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MINERAL RESOURCES OF THE TEXAS COASTAL PLAIN

(Preliminary Report)

By

Joseph M. Perkins and John T. Lonsdale

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INTRODUCTION

This report has been prepared under terms of a contract between the United States (Bureau of Reclamation) and The University of Texas (Bureau of Economic Geology). The University of Texas agreed, within the limits of time and money available, to secure and supply available data on the location, quantity, and quality of mineral resources in the Texas Coastal Plain that lend themselves to manufacture of products in national demand. Inasmuch as the Bureau of Reclamation will use the data presented in planning water conservation in Texas, the report will indicate those mineral resources requiring large quantities of water in development and processing.

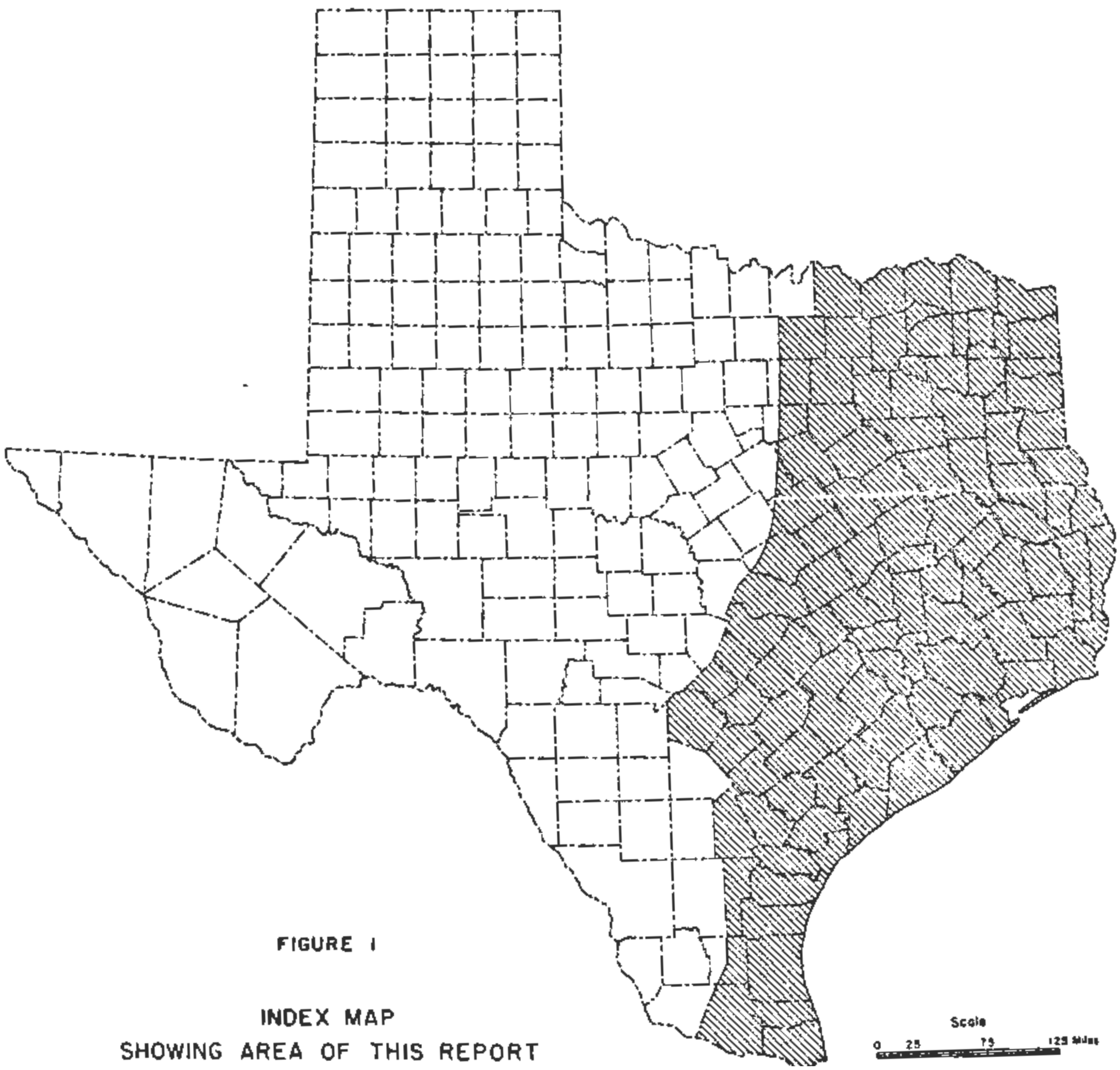


FIGURE 1

INDEX MAP
SHOWING AREA OF THIS REPORT

The area included in the report is shown on figure 1. It includes all or parts of 109 counties. It extends inland slightly beyond the conventional boundary of the Coastal Plain to include mineral resources "that lend themselves to manufacture of products in national demand" and excludes several counties in southwest Texas. Mineral resources in the area for which data are presented include clays, gypsum, industrial limestone, iron ore, lignite, natural gas, oil, salt, shell, and sulfur.

Precise determination of the reserves of a single mineral deposit is an exceedingly difficult matter. A final or complete determination can be made only if all of the details of occurrence are known. For many mineral materials these details can be obtained only by drilling or other exploration procedure. Estimations of all of the reserves of mineral resources in large areas such as the Texas Coastal Plain should never be considered more than approximations. In planning studies such as those contemplated by the United States Bureau of Reclamation, this is not a serious defect provided the estimates are of the proper order of magnitude.

Information on quantities of mineral resources in the Texas Coastal Plain varies greatly among the mineral commodities. For example, the extent of the shell resources in the Texas bays is unknown. The Texas Game and Fish Commission is now conducting a survey of this material. Until this survey is completed, an estimate of reserves can be based only on the considered opinions of the officials of the Commission and of the producers, the people most familiar with the shell deposits. On the other hand, essentially adequate figures are available for oil reserves. Through surveys like the recently published "The Oil Resources of Texas," by Fancher, Whiting, and Cretsinger, annual summaries in trade journals, and information currently compiled by oil companies, it is reasonably certain that figures which are of the proper order of magnitude and adequate for long-range planning can be presented.

In the discussions of mineral resources which follow, estimates of quantities available or of reserves are based, as far as possible, on determined occurrences of the materials. As far as available data will permit, the estimates are limited to "measured" and "indicated" reserves and exclude "inferred" reserves. It has been necessary to make certain assumptions and establish specifications concerning minimum thickness, maximum depth of cover, and other conditions limiting possible utilization of material in a given deposit. For example, the quantity of lignite in the Texas Coastal Plain in beds less than 5 feet thick or under a considerable cover is very great. In the foreseeable future, such lignite cannot be mined for use as solid fuel or for use in chemical manufacture and, therefore, is excluded from the estimate of available lignite in Texas.

All available sources of information, supplemented by field work in critical areas, have been used in making the estimates for the various mineral materials. Publications of the Bureau of Economic Geology, and other agencies of The University of Texas, and the United States Geological Survey have been important sources of information. However, the estimates could not have been made without information, suggestions, and help from representatives of the mineral producing companies operating in Texas. They recognized that proper planning for water conservation in Texas is important to continued industrial development in the State, and that major mineral resources are basic materials in the industrial economy. The writers of this report are greatly indebted to these individuals and their companies for this whole-hearted cooperation.

OIL AND NATURAL GAS

Oil and natural gas fields are present in 93 of the 109 counties in the area of this report. Locations of the fields, many of which produce both oil and gas, are shown on figure 2. The accumulations of these materials are in many different types of traps and reservoirs, but it is beyond the scope of this report to discuss these geological features. The oil and natural gas constitute the major energy and raw material source for the present and future industrial development in the Texas Coastal Plain. This area contains most of the oil refineries and petrochemical plants in Texas. There is also a great concentration of chemical and other plants which use natural gas.

The extent of the reserves of these materials is a matter of very great importance. It is obvious that in a study such as this a separate independent determination of reserves is impossible, and the authors must depend upon other sources of information. In a recently published report on "The Oil Resources of Texas," by Fancher, Whiting, and Cretsinger, detailed estimates are given as of January 1, 1952, not only of reserves recoverable by usual production methods but also of reserves recoverable by secondary recovery methods. Other estimates of oil reserves are in general agreement with those presented by Fancher, Whiting, and Cretsinger. Accordingly, by allowing for production and discoveries since January 1, 1952, it is believed that the reserve figures presented are adequate for planning purposes. The estimates exclude any consideration of future discoveries, either on the mainland or on the tidelands.

Estimates of natural gas are published annually by the American Gas Association. The total recoverable reserves of Texas as of January 1, 1955, were stated to be 105,129,062 million cubic feet. More recently, Breitung has shown the reserves by counties so that detailed figures are available for the area covered by this report. Breitung's estimates are in general agreement with those from other sources. As with oil, the estimates exclude any consideration of future discoveries, either on the mainland or on the tidelands.

Oil Production and Reserves

Oil production and reserves for the area as of January 1, 1952, according to Fancher, Whiting, and Cretsinger, are shown in Table 1. The reserves recoverable by primary methods were stated to be 7,738,767,813 barrels and the reserves recoverable by secondary methods 1,297,430,242 barrels. The primary reserves were about 50 percent of the total for Texas, which was 15,661,839,542 barrels. According to the Railroad Commission of Texas, approximately 1,320,717,000 barrels of oil were produced from the Texas Coastal Plain during the years 1952 to 1954, inclusive. However, according to the same source, discoveries during the period added reserves so that remaining primary reserves for the State as of January 1, 1955, were 14,982,003,000 barrels. A consideration of the available data indicates that in the Texas Coastal Plain, remaining reserves recoverable by primary methods, January 1, 1955, are approximately 7,490,000,000 barrels. The reserves recoverable by secondary methods may be considered to be as great as those for 1951, shown in Table 1.

Table 1. Oil production and reserves, Texas Coastal Plain, January 1, 1952.

(Source of data: Fancher, Whiting, and Cretsinger, The oil resources of Texas, Texas Petroleum Research Committee, 1954.)

County	Cumulative production (barrels)	Primary recovery reserve (barrels)	Secondary recovery reserve (barrels)
Anderson	67,926,882	58,074,867	54,400,000
Angelina	94,706	45,655	0
Aransas	5,376,895	8,091,618	352,000
Austin	49,738,499	29,424,572	4,800,000
Bastrop	5,903,939	675,318	1,399,000
Bee	44,518,745	21,821,354	5,620,597
Bell	0	0	0
Bexar	2,947,808	545,971	1,433,271
Bosque	0	0	0
Bowie	278,924	321,076	0
Brazoria	477,413,286	820,056,014	80,225,000
Brazos	0	0	0
Brooks	23,216,751	24,217,988	7,981,866
Burleson	28,920	71,070	33,000
Caldwell	156,091,081	30,271,785	569,151
Calhoun	42,853,562	17,152,865	3,120,000
Cameron	0	0	0
Camp	2,277,722	2,722,278	1,400,000
Cass	12,230,867	39,813,101	2,600,000
Chambers	273,445,408	313,383,186	29,800,000
Cherokee	7,349,997	1,146,631	0
Collin	0	0	0
Colorado	1,641,315	2,155,226	0
Comal	0	0	0
Dallas	0	0	0
Denton	954,336	3,551,664	2,900,000
DeWitt	1,458,055	321,744	204,000
Ellis	0	0	0
Falls	107,838	8,500	0
Fannin	0	0	0
Fayette	391,481	686,667	0
Fort Bend	247,155,957	189,712,827	32,820,000
Franklin	142,180,915	72,345,600	15,964,252
Freestone	23,718,082	312,105	900,000
Galveston	83,455,616	103,843,764	20,100,000
Goliad	17,464,857	22,254,205	4,793,500
Gonzales	30,682	0	0
Grayson	5,389,208	27,848,048	11,546,000
Gregg	2,811,104,354	2,389,196,242	420,000,000
Grimes	973	0	0
Guadalupe	80,088,265	18,890,914	266,400
Hardin	191,293,883	133,363,669	6,000,000
Harris	536,040,398	540,748,558	4,535,000
Harrison	2,128,635	13,120,433	3,500,000
Hays	0	0	0

Table 1. Oil production and reserves, continued.

County	Cumulative production (barrels)	Primary recovery reserve (barrels)	Secondary recovery reserve (barrels)
Henderson	7,339,855	7,223,145	3,674,000
Hidalgo	9,094,345	921,356	2,258,200
Hill	0	0	0
Hopkins	25,744,989	14,151,011	35,182,000
Houston	6,085,448	3,573,528	2,000,000
Hunt	1,591,671	912,329	0
Jackson	146,382,474	448,576,615	3,082,268
Jasper	67,068	1,292	0
Jefferson	250,164,669	104,277,584	20,050,000
Jim Wells	168,340,265	150,392,504	94,615,427
Johnson	0	0	0
Karnes	17,390,862	7,994,604	4,882,694
Kaufman	1,061,603	1,718,387	872,000
Kenedy	451,568	1,284,429	0
Kleberg	5,287,574	11,051,008	8,984,052
Lamar	0	0	0
Lavaca	656,767	964,170	0
Lee	10,412	39,588	0
Leon	377,661	4,963,544	2,150,000
Liberty	190,911,517	111,313,367	25,050,000
Limestone	106,269,936	6,091,664	831,000
Live Oak	4,057,817	685,394	2,308,347
Madison	42,222	48,525	0
Marion	4,168,939	1,279,578	1,000,000
Matagorda	65,489,220	103,806,615	4,500,000
McLennan	136,117	13,883	100,000
Milam	3,973,519	246,374	4,200,000
Montgomery	307,900,473	367,733,144	0
Morris	0	0	0
Nacogdoches	435,126	0	0
Navarro	152,245,662	11,837,503	14,835,000
Newton	2,073,583	6,574,407	0
Nueces	242,842,819	76,865,559	112,731,150
Orange	55,499,375	38,166,511	1,000,000
Panola	1,543,117	3,611,426	1,600,000
Polk	33,456,629	28,072,507	0
Rains	0	0	0
Red River	0	0	0
Refugio	312,335,711	263,099,501	16,913,374
Robertson	656,971	445,029	2,000,000
Rockwall	0	0	0
Rusk	2,557,523	6,381,542	2,500,000
Sabine	0	0	0
San Augustine	12,000	0	0
San Jacinto	9,703,405	14,011,586	400,000
San Patricio	168,913,769	93,534,708	29,206,506
Shelby	47,876	7,693	0
Smith	9,800,803	25,245,430	15,305,000

Table 1. Oil production and reserves, continued.

County	Cumulative production (barrels)	Primary recovery reserve (barrels)	Secondary recovery reserve (barrels)
Tarrant	0	0	0
Titus	2,328,828	12,671,172	4,200,000
Travis	68,413	5,103	52,000
Trinity	0	0	0
Tyler	7,845,030	2,730,681	6,150,000
Upshur	0	0	0
Van Zandt	220,173,113	293,459,025	745,000
Victoria	75,986,395	112,653,002	9,330,323
Walker	23,477	376,523	150,000
Waller	3,528,851	1,532,149	0
Washington	7,264,741	2,039,421	0
Wharton	100,505,320	104,070,089	11,563,000
Willacy	25,939,895	20,874,049	0
Williamson	7,784,703	1,509,673	382,864
Wilson	273,830	659,370	1,285,000
Wood	178,069,651	382,974,994	134,078,000
Total	8,261,248,449	7,738,767,813	1,297,430,242

Natural Gas Production and Reserves

Fields producing significant volumes of gas are located in 57 of the 109 counties included in this report. On figure 2 are tabulated the number of oil and gas fields in each county and the number of fields in each county which, in 1954, produced 1,000,000 cubic feet of gas, or more, daily. A study of the gas production reveals that within the Texas Coastal Plain there are certain areas with relatively large production (fig. 2). In general, these areas also contain larger reserves of natural gas. Among these areas are the following:

(1) All or parts of Gregg, Harrison, Panola, Rusk, Cherokee, and Smith counties.

(2) Parts of Waller, Harris, Fort Bend, Wharton, Lavaca, Colorado, and Austin counties.

(3) All or parts of Galveston, Brazoria, Fort Bend, Matagorda, Wharton, Jackson, Calhoun, Victoria, Aransas, and Refugio counties.

(4) Parts of San Patricio, Nueces, Jim Wells, Brooks, Kenedy, and Kleberg counties.

Many other of the 109 counties produce gas in lesser amounts, although their aggregate production is a very considerable volume of gas.

Recoverable natural gas reserves of the area as of January 1, 1955, according to Breitung, are shown in Table 2. The total recoverable reserves, including dissolved and associated gas and nonassociated gas, were stated to be 63,512,700 millions of cubic feet. The areas of large production listed above generally are also areas of large reserves. In addition, certain other counties including Anderson, Bee, Chambers, Goliad, Hardin, Hidalgo, Jefferson, Live Oak, Montgomery, and Wood have large or notable reserves.

The reserve figures are of recoverable reserves. The part of these reserves already dedicated in contracts or to field use is not shown. This is known to be large but a consideration of this aspect of gas reserves is beyond the scope of this report.

Water Requirements

Conventional refining processes and many of the manufacturing processes in which oil and natural gas are used as raw materials require large quantities of water. The water requirements of an oil refinery are four or five times the volume of the oil refined, and for many petrochemical plants the water requirements are even greater. The water requirements for the processing of oil and natural gas and manufacturing of derived products are greater by far than for any of the other mineral commodities included in this report.

Table 2. Natural gas reserves, Texas Coastal Plain, January 1, 1955.

(Source of data: Breitung, C. A., Texas gas reserves, 100 trillion cubic feet: Oil and Gas Jour., vol. 54, no. 6, pp. 198-201, June 13,1955.)

County	Millions of cubic feet	County	Millions of cubic feet
Anderson	636,600	Kaufman	3,100
Angelina	3,000	Kenedy	269,400
Aransas	649,400	Kleberg	343,100
Austin	270,600	Lavaca	336,200
Bastrop	2,000	Leon	352,200
Bee	427,300	Liberty	441,000
Bexar	900	Limestone	90,200
Bowie	500	Live Oak	708,300
Brazoria	6,520,300	Madison	110,700
Brazos	9,200	Marion	345,300
Brooks	1,794,500	Matagorda	1,586,900
Caldwell	12,200	Milam	700
Calhoun	425,300	Montgomery	1,162,800
Cameron and Hidalgo	3,559,600	Nacogdoches	356,800
Camp	3,400	Navarro	26,400
Cass	404,400	Newton	45,800
Chambers	1,667,000	Nueces	5,633,500
Cherokee	27,800	Orange	334,100
Colorado	1,706,600	Panola	6,016,200
DeWitt	242,000	Polk	103,200
Fayette	1,600	Rains	18,700
Fort Bend	781,400	Refugio	1,765,000
Franklin	50,600	Robertson	3,400
Freestone	363,700	Rusk	137,700
Galveston	643,500	San Jacinto	106,300
Goliad	527,200	San Patricio	745,300
Grayson	38,900	Shelby	290,800
Gregg	1,281,000	Smith	368,100
Guadalupe	14,500	Titus	29,400
Hardin	566,100	Trinity	28,000
Harris	2,120,200	Tyler	95,200
Harrison	1,184,300	Van Zandt	158,700
Henderson	260,400	Victoria	1,247,900
Hidalgo	(see Cameron)	Walker	600
Hopkins	34,300	Waller	5,927,300
Houston	174,800	Washington	18,000
Hunt	1,600	Wharton	1,144,200
Jackson	1,290,600	Willacy	176,000
Jefferson	919,600	Williamson	1,300
Jim Wells	3,370,700	Wilson	800
Karnes	205,300	Wood	791,200
		Total	63,512,700

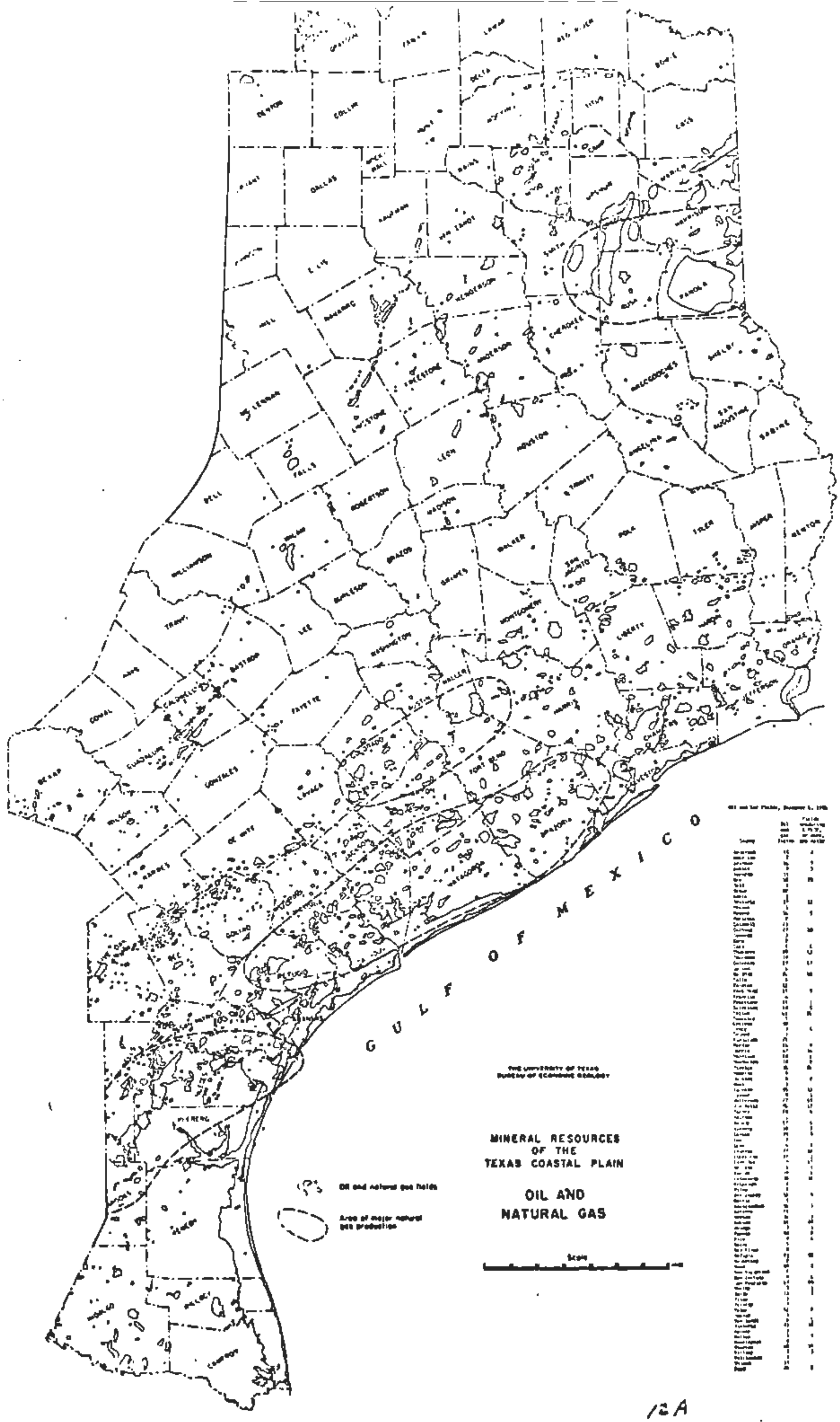
References

Oil and Gas Division, The Railroad Commission of Texas, Annual Reports, 1951-1954.

Breitung, C. A., Texas gas reserves, 100 trillion cubic feet: Oil and Gas Jour., vol. 54, no. 6, pp. 198-201, June 13, 1955.

Fancher, G. H., Whiting, R. L., and Cretsinger, J. H., The oil resources of Texas, Texas Petroleum Research Committee, 1954.

Gas facts, 1954 data, American Gas Association, 1955.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OF THE
TEXAS COASTAL PLAIN
OIL AND
NATURAL GAS
Oil and natural gas fields
Area of major natural gas production
Scale

SULFUR

Introduction

Sulfur is an exceedingly important industrial mineral. Its principal use is in the manufacture of sulfuric acid, and the acid along with sulfur enters into a vast number of industries and a multiplicity of uses. The principal uses of sulfur and sulfuric acid, in approximate order of importance, are in fertilizer, chemicals, petroleum refining, paint, metallurgy, rayon and film, pulp and paper, insecticides, rubber, and explosives.

Sulfuric acid is also manufactured from pyrites (iron sulfide) and from sulfur-bearing gases evolved at metal sulfide smelters. In the United States in 1952, the last year for which complete figures are available, the equivalent sulfur from materials other than elemental sulfur was only approximately 12 percent of the total. In the same year approximately 95 percent of the elemental sulfur was produced in the coastal regions of Texas and Louisiana. The remainder came from coal and petroleum gases and from a very small production from native sulfur mines in California, Wyoming, Nevada, and Utah. The sulfur in the coastal region, except for a small quantity recovered from petroleum gases, was native sulfur, and the Texas production amounted to about 71 percent of the total.

Occurrence

The native sulfur produced in Texas occurs in the cap rocks of piercement salt domes in the coastal area and is recovered by the Frasch process. Such sulfur sometimes is called Frasch sulfur. The piercement salt domes are structures in which a central plug or core of salt has been intruded upward through overlying sedimentary rocks. The salt plugs range from about half a mile to over 4 miles in diameter. The salt contains an average of 5 to 10 percent anhydrite (calcium sulfate), and the salt in many domes is overlain by a cap rock composed of anhydrite, gypsum, and limestone. Generally, the limestone portion of the cap rock lies above the anhydrite and gypsum but this arrangement is not uniform throughout the domes. In a small percentage of the domes, native sulfur is present in the limestone part of the cap rock and to a lesser extent in the anhydrite-gypsum part. It is believed, although not completely proved, that the cap rock resulted from concentration of the anhydrite by solution of salt and later chemical alteration of anhydrite to produce gypsum, limestone, and sulfur. Apparently, rather specialized conditions of depth, circulation of ground water, and chemical environment were necessary to produce salt-dome cap rock with accompanying commerical deposits of sulfur.

Sulfur domes.--Sulfur does not occur in all of the salt domes but is restricted to a small number of the coastal domes. Of the 231 salt domes reported in Texas, Louisiana, Mississippi, and Alabama, only 16, or about 7 percent--all in Texas and Louisiana--have been found to contain deposits of sulfur of commerical significance. Most of the commercial deposits are at depths of 1,500 to 2,000 feet and the deepest production, from Hoskins Mound in Brazoria County, is from 2,400 feet. Available data on Texas domes known to contain sulfur are given in Table 1, and locations of the domes are shown on figure 3.

Mining

Sulfur is produced from the salt domes by the Frasch process. This was developed by Herman Frasch, an industrial chemist, and was first successfully used at Sulphur dome in Louisiana in 1894. It was developed because of the disseminated arrangement of the sulfur in the cap rock and the presence of hydrogen sulfide, other poisonous gases, and excessive ground water, which prohibited mining by conventional underground mining methods. Probably no other method can be used in the coastal area.

Table 1. Sulfur domes in Texas.

Dome	County	Operator	Remarks
Domes depleted and abandoned--			
Bryan Mound	Brazoria	Freeport Sulphur Company	Total production 5,001,000 tons
Gulf	Matagorda	Texas Gulf Sulphur Company	Total production 12,350,359 tons
Palangana	Duval	Duval Texas Sulphur and Potash Company	Total production 237,607 tons
Producing domes--			
Boling	Wharton	Texas Gulf Sulphur Company	
Clemens	Brazoria	Jefferson Lake Sulphur Company	Nearing depletion
Damon Mound	Brazoria	Standard Sulphur Company	Small producer
Hoskins Mound	Brazoria	Freeport Sulphur Company	Nearing depletion
Long Point	Fort Bend	Jefferson Lake Sulphur Company	
Moss Bluff	Liberty	Texas Gulf Sulphur Company	
Nash	Fort Bend	Freeport Sulphur Company	Small producer, nearing depletion
Orchard	Fort Bend	Duval Texas Sulphur and Potash Company	
Spindletop	Jefferson	Texas Gulf Sulphur Company	
Domes potentially productive--			
Allen	Brazoria		
Fannett	Jefferson		
High Island	Galveston		
Hockley	Harris		
*	*		
Domes containing sulfur, probably not potentially productive--			
Barbers Hill	Chambers		
Big Hill	Jefferson		
Blue Ridge	Fort Bend		
Brenhan	Washington		
Gyp Hill	Brooks		
Humble	Harris		
Pierce Junction	Harris		
South Liberty	Liberty		

*One dome not identified

Simply stated, the Frasch process involves melting the sulfur in the cap rock by superheated water and forcing the liquid sulfur to the surface. A specially designed system of pipes is installed in the wells drilled into the sulfur-bearing cap rock. Water at 325° F. is forced into the formation. The sulfur, which melts at temperatures from 234° to 248° F., collects in the bottom of the system. From there it is forced by compressed air to the surface and carried by insulated and heated pipe-lines to storage bins, or in some instances to insulated transport barges, for delivery in the liquid state. After it solidifies in the bins, it is marketable without additional purification. According to Lundy (1949), sulfur produced by the Frasch process frequently averages 99.8 percent and is guaranteed to contain not less than 99.5 percent sulfur and to be practically free of arsenic and selenium.

Mining by the Frasch process is highly specialized. Successful and profitable operation depends on good distribution of the sulfur in permeable cap rock, which permits maximum circulation of the hot water, and on an impervious cover and floor to the sulfur-bearing rock to reduce loss of hot water and escape downward of the molten sulfur. Ideally the sulfur is localized in the uppermost part of the cap rock. Under this condition the depleted cap rock caves readily and acts as a seal to prevent loss of the hot water.

Available information indicates that 5 percent is the approximate minimum sulfur content that can be mined by the process under existing conditions. Maximum depth at which sulfur can be mined by the Frasch process has not been established. Deepest production is 2,400 feet at Hoskins Mound. According to Lundy (1949), depth limitation probably will be determined by costs rather than engineering difficulties.

Production

Production of sulfur in Texas as far as figures are available is shown in Table 2. From an initial production of 12,000 tons in 1913, the production has increased to 3,450,000 long tons in 1954. Sulfur is the third most valuable mineral resource in Texas, exceeded only by oil and natural gas.

Table 2. Sulfur production in Texas Coastal Plain.

(Production figures 1912 through 1953 from Jefferson Lake Sulphur Company; 1954 from Comptroller of Public Accounts, State of Texas.)

Dome	Dates of operation	Cumulative production to January 1, 1955 (long tons)	Producer
* Bryan Mound	1912 to 1935	5,001,000	Freeport Sulphur Company
* Gulf	1919 to 1936	12,350,359	Texas Gulf Sulphur Company
Hoskins Mound	1923 producing	10,798,124	Freeport Sulphur Company
* Palangana	1928 to 1935	237,607	Duval Texas Sulphur and Potash Company
Boling	1935 to 1940	571,237	Duval Texas Sulphur and Potash Company
Boling	1929 producing	43,228,580	Texas Gulf Sulphur Company
Long Point	1930 to 1938	402,170	Texas Gulf Sulphur Company
Long Point	1946 producing	1,678,227	Jefferson Lake Sulphur Company
Clemens	1937 producing	2,382,617	Jefferson Lake Sulphur Company
Orchard	1938 producing	3,246,923	Duval Texas Sulphur and Potash Company
Moss Bluff	1949 producing	1,549,963	Texas Gulf Sulphur Company
Spindletop	1952 producing	733,920	Texas Gulf Sulphur Company

*Depleted

Reserves

Detailed information concerning Frasch sulfur reserves is not available. In 1952, the President's Materials Policy Commission estimated reserves and concluded that Frasch reserves probably are not large enough to supply the growing requirements for many years and by 1975 other sulfur minerals would become increasingly important. Information secured in the present study indicates that this situation applies to the Texas mainland reserves as well as those of Louisiana, the only other state producing Frasch sulfur. The most optimistic estimate indicates a mainland reserve in Texas of about 80,000,000 tons sufficient for twenty-five years at the anticipated rate of consumption. The least optimistic estimate indicates a reserve about half as large.

Future discoveries.--Inasmuch as commercial sulfur deposits occur only in piercement domes at relatively shallow depths and because of the intensive search for salt domes by modern geophysical methods, it is considered unlikely that additional sulfur domes will be discovered on the mainland. There is a general belief among geologists and engineers familiar with the situation that all of the shallow domes on the mainland capable of producing sulfur have been discovered. It has been reported that a salt dome with a large deposit of sulfur has been discovered in the Louisiana tidelands. Discoveries are to be expected in Texas tidelands, but at the present time their potential importance cannot be evaluated.

Mexican sulfur.--Within recent years production of Frasch sulfur has been established in the Isthmus of Tehuantepec in Mexico. Two companies produced 85,000 long tons in 1954 and together with a third company plan to produce 790,000 long tons in 1955. This indicates substantial reserves.

Sulfur from other sources.—Recovery of elemental sulfur from petroleum gases is increasing. There was one producer in Texas in 1952, but in 1953 production was reported by nine companies. The amount of production in 1953 was 48,101 tons, slightly more than 1 percent of the total production of sulfur in Texas. In 1954 the production amounted to 119,639 tons, of which 31,400 tons was from the coastal area. It can be expected that production from this source will continue to increase.

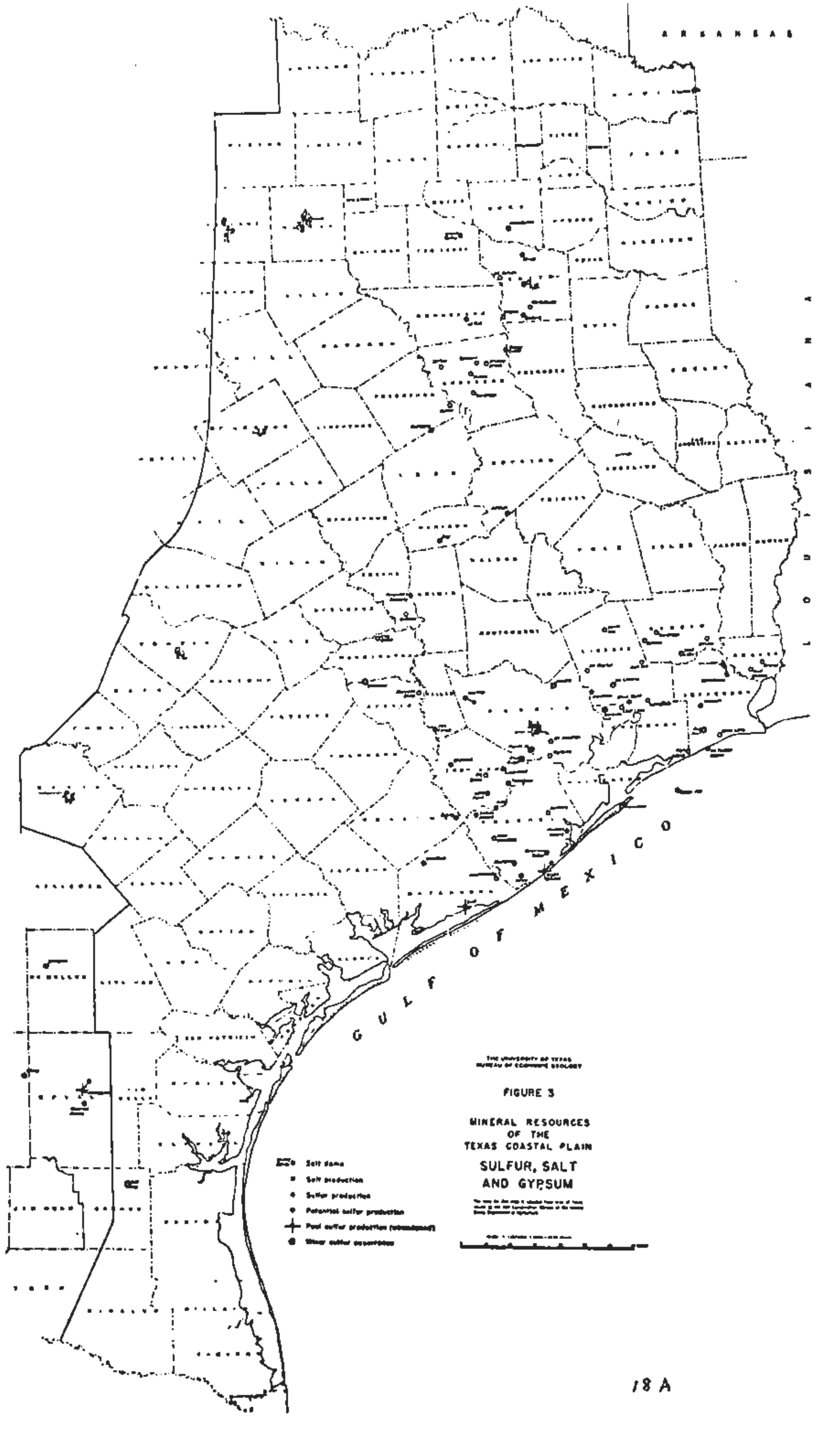
Water Requirement

The Frasch process requires 1,000,000 to 10,000,000 gallons of water per day depending on the size of the plant. Until recently the process required that the water be fairly pure and that it be treated to control corrosion and scale. It is reported that with recently designed equipment it is now possible to use brackish water in the process.

References

Lundy, W. T., Sulphur and pyrites, in Industrial rocks and minerals: Amer. Inst. Min. Met. Eng., pp. 989-1017, 1949.

Resources for Freedom. A report to the President by the President's Materials Policy Commission, Vol. II, p. 85, 1952.



THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY

FIGURE 3

MINERAL RESOURCES
OF THE
TEXAS COASTAL PLAIN

SULFUR, SALT
AND GYPSUM

SALT

Uses

Salt is one of the most important industrial minerals and is said to have 1,400 uses, the largest of which is in the preparation of soda ash. Vast quantities of salt also are used in other chemical processes in the food industries, refrigeration, agriculture and the livestock industry, metallurgy, water treatment, and household uses.

Occurrence

In the Coastal Plain of Texas, salt occurs in each of the salt domes as the central mass or plug that has been intruded upward through the sedimentary rocks toward the surface. All of the salt thus far produced in the Coastal Plain and in east Texas has been from salt domes. Thickly bedded salt is also known to occur deeply buried under much of the Coastal Plain and east Texas. This salt was discovered in drilling for oil and is known to geologists as the Louann salt.

Mining

Salt is produced by several methods. Solar evaporation of sea water is one of the oldest and is still in use in many countries, including the United States. The natural brines in inland bodies of water such as Great Salt Lake, Searles Lake, and the Dead Sea are sources of salt recovered by either solar or mechanical evaporation.

Relatively shallow mining of salt is by conventional underground mining methods. Deep salt is usually mined by the solution method. This is accomplished by drilling into the salt body and circulating unheated water in and out of the salt until a cavity is dissolved sufficiently large that the recovered brine is of the desired salinity, approaching saturation. This development stage may require pumping for a period of several months and the use of large quantities of water. After the brine has reached the desired salinity, only make-up water is required for further operations.

Salt mining by the saturation method is a highly specialized operation, and when it is skillfully conducted, the brine is produced with a minimum of effort and cost. In West Virginia, salt more than 6,000 feet below the surface is produced by this method, and still deeper salt could be produced under favorable conditions.

Production

The annual salt production in Texas is about 2,700,000 tons, nearly all of which is from domes in the Texas Coastal Plain.

Salt production in the Coastal Plain commenced in 1845 at the Grand Saline dome in Van Zandt County; until 1929, all of the salt produced there was by evaporating artificial brines obtained from wells drilled into the salt. Since 1929, salt has been produced there by that method and also by underground mining of the dry salt.

At the present time, salt is mined at Hockley in Harris County and at Grand Saline in Van Zandt County. Salt brine is produced at Bryan Mound and Stratton Ridge in Brazoria County, Barbers Hill in Chambers County, Palangana in Duval County, Blue Ridge in Fort Bend County, Pierce Junction in Harris County, and Grand Saline in Van Zandt County (fig. 3).

Quality

The salt produced from Texas salt domes runs better than 98 percent NaCl. The principal impurity is anhydrite, but by careful underground mining, salt of the above purity is being produced.

A typical analysis of a nearly saturated brine being produced in large volume by one of the chemical companies on the Texas Coastal Plain is:

	Grams per liter
Sodium chloride	309.9
Calcium sulfate	3.91
Calcium chloride	0.19
Magnesium chloride	0.07

Texas brines compare favorably with those produced in other sections of the United States and Canada.

Reserves

Salt reserves in the Texas Coastal Plain are so great that for all practical purposes they are unlimited. As a matter of interest, the quantity of salt in the salt domes under less than 2 miles of cover has been computed and tabulated (Table 1). The total is approximately 242 cubic miles. Annual world production of salt is approximately 54,000,000 metric tons, equivalent to only a few thousandths of 1 cubic mile.

The volume of Louann salt in northeast Texas has not been computed, but records concerning its occurrence are shown in Table 2.

Water Requirement

The solution method of salt production requires water as an essential agent. In the initial development stage, considerable quantities are required. After production is established, only make-up water is required at about the ratio of 800 gallons of water to one ton of salt. The present and future points of production are so widely dispersed that the total annual requirement of water would not be of importance in planning.

Table 1. Salt in salt domes, Texas Coastal Plain.

Dome	County	Depth to top of salt (feet)	Area of salt (square miles)	Volume of salt (cubic miles)
Allen	Brazoria	1,380	0.45	0.79
Arriola	Hardin	3,933	0.78	0.98
Barbers Hill	Chambers	1,000	2.83	5.12
Batson	Hardin	2,050	2.01	3.24
Bethel	Anderson	1,600	4.68	7.96
Big Creek	Fort Bend	650	0.94	1.76
Big Hill	Jefferson	2,000	1.61	2.61
Block 144	Galveston	No salt yet encountered	?	?
Blue Ridge	Fort Bend	143	0.66	1.30
Boggy Creek	Anderson and Cherokee	1,829	6.80	11.22
Boling	Wharton	975	17.19	31.29
Brenham	Washington and Austin	1,150	0.75	1.33
Brooks	Smith	220	2.39	5.46
Brushy Creek	Anderson	3,570	2.34	3.09
Bryan Mound	Brazoria	1,136	0.85	1.51
Bullard	Smith	527	1.56	2.98
Butler	Freestone	312	0.78	1.51
Clam Lake	Jefferson	8,230	0.94	0.41
Clay Creek	Washington	2,854	1.49	2.17
Clemens	Brazoria	1,400	1.09	1.88
Concord	Anderson	5,994	1.56	1.31
Damon Mound	Brazoria	529	2.26	4.29
Danbury	Brazoria	6,231	2.34	1.92
Davis Hill	Liberty	1,200	3.12	5.52
Day	Madison	3,153	?	?
Dilworth Ranch	McMullen	7,736	0.78	0.41
Esperson	Liberty	7,055	1.25	0.83
Fannett	Jefferson	2,200	0.62	0.98
Ferguson's Crossing	Brazos and Grimes	4,038	0.62	0.75
Grand Saline	Van Zandt	235	3.90	7.60
Gulf	Matagorda	1,100	0.37	0.66
Gyp Hill	Brooks	1,175	1.56	2.76
Hainesville	Wood	1,229	4.68	8.28
Hankamer	Liberty	7,582	1.56	0.87
Hawkinsville	Matagorda	600	2.34	4.42
High Island	Galveston	1,300	1.19	2.08
Hockley	Harris	1,000	3.39	5.94
Hoskins Mound	Brazoria	1,150	0.45	0.80
Hull	Liberty	700	1.38	2.58
Humble	Harris	1,200	5.49	9.72
Keechi	Anderson	2,162	0.69	1.10
Kittrel	Houston	3,855	1.56	1.98
La Rue	Henderson	4,450	4.68	5.43
Long Point	Fort Bend	930	1.51	2.75
Lost Lake	Chambers	5,430	1.56	1.51

Table 1. Salt in salt domes, continued.

Dome	County	Depth to top of salt (feet)	Area of salt (square miles)	Volume of salt (cubic miles)
Markham	Matagorda	1,360	1.09	1.90
McFaddin Beach	Jefferson	2,580	1.56	2.36
Millican	Brazos	5,170	0.62	0.63
Moca	Webb	6,366	1.56	1.23
Moss Bluff	Liberty	1,170	6.34	11.22
Mt. Sylvan	Smith	613	1.56	2.93
Mykawa	Harris	7,100	0.78	0.51
Nash	Fort Bend	950	1.09	1.98
North Dayton	Liberty	800	0.94	1.73
Oakwood	Freestone and Leon	800	1.56	2.87
Orange	Orange	7,120	3.12	2.03
Orchard	Fort Bend	375	0.62	1.20
Palangana	Duval	1,200	2.04	3.61
Palestine	Anderson	122	1.57	3.09
Piedras Pintas	Duval	1,350	1.58	2.62
Pierce Junction	Harris	960	0.69	1.25
Port Neches	Orange	7,250	1.41	0.88
Raccoon Bend	Austin	11,004	Depth greater than 2 miles	?
an Felipe	Austin and Waller	4,755	4.68	5.15
Saratoga	Hardin	1,900	1.25	2.05
Sour Lake	Hardin	719	1.09	1.84
South Liberty	Liberty	500	2.83	5.38
South Houston	Harris	3,933	0.78	0.97
Spindletop	Jefferson	1,200	1.00	1.77
Steen	Smith	300	1.00	1.94
Stratton Ridge	Brazoria	1,300	5.46	9.55
Sugarland	Fort Bend	4,280	1.57	1.87
Thompson	Fort Bend	9,298	1.56	0.37
Tyler	Smith	890	2.34	4.28
West Columbia	Brazoria	800	0.43	0.80
Whitehouse	Smith	2,009	1.56	2.52
			Total	241.63

Table 2. Records of Louann salt in northeast Texas.

County	Location	Depth to top of salt (feet)	Salt penetrated (feet)
Anderson	Cayuga field	13,726	78*
Franklin	Taloo field	9,062	20*
Harrison	Harleton field	12,510	930
Hunt	Wieland field	9,513	10*
Limestone	Kosse field	8,995	797
Navarro	South Kerens area	11,790	1,272*
Panola	Bethany gas field	11,067	236*
Rains	Ginger area	11,900	1,585
Shelby	Tenaha area	11,535	93
Van Zandt	Van field	11,586	125*
Wood	Quitman field	11,158	5*
Wood	Hawkins field	14,490	10*
Wood	Yantis field	13,281	975*

*Stopped in salt.

GYPSUM

Uses

Gypsum, hydrated calcium sulfate, is an important industrial mineral, especially as a construction material. About 25 percent of the gypsum used in the United States is sold in crude or raw state as fertilizer, filler in various products, fluxing agent, and as a retarder in cement. The remainder is calcined for use in various types of plasters, plaster board, tiles, and blocks. The products from calcined gypsum account for about 94 percent of the market value.

Occurrence

The largest deposits of gypsum are in beds interbedded with salt, dolomite, and other sedimentary rocks. Gypsum in these deposits is believed to be derived by alteration of anhydrite ($CaSO_4$), which was deposited in beds through evaporation of sea water. In the Texas Coastal Plain, bedded gypsum has been recorded in Cretaceous rocks in deep oil tests in Franklin, Camp, Harrison, Panola, Smith, Henderson, Hill, Limestone, and other counties. This gypsum is too deeply buried to be of commercial importance.

A number of salt domes in the Coastal Plain contain gypsum in their cap rocks. This gypsum of the salt dome cap rocks probably was derived from anhydrite, which is present in the cap rocks of many domes, and is the only gypsum of potential commercial importance in the area. Ground water occurs abundantly in the sediments above and around the cap rocks, and hydrogen sulfide gas is present in most cap rocks. Accordingly, only cap-rock gypsum at or near the surface can be successfully mined.

Production

Gypsum has been mined at Hockley dome in Harris County and at Gyp Hill dome in Brooks County (fig. 3). At the Hockley dome, slightly more than 15,000 tons of gypsum was mined from 1928 to 1930 and 1944 to 1947. The mine was abandoned in 1947 because of difficulty in handling the water.

At Gyp Hill, production was intermittent from 1929 to 1942. The total production was approximately 350,000 tons.

Quality

The gypsum at Hockley dome varies somewhat in composition. Principal impurities are anhydrite, shale, sand, and sulfur. Much of it, however, is higher than 96 percent $CaSO_4.2H_2O$. Analyses are not available for the gypsum at Gyp Hill, but the material apparently is of higher grade than that at Hockley. At both localities and in other occurrences in salt domes, probably most of the gypsum is sufficiently pure for commercial requirements.

Reserves

At Hockley, test drilling has shown that the gypsum mass varies in thickness, but the total tonnage of gypsum above a depth of 200 feet is very great. Mining operations here were not successful. Although a large tonnage of gypsum is available, the difficulties connected with mining operations may prevent the exploitation of the deposit.

At Gyp Hill, the gypsum cap rock of the dome is at the surface. Mining was from a surface pit approximately 350 feet wide, 800 feet long, and 35 feet deep. In an area of 200 acres, similar production is feasible with about 13,000,000 tons of gypsum in sight. Deeper mining probably is practicable and the additional reserves are very great because the gypsum is known to extend downward at least 500 feet. This deposit, unquestionably, is the most promising urce of gypsum in the Coastal Plain.

A very great quantity of gypsum is present in the cap rocks of other salt domes in the Coastal Plain. In most of these domes, however, the gypsum is at least several hundred feet beneath the surface, and because of the difficulties connected with underground mining in salt dome cap rock, it is unlikely that much of this gypsum will ever be utilized.

Water Requirement

The mining and processing of gypsum do not require large quantities of water.

LIGNITE

Uses

The principal uses of lignite in Texas in the past have been as a solid fuel for domestic and industrial requirements and as a raw material for the manufacture of activated carbon. Utilization for these purposes has been restricted geographically to areas not far from mining operations, and it is believed that this limitation will continue in any future major use of lignite.

In the future, it is probable that lignite will be used for additional purposes. It will continue to be used as a source of activated carbon and possibly as a solid fuel in large power plants. It seems probable, however, that major future use of the material as a fuel will employ processes which also will yield by-products. The Parry char process, for example, now used in the plant of the Aluminum Company of America at Rockdale, Texas, produces char, a solid fuel, and tar, a basic raw material for the chemical industry. Lignite from east Texas has yielded as much as 40 gallons per ton of tar, and Texas lignite, generally, is sufficiently rich in recoverable tar to be used in this process. Lignite, likewise, is a potential basic raw material for synthetic liquid fuel and other products. The future large-scale utilization of Texas lignite for these various uses will depend on a number of factors, but it is apparent that the material is potentially important in future industrial development in the State.

Occurrence

Lignite occurs in the Texas Coastal Plain in sedimentary rocks of Tertiary age. The lignite is widely distributed in these rocks, but many of the beds or seams are either too thin or of insufficient extent to be of commercial importance. Lignite of commercial importance is restricted mainly to two belts underlain by strata of the Wilcox group and the Yegua formation. It is possible that lignite beds of commercial importance occur also in strata of the Jackson group, but information is so incomplete that this lignite cannot now be regarded as of much importance. The strata generally dip coastward so that some lignite lies at relatively shallow depths coastward from the respective belts of outcrop. Likewise, Wilcox and Yegua lignites have been recorded in wells in structurally high areas considerable distances down dip from the outcrop areas. Figure 4 shows the location of the Wilcox and Yegua belts of outcrop. The Jackson strata crop out immediately coastward beyond the Yegua belt. In general, these belts extend completely across the Coastal Plain roughly parallel to the coast. In east Texas there is a detached area of Wilcox outcrops on the western flank of the Sabine uplift in Harrison, Gregg, Panola, Rusk, Nacogdoches, Shelby, and Sabine counties.

Individual lignite beds are lenticular. The lignite was formed from vegetation which in Tertiary time accumulated in undrained marshes, lagoons, ponds, and lakes. Present-day peat bogs illustrate the manner of accumulation. The size of Tertiary peat bogs determined the areal extent of the lignite lenses. It follows that a single lignite bed or lens does not extend for great distances, but in some areas such beds are at about the same stratigraphic level, which represents an old land surface on which were many marshes and swamps. The thickness of the peat and the resulting lignite vary from bog to bog.

There is a wide range in the thickness and extent of the lignite beds in the Coastal Plain. Some are only a few inches in thickness and traceable only a few hundred feet. There is record of one bed 25 feet thick, and incomplete data indicate that in one area lignite beds are continuous over an area of at least 16 square miles. In some areas two or more beds of lignite are present in a comparatively small vertical distance.

Quality

Stenzel and others (1948) stated that in the lignite produced in the Trinity River tributary area, the moisture content (as received) varied from 12.60

to 41.50 percent with an average of 29.60 percent; ash varied from 6.42 to 20.80 percent; sulfur from 0.53 to 2.27; the heating value from 6,605 to 8,338 B.T.U. with an average of 7,703 B.T.U. as received. These figures probably apply fairly well to all of the lignite in the Coastal Plain. However, the figures were computed from all available analyses, and some of these were of samples of thin and non-commercial beds which probably differ somewhat from thicker beds.

Operators state that lignite between the Colorado and Trinity rivers averages about 7,500 B.T.U. and sulfur averages about 1.0 percent. According to the same source, the best lignite lies east of Trinity River and averages about 7,800 to 8,000 B.T.U. with a sulfur content less than 1.0 percent. The operators have found that lignite southwest of Colorado River is inferior to that farther east. Campbell (1929) noted this same regional variation and attributed it to differences in conditions of deposition of the parent material. In general, also, the Wilcox lignite appears to be better than the younger lignites, though analyses of the latter are not as numerous as those of Wilcox lignite.

Production

At the present time (1955) lignite is produced in Harrison and Milam counties. In the past, lignite was mined in other counties including Anderson, Bastrop, Fayette, Henderson, Hopkins, Houston, Leon, Medina, Milam, Rains, Robertson, Shelby, Titus, Trinity, Van Zandt, Washington, and Wood. The once flourishing lignite industry gradually declined as fuel oil and natural gas became available in Texas and virtually ceased to exist, for a period of time, shortly after World War II. Within the last two years with the development of the Parry char process and establishment of the plant of the Aluminum Company of America near Rockdale in Milam County, lignite is again being mined for fuel use. Records of lignite production go back to 1890. Including 1948, the last year for which figures are available, the total Texas production has been approximately 73,900,000 tons.

Reserves

Past estimates of the quantity of lignite originally present in Texas have ranged from 30,000,000,000 to 23,000,000,000 tons. The latter figure is the estimate Campbell made in 1913 and is the latest published figure. Because of limited data, he assumed an average thickness of lignite beds and that they extended uniformly throughout known lignite areas. In addition, it was assumed that lignite beds 3 or more feet in thickness were workable. These assumptions also made broad statistical allowance for inferred reserves in all thicknesses to considerable depths below the surface and yielded the very large tonnage figure mentioned above. This estimate, like many of the older ones, had to be highly generalized and was intended to represent total possible reserves in both thick and thin beds and under both light and heavy overburden.

The United States Geological Survey is now preparing a reappraisal of the coal reserves of the country, utilizing the increasing volume of geologic data available. These recent estimates have been prepared on a more conservative basis than the older estimates, and many of those recently completed are considerably smaller than the earlier ones.

In 1952, the Paul Weir Company, in a report by Ford, Bacon & Davis, Inc., on the synthetic liquid fuel potential of Texas prepared for the United States Bureau of Mines, considered Texas lignite reserves. It was recognized that a very large tonnage of lignite is present in Texas, but it was concluded that data upon which to base reserve estimates were not adequate for other than generalized estimates.

In the present report an attempt has been made to assemble all available records of lignite in the area covered by the report and to prepare estimates less generalized than the earlier ones. In addition to records in published and unpublished reports on mines, exposures, and lignite drilling, records of thousands of wells drilled for oil have been examined and lignite occurrences recorded and evaluated as to accuracy. The density of the data used is shown on figure 4, although not all points used in the calculations are included. The procedures used have been established after consideration of the following conditions:

(1) Lignite beds are exceedingly lenticular and few individual lenses are greater in area than 10 square miles.

(2) Nearly everywhere the lignites and associated strata dip toward the coast or away from major structures, such as the Sabine uplift, so that in a relatively short distance the lignite beds are too deep for mining. With increasing depth, especially in the Wilcox, large quantities of ground water are to be expected, which would make mining difficult or impossible.

(3) A minimum thickness of 5 feet is the approximate present-day limit for economical mining. Future development of lignite mining probably will be in connection with large power and by-product installations. Only large and thick lignite deposits can support such operations.

(4) Commercial deposits of lignite lying within 90 feet of the surface are generally considered minable by the strip or open-pit method, although some operators visualize open-pit mining as deep as 125 feet. The ratio of overburden to minable lignite is expressed as a fraction. For example, 6/1 would mean six times as much overburden as minable lignite. The economic limit is considered to be 10/1. Production of lignite lying too deep for open-pit methods would require conventional underground mining.

(5) The average recovery in underground mining is 50 percent, the remaining 50 percent being waste. In open-pit mining the recovery is somewhat greater and in some operations has reached 80 or 90 percent. A good average recovery is 75 percent.

In this report the position has been taken, as far as lignite in Texas is concerned, that for many years to come strip or open-pit mining will be the accepted type of operation. It is believed that for the purpose of this report, the estimates should include only lignite which is actually known to exist and only those beds of sufficient thickness to be minable under present conditions or conditions in the not too distant future. Accordingly, the following procedures have been followed in arriving at the quantity of lignite originally present in Texas:

(1) Lignite beds less than 5 feet thick are excluded as also are beds deeper than 500 feet.

(2) Two depth categories are used. Shallow lignite is 90 feet or less below the surface and deep lignite is more than 90 feet below the surface.

(3) Only measured and indicated reserves are considered. The assumptions made concerning them are as follows:

(1) It is assumed that wherever lignite is present in a drill hole, at an outcrop, or other point, there is established a measured reserve of lignite of the observed thickness within a circle of one-fourth mile radius drawn around the point.

(2) It is further assumed that there is also an indicated reserve of lignite of the observed thickness outside this circle but within an outer circle of half a mile radius drawn around the same point.

(3) The average specific gravity of Texas lignite is assumed to be 1.2 and a bed 5 feet thick would contain 8,195 short tons per acre.

The procedures which have been followed result in an estimate for the original reserves of 7,069,876,000 short tons of lignite in beds 5 feet or thicker. The reserves remaining January 1, 1955, are 6,995,976,000 short tons. Slightly more than 1 percent of the original reserves has been depleted through mining operations. Tables 1 and 2 show the reserve calculations in greater detail.

The reserve estimates in this report admittedly are conservative and are subject to change as new information is obtained. Probably, additional exploration would reveal substantial or possibly large reserves of lignite not included in this report. The calculations are based on a series of assumptions concerning the continuity and thickness of the lignite beds. Different assumptions would result in modification of the present estimates because only slight changes in the basic assumptions would make great changes in the resulting figures.

Inferred reserves.--Inferred reserves, those for which tonnage estimates are based largely on geologic information supported by a few widely spaced points of observation, are excluded from this report because of the highly lenticular character of the lignite beds. It is believed that the available data justify only the estimates presented, even though the inclusion of inferred reserves would greatly increase the total reserve figures.

Major areas of occurrence.--Data on the occurrence of lignite in Texas are not sufficient to yield detailed information concerning individual deposits. Points of observation fall into patterns which show general areas in which substantial deposits probably are present. Some of these are:

Southern Milam County

Western Robertson County

Parts of Bastrop County

Southern Harrison and northern Panola counties

Southern Freestone County

South-central Van Zandt County

Water Requirement

Mining of lignite for strictly solid fuel purposes does not require a great quantity of water. On the other hand, synthetic liquid fuel plants and possibly others require large quantities, mainly for cooling purposes in the process. According to the Ford, Bacon & Davis report, a unit plant for the natural gas synthine process with a capacity of 5,000 barrels per day would require about 3,737,000 gallons per day. It is assumed that a plant using lignite rather than natural gas would have about the same requirement.

Table 1. Original reserves of lignite in Texas Coastal Plain.
(in short tons)

Measured reserves		Indicated reserves	
0-90 feet overburden	more than 90 feet overburden	0-90 feet overburden	more than 90 feet overburden
Wilcox lignite			
927,476,000	704,000,000	1,954,600,000	2,164,200,000
Yegua lignite (includes lignite of Jackson age)			
100,100,000	154,800,000	300,300,000	764,400,000
Total 1,027,576,000	858,800,000	2,254,900,000	2,928,600,000
Total, original reserves all categories			7,069,876,000

Table 2. Remaining lignite reserves of Texas Coastal Plain, January 1, 1955.
(in short tons)

Total original reserves	Production plus loss in mining, assuming past losses equal production	Remaining reserves	Recoverable reserves, assuming 50% recovery for deep and 75% for shallow beds
7,069,876,000	73,900,000	6,995,976,000	4,300,232,000

References

Campbell, M. R., General introduction, in Coal fields of the United States: U. S. Geol. Survey Prof. Paper 100, pp. 1-33, 1929.

Ford, Bacon & Davis, Inc., The synthetic liquid fuel potential of Texas: Report for Bureau of Mines, Dept. of the Interior, 1952.

Stenzel, H. B., Fountain, H. C., Hendricks, T. A., and Miller, R. L., Bituminous coal and lignite, in Geological resources of the Trinity River tributary area in Oklahoma and Texas: Univ. Texas Pub. 4824, pp. 31-44, 1948.

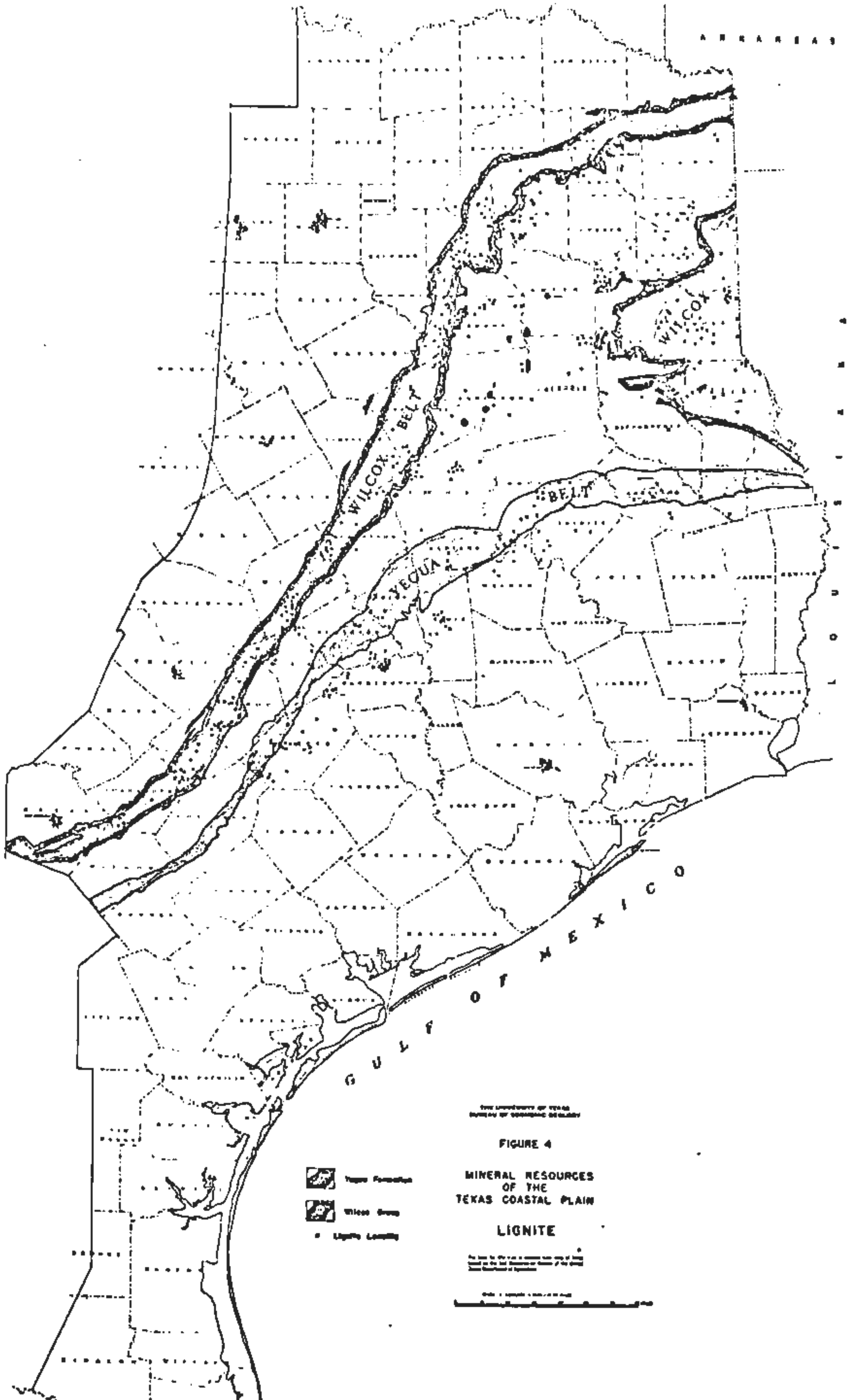


FIGURE 4

MINERAL RESOURCES
OF THE
TEXAS COASTAL PLAIN

LIGNITE

36A

CLAY

Although the Texas Coastal Plain contains vast deposits of various kinds of clay, few are suitable for manufacture into products in national demand. Clay products, which are abundantly produced in the United States, are relatively low priced and bulky; consequently, the economic limit of their distribution rarely exceeds a few hundred miles. Unglazed or common brick rarely are marketed more than 300 miles from their point of origin. Glazed brick and tile and certain types of bentonite, because of their higher price, can move to more distant markets. Nevertheless, because they are used in materials for construction and have special uses in heavy industry, the clays of the Texas Coastal Plain should be given due consideration in industrial planning.

For convenience, these clays may be classified according to their uses into burning clays, bleaching clays, and drilling clays, although some are suitable for more than one use.

Burning Clays

The burning clays are those used in the manufacture of structural clay products (including building and facing brick, building and facing tile and drain tile), refractories, sewer pipe, terra cotta, and wall tile. All of these products, except terra cotta, are manufactured from clays in the Texas Coastal Plain.

The greatest concentration of ceramic plants is along the belt of outcrop of the Wilcox strata (fig. 4). Clays suitable for a great variety of burned clay products are abundant in this belt, and there is a favorable transportation net. Clay plants using Wilcox clays are located in Bexar, Freestone, Guadalupe, Harrison, Henderson, Limestone, Nacogdoches, and Rusk counties. Among the products which are manufactured in considerable quantities are building and facing brick, structural clay tile, drain tile, unglazed facing tile, refractory brick, ceramic glazed brick and tile, and sewer pipe.

In the Texas Coastal Plain, clays of Gulf Cretaceous age also are utilized in some areas inland from the Wilcox outcrop. Most of the plants utilizing these clays are in the general area of a triangle bounded by Corsicana, Dallas, and Fort Worth. Products manufactured in quantity include building brick and structural clay tile.

Brick and tile plants at Mission, Palacios, Houston, and Beaumont, primarily concerned with the manufacture of building brick, facing brick, and structural clay tile, utilize clays found along the coast.

Many of the formations of Gulf Cretaceous and Tertiary ages and many of the still younger formations contain clays or shales suitable, at least, for the lower grade products. There is also a limited utilization of these clays in ceramic plants.

A special type of burned clay product becoming increasingly more important is the expanded, or bloated, clay material used in lightweight concrete aggregate, some of which is called Haydite. A great many clays will bloat, or expand, on heating to incipient fusion under specially controlled conditions, and the resulting materials are light and strong. Their specific gravity is 1.15 to 1.20, less than half that of gravel. Plants manufacturing this material are located at Dallas, San Antonio, and at Rosenberg and Stafford, in the Houston area. In 1945, there were seven plants in the United States producing this material. Currently, there are eight such plants in Texas, and the State leads in production of the material.

Bleaching Clays

Bleaching clay is a general term applied to clays that in their natural state or after chemical or physical activation have the capacity for adsorbing coloring matter from oil. Most, if not all, of the bleaching clays in the Texas Coastal Plain are bentonite, or at least bentonitic. Bentonite contains the clay mineral montmorillonite as its principal mineral, and many of the special properties of bentonite are due to the behavior of the crystal structure of the mineral under various conditions. Some bentonites adsorb large quantities of water and swell greatly; others adsorb only slightly more water than ordinary plastic clays.

Most of the bentonitic clays of the Texas Coastal Plain produced as bleaching clays are of the non-swelling type, and many of them were derived through the alteration of volcanic ash. Those of commercial importance occur mainly in Tertiary strata, especially those of the Jackson group of Eocene age and the Catahoula formation of Oligocene age. They include both active and activable clays.

The belts of outcrop of the Jackson and Catahoula strata extend across the State, but most of the production of bleaching clays has been east of San Antonio. At the present time, there is production from Angelina, Fayette, Gonzales, Jasper, and Walker counties, but in the past, there has been production in a number of other counties along the belt and as far southwest as Live Oak County.

Much of the bleaching clay produced in the Texas Coastal Plain is used as a decolorizing agent in petroleum refining, some is used in the refining of vegetable oils, and some is used as a carrier for insecticides. It is possible that some of this type of clay in the area is used as a catalytic agent in various petrochemical operations. This use again depends on certain properties of the crystal structure of the clay minerals.

Drilling Clays

Drilling clay, or "drilling mud," is any clay which is a suitable medium for removing rock cuttings from drill holes and for cooling and lubricating the drill tools in rotary drilling. In addition, "drilling muds" also serve to seal off the walls of the drill hole and to prevent high pressure gas blowouts.

Many of the bleaching clay deposits also contain clay suitable for use as drilling clay, and there is a substantial production of clay for this use. At the present time, clays from Angelina and Fayette counties are used for this purpose. Much of the clay produced for this use is mixed or blended with clay from other areas to meet the specifications for a given drilling mud.

Production and Reserves

Figures available on the production of burning clay show only the quantity and value of the unprocessed clay and not the value added through manufacture. It is known, however, that production of burned clay products is increasing in the Texas Coastal Plain. Separate figures for burning clay for Texas are available for 1952 when 1,252,483 short tons valued at $2,172,653.00 were produced. In the same year, bleaching clay and drilling mud clay production in Texas was 136,951 short tons valued at $1,614,943.00. The major part of the production was from the area of this report. In 1953, total production of burning, bleaching, and drilling clays in Texas was 1,693,466 short tons valued at $4,001,465.00, and in 1954, it was 1,800,000 short tons valued at $4,300,000.00.

Reserves of all three types of clay are adequate. Reserves of clay suitable for the making of common brick are practically unlimited. Clays suitable for the more specialized types of ceramic products are less abundant. The greatest supply is in the Wilcox, and careful prospecting and testing are necessary to establish deposits of the required volume for a contemplated clay plant. However, reserves available appear to be sufficient for any foreseeable need.

Bleaching and drilling clays of proper quality are less abundant than burning clays. Such clays can be proved only by actual testing for a specific use. Detailed surveys of these clays in the Texas Coastal Plain have not been made, but there is sufficient information available to indicate that the present rate of production could be maintained for many years.

Water Requirement

The mining and processing of burning, bleaching, and drilling clays do not require large quantities of water.

IRON ORE

Occurrence

The iron ores of east Texas lie within the area of this report. They have been known for well over a hundred years but were not mined extensively until late in World War II. Mining activity stimulated by the war has continued, and at the present time, the Lone Star Steel Company near Daingerfield and the Sheffield Steel Division of Armco Steel Corporation at Houston are producing iron and steel from east Texas ores. In 1953 the production of usable ore was 1,029,327 long tons and in 1954 was 834,750 long tons.

These iron ores occur in two separate areas called the North Basin and the South Basin. North Basin includes much of Cass and parts of Marion, Morris, and Upshur counties. South Basin includes most of Cherokee and parts of Anderson, Henderson, Smith, Rusk, and Nacogdoches counties (fig. 5).

Two types of ores, brown ore or limonite and carbonate ore or siderite, have been derived from the Weches formation of Eocene Claiborne age. These strata contain glauconite (a complex iron silicate) and other iron minerals, which by weathering have produced the iron ore. The Weches formation, once continuous in the area, now is present only as erosion remnants in flat-topped areas on stream divides or in isolated hills. Many of the larger areas are capped by a mantle of sand or sandy soil of the overlying Sparta formation.

In most of the narrow ridges and small isolated hills the Weches is completely weathered. In the larger Weches areas with considerable cover, weathering has been less extensive, and the resulting weathered material containing brown ore occurs within a zone around the ridges and hills. Most brown ore is found to be above the permanent water table; carbonate ore, if present, is below it. Surface exposures of carbonate ore are rare.

In both basins brown ore is much more plentiful than carbonate ore. In North Basin the brown ore occurs as nodules or concretions sometimes coalesced into irregular ledges or beds from a few inches to several feet in thickness, possibly averaging 12 feet. The ore deposits are not in continuous beds but are lenticular. In South Basin, brown ore occurs as a nearly continuous laminated ledge about 2 feet thick at the top of the Weches formation and also under a ferruginous sandstone "cap rock" of the overlying Sparta formation.

Carbonate ore is plentiful only in North Basin. Very little has been found in South Basin. It occurs as rounded, irregular nodules and as thin lenses, usually only a few inches thick, but its thickness is quite variable, in places being as much as several feet. As a general rule, it lies below brown ore, but where overburden is exceptionally thick, carbonate ore may occur alone. In many localities where the overburden is thin, both brown ore and carbonate ore are present, although carbonate ore is absent in some.

Quality

Selected samples of both brown and carbonate ores contain 50 percent or more of iron. However, the ores as mined invariably contain clay and sand and must be beneficiated by washing. From the standpoint of present practice in the district, the significant ore grade is that of the washed ore. According to Lloyd, the washing plant of the Sheffield Steel Company at Rusk beneficiates brown ores from both basins to an average composition of iron 44.74, silica 13.54, alumina 7.91, phosphorous 0.315, and moisture 5.7. Available information indicates that washed carbonate ore contains 40 to 45 percent iron.

The iron ores of east Texas are lower in iron content than those of many other districts in the United States. Their strategic location near the oil and gas fields and the heavy industry of the coastal area partly accounts for their utilization.

Mining and Beneficiation

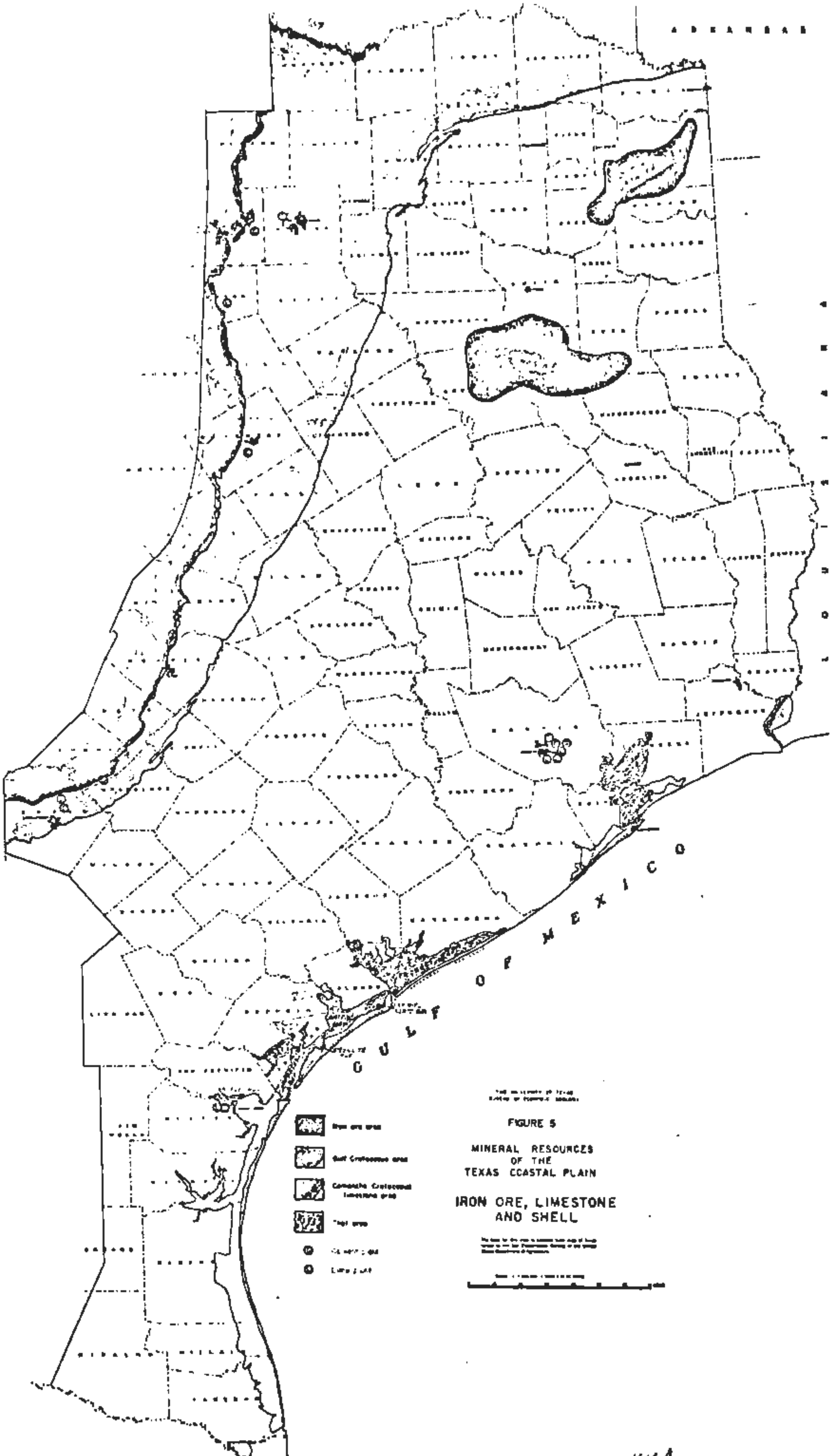
Production of east Texas iron ore is by open pit or stripping methods, and it is apparent that future mining will be by similar methods. Overburden and ore are removed by drag-line or power shovels. The ratio of material removed to commercial ore ranges from 5 to 1 to 10 to 1.

Both the brown and the carbonate ores require washing to remove sand, clay, and other impurities. This is done at central washing plants to which the ore is trucked from the various mining sites. The washing plant of the Lone Star Steel Company is near the steel plant. The Sheffield Steel Company's washing plant is at Rusk, where the ore is washed before shipment by rail to the steel plant at Houston. Some of the brown ore is dehydrated in kilns after washing. Before it is treated in the blast furnace, carbonate ore requires not only washing to remove clay and sand but also sintering to remove carbon dioxide.

Reserves

The mode of occurrence of the iron ores makes determination of reserves very difficult. The effect of weathering and the extent of ore formation at a given locality cannot be predicted from surface inspection. Exposed ore is misleading in that in many places it suggests more and better ore than actually is present. Only detailed geologic mapping, followed by extensive test-pitting, will yield data from which essentially final reserve figures can be calculated.

In 1938, E. B. Eckel of the United States Geological Survey estimated the reserves in terms of ore probably available now or in the near future and ore possibly available but too thin or too low grade for large-scale operations. He estimated a total of 180,608,000 long tons in these two categories. New reserve figures compiled from all available information and presented in Table 1 should be regarded merely as the best estimates as of today and are subject to revision whenever new data are available. The total of all types of ore is 216,994,000 long tons, a figure considerably larger than that of Eckel. The increase is due,


GULF OF MEXICO
FIGURE 5
MINERAL RESOURCES
OF THE
TEXAS COASTAL PLAIN
IRON ORE, LIMESTONE
AND SHELL

primarily, to the larger reserves of the carbonate ore, especially in the North Basin. Mining development and prospecting since World War II have demonstrated that this ore is much more abundant than was previously realized. Approximately one-third of the total reserves in the North Basin is shown as carbonate ore.

Table 1. Iron ore reserves, Texas Coastal Plain, January 1, 1955.

	Measured	Indicated	Potential
North Basin			
Brown ore	26,478,000	57,535,000	22,038,000
Carbonate ore	12,804,000	14,684,000	23,659,000
South Basin			
Brown ore	29,615,000	17,210,000	10,706,000
Carbonate ore	1,559,000	143,000	563,000
Totals	70,456,000	89,572,000	56,966,000

Measured ore designates tonnage of commercial ore computed from field data.

Indicated ore is used for tonnage of commercial ore computed from field data projected a reasonable distance.

Potential ore includes material of lower grade than is now mined and material of usable grade but in deposits less than minable size.

Water Requirement

Water requirements in the mining of iron ore are negligible, but relatively large quantities are required in beneficiation and processing. An integrated operation, such as that of the Lone Star Steel Company, involving mining, washing, sintering, and iron and steel making, requires approximately 18,000 acre feet of water per year.

References

Eckel, E. B., The brown iron ores of eastern Texas: U. S. Geol. Survey Bull. 902, 1938.

Lloyd, C. L., How Sheffield's beneficiation plant upgrades Texas iron ores: Eng. Min. Jour., vol. 155, no. 11, pp. 98-100, 1954.

INDUSTRIAL LIMESTONE AND SHELL

Limestone is a sedimentary rock composed mainly of the mineral calcite, which chemically is calcium carbonate. Many types of limestone occur, but in a general sense, the term implies essentially massive, bedded material. Softer and less coherent types include chalk and marl. Limestone with more than 95 percent of calcium carbonate is called high calcium limestone.

The physical and chemical properties of limestone generally determine its uses. High calcium limestone is required in many chemical plants and in the manufacture of lime and is preferred as a source of calcium in stock and poultry feeds. Less pure limestone is entirely satisfactory for many uses, including cement manufacture, aggregate material, ballast, rip-rap, dimension stone, and as a base for roads.

In many other uses, especially in an industrial complex like that of the Texas Coastal Plain, the lime (CaO) content is the important property. In the absence of high calcium limestone in the coastal area, other relatively pure calcium carbonate materials, such as oyster and other shells, are utilized. Had there been ample deposits of high calcium limestone along the coastal area, possibly the shell reefs might never have been disturbed. A few of the chemical uses require certain physical properties which are present in limestone but not in shell. In some soda ash plants, for example, limestone is used rather than shell because the process requires sizes larger than those of shells. The same situation exists with regard to flux stone in some metallurgical processes. In general, shell can be used in any process in which larger sizes are not essential.

Lime (CaO) ordinarily is produced by heat treatment of limestone or other materials containing relatively large quantities of calcium carbonate. It is an exceedingly important industrial chemical. As a neutralizing agent it is used in water treatment, sewage treatment, gasoline making, manufacture of calcium phosphate, and fine chemicals. As a raw material it is used in the manufacture of soap, greases, organic chemicals, and ammonia. As a flocculation agent it is used in sugar refining, water treatment, and treatment of industrial waste. As a caustic agent it is used in the making of soda and sulfate pulp and caustic soda. There are many other industrial uses based on chemical properties of the lime.

The quantities of limestone and shell used are not great as compared with many other mineral commodities, yet their fundamental and basic importance is out of all proportion to the quantities involved. An abundant and low priced supply of chemical grade limestone or equivalent shell is an essential in an industrial chemical manufacturing complex such as that present in the coastal area of Texas.

The Texas Coastal Plain is peculiarly situated with regard to supplies of limestone and other calcium carbonate materials. High calcium limestone is available only 150 to 175 miles inland along the general line of Dallas, Waco, Austin, and San Antonio. Along this line, limestone of Comanche Cretaceous age is abundant, and many deposits contain high grade material with 97 to 99 percent of calcium carbonate (fig. 5). This line from Waco south is approximately the well-known Balcones fault line. Immediately coastward are impure limestones and chalks of Gulf Cretaceous age which are suitable for the manufacture of cement and are utilized for that purpose at a number of places. Between this belt of Gulf Cretaceous rocks and the coastal region, only a few small and impure deposits of limestone are present. There is a considerable amount of caliche, an impure secondary calcium carbonate rock, which has limited use as road base material.

Shell is dredged from many of the coastal bays, including Aransas, Copano, Espiritu Santo, Galveston, Hynes, Lavaca, Matagorda, Mesquite, San Antonio, and Trinity bays, and the Texas side of Sabine Lake (fig. 5). This shell is used extensively in cement and chemical plants which do not require fragment sizes larger than the shells. At the present time, shell is dredged to a maximum depth of 32 feet below water surface. There is no engineering obstacle to the construction of equipment capable of dredging at greater depths.

Production and Reserves

Much of the calcium carbonate materials produced in the Texas Coastal Plain is used to make cement and lime. Locations of cement and lime plants are shown on figure 5. Some high calcium limestone is shipped to the coastal area for use in chemical plants, as flux, and for various physical uses. Shell is used as the lime source in cement and to produce lime and also for road materials. Both cement and lime are shipped from the inland area to the Coast.

Production figures for cement, lime, and chemical limestone in the area are not available. However, a large part of the State production of these materials is in this area. In 1954, cement production in Texas was 21,350,000 barrels and lime was 340,000 short tons. Shell production, all from the Coast, for the same year was 8,658,544 short tons.

Reserves of limestone suitable for cement making, in combination with clay or shale, along the belt of Gulf Cretaceous rocks are very large, sufficient for all foreseeable needs. Reserves of high calcium limestone of Comanche Cretaceous age likewise are great. They are more erratic in occurrence than the lower grade limestones, and careful prospecting and chemical control are necessary in determining commercial deposits. However, the supply available is probably sufficient for many years to come.

According to the Texas Game and Fish Commission, shell production from 1912 (the earliest record) to August 31, 1954, was approximately 92,441,523 short tons. Production for fiscal year 1951-1952 was 7,337,892 short tons; 1952-1953, 8,089,457 short tons; and for 1953-1954, 8,658,544 short tons.

Accurate estimates of reserves of shell in the Texas bays cannot be made at this time. No comprehensive survey of the shell deposits has been made. The Texas Game and Fish Commission and producers recently have commenced surveys, and within a few years reasonably complete information should be available. It is the considered opinion of officials of the Commission and shell producers that the supply in the shallower deposits of the type currently produced is several, perhaps many, times the amount of past production. It is known that mud-covered deposits exist at depths within the limit of current dredging practice. It is known also that deposits at still greater depths are present, and these probably will be recoverable in the future. An entirely tentative and preliminary estimate of the shell reserves available under present production methods and in the future is on the order of many times the past production.

Water Requirement

Limestone production and lime making do not require great quantities of water. Shell production requires water for washing mud and sand from the dredged shell, but sea water is used.