934), p. 2.

Sulphur water encountered in the second test well at a depth of 1735 feet, and traces of sulphur appearing in the caprock formation of the third well at 1527 feet prompted exploration for sulphur.

Sulphur Prospecting

When samples of sulphur bearing strata appeared, which indicated possibilities of a deposit worthy of exploitation, Freeport Sulphur Company commenced negotiations to secure the sulphur rights. Their acquisition came in early 1932. The company immediately inaugurated a program of prospecting, with a view toward subsequent development. A complete geophysical survey revealed the size, depth and shape of the caprock formation. Sulphur prospecting began at the Grande Ecaille Dome in April, 1932, and within a year eighteen wells were completed and sampled.

To overcome difficulties experienced by oil prospecting, specially designed barges were employed to support drilling equipment and accessory tools. The 96 foot derrick, engines, water pumps, mosquito blowers, and lighting system mounted on a barge 36 by 80 by 6 1/2 feet, allowed mobility and proved exceedingly efficient.[4] The barge, divided into water tight compartments by heavy bulkheads placed lengthwise and across, also served as a storage space for the necessary drilling mud. Extending from the bow to the center of the barge, an opening four feet wide permitted moving on and off a well location where casing had been set. A thirty-six foot spud made of heavy steel pipe, used at each corner of the barge, held it in position over a location. In operation of the barge, the practice pursued consisted of dredging a canal forty-five feet wide and six feet deep to the location.

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4 Ibid., pp. 5-6.

At this point, to facilitate the handling of material barges, enlargement of the canal became necessary. Generally, widening to 70 feet for a distance of about 175 feet allowed adequate space around the location. Completion of the canal provided the means for towing the drilling rig into position, after anchoring the rig, by using the spuds, drilling commenced immediately. This procedure, carried out with two like barges particularly well adapted to the peculiar terrain at Grande Ecaille, enabled successful prospecting at a great saving of time and expense.

The prospecting drills penetrated sedimentary formations consisting of gumbo, sand, sandy shale and a few boulders, offering little resistance.[5] The caprock about 250 feet thick and usually encountered at a depth of about 1250 feet at Grande Ecaille consists of sulphur, limestone, gypsum, calcite, anyhrite, barite, pyrite and celestite.

The Plant Equipment

The chief problem in constructing and equipping a mine existing in such a terrain as described above lay in the selection and type of foundations. After exhaustive tests, it was ascertained that heavy reinforced concrete mats, supported by piling for building foundations and piling for supporting the sulphur vats, would solve the problem. Fills, made by hydraulic means, gave additional support to the mine area.

Varying differences occur in the formations of the alluvial Mississippi valley, compared to the adjacent areas. Originally, extending from Cairo, Illinois seaward, the present Mississippi valley was an estuary.[6] Upon

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[5] K. T. Price, General Manager, Freeport Sulphur Company, Port Sulphur, Louisiana, Correspondence to the Writer, (December 11, 1948).

[6] Johnson, Loc. cit., p. 379.

Figure 4. Port Sulphur Loading Docks

(Courtesy, Freeport Sulphur Company)

becoming filled with silt, the river carved its present meandering course through the valley. The river did not cut its course through the valley's center at all points, however below Baton Rouge, Louisiana, the river generally lies well within the central portion of the valley. Difficult foundation conditions prevail in the lower reaches of the valley. These varying conditions improve near the river due to the natural levee that lies along its banks. Soil conditions, capable of supporting pressures up to 1200 pounds per square foot exist at various places, while at others such burdens would result in unrestricted settlement. Massive structures must, for this reason, be constructed on piling. In the lobate delta of the Mississippi, especially some distance from the river, a foundation composed of pile is imperative since the soil possesses very little supporting power.

Numerous tests revealed that 75 foot piling placed four in a group, forming a cluster of sixteen would support the weight of necessary materials used in construction of the plant. During the driving operations, the soil in its upper portions offered practically no resistance. The piles penetrated, almost uniformly to a depth of forty-five feet, under their own weight and the weight of the hammer before a blow was struck. Below the forty-five foot depth, heavier soils encountered required considerable driving of all piling.

Heavy concrete mats distribute the load uniformly and give adequate strength for variations occurring in the individual supporting power of the piles. The total piling requirements, at Grande Ecaille, amount to over 20,000, varying in length from forty to eighty feet. In addition to the piling, approximately 10,000 cubic yards of concrete provide adequate foundations for buildings.

The Water Supply

All water in the lakes, lagoons and bayous around the Grande Ecaille deposit contain large quantities of salts. Well water that can be obtained in the area is brackish and it became imperative to develop some other source. Investigation disclosed that water comparatively low in salt content could be obtained from the Mississippi River.[7] A reservoir, with a capacity of fifty million gallons, constructed near the Mississippi River assures an adequate water supply. Water is delivered to the reservoir from the river by pumps, then passes through a pipe line, approximately nine miles in length, to the plant. The power required for pumping is derived from an electric transmission line of the same length. Storage space for 2,000,000 gallons of water at the plant provides additional assurance for maintaining continuous operation should it become necessary to make repairs or adjustments to the main reservoir, pumping equipment, or pipe lines.

The Mississippi River water, though very low in salt content, requires treatment to prevent objectionable deposits in boilers, heaters and pipe lines. The method used includes hot lime-soda treatment for boiler water and lime treatment for the water used in mining operations.

The Fuel Supply

Fuel oil utilized at Grande Ecaille is received by three storage tanks, with a 55,000 barrel capacity, from regularly scheduled tankers.[8] These tanks, located about 1500 feet from the Mississippi River, are built on an earth fill, covered with sand. Oil barges operating through the dredged canal deliver the oil to the mine site, where two 15,000 barrel firing tanks

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[7] George W. Leppert, General Manager, Freeport Sulphur Company, New Orleans, Louisiana, Correspondence to the Writer, (December 14, 1948).

[8] K. T. Price, Correspondence to the Writer, *op. cit.*

receive it. These tanks, as well as the water storage tanks, rest on piling foundations covered with concrete mats. Gravity enables the fuel oil to flow from the tanks to the pumps where it is heated and pumped to the burners with pressure.

Facilities and equipment, installed at the power plant, allow an immediate change to the use of natural gas or powdered lignite for fuel, should oil supplies be interrupted.

Fuel constitutes one of the major items of cost in mining sulphur. The necessity for high plant efficiency is, therefore, of great importance. Over eighty percent boiler efficiency and seventy-seven percent over-all efficiency accrues at Grande Ecaille.

Construction of the Plant

The power plant and all permanent buildings are constructed of steel which have corrugated asbestos roofing and siding.[9] Aluminum bolts and clips serve as fastenings. Materials used are those most resistant to corrosion, which is increased by the nearness to the sea. Brackish water contains corrosive agents not present in fresh water, therefore care exercised in selecting construction materials, result in less repair. Galvanized steel window sashes, aluminum gutters, and downspouts minimize corrosive effects.

Hurricanes, prevalent in the area, cause severe damage to buildings, derricks and other equipment. Recognizing this fact the steel frames of all buildings are designed to withstand 125 miles per hour winds.

The floor of the plant, elevated twelve feet above mean Gulf tide, provides ample protection to the plant during storms and high tides. By cutting off

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[9] H. S. Burns, "Building Grande Ecaille", Chemical Industries, Volume 34, (June 1934), pp. 503-506.

the piling about one foot above the marsh, capping it with a thick concrete mat and constructing piers to support the plant floor and equipment, space for water storage between the floor and mat is provided.

Foundation costs for the auxillary buildings averaged $2.11 per square foot of floor space and the plant buildings $2.20 per square foot. Concrete costs amounted to $17.30 per cubic yard. The complete cost of installing all necessary operating equipment ran high before production began. Material cost includes 2,500,000 board feet of lumber used; 2700 tons of steel and metal piping, and the moving of over 5,500,000 cubic yards of earth. Further costs cover dredging, field equipment, plant equipment, docks and loading facilities, and numerous miscellaneous necessary work and materials. The initial over-all expenditure exceeded $4,000,000.00

Production

Initial production began, at this operation, December 8, 1933, about ten months following the beginning of plant construction. From the outset workmen encountered trouble.[10] It became necessary to pump mud into the mines in order to attain thermal efficiency great enough for substantial production. Until substantial progress in imporving this procedure was later made, production continued relatively low and costs remained high.

While sulphur from the Grande Ecaille deposit contains very little ash and is commercially free of arsenic, selenium, and tellurium, a discoloration exists, imparting a dark color to the sulphur. Caused by traces of crude oil, this impurity, removed by distillation methods, provides sulphur with a purity of 99.5 to 99.9 percent.

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[10] John C. Carrington, Assistant to the President, Freeport Sulphur Company, New York City, Correspondence to the Writer, (December 20, 1948).

The following production statistics show steady increases but indicate recessions.[11]

Year	Long Tons
1933	17,705
1934	153,362
1935	348,810
1936	279,660
1937	342,230
1938	328,405
1939	422,600
1940	535,910
1941	502,010
1942	557,780
1943	649,670
1944	543,985
1945	772,425
1946	790,220
1947	819,380
1948	1,034,799

Aside from minor operational difficulties, a heavy sulphur tax imposed by the State of Louisiana, contributed chiefly to low outputs in 1936, 1937 and 1938. Taxes increased from sixty cents per long ton to two dollars in July 1936. At the same time the sulphur tax in Texas remained at one dollar three cents per long ton, where production increased thirty-eight percent.

Although highly localized the sulphur industry commands no wide political influence, its product passes through every channel of trade, entering innumerable industries, therefore the Louisiana sulphur tax became known in all industrial enterprises. The sulphur tax of 15 1/2 percent of value contrasted with an oil tax of about 2 3/4 percent of value was not conducive to production. Finally in 1938, after much political wrangling, a severance

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[11] "Department of Revenue", <u>State of Louisiana</u>, Baton Rouge, Louisiana.

tax levy of one dollar three cents per long ton became the practice. This measure induced greater production, which steadily increased.

Supplying part of the sulphur demand for national defense during World War II, became important at the Grande Ecaille operation. During this period the price of sulphur remained steady. The Federal Government allowed the sulphur producing companies in Louisiana and Texas to establish their own price. These prices, of $18.00 per long ton f.o.b. mine and $22.00 per long ton f.o.b. ship remained unchanged, although sulphur sold on the black market as high as $45.00 per long ton. Sulphur requirements during the war greatly exceeded peace time needs, and the Grande Ecaille operation furnished approximately twenty percent of the adequate supply available at all times.

Port Sulphur

A site on the west bank of the Mississippi River, accessible by both rail and highway, serves the Grande Ecaille operation with loading and shipping facilities. Around these docks grew a model community.

The location, on a natural levee, required extensive land fills but no piling for the foundation. Land at this point sells by the front foot along the river bank, instead of by the acre. Freeport Sulphur Company secured 2800 front feet along the river bank and extending 7600 feet in depth. Included in the transaction was an easement on a 1000 foot strip, leading to the mine site. Through this easement passes the canal to the mine.

A major consideration in planning Port Sulphur included the elimination of highway traffic from the town proper.[12] A plot sixty-five feet wide,

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[12] Annotation. "Model Community of Port Sulphur," Chemical and Metallurgical Engineering, Volume 46, (December 1939), pp. 762-763.

extending the full length of the residential area and paralleling the state highway serves as a screen. Immediate roadways connect, at intervals, with the highway.

The town plan, based on garden city principles, has houses facing the gardens, and set eighty feet apart. Walks provide access to the houses. Rear entrance drives eliminate dust, traffic, and noise and places the fronts of the houses on gardens or parks instead of streets. This arrangement, serving also as a saftey means, helps eliminate traffic hazards to children. Motorways, connected with fifty foot streets, constitute the main traffic arteries. Open spaces provide areas for parks and squares, which serve as playgrounds.

Houses provide three, four and five room dwellings for employees and their families. Climatic conditions and construction materials dictated the colonial-type architecture, which utilized twenty-seven distinct designs to obtain variety. Various roof lines, types and color schemes provide a cheerful living atmosphere.

Port Sulphur provides community facilities usually found only in larger cities. Among these facilities are a community house, a central boarding house for single employees, theater, library, lighted tennis courts, baseball and softball fields, a modern hospital and a school, second to none in Louisiana.

The community is closely tied through social, education and welfare organizations. Focal point of community life centers in the community house wherein assembles the parent-teachers association, 4-H Club, athletic club, theater guild and other meetings.[13]

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[13] K. T. Price, Personal Interview, Port Sulphur, Louisiana, (August 9, 1947).

Figure 5. Port Sulphur Housing Facilities
(Courtesy, Freeport Sulphur Company)

In addition to the company's policy of providing facilities for its employees residents of the entire Plaquemines Parish enjoy these advantages at Port Sulphur. Freeport's management continually encourages furthering community and Parish projects.

Port Sulphur's stores, operated separately from the Freeport Company, make available to the community all necessities and luxuries desired.

Rents remain at a minimum on all homes in Port Sulphur. Insurance, provided by the company, gives protection to the employee and his family. This industrial village has progressed immeasurably toward the solution of many employee public relations problems, offering potential obstacles to the nation's economic life.

Employees commute to work in company owned motor launches. The canal connecting the mine with the Mississippi River provides means of travel and recreation as well as supplying a method of shipping sulphur.

The loading and shipping docks occupy a front over 1,000 feet in length along the Mississippi. The docks accommodate vessels having a draft as much as thirty-five feet. A railroad also links Port Sulphur with New Orleans and by means of rail and water transportation, sulphur from the Grande Ecaille Mine leaves for domestic and foreign use.

CHAPTER VI

ECONOMIC CONSIDERATIONS OF SULPHUR IN INDUSTRY

Sulphur has always been referred to as "a very subtle matter." It penetrates many industries. It possesses qualities desirable and satisfying for a variety of uses, foremost among these include the ability to assume many forms and adaptability to varying conditions and circumstances. Birth of new industries generally finds sulphur playing a role. This does not necessarily imply that sulphur always remains as a leader, for new techniques and changes in procedure may diminish uses of sulphur in its importance in the manufacture of a given commodity. Equally probable, with its vitality and versatility, it will adapt itself to the situation; sometimes even helping displace the product which it helped create. Obviously it is impossible to trace sulphur through all its branches of use in industry, or list its multifarious uses in history, but an attempt will be made briefly to trace some of the influences that sulphur and particularly sulphuric acid has had on the development of American industry. As about 90 percent of all sulphur used is burned to sulphur dioxide, many sources of raw material are available to sulphur consuming industries. Accordingly no attempt will be made to differentiate between the various materials.

The Sulphur Cycle and Sulphur in Soils

The transformation of primary sulphur and its compounds found in soils, into sulphates, its absorption and assimilition into proteins, and its release by combustion or putrefaction and return to the earth are referred to as the sulphur cycle. The first stage in this cycle begins with a primary sulphide of a metal such as lead, zinc or iron and copper pyrites. Oxidation of these to the second stage results in the formation of sulphates. The sulphates when in solution and ionized are obsorbed from soils by plants, where they enter into the third stage in living proteins and other complex constituents of the living plants. When a plant ceases to grow or is harvested, the fourth stage, putrefaction, may set it, amino acid formed during humification, releasing the sulphur as hydrogen sulphide, or the sulphur may be released by combustion as sulphur dioxide. Sulphur dioxide is soluable in water, forming sulphurous acid, which again is readily further oxidized, forming sulphuric acid. When any of these sulphur products are present in the atmosphere, they are likely to be absorbed in rain and returned to the earth.[1] Bearing in mind that matter cannot be destroyed, but its form can be changed, the sulphur cycle is easily understood.

During the sulphur cycle, sulphur brought to the earth in rain or dew, added to the soil in irrigation water, and returned in manures is frequently insufficient to balance the loss in drainage water and crop removal. Fertilizer helps compensate the loss of sulphur in soils during the sulphur cycle. Sulphur is important in the fertilizer industry because it is used in the form of sulphuric acid in preparation of phosphate fertilizers. Sulphur is also used as a dust, in fungicides and insecticides. Furthermore it is a valuable ingredient of fertilizer itself, although until recently more attention was given to nitrogen, potash and phosphates. Today there is a general recognition of the fact that sulphur is a necessary building material

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[1] W. P. Kelley, "The Reclamation of Alkali Soils," California Agri. Expt. Sta. Bulletin No. 455, (1928), pp. 2-3.

for various plant substances and produces important formative effects.[2] It seems to play a part in chlorophyll development, as plants are usually light green in color if there is a sulphur deficiency. Sulphur gives strong root growth, greatly increases nodule development in alfalfa and clover, stimulates seed production and generally encourages more vigorous plant development.[3] This combination of factors causes agriculturists to give increasing attention to sulphur as a plant nutrient.

Although there was no direct effort to introduce sulphur into fertilizer through superphosphate, the treatment of phosphate rock with sulphuric acid has done so. As the South contains the greatest deposits of phosphate rock, this area became the largest consumer of fertilizer and the method of fertilizer manufacture accounts for the development of the acid industry in that area. In 1884 the fertilizer industry used about forty-five percent of the total sulphuric acid produced,[4] but with the development of general industry in the United States this proportion gradually decreased until about one-third of the sulphuric acid produced finds its way into the fertilizer industry.[5]

Although few outstanding changes have occurred in the industry, technicians have devoted much time and thought to improving methods and processes of acid manufacture. Numerous efforts and experiments have been made to replace sulphuric acid. Basic slag for fertilizer purposes was made,

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2 G. H. Godfrey and Herbert Rich, Texas Expt. Sta. Progress Rpt. No. 675. J. L. Wursten and W. L. Powers, "Reclamation of Virgin Black Alkali Soils", Journal of American Society of Agronomy, Volume 26, (1934), pp. 752-762.

3 A. L. Walker, "Sulphur and Agriculture", Fertilizer Review, (September-October 1947), p. 3.

4 W. W. Duecker and E. W. Eddy, "Sulphur's Role in Industry", Reprinted from Chemical Industries, (February 1942), p. 5.

5 Walker, op. cit., p. 4.

in 1872, in a blast furnace from iron ore containing phosphorus.[6] Other means have come into practice, but sulphur still retains its position in the industry. This is due to its ease of application, cheapness, supply, adaptability and the enterprise of fertilizer manufacturers.

During the years immediately prior to World War II about 1,500,000 tons of acid, 100 percent basis, were used for fertilizer. Greatly stimulated by the war this demand has increased following the cessation of hostilities.[7] Domestic requirements and foreign shipments have resulted in fertilizer production reaching all-time highs. The year 1946, saw 3,020,000 tons of sulphuric acid, 100 percent basis, used for fertilizer. These figures were increased substantially in 1947, when foreign shipments and the Marshall Plan became responsible for a large percent of the amount produced and consumed.

The important effects of sulphur on soils and crops include:[8]

1. Improvement in soil structure or physical condition.
2. Modification of soil reaction with improvement of arid soils.
3. Increase in moisture holding capacity of the soil.
4. Correction of alkali soils.
5. Improvement in the supply of sulphate, which is an essential plant nutrient.
6. Liberation of basic nutrients, such as calcium, magnesium and potassium.
7. Liberation of phosphates.
8. Stimulation of beneficial micro-organisms concerned with ammonification or nitrification and sulphur oxidation.
9. Increase in chlorophyll and probably Vitamin A. content of plants.
10. Increase in root and root nodule development.
11. Increase of sulphur and protein contents of the plant.
12. Increase leafiness with less shattering of legume hay.

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[6] Duecker and Eddy, op. cit., p. 5.

[7] Chemical Engineering, (February 1947), pp. 108-109.

[8] F. L. Duley, "The Relation of Sulphur to Soil Productivity", Journal American Society of Agronomy, Volume 8, (1916) pp. 154-160. W. P. Kelley, "Replaceable Bases in Soils", University of California Agri. Expt. Sta. Tech. Paper No. 15, (1924). O. M. Shedd, "The Relation of Sulphur to Soil Fertility", Kentucky Expt. Sta. Bul. 188, (1914), pp. 595-630. R. Stewart, "Sulphur in Relation to Soil Fertility", Illinois Agri. Expt. Sta. Bul. 227, (1920).

Sulphur has long been known as an essential plant nutrient, but the amounts needed by plants relative to the supply in soils were until recently undetermined. Numerous and varied experiments have been conducted with others being currently carried out to determine needs of various soils, in order to achieve maximum productivity at minimum inputs of capital. The previously noted facts are reached by careful experiments.

Crude sulphur sufficiently fine for use as soil sulphur is available at a satisfactory price to meet soil needs or plant requirements. Sulphur suitable for soil use oxidizes in a period of five months.[9] Farmers follow the general practice of applying sulphur on a calm day accompanied by immediate harrowing. Harrowing aids distribution and converts the sulphur to an effective sulphate form, along with preventing its blowing or washing away. The landplaster serves as a desirable tool for spreading. Sulphur should not be mixed with fertilizers containing nitrates, as such mixtures may cause serious explosions.

Sulphuring the soil becomes the permanent practice of many farmers and results in increased returns for crops. Black alkaline soils respond best to sulphur treatment. Many localities with acid soils find a treatment of lime and sulphur highly practicable.[10]

Crop Insect Control

Farmers in the cotton, peanut and fruit producing areas for the past two decades have relied upon the control of insects by sulphur dusting. Our cotton crops ranks as one of our great agricultural resources. Millions of people throughout the South depend upon cotton for their livelihood. Sulphur plays a great part in lowering the production costs and increasing the yields.

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[9] Duley, op. cit., p.159.

[10] Wursten and Powers, Loc. cit., p. 757.

Control of the Cotton Flea Hopper

The cotton flea hopper, a small insect about one-eighth inch long, greatly hampers cotton production. Flea hoppers inflict the most serious damage to small cotton terminal buds and squares. The square dies, and due to the small size of the insect, many farmers attribute such losses to unfavorable weather conditions.

The Bureau of Entomology and Plant Quarantine has conducted experiments at Port Lavaca, Texas for the control of the cotton flea hopper. Extending over a period of years, experiments showed an increase of a yearly average profit of $4.75 per acre, where large-scale sulphur dusting was conducted.[11]

Twelve pounds of sulphur per acre, applied at five day intervals when the air is calm and the cotton is damp, until infestation is under control, usually gives satisfactory results.[12] Early application in sections where cotton root rot is prevalent, are advisable in order to establish an early crop before root rot proves fatal. Where such conditions prevail, applications should start when the cotton plant begins to square.[13]

Of various dusting machines used for control purposes, the airplane proves the most effective and efficient, and its use has become widespread in areas infested with crop devastating insects.[14]

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[11] K. P. Ewing and R. L. McGarr, "Sulphur as an Economical Control for the Cotton Flea Hopper", Mimeo Cir. E-348, Bur. of Ent. and Plant Quar., United States Department of Agriclture, (April 1935), p. 1.

[12] Ewing and McGarr, op. cit., p. 5.

[13] F. F. Bibby and F. L. Thomas, "Field Tests in Controlling Cotton Flea Hopper", Mimeo Cir., Texas Agri. Expt. Sta., College Station, (1933-1935), p. 1-2.

[14] F. F. Bibby and J. C. Gaines, Texas Agri. Expt. Sta, 47th Annual Report, College Station, (1934), p. 45.

The Boll Weevil and Red Spider

Dusting cotton with finely ground sulphur at the rate of ten pounds per acre controls the red spider. Very destructive to cotton, this mite devastates large areas in the Southwest.

For control as a combined boll weevil and red spider application, eight pounds of sulphur mixed with four pounds of calcium arsenate for each acre, is recommended by the United States Department of Agriculture.[15]

Farmers also recommend sulphur dusting for controlling the cotton plant bug, the tarnished plant bug, and cotton dauber, as well as for the flea hopper.[16]

Compounds and admixtures of sulphur successfully combat insects and fungi harmful to fruit culture, trees, tuber crops, tobacco, onions and other fruits and vegetables.[17]

From the foregoing facts, sulphur as an essential to soils and agriculture cannot be over-emphasized. Practically no plant life exists without sulphur, and in soils deficient in the element, sulphur treatment gives an optimum return from crops.

The sulphur industry supplies the major portion of the necessary raw material for the manufacture of sulphuric acid used in the production of fertilizer and for soil use. In 1947 the mines of Louisiana and Texas produced 4,364,693.54 tons of sulphur, thereby furnishing ample supplies not

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[15] Dr. J. W. Folsom, Farmer's Bulletin, Number 1688, U. S. Department of Agriculture, (July 11, 1943), p. 15.

[16] Folsom, op. cit., pp. 18-19.

[17] W. T. McGeorge, "Some Aspects of Citrus Tree Decline as Revealed by Soil and Plant Studies," Arizona Agri. Expt. Sta. Tech. Bul. No. 60. (1936). W. H. Martin, "The Relation of Sulphur to Soil Acidity and to the Control of Potatoes Scab." Soil Science, Volume 9, (1920), pp. 393-408.

only for domestic use but for foreign consumption.[18] Fertilizer manufacturers now face the responsible problem of increasing tonnage output to meet the requirements of the entire world. Long range planning by sulphur producers, makes available sufficient supplies of sulphur to make possible the production of greater quantities of fertilizer required and also supplies the farmer with the much needed sulphur for insecticides.

Chemicals and Defense[19]

Restrictions placed on critical material for defense and war purposes limit data and statistics for sulphur used in chemicals and acids. Chemicals for defense purposes have consumed approximately 27 percent of the total amount of sulphuric acid produced since 1940.[20] Therefore chemical manufacturers use about 1,400,000 long tons of sulphur annually.

Sulphates, sulphides and sulphites contain sulphur in varying quantities. Initially the production of bromine and chlorine involved the use of sulphuric acid, although chlorine was subsequently made by an electoytic process. Since 1832 bromine has continued to be made with sulphuric acid, however there was a decline shortly after 1870 because of the development of a new process of making photographs.[21] Suddenly, in the early 1870's, a new demand for bromine appeared. The petroleum industry began to demand increasing quantities of bromine for manufacturing lead tetra ethyl gasoline. Sulphuric acid and sulphur dioxide were applied in a process of recovering bromine

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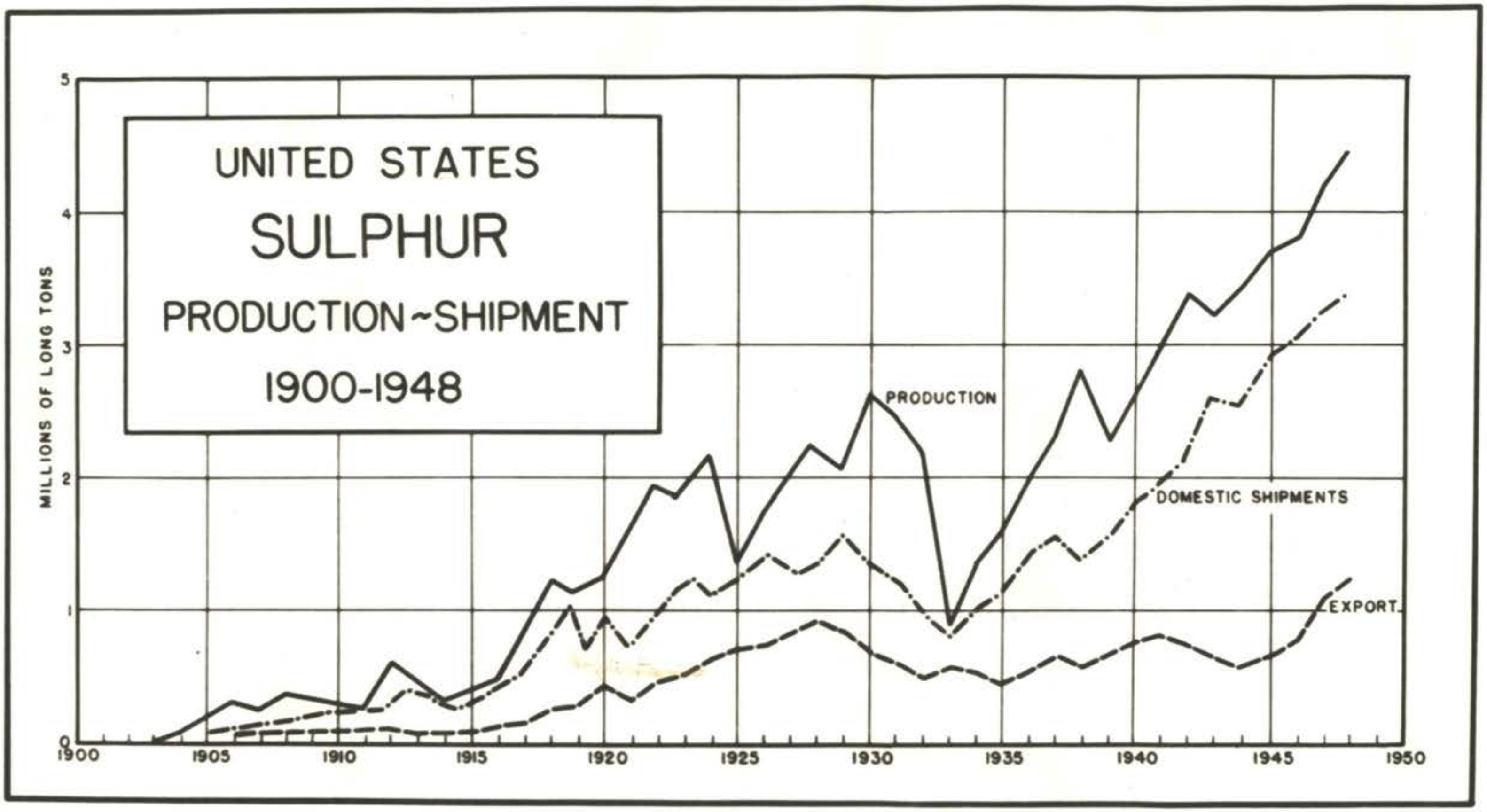
[18] George H. Sheppard, "Official Figures", Collector of Internal Revenue State of Louisiana, (June 17, 1948). W. A. Cooper, "Official Figures", Collector of Internal Revenue, State of Texas, (June 17, 1948).

[19] Combined to avoid disclosing estimates of direct war application.

[20] Chemical Engineering, Volume 54, Number 2, (February 1947), p. 109.

[21] Duecker and Eddy, op. cit., p. 7.



UNITED STATES
SULPHUR
PRODUCTION~SHIPMENT
1900-1948
MILLIONS OF LONG TONS
PRODUCTION
DOMESTIC SHIPMENTS
EXPORT
0
1
2
3
4
5
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950

Plate IV.

from sea water which resulted in the consumption of considerable quantities of sulphur in producing a chemical which formerly had only limited use in medicine and photography.

Although the major portion of chlorine is made by electolytic processes, sulphur compounds are again being considered for its production. Chlorine shortages have caused the contemplating of replacing millions of cubic feet of chlorine per day with hydrochloric acid made by reacting salt with sulphuric acid. Attention is also given to a process of producing chlorine by reacting salt with sulphur trioxide.

The greater portion of sulphur consumed by chemical manufacturers goes to sulphuric acid plants where it is turned into sulphuric acid. In this form it enters other chemical manufacturers, oil refineries, fertilizer plants, and other essential industries.

Major industrial consumers of sulphuric acid include the iron and steel industry, tanning industry, bakelite, rayon, explosive and petroleum industries. Other chemical concerns consume lesser quantities, but remain significant in our economy.[22]

The petroleum industry, iron and steel and chemical industry accounts for approximately two-thirds of the annual consumption of sulphur classified in the chemical and defense category.

Comparison of the distribution of sulphuric acid plants with oil refineries and iron and steel mills indicates the close relationship of the industries. The Great Lakes area ranks second in sulphuric acid plants and a ready market awaits the product at the nearby steel mills.

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22 Ibid., p. 7

In the petroleum industry numerous refineries in the Gulf Coastal area secure necessary sulphuric acid supplies from acid plants located nearby.

Plastics consume large quantities of sulphur, however defense measures prohibit revealing detailed statistics on chemicals used in the industry. Available statistics provided by Chemical Engineering in 1939 indicated the industry is gradually increasing the use of sulphur. The total amount of sulphur consumed by the industry each year ranges over 350,000 tons.

Pulp and Paper Industry

In the early days wood pulp paper was made by mechanical processes or with aid of caustic soda. Sulphur entered the industry in 1866 when it was found that wood pulp could be made by cooking wood in water containing calcium or magnesium bisulfite.[23] Commercial operation of this process evolved about 1884, and since then the industry continued to consume sulphur in quantity. That it is a consumer cannot be doubted when today approximately two hundred fifty pounds is consumed in producing one ton of sulfite pulp. Sulfite pulp is a standard raw material for paper manufacturing and the sulfite pulp prepared for paper manufacture is also successfully used in synthetic fibers.

Soon after the sulfite paper industry became well established a competitive pulp appeared. The sulfate pulp process produced in 1907 again brought sulphur into the pulp industry, but in the form of sodium sulfate.

In the wood pulp industry two competitive pulping processes utilize sulphur and the active pulping agent is a sulphur compound. Sulphur dioxide is also used as a bleaching agent, while in the form of alum compounds and certain pigments in it imparts special properities to paper.

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[23] H. A. Maddox, "Common Commodities and Industries, Paper", London, (1909), p. 64.

In the wood pulp industry sulphur again reaches many sections of the world. Norway, Sweden, Canada, United States and other Northern European Countries consume sulphur in quantity, in the wood pulp industry.

The Explosives Industry

Our first explosive was gunpowder which in current practice consists of a mixture of seventy-five parts saltpeter, thirteen parts of charcoal, and twelve parts sulphur. In 1845 Schonbein prepared "guncotton" by treating cotton with a mixture of strong nitric and sulphuric acid.[24] Several severe explosions resulted in 1847 - 1848 while conducting experiments for the manufacture of guncotton.[25] This lead to discontinuance of the practice. Later the United States Torpedo factory at Trenton, New Jersey and the DuPont Company began its manufacture for service use.

The discovery of preparing guncotton led to the development of smokeless powder, gelatin dynamite, blasting gelatin, T.N.T. and picric acid, all of which require compounds of sulphur in their preparation. Sulphuric acid, the most used agent, is restricted to dehydrating purposes. It requires 0.2 pound of sulphur to prepare one pound of smokeless powder and 0.035 pound of sulphur for one pound of T.N.T., a fact extremely important to National Defense. It is fortunate that the requirements of sulphuric acid are less today than during the 1914-1918 period, because the supply could not be furnished. It is necessary in all practice to recover all unused amounts of the acid required as catalysts or reagents, in order to insure a supply.

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24 Walke, Willoughby, Lt., "Lectures on Explosives," (Prepared for United States Artillery School), New York: John Wiley & Sons, (1897), p. 208.

25 *Ibid.*, p. 210.

National Defense measures prohibit publication of amounts of sulphur entering into the explosives industry and for that reason a certain percent is included under chemicals. Explosives, aside from those directly utilized in National Defense, consume approximately 90,000 tons of sulphur annually.[26]

The Dye and Textile Industry

Soon after the colonies established their independence, woolen and linen goods were produced for domestic and foreign sales. A sulphur demand for bleaching was thus developed. Sulphuric acid replaced sour milk for bucking and souring of textiles. In 1797 a sulphuric acid plant established at Philadephia supplied the entire textile industry with the needed acid. Later the same plant began the manufacture of alum, copperas and other chemicals used by the textile industry. Thus the establishment of one of the first industries in the United States coincides with the first industrial use of sulphur in this country. Expansion of the textile industry increased the demand for sulphur compounds. Chlorine, produced by the aid of sulphuric acid, serves as a bleach for cotton goods and other textiles. Nitric, hydrochloric and acetic acid, each used in the textile industry and requiring sulphuric acid for their production, further increased the demand for sulphur.

When rayon production began in the United States in 1911, the textile industry became a larger consumer of sulphuric acid along with carbon bisulphide.

The appearance of cellulose acetate on the market in the second decade of the twentieth century, followed by other special sulfonated chemicals used

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[26] Minerals Yearbook, (1946), p. 1186.

by the textile industries gave further impetus to uses of sulphur. Discoveries each year stimulate the sulphur demand in the textile industry. Currently the industry annually consumes about 80,000 long tons of sulphur.

<u>Miscellaneous Industries</u>

The rubber, food processing and paint manufacturing industries normally require approximately 175,000 long tons of sulphur each year. Rubber is useless unless vulcanized. Sulphur enables vulcanization of rubber by giving hardness and strength.

The paint and lacquer manufacturing industry draws upon sulphur stockpiles for various sulphur compounds. The element enters the paint industry indirectly, as compounds or mixtures, and usually about 100,000 long tons are consumed yearly by paint manufacturers.

Miscellaneous uses include medicines, processing of ores, coke and steel, processing of food, liquor distilling, sugar refining and others too numerous to mention.

CHAPTER VII

SULPHUR: TODAY AND TOMORROW

Competition and Substitutes

Curves of sulphur sales correspond to and parallel with accuracy years of prosperity and years of recession. Sulphuric acid statistics —— production consumption, and stocks —— indicate the pattern for the general indexes, which shows the most accurate picture of trade. Since most of our sulphur tonnage is converted into sulphuric acid, a glance at sulphuric acid statistics generally reveal sulphur trends.

Sulphur enters largely into the production of fertilizers, newsprint and wrapping papers, rayons, steel, paint pigments and insecticides. In the manufacture of one hundred fifty important industrial chemicals the number of times different basic raw materials are regularly employed has been carefully calculated as follows:[1]

Index number indicating the frequency of use of raw materials.

1. Water...........99	6. Limestone 63
2. Air..............96	7. Sulphide ores.......33
3. Coal.............91	8. Brines..............24
4. Sulphur..........88	9. Petroleum...........23
5. Salt.............75	10. Natural gas.........10

No article of commerce reaches the ultimate consumer without having sulphur used at some stage in its manufacture. The average automobile, for example, has been estimated to use, including tires, thirty-five pounds of sulphur. Sulphur sales maintained growth during the 1930's when the repeated cycle of depression, recovery and recession upset the normal course of

[1] R. N. Keller and T. T. Quirke, "Mineral Resources of the Chemical Industries", Economic Geology, Volume 34, (May 1939), pp. 287-296.

business. During this same period, notable changes occurred in the sulphur market, especially in consumption and competition.

Since the American sulphur industry occupies a commanding position in world trade, it has been directly affected by developments abroad; notably, a process for recovery of elemental sulphur from pyrites in Norway, and a growing output of brimstone in Chile and Japan.[2]

The years following World War I show sulphur gaining in the long and competitive battle with pyrites as a source of material for sulphuric acid manufacture. From 1920 to 1929, sulphuric acid manufacturers performed few experiments for raw material sources or with plant processes. These busy years culminated with 8,491,114 short tons of sulphuric acid, a record production at that time. Immediately following 1930 conditions emphasized costs to the manufacturer. Technical development led to less consumption of sulphuric acid in the petroleum and other industries. The trend toward reclaiming acid from residual products of acid consuming industries and from waste products of oil refinery sludge, sulphates and solutions, somewhat curtailed sulphuric acid production. The later development of high grade motor fuel necessitates removing sulphur from gases used in cracking processes.

Since 1940 the use of acid has increased due largely to World War II. Explosives demanded vast quantities of the compound and also other chemical production shortages existed.

During both World Wars, Germany endeavoured to meet her sulphuric acid needs by introducing other chemicals. No deposits of native sulphur exist in

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[2] M. P. Appleby, "Recent Developments in the Chemistry of Sulphur", _Journal of the Society of Chemical Industry_, Volume 53, (December 28, 1934), pp. 1097-1101.

Germany and she relied largely upon imported pyrites from Spain, Norway, Cyprus and both pyrites and sulphur from Italy. Increased wartime requirements forced her to derive sulphuric acid from barium sulphate and calcium sulphate. Processes developed by the I. G. Farbenindustrie plant at Wolfen enabled Germany to meet demands until her industry was destroyed. She has demonstrated that substitutes for both sulphur and pyrites can sustain a large diversified, national industrial establishment. It remains extremely unlikely that countries possessing either sulphur or pyrites will resort to substitutes, except during the most dire emergency.

Brimstone is the most favored sulphur material. Cheapness, availability, the ease of converting to oxides or acid and its purity coupled with other properties support its practability. Manufacturers of various sulphur compounds must consider the initial plant investment, depreciation, labor, power, maintenance and new yields from two raw materials. In terms of these items of capital and operating expenses elemental sulphur outweighs the sulphur from pyrites. From plants of identical size twenty-five to thirty percent more acid production results when using native sulphur. Maintenance remains considerably greater when using pyrites with depreciation charges higher than when using sulphur. Personnel needed when using pyrites doubles that of sulphur consuming plants.[3] The acid maker maintains a more flexible installation if he uses brimstone than can be maintained by a pyrites consuming plant. This brings forth the conclusion that manufacturers can actually pay more per pound for elemental sulphur as compared to a pound of sulphur from pyrites.[4]

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[3] T. H. Pough, President Southern Acid and Chemical Company, St. Louis, Missouri. "Correspondence to the Writer," (December 13, 1948).

[4] A. E. Wells and D. E. Fogg. "The Manufacture of Sulphuric Acid in the United States", United States Bureau of Mines, Bulletin 184, (1920), 37.

Sulphur is a basic mineral and increased activity in the manufacture of automobiles, textiles, fertilizers, paints, petroleum products, iron and steel, explosives, war materials, drugs, pulp and paper stimulates the sulphur industry. Wartime demands are greater than peacetime demands but are unstable therefore less desirable. Normal demands require and give rise to experimentation in pricing, providing competition among producers with each company seeking steady buyers of large shipments. The American sulphur mining industry is highly localized but commands wide attention among industrial circles. The industry, favored with raw material, power, transportation and water supplies employs directly comparatively few people but indirectly maintains an influence on every American citizen.

Sulphur Reserves

Conservative estimates place United States sulphur reserves sufficient to last twenty-five years under present mining and pricing practices.[5] The Frasch Process of extraction allows mining at depths of twenty-five hundred feet providing ideal underground conditions prevail. Possibly a partial solution lies with the price. No doubt the supply can be extended several years by raising the price considerably, since known deposits have been abandoned because of uneconomical operations. Developing other mining and recovery methods may alleviate the situation. Prospected but undeveloped deposits exist in Alaska, New Mexico and Iwo Jima, with other possibilities in Colorado, Nevada, Utah and Wyoming, where lesser deposits have been spasmodically operated but capital expenditure requirements would mount rapidly if fully developed. Equipment being currently installed at a

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[5] L. L. Norton, President Mexican Gulf Sulphur Company, Correspondence to the Writer, August 26, 1948.

deposit in the Vera Cruz Province of Mexico promises a daily output of fifteen hundred tons, however reserve estimates have not yet been made available. Mining practices in the United States permits conservation and provides complete recovery of the mineral from each well steamed until exhausted.

Modern sulphur mining methods will enable the United States to maintain its world position in industry, agricIture, science and warfare until exhaustion of the deposits. Reliable information indicates the American sulphur resources will supply domestic and, partially supply, foreign requirements for many years before depletion of the reserves. During this period the United States faces the problem of developing a substantial substitute for the element or relying on imports when the reserves become exhausted. The problem remains an important concern of engineers at present and Americans may well be aware that the future of our country's industry will partially depend on our sulphur supply.

APPENDIX

APPENDIX A

THE PROPERTIES OF SULPHUR

Synonym: Brimstone.
Chemical Symbol: S.
Color: Bright, clear sulphur-yellow, straw- or honey-yellow, yellowish brown, greenish, reddish to yellowish gray.
Luster: Resinous, streak, light yellow, white.
Cleavage: Imperfect.
Fracture: Conchoidal to uneven, rather brittle to imperfectly sectile.
Hardness: 1.5 to 2.5 (Moh's scale).
Specific Gravity: 2.05 to 2.09.
Angle of Repose: 35 degrees.
Density: Crystal — 130 lbs. per cu. ft.; liquid, 113 lbs. per cu. ft. at 115 degrees C. (239 degrees F.) bulk, 85 to 95 lbs. per cu. ft.
Atomic Weight: 32.06; atomic number 16.
Valence: 2, 4, 6.
Melting Point: Rhombic form, 112.8 degrees C. (235 degrees F.); monoclinic form, 118.9 degrees C. (246 degrees F.).
Boiling Point: 444.6 degrees C. (832.28 degrees F.).
Ignition Temperature: In the air, approximately 261 degrees C. (501.8 degrees F.).

APPENDIX B

SULPHUR PRODUCTION IN THE UNITED STATES: 1880-1946)[1]

(Long Tons)

Year	Production	Imports	Exports
1880	536	88,119	......
1881	536	105,266	......
1882	536	97,721	......
1883	893	94,734	......
1884	446	105,416	......
1885	648	97,074	......
1886	2,232	117,867	......
1887	2,679	97,245	......
1888	......	98,406	......
1889	402	135,958	......
1890	679	162,789	......
1891	1,071	117,187	......
1892	2,400	101,122	......
1893	1,071	105,823	......
1894	446	125,459	......
1895	1,607	122,096	......
1896	4,696	139,280	......
1897	2,031	141,905	......
1898	1,071	164,504	......
1899	4,313	141,533	......
1900	3,147	167,712	......
1901	6,866	175,243	......
1902	7,443	174,939	......
1903	7,382	191,033	......
1904	85,000	129,532	3,000
1905	220,000	84,339	11,522
1906	295,123	74,241	14,437
1907	188,878	22,523	35,925
1908	364,444	21,136	27,894
1909	273,983	30,589	37,142
1910	247,060	30,833	30,742
1911	205,066	29,144	28,103
1912	787,735	29,927	57,736
1913	491,080	22,605	89,221
1914	417,690	26,135	98,163
1915	520,582	26,367	37,312
1916	649,683	22,235	128,757
1917	1,134,412	973	158,736
1918	1,353,525	82	131,092
1919	1,190,575	101	224,712
1920	1,255,249	136	447,450

SULPHUR PRODUCTION IN THE UNITED STATES: 1880-1946) - (Continued)

(Long Tons)

Year	Production	Imports	Exports
1921	1,879,150	50	285,762
1922	1,830,942	269	485,664
1923	2,036,097	465	472,525
1924	1,220,561	1,005	482,114
1925	1,409,262	100	629,401
1926	1,890,027	48	576,966
1927	2,111,618	3,384	789,274
1928	1,981,873	4,787	685,051
1929	2,362,389	1,163	855,183
1930	2,558,981	29	593,312
1931	2,128,930	....	407,586
1932	890,440	....	352,610
1933	1,406,063	4,773	522,515
1934	1,421,473	5,839	507,115
1935	1,632,590	1,978	402,383
1936	2,016,338	729	547,200
1937	2,741,970	628	675,297
1938	2,393,408	2,603	597,107
1939	2,090,979	13,976	627,819
1940	2,732,088	27,845	746,468
1941	3,139,253	28,631	760,776
1942	3,460,686	25,632	585,279
1943	2,538,786	16,658	682,472
1944	3,218,158	33	675,232
1945	3,753,188	33	942,662
1946	3,859,642	35	1,245,820

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[1] Data from "Mineral Resources of the United States," 1885 through 1931; 1932 through 1946 from "Minerals Yearbook".

APPENDIX C

UNITED STATES SULPHUR PRODUCTION BY MINES, THROUGH 1948

Deposit	Company	Production Dates	Long Tons Produced (In round figures)
Sulphur Mine, La.	Union	12/29/95-12/23/24	9,400,000
Bryanmound, Tex.	Freeport	11/12/13- 9/30/35	5,000,000
Big Hill, Tex.	Texas Gulf	3/19/19- 9/19/32	
Big Hill, Tex.	Texas Gulf	1/ 1/36- 8/10/36	12,350,000
Hoskins Mound, Tex.	Freeport	3/31/23-operating 1949	12,145,244
Big Creek, Tex.	Union	3/ 6/25- 2/24/26	2,000
Palangana, Tex.	Duval	10/27/28- 3/10/35	240,000
Boling, Texas	Union	11/14/28- 8/30/29	8,000
Boling, Texas (Newgulf)	Texas Gulf	3/20/29-operating 1949	27,853,541
Boling, Tex.	Duval-Texas	3/23/35- 4/25/40	570,000
Boling, Tex.	Baker-Williams	6/ 2/35-12/ /35	2,000
Long Point, Tex.	Texas Gulf	3/19/30-10/19/38	400,000
Jefferson Island, La.	Jefferson Island	10/20/32- 2/ /36	425,000
Grande Ecaille, La.	Freeport	12/ 8/33-operating 1949	8,098,951
Clemens, Tex.	Jefferson Lake	5/ 3/37-operating 1949	2,321,545*
Orchard, Tex.	Duval-Texas	1/29/38-operating 1949	2,043,596*
		Total........................	80,469,877

* 1947 and 1948 production figures are carefully computed estimates; complete statistics not available.

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