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Mineral Resources of South Texas

Region Served Through the Port of Corpus Christi

By

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ABSTRACT

This report is a compilation of all available data on mineral resources (exclusive of oil and gas) in 39 south Texas counties. Information from published and unpublished sources was checked and supplemented by field investigations. The study was carried out in cooperation with the Corpus Christi Chamber of Commerce to provide an inventory of mineral resources in the trade area served through the Port of Corpus Christi.

The rock and mineral resources in the northwestern part of the trade area in and associated with Cretaceous formations include high-calcium limestone, Portland cement materials, clay for structural clay products, asphaltic limestone, gravel, and limited amounts of low-grade manganese, barite, celestite, and guano. The principal mineral resources in the Tertiary and Quaternary formations of the Gulf Coastal Plain are uranium minerals, industrial sand, gravel, bleaching clay, drilling mud, expanded clay aggregate, structural clay products materials, caliche for road surfacing, crushed stone, peat, lignite, bituminous and cannel coal, salt, gypsum, sulfur, and oyster shell.

INTRODUCTION

GENERAL STATEMENT

This publication presents the results of a study of mineral resources (other than oil and gas) in 39 counties of south Texas. It is a compilation of available published and unpublished data supplemented by field studies, sampling, testing, and analyses. The objective is to present a practical inventory of the mineral resources of the area from which an evaluation of their commercial possibilities can be made. Technical language and theoretical geological discussions are kept to a minimum. Existing published data have been summarized, and complete references, which give additional technical and engineering detail, are given in bibliographies following presentation of each mineral commodity. Many publications cited are available at The University of Texas and at larger libraries in the State.

This study was instigated by the Corpus Christi Chamber of Commerce and made possible by a grant-in-aid from that organization to the Bureau of Economic Geology of The University of Texas to defray in part the costs of the work. The Chamber of Commerce also furnished some of the special testing equipment required.

This mineral inventory is part of a larger economic study of south Texas being conducted by the Corpus Christi Chamber of Commerce. The over-all study is designed to provide the basis for industrial expansion and diversification in the Corpus Christi trade area.

AREA OF STUDY

The area included within this study comprises 39 counties in south Texas bounded on the southeast by the Gulf of Mexico, on the southwest by the Rio Grande and Mexico, and extending as far as the north latitude of Val Verde and Edwards counties (fig. 1). It is a roughly triangular area of about 45,624 square miles. Corpus Christi, an industrial city of approximately 170,000 located on the Gulf of Mexico about midway on the southeast side of the triangle, is the major port serv-

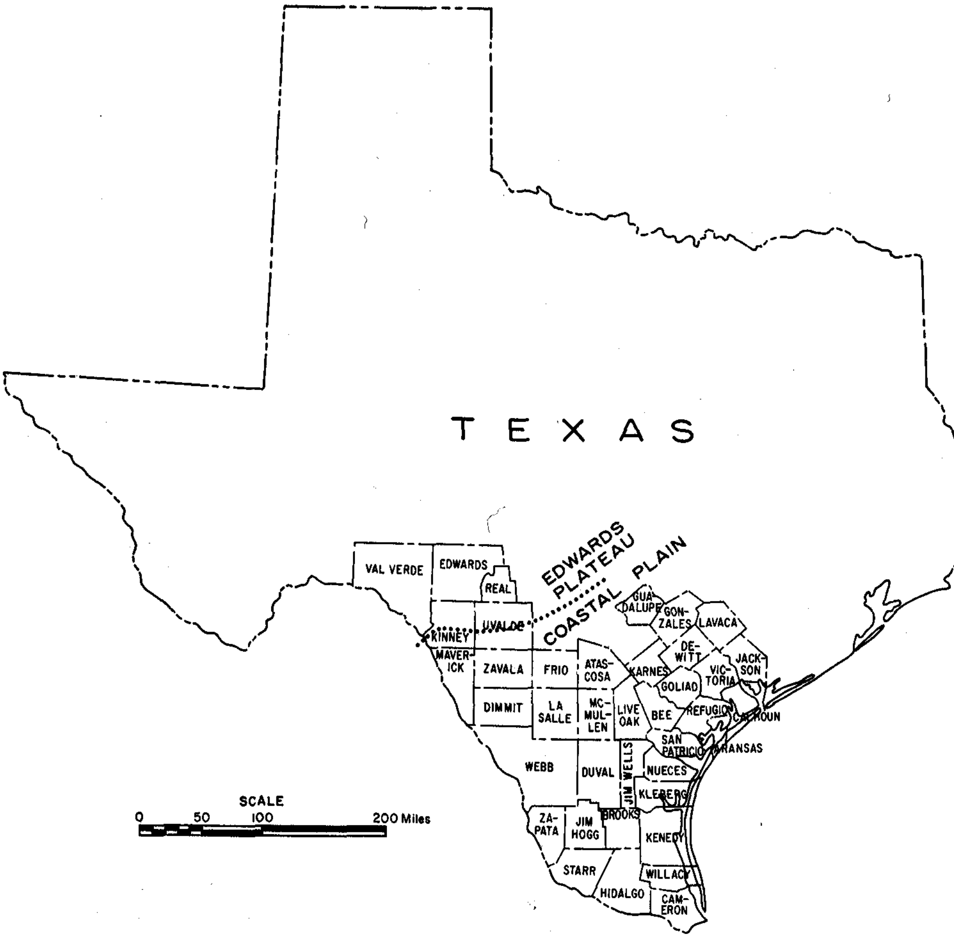

FIG. 1. Index map of South Texas area.

ing the area. The region is served by a network of Federal and State highways and numerous farm-to-market roads. Railroads include the Southern Pacific, Missouri Pacific and their affiliated companies, Texas Mexican, and the Santa Fe. Although known principally as a ranching and oil and gas-producing area, there is a growing chemical and metallurgical industry centered along the coast.

ACKNOWLEDGMENTS

Many persons had a part in the preparation of this report, and their help is greatly appreciated. The late John T. Lonsdale, Director of the Bureau of Economic Geology at the time this investigation was started, was especially interested in the nonmetallic commodities of south Texas, and his guidance in the organization of the study was most helpful. Billy R. Jones and Bill E. St. John each spent three months in field studies. Jones' work was chiefly in Cameron, Dimmit, Edwards, Hidalgo, Jim Wells, Kenedy, Kinney, Kleberg, Maverick, Medina, Nueces, Real, San Patricio, Uvalde, Val Verde, Willacy, and Zavala counties; St. John worked in Aransas, Atascosa, Bee, Brooks, Calhoun, DeWitt, Duval, Frio, Goliad, Guadalupe, Jackson, Jim Hogg, Karnes, La Salle, Lavaca, Live Oak, McMullen, Refugio, Starr, Victoria, Webb, and Zapata counties. Special acknowledgment is made to the many landowners who permitted field personnel to enter upon private property to make investigations and to collect samples. Appreciation is also due the many Central Power and Light Company and Chamber of Commerce managers, public officials, and private citizens who collected data, made introductions, helped to confirm reports, and otherwise aided in the field studies.

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John T. Twining, Shell Oil Company, Corpus Christi, Texas, made his notes on the brick clays of south Texas available to the writer.

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Christian Dullnig, Jr., prepared the bibliography, summarized a great deal of the literature, and plotted well locations where lignite had been recorded in drillers' logs. Miss Roselle M. Girard also aided in the bibliographic work. Cader A. Shelby made some of the petrographic determinations. Mrs. Eloise Hill aided in the preparation of tables and tabulated data and typed the manuscript.

Chemical analyses and physical testing of lignite, clay, limestone, and other mineral materials were performed at the Mineral Technology Laboratory of the Bureau of Economic Geology under the direction of Daniel A. Schofield.

The writer is deeply grateful to all persons who gave generously of their time to the improvement of this publication.

GEOLOGIC SETTING

The area of study includes parts of two major geologic provinces. Most of the region lies within the Texas Gulf Coastal Plain but the northwestern counties fall partly within the Edwards Plateau (fig. 1). These two provinces differ physiographically and geologically and the change from the rolling prairies of the Coastal Plain to the ruggedly dissected Edwards Plateau is an abrupt transition—this change is manifested in the economy of the two provinces. The rough limestone hill country of the Edwards Plateau is devoted to ranching while the broadly undulating prairies to the south support an agricultural economy. In the same manner, the geology of a region determines the kind of mineral deposits which occur and thus the mineral resources of the Edwards Plateau include different commodities than are found to the south in the Coastal Plain.

EDWARDS PLATEAU

South and east of a line joining San Angelo, Big Spring, and Midland there begins a plateau surface developed for the most part on a cherty limestone called the Edwards limestone. This surface slopes southeastward from an elevation of 3,000 to 4,000 feet on the west to 700 to 1,000 feet on the east. This limestone plateau is bordered on the south and east by the Balcones escarpment, a Gulf-facing escarpment which ranges from 300 feet high near Austin to 1,000 feet high in Kinney and Val Verde counties. The southeastern part of the Edwards Plateau is dissected by a number of south-draining rivers resulting in a belt of hills and valleys known as the “Hill Country.” This country is the best-watered part of the Edwards Plateau, and in many places large caves indicate the solution of limestone by ground waters acting in permeable zones of the rock.

The Balcones escarpment is the topographic expression of a long arcuate zone of faulting along which the rocks on the northwest side have been raised relative to those on the southeast side, bringing the hard cherty limestones of the Comanche sequence against the softer chalk, marls, and shales of the Gulf sequence. South and east of the Balcones escarpment is a belt of flat to rolling farmlands whose black soils nourish cotton, corn, and grain sorghums; north and west of the escarpment are cedar-covered rocky limestone hills separated by valleys that support oak and cypress along the larger streams. This ranching country is the center of the mohair industry of Texas. The Balcones escarpment is also the site of many large springs that flow from the porous limestone and help to feed rivers such as the Nueces, Frio, Medina, San Antonio, Guadalupe, and Colorado. These springs played an important part in the location of such Texas towns as San Marcos and New Braunfels.

Geologically, the Edwards Plateau is a sequence of flat-lying sedimentary rocks composed mostly of limestone but including some shale and marl. Sandstones are present at the base. Within the area of study the most prominent formations are the Georgetown, Edwards, and Glen Rose limestones and the Travis Peak formation, which are part of the Comanche series (table 1; in pocket).

That part of the Edwards Plateau that lies within the area of this study includes parts or all of Val Verde, Kinney, Uvalde, Real, and Edwards counties. Within the Comanche limestone sequence some of the units contain deposits of high-calcium limestone as well as limestone suitable for dimension stone or crushed stone. There are extensive limestone-chert gravel deposits along the rivers and locally on the ridge tops. There are small sporadic deposits of manganese, barite, and celestite; some of the caves contain limited tonnages of bat guano. Kaolin deposits of limited size occur in collapse structures in the limestone.

The Edwards limestone is a very porous formation and in the subsurface of the Coastal Plain is an important aquifer and a source of irrigation water.

GULF COASTAL PLAIN

The name Gulf Coastal Plain does not merely apply to the narrow strip of land bordering the Gulf of Mexico but also refers to a wide belt of country lying between the Gulf and the Balcones escarpment (fig. 1). Geologically, it is part of a continuous plain thousands of miles long that extends from southern Mexico to New Jersey bordering the Gulf of Mexico and the Atlantic Ocean. The Gulf Coastal Plain of Texas trends northeast-southwest and ranges from 140 to 250 miles in width, reaching its maximum width in the Rio Grande embayment; it is broad rolling country characterized by a number of cuestas with wide plains between them. The cuestas are supported by harder more resistant rocks, mainly sandstones, and the intervening valleys are developed on softer shales. Most of the rock formations and geologic structures strike parallel to the general trend of the Coastal Plain—northeast-southwest—and the physiographic features accurately reflect the geologic trends. The interior part of the Coastal Plain in Texas ranges in altitude from about 400 feet in the extreme northeast to about 1,000 feet in the extreme southwest. The eastern part of the Texas Gulf Coastal Plain receives 40 to 50 inches of rain per year while the southwestern part, within the area of this study, receives 18 to 24 inches of rain per year, or just about one-half as much. The difference in amount of precipitation is reflected not only in the type and amount of vegetation but also in the topography of the land itself. In the large view, the same rock formation extends throughout the Coastal Plain, but in the relatively well-watered northeast the land profile is soft and subdued and the hills are round, whereas in the drier southwest the face of the land is harsher and bold-edged mesas replace round hills. Thus the change in amount of rainfall is responsible for the change from piney woods to brush country. In the timbered part of the Coastal Plain, pines and post-oak follow belts of sandstone on which there are sandy soils, and mesquites follow belts of shale on which there are clay soils.

Geologically, the Coastal Plain is made up of a sequence of sedimentary rock units which dip gently south so that successively younger formations crop out Gulfward. Immediately south of the Balcones escarpment these rocks are of Late Cretaceous age and constitute the Gulf series. They are mostly impure chalky limestone, marl, and shale. Farther south younger formations of Tertiary age are exposed. These are mostly sandstone, shale, and clay but include lenticular bodies of lignite and accumulations of fragmental volcanic material in the form of volcanic ash or tuff. Farther south, bordering the present Gulf of Mexico, still younger sandstones, sands, shales, and clays of Quaternary and Recent age make up the Coastal Plain.

The sea floor along the south Texas coast is a submerged, even, gently sloping sand-covered shelf that extends seaward for several miles. The tide, waves, currents, and wind action pile the sand from this sand-covered shelf into ridges and barrier beaches that form a long narrow fringe of islands and peninsulas along the coast. These features, which do not exceed a height of about 20 feet above sea level, include Padre, Mustang, St. Joseph, and Matagorda Islands along the shore-line area of this report, and Galveston Island and Matagorda and Bolivar Peninsulas farther northeast.

The mainland shore is very irregular and indented by a series of reentrants, shallow bays, and lagoons that lie between the mainland shore and the offshore island fringe. Most of the major streams that drain the Coastal Plain discharge into these bays or lagoons, which add further irregularities to the shoreline. Dune sand covers practically all of a 4- to 7-mile wide strip of the coastal area adjacent to the coastal bays in Aransas, Calhoun, Kleberg, Nueces, and San Patricio counties. This coastal dune strip merges into a more extensive triangular-shaped sand-dune area in parts of Brooks, Hidalgo, Jim Hogg, Kenedy, and Willacy counties. Most of the surface material is fine-grained, white to gray unconsolidated dune sand that has been accumulated by the waves and drifted or transported inland by the wind. Many of the dunes near the shore are still active, but some of the sand accumulations that are farther inland, and especially those in the triangular-shaped sand-dune area, are covered with vegetation and no longer migrate. Still farther inland behind the sand dune belt are a few isolated salt marshes and many swamps.

In Uvalde and Kinney counties the Cretaceous rocks of the interior part of the Coastal Plain (and to a lesser extent the older rocks of the Edwards Plateau) have been pierced by numerous intrusions of igneous rocks that are mostly basalt and gabbro (Pl. I).

The belt of impure chalky limestone, marl, and shale that forms the interior part of the Coastal Plain is lacking in high-calcium limestones that characterize the Edwards and Georgetown limestones north of the escarpment. However, the marls and shales are suitable for blending to manufacture Portland cement, and some of the limestones are a natural cement rock. The soft chalky limestone is used for road construction. The shales are used at D'Hanis to manufacture heavy ceramic construction materials, and similar materials are present at other localities. The Anacacho limestone (a unit in the Gulf series) is the host rock for the Uvalde asphalt deposits. The heavy hard black igneous rock from Uvalde and Kinney counties is quarried, crushed, and sold for railroad ballast, aggregate, and other construction purposes. Gravel deposits occur on the high divides and in terraces along the principal drainages.

Farther south in the Coastal Plain, lignite, cannel coal, and sub-bituminous coal have been mined from Tertiary and Cretaceous rocks in Atascosa, Frio, McMullen, Webb, Zavala, and Maverick counties. Pumice and pumicite occur within the volcanic sequence from Gonzales County southward to the Rio Grande, and bentonitic clays, derived from the weathering of volcanic ash, are well developed in Gonzales County. Uranium deposits occur in sandstone in Karnes, Atascosa, and Duval counties and mineralization has been found as far south as Starr County. Salt, brines, and sulfur are found on salt dome structures in Duval, McMullen, Brooks, and Webb counties; gypsum caps a salt dome in Brooks County. Sand and gravel deposits occur along the major streams and caliche caps ridges and mesas. Oyster shell in the shallow bays along the coast is used for the manufacture of lime, cement, aggregate, and road material.

DESCRIPTION OF MINERAL MATERIALS AND DEPOSITS

BARITE

USES

Barite is ground and processed at Corpus Christi, Brownsville, Houston, and Carthage, but most of the raw material is received from other states or imported from foreign countries and only occasionally are small shipments of Texas barite used. Although barite is an essential mineral used in the processing of some glass, paint, rubber, and various chemicals, the principal use in Texas is in the preparation of drilling muds for the oil and gas industry. Small marginal to sub-marginal deposits of barite occur within the area of this report and a description of each known deposit follows.

OCCURRENCE IN SOUTHWEST TEXAS

KINNEY COUNTY.—Barite occurs in Gulf shales (Austin?) about 2 miles east and slightly north of Spofford. The locality is at the south end of an earthen tank dam about 700 feet north of a high line in the Wolf Hill pasture of the Louis Hobbs ranch. Crystalline masses of barite up to 10 inches in diameter and veinlets filling cracks in the shale up to 5 inches wide are weathered from the shale in the outcrop area. Bedrock exposures are poor and the extent of the barite-bearing shale is not known because of a cover of alluvial debris. Evans (1945, p. 109) concluded that the barite is too sparsely distributed to be produced profitably.

At the present time there is probably not more than several truckloads of barite available at the Spofford locality. However, possible additional concentrations of barite may occur beneath the alluvial cover over a wider area. Additional prospecting is necessary to determine the extent of the barite-bearing shale.

LIVE OAK COUNTY.—Small nodules and irregular crystalline masses of barite are found in the Tertiary bentonitic clays exposed along Sulphur Creek about 1 mile north of the Three Rivers–Karnes City road and at a locality a few hundred yards above the junction of Best Branch with Sulphur Creek. There appears to be only a small quantity of barite in the clay; it is most easily found where it has formed a local concentration on the weathered surface of the clay slopes. The deposit appears to be small and probably has no economic importance.

VAL VERDE COUNTY.—Barite occurs in a massive cherty limestone on the Mills ranch about 1.35 miles by road southwest of Pandale (Pl. II, Loc. 2–7[1] and fig. 6). The deposit was first described by Barnes (1939, p. 3) and later by Evans (1945, pp. 109–110), who studied the area following a brief period of mining during which about 100 tons of barite was produced. Evans (1945, p. 110) described one relatively large pit from which a barite body 1 to 5 feet wide and 35 feet long had been mined. Barite was also encountered in a small test hole 60 feet north of the large pit and in a small excavation near the bottom of the arroyo 100 feet south of the large pit. Analysis of a sample from locality 2 (Min. Tech. Lab. No. 60152) showed a barium sulfate ($BaSO_4$) content of 97.60 percent.

The limestone beds in the vicinity of the barite deposit dip in different directions at angles up to 10 degrees, whereas the beds exposed in the surrounding area are essentially horizontal. This suggests slump of the surface layers into a collapsed cavern approximately 100 to 150 feet across. All surface barite exposures examined are small fissure and cavity fillings in limestone and occur within an area a few hundred feet in diameter. The principal barite mass, which is mostly crystalline and clear, appears to have filled a surface fissure that extended downward at a rather

[1] Localities are shown by numbers on Plates I-V; each county numbering begins with 1.

steep angle into the collapsed cavern. Below the ground surface the ore body flattens and spreads laterally within the cavern. The barite exposed in the small test hole 60 feet north of the large pit is also the clear crystalline variety similar to that exposed in the large excavation, suggesting that the ore body may be continuous between the two openings. The barite exposed in the small pit near the bottom of the arroyo 100 feet south of the large pit, is granular and appears to have replaced the limestone beds along the margin of the collapse structure.

Mr. Mills reported (oral communication, June 13, 1960) that there has not been any barite mined at this locality since Evans' (1945) report was published. Mr. Mills also stated (oral communication, June 13, 1960) that the area was core drilled, probably in 1952, but the results of that exploration are not available. The ore body is probably small but the collapse area is worthy of further exploration to determine the thickness and lateral extent of the barite. Also worthy of further exploration is the granular barite exposed at the southernmost pit. There may be a sizable volume of low-grade replacement ore at this locality.

Another exposure of barite on the Mills ranch occurs along the base of the south wall of Howard Draw about 300 to 850 feet north of the first Pandale-Langtry road crossing (Pl. II, Loc. 6, and fig. 6). The barite partly replaces two or more beds of massive limestone and is white and fine-grained similar to the host rock. Small lenses and veins of crystalline barite are present. The crystalline masses most frequently occur adjacent to honeycombed solution cavities in the limestone, which are in part filled with brown residual clay, and thin stringers or veins of the crystalline barite commonly extend laterally along the bedding planes or occur in joints.

Evans (1945, p. 110) reported that an effort to develop the deposit at this locality resulted in the production of about 100 tons of crude barite. Evans concluded that the deposit probably contained a large tonnage of low-grade ore but stated that the operation was abandoned because of high costs for concentrating a marketable product and for transportation. During the current investigation Mr. Mills reported (oral communication, June 1960) that about 120 tons of barite was shipped from this locality in 1952. The barite was sold to the Milwhite Company, Inc., in Houston, Texas.

So far as known, the Howard Draw deposit has not been systematically explored in order to determine the extent of the mineralization. The host rock is relatively porous, and both bedding planes and joints permit easy movement of ground water. Most of the mineralization appears to be the result of limestone replacement and there may be larger deposits that have not been exposed.

There is considerable uncertainty as to the total tonnage of available barite at the two localities on the Mills ranch. It is important that the quantity and grade of ore be determined in order to evaluate the potential of the deposit. In the case of a high-grade ore requiring no beneficiation in order to meet market requirements and capable of being cheaply mined, a comparatively small deposit may be profitably worked; a much larger quantity of low-grade ore must be available in order to justify the cost of installation of milling equipment to upgrade the ore to meet market specifications. Transportation costs also have an important bearing on the success of an operation. It is approximately 30 miles over a graded gravel road to the Southern Pacific Railroad siding at Langtry and an equal distance to U. S. Highway 90. Normally the value of a mineral deposit decreases with increase in distance from the mine to the point of consumption, and transportation costs may nullify the value of a mineral deposit that meets all other economic requirements.

TERRELL COUNTY. — Terrell County is not included in the area of this investigation, but a small barite deposit has been located near Hackberry Creek on the Andy White ranch, about 1 mile west of the Terrell–Val Verde County line (Pl. II, Loc. 4a-b, and fig. 6); because of the proximity to the Pandale area, a brief description of the deposit is included. The barite is celestine blue and does not appear to be a replacement deposit. The barite is exposed in two pits, about 150 feet apart, located on a hill, and as there are no barite outcrops in the cliffs at either side, the deposit is assumed to be a cave or sinkhole filling. There are several small debris-filled caverns or sinks adjacent to the outcrop. Systematic exploration will be necessary before a valid estimate of the available tonnage can be determined. Samples tested at the Mineral Technology Laboratory (Nos. 60154 and 60155) showed a barium sulfate ($BaSO_4$) content of 93.80 and 90.50 percent, respectively. Another barite deposit has been reported from a locality about 2 miles north of the Andy White ranch.

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BUILDING MATERIALS

DEFINITIONS, VARIETIES, AND PROPERTIES

Building materials as used in this report include dimension stone, crushed stone, riprap, gravel, sand, and "caliche." Dimension stone is the term applied to solid stone sold in blocks or slabs of specific shapes and sizes as contrasted with crushed or broken stone. Cut stone, rough building stone, paving blocks, curbing, and flagstone are among the common types of dimension stone.

At one time elaborate physical tests were required to determine the suitability of a rock for dimension stone. These are now largely disregarded because most stone is used as a facing rather than structurally so that any sound stone, suitable in other respects, is stronger than is required for any ordinary present use. Generally, durability under weathering is of prime importance, and tests are available to give an index of the expected behavior of the stone. There are a few special specifications for some uses, such as sanitary floors and in laboratories.

Architects and builders exercise great freedom in the selection of a stone for a specific structure, and the specifications are frequently in terms of workmanship and surface finish rather than color, texture, or general appearance. Once established in the trade, a stone is difficult to replace even by one of equal quality and lower cost. In most buildings the cost of the stone is only a small part of the total cost, and many contractors are willing to pay a higher price for a stone that is currently popular. The Bedford stone of Indiana is an example. Trade names are commonly applied to the products from individual quarries; Cordova Cream and Cordova Shell are such names applied to products from Cretaceous limestone quarries in central Texas.

The most common uses for crushed stone are as base material in highways, as a concrete aggregate, as railroad ballast, and to make filter beds. The basic physical properties of the crushed stone that affect its behavior when used for various structural purposes are hardness, toughness, and the properties that control the resistance of the rock to the disrupting action of weathering agents. Specifications and tests for the various uses have been established. The stone must meet these specifications and also must lend itself to economical production and preparation for the market. Crushed stone used for the purposes mentioned above is a low-unit value product and generally is marketed locally. In 1959 the stone sold or used by producers in Texas comprised slightly more than 31,500,000 short tons valued at approximately $31,250,000, or slightly less than $1.00 per short ton.

Because crushed stone is a low-value aggregate which is normally produced locally, the aggregate material should be carefully tested before using, because some aggregates chemically react with certain constituents in Portland cement to lessen the optimum strength in large concrete structures. These constituents are the alkalies, sodium and potassium, which normally comprise about 0.4 to 1.3 percent of Portland cement. Although these elements occur in small amounts, they normally are present in sufficient amounts to cause a very undesirable condition in large concrete structures when used with the wrong type of aggregate. The specific rock types which are found to be most reactive to the alkalies in Portland cement are those which contain amorphous (opaline) silica and volcanic glass. Amorphous silica may occur in limestone, shale, chert, and chalcedony fragments. The glass occurs only in rocks of volcanic origin.

Rexford (1950, p. 397) reported that in most cases, small amounts of from 1 to 5 percent of the reactive ingredients will cause more serious results than larger amounts. He cited as examples the Sixth Street bridge over the Los Angeles River in Los Angeles, California, where a small amount of opal-bearing shale caused serious cracking and "pop-outs," and several dams in Arizona, which were similarly affected because of the presence of volcanic glass particles.

Workable exposures of rock that can be quarried at low cost close to centers of use are becoming increasingly rare. This is especially true in much of the outer Coastal Plain area where most of the rock materials are poorly consolidated. Of the 31½ million short tons of crushed and dimension stone produced in Texas during 1959 only a small part came from the area of this investigation. Large volumes of stone suitable for processing and utilization in the crushed stone industry are available in the northwestern part of the area but they have not been developed to any great extent. Transportation makes up such a great part of the delivery cost for crushed stone that quarries must be located as close as possible to the market. With transportation costs increasing, a substantial freight cost can well mean economic failure for any quarry site. Prospecting for suitable solid rock commonly involves: (1) sinking test pits and/or drilling to determine the nature and extent of the deposit and the thickness of overburden and (2) testing to determine if the rock will meet market specifications.

Granules and terrazzo chips are special types of crushed stone that command higher prices than crushed stone used in common construction uses. Granules are used to form a protective or decorative coating on the weather surface of composition roofing or siding and in built-up roofing. Resistance to weathering and stability of color are more important than strength or toughness, so that the specifications are different than those for crushed stone used in construction. The material should be sufficiently tough, however, to withstand handling by mechanical equipment and should be uniform in physical and chemical composition so that large quantities of granules with consistent color and size can be produced.

Color of the finished product is of special importance because shingles, roofing, and other materials using granules are sold on the basis of color appeal. A color once established in the trade must be maintained with only slight variations, so that the product furnished at one time will exhibit only slight color difference from that produced at another. Green, red, black, blue, and buff are among the colors in common use for most products.

Terrazzo chips are used to produce pleasing color patterns in the familiar terrazzo floors much used in recent years. The chips are embedded in a specially colored or uncolored cement surface, ground to a smooth surface, and polished. The great popularity of this material is attributed to the attractive appearance of the surface, ease of cleaning, and durability. The material is neither stronger nor more durable than ordinary concrete aggregate made from the same materials. In recent years terrazzo has been used as exterior decorative stone, for roller-skating floors, and in floors for outdoor cafes and bowling alleys; probably these uses will increase.

Terrazzo aggregates for use in floors must meet specifications for abrasive hardness, bulk specific gravity, water absorption, and toughness. These are somewhat less restricted than those for certain other types of concrete aggregate used in construction, but it is obvious that the material, in many uses, is subject to continuous abrasion and other external forces. Many kinds of materials are used for terrazzo chips, but compact noncleavable materials are desirable. In the area of this study, the most desirable raw materials occur in the massive Cretaceous limestones of the western part of the Edwards Plateau and in the intrusive igneous rocks in Uvalde and Kinney counties.

Sand and gravel are the loose unconsolidated materials that appear on the earth's surface as a result of natural disintegration of rock. Both normally appear together but in a wide variety of sizes, types, and degree of consolidation. Sand

and gravel have a multiplicity of uses, most common of which are as aggregate in concrete, mortar, plaster, and asphalt-paving materials. Together they constitute the largest volume of mineral raw materials produced from the earth. In Texas approximately 35¼, million short tons valued at approximately 34¾ million dollars were sold or used by producers in 1959.

Because sand and gravel are low-value commodities, but are used in nearly all construction projects, they are produced in almost every county in the United States. Many operations, particularly those established to supply the needs of major dams that are under construction or of a major segment of new highway, are temporary in nature, and the equipment installed is more or less portable. Some producers have developed a steady market and operate for years from the same locality, but whether it be a permanent or temporary installation, sand and gravel used for construction purposes is normally not transported for great distances.

Local conditions, the size, and permanency of the operation are generally the controlling factors in the selection and use of equipment. Commonly, the sand is excavated, dumped into trucks or directly into a hopper, and fed to a conveyer for movement to the screening-washing plant. The oversize material may or may not be crushed. When the sand and gravel is cleaned and screened, it is stockpiled ready for market.

Caliche is a term that has different meanings in various parts of the Western Hemisphere. In Mexico and southwestern United States, caliche is technically calcium carbonate gravel containing some sand or sand and gravel. However, in the building and construction industries the term caliche refers to any light-colored, rather soft, partly decomposed rock with sufficient calcium carbonate so that when crushed and wetted the fragments will rebond to make a stable base for road construction. There are millions of tons of caliche in south Texas. The variety of rock materials grouped under the term caliche have been extremely important in the development of the highway system in this region.

OCCURRENCE AND DISTRIBUTION

Edwards Plateau

Comanche limestones

Massive Comanche limestone formations crop out over extensive areas in Edwards, Kinney, Real, Uvalde, and Val Verde counties. Many of the limestone beds are hard, dense, of uniform grain size, color, and thickness, and are suitable for production of dimension stone, rough building stone, riprap, and crushed stone. The limestone beds are generally flat-lying and crop out in steep-walled canyons, gentle plateau slopes, and flat-topped hills. The Edwards and Georgetown units contain high-calcium limestones, and almost all the Comanche limestone units, when blended with the adjacent Gulf shale formations, are suitable for the manufacture of cement. The limestone layers of the Glen Rose, and to a lesser extent the Edwards and Georgetown units, are interbedded with zones of marl or calcareous shale which are used as caliche for road construction projects.

The Edwards Plateau region is a sparsely settled ranch country with the larger towns located along the southern border of the plateau or along stream valleys north of the area of this report. Comparatively few highways traverse the plateau and some of the best limestone localities are several miles from a highway or a few score miles from a railroad. The distance to market is no doubt the principal reason why there has been so little development of the limestone resources. Most stone products are both bulky and heavy and normally are not transported great distances; to date only relatively small amounts of crushed stone and caliche have been produced for local use as concrete aggregate, railroad ballast, and for road construction needs. The limestone resources are virtually unlimited; were they located near large population centers, there is little doubt that stone product industries would have been developed.

Belt Adjacent to Edwards Plateau on Southeast

Gulf limestones

The Eagle Ford and Austin units of the Gulf series crop out in a more or less continuous band from east-central Uvalde County, westward across Kinney County, extending northwestward intermittently across Val Verde County. The Anacacho limestone crops out south of the Austin belt in southern Uvalde and southeastern Kinney counties. The Eagle Ford is predominantly an impure, argillaceous, flaggy limestone; it is from the Eagle Ford that the flagstone in Val Verde County is produced. The Austin is a white or gray-white, friable, chalky limestone, in general more massive than the Eagle Ford but at some localities it is flaggy. The Austin is very low in magnesium carbonate but carries 5 to 15 percent silica dioxide, 2 to 8 percent alumina, and in most outcrops about 70 to 90 percent calcium carbonate. This qualifies the Austin as a potential source of natural cement rock, especially Type II (*see* p. 31) which has moderately low heat and sulfate-resisting values. The Anacacho limestone contains the Uvalde rock asphalt deposits, but where asphalt is absent the rock is generally a cream or buff, porous, coarse- to fine-grained coquina. The porosity and the amount of consolidated shell debris vary between localities, but some beds with reasonably uniform physical characteristics are suitable as a source for cut stone and rough building stone. The rock asphalt and flagstone industries, which are described in detail (pp. 17–21), represent the only attempts to utilize the Gulf limestones in the area of this report. Road materials have been obtained from numerous caliche pits in both the Eagle Ford and Austin units and to some extent from the Anacacho limestone.

ASPHALT ROCK.—Asphaltic Anacacho limestone crops out intermittently along a belt about 60 miles long that extends from near the Bexar County line westward across southern Uvalde County to near Spofford in Kinney County. The better known asphalt deposits are about 13 to 20 miles southwest of Uvalde in southwestern Uvalde County and southeastern Kinney County. The asphaltic limestone is quarried, crushed, screened, and used primarily for surfacing highways, city streets, parking areas, sidewalks, and similar areas where an all-weather pavement is desired. The area is served by both the Southern Pacific and the Missouri Pacific Asphalt Belt railroads and by all-weather highways leading east, west, north, and south from Uvalde.

The Anacacho limestone is a porous limestone composed mainly of broken shell fragments (a coquina), and in some areas the pores contain an asphalt residue. The asphalt is irregularly distributed throughout the formation, its occurrence being controlled by the size and distribution of the pores. Many of the surface rocks show little or no asphalt, while others contain only irregular bands and stringers. In some of the larger accumulations there is considerable variation in the thickness and lateral extent of asphalt saturation.

The rock asphalt deposits in Uvalde and southeastern Kinney counties have been studied by many geologists, and several reports regarding the geology of the area, distribution and origin of the asphalt, quarrying methods, reserves, grade of material, history of production, and uses of the asphalt have been published (Vaughan, 1897; Getzendaner, 1931; Baker, 1935; Gorman and Robeck, 1945; and Hazzard, 1956).

Operations in the Uvalde rock asphalt district began in 1891, when H. L. Terrell opened the No. 1 Original quarry at Carbonville (now Blewett). In 1893, the Litho Carbon Company acquired from Terrell rights to operate the quarry and market the asphalt (excepting paving material). The rock was quarried and crushed and the asphalt extracted in a battery of cast-iron retorts and condensers; the product was marketed under the trade name "litho-carbon" and was sold to paint and varnish manufacturers. In 1896, asphalt from the Island of Trinidad was offered for sale at prices with which the Uvalde product could not compete. The Litho Carbon Company went into receivership and the property was sold to R. T. Rockeby. In 1897, the Rockeby assets were sold to the Uvalde Asphalt Company; for a time the Uvalde Asphalt was shipped to New York City where it was used for paving.

About 1900, the Parker Washington Company opened a quarry and used the crushed asphaltic limestone for paving streets in San Antonio. This was the first use of the crushed asphaltic rock for paving purposes—all former operators had extracted the asphalt from the host rock and added the waxy residue to other materials. The quarry was again closed about 1901 and there was no important activity until 1912.

In 1910, J. B. Smith acquired the lands formerly owned by the Litho Carbon Company; he organized the Uvalde Rock Asphalt Company which in 1912 began marketing crushed asphaltic limestone from the No. 1 Original quarry for highway and city street paving. The venture was a success from the beginning and the company subsequently opened and operated No. 1 South, No. 1 East, No. 1 Turkey Creek, No. 1 Gato, and No. 1 South Gato quarries. The present quarry is the No. 1 Gato, which was opened in 1927; all other quarries are idle.

About 1922 the Texas Rock Asphalt Company opened the No. 2 Original quarry at Dabney, about 3½ miles (by road) west of the present Uvalde Rock Asphalt Company's quarry. They operated the No. 2 Original in conjunction with the No. 2 East quarry until 1941. In 1922, B. Y. Sharpe opened the No. 3 Sharpe quarry which was operated for about one year. In 1923 White's Uvalde Mines opened No. 4 White's Turkey Creek quarry and later No. 4 White's North quarry and White's Uvalde Mines. They have been at their present location at Dabney since 1948.

The Standard Rock Asphalt Company opened their No. 5 quarry in 1931 and operated until 1933; Brown and Root opened and worked three quarries from 1931 to 1932. At present only the Uvalde Rock Asphalt Company and White's Uvalde Mines are producing crushed rock asphalt for paving (Pl. I).

The rock asphalt deposits in the Uvalde district are for the most part covered by 20 to 30 feet of shaly limestone, shale, and alluvial debris. This overburden is stripped off and asphaltic limestone is quarried by the bench method. The degree of asphalt impregnation ranges from about 5½ to 9 percent. Some layers and lenticular masses contain little or no asphalt, and by selective quarrying, blending, and crushing, operators can furnish a product to meet specifications ranging from 2 to 12 percent asphalt.

The thickness of rock asphalt exposed in the quarry walls of the Uvalde district ranges from 10 feet in some of the older pits to about 75 feet in the present quarries. In the deepest excavations the base of the asphalt accumulation is not exposed. It has been reported that some of the known accessible deposits are as much as 150 feet thick, and asphalt beds 200 feet thick have been reported from wells. The area adjacent to both quarries has been systematically drilled, but the results of those surveys are not available for publication. There seems no reason to doubt but that either company can continue to mine at their present rate of operation for at least another 20 years. Gorman and Robeck (1945) estimated 200,000,000 cubic yards of minable reserves; 105,000,000 cubic yards are indicated by geologic evidence and 95,000,000 yards were inferred. The Uvalde Rock Asphalt Company and White's Uvalde Mines have joint ownership of the rock asphalt on the 30,000-acre White ranch.

The total annual production from the Uvalde district is valued at approximately 1 to 1½ million dollars. About 50 to 65 percent of the rock asphalt is used by state highway paving contractors and the remainder goes for paving city streets, parking areas, private drives, sidewalks, tennis courts, and small airport runways; some is bagged and sold for home patching and other purposes.

The Anacacho limestone also crops out in a belt east of Uvalde and is asphaltic in the vicinity of Sabinal. Although the presence of asphalt in the Sabinal area has been known for 30 or more years, none of the deposits has been thoroughly investigated. An area that has promise and should be more thoroughly investigated is on the Jessie Howard ranch, immediately north of the old highway about 3 miles east of Sabinal and about one-fourth to one-half mile north of the Southern Pacific tracks (Pl. I). Small lenses and stringers of asphaltic deposits in the Anacacho limestone are exposed along Ranchero Creek. A sample of rock asphalt collected from a block of limestone reported to have been taken from a pit about 4 feet below the bed of Ranchero Creek on the Howard ranch was tested by the Bureau of Economic Geology and showed an asphalt content of 9.1 percent (Min. Tech. Lab. No. 60080). At the time the pit was visited for this present investigation, it was filled with water and could not be examined.

Mrs. Jessie Howard reported (oral communication, June 1960) that in 1958 asphaltic limestone was encountered in five core holes over a 45-acre tract. The asphaltic zone averaged about 20 feet thick in four of the holes; one hole bottomed in asphaltic limestone at 45 feet. The top of the asphaltic rock is from 9 to 35 feet below the surface. The cores had been removed from the Howard ranch and were not available for study or testing. The following analysis, made by the Albuquerque Testing Laboratory, Albuquerque, New Mexico, was supplied by Mrs. Howard:

	Percent
Moisture and volatiles by AASHO method, T-110-42	0.3
Moisture and volatile content after oven drying	0.9
Bitumens by weight of rock asphalt	7.42
Specific gravity of aggregate	2.58

The Jessie Howard deposit is within half a mile or less of the Southern Pacific Railroad tracks and within a quarter of a mile of a paved road to Sabinal. A power line extends across the 45-acre tract. As projected from the drill-hole data, the asphalt beds should come to the surface within half a mile or less northwest of the northwesternmost core hole, but the area between drainage channels is covered with alluvium and no outcrop was found.

The Robert Habermacker property joins the Jessie Howard ranch on the southeast. Asphaltic rock was encountered at a depth of 40 feet in a well about 1 mile east of the Jessie Howard residence (Pl. I). Asphaltic rock was also encountered at about 40 feet in a well at the Wagon Wheel Cafe in Sabinal. Mr. August Smith, Manager of the Central Power and Light Company office in Sabinal, reported (oral communication, June 9, 1960) that most wells in the vicinity of Sabinal encounter asphaltic rock at depths of less than 50 feet. Small bodies of asphaltic limestone and some float blocks of asphaltic sandstone occur along Blanco Creek (River), on the Woodley Estate south of U. S. Highway 90, and rock asphalt crops out on the Bud Henry ranch north of Sabinal (Pl. I).

The Sabinal area has not been thoroughly investigated and the potential of the deposits is not known. The area of known asphaltic rock is about 10 to 12 square miles.

Vaughan (1897, pp. 932–934) described asphalt-impregnated sandstone at several localities along the Nueces River in the vicinity of the Uvalde-Zavala County line. The asphalt is in the Escondido formation overlying the Anacacho limestone which contains the asphalt in the Uvalde and Sabinal areas. The most accessible outcrop is at Black Wax Falls (Waxy or Asphalt Fall of Vaughan) about 10 miles southwest of Uvalde at a point where the Missouri Pacific railway crosses the Nueces River (Pl. II). The piers for the railroad bridge are set in the asphaltic zone, which is a fine- to medium-grained sandstone that weathers gray. The highest asphaltic concentration is in a sandstone 5 feet thick at the base of the falls. The basal bed is overlain by 10 feet of sandstone that is less highly impregnated. Tests made by the Bureau of Economic Geology (Min. Tech.

Lab. No. 60081) from samples collected at this locality show an asphaltic content up to 14.2 percent.

At Black Wax Falls the Escondido formation is exposed along the crest of the Pulliam anticline. Several small faults have broken the limb of the fold; the asphaltic sandstone unit has been repeated and is intermittently exposed along the Nueces River for at least 3 miles above the falls. Most of the outcrops are partly covered either by slump along the banks of the river or by alluvium in the uplands away from the river channel. Without doubt the best exposure of asphalt is at Black Wax Falls where the asphaltic rock ledges are swept clean by the water currents. A very small exposure of unknown extent was seen low in the river bank about a quarter of a mile below the railroad bridge.

The total lateral extent of the asphaltic sandstone unit of the Escondido formation is not known, but geologic data indicate that asphalt is present at shallow depths over an area 10 or more miles square. Mr. George Horner, who lives about half a mile below Black Wax Falls, reported (oral communication, June 6, 1960) that many years ago several attempts to drill wells up to 1 mile or more west of Black Wax Falls failed because the light churn drill equipment could not penetrate the waxy asphalt. He also reported that at a locality about 2 miles north of the falls a well penetrated 300 feet of rock with a low asphalt content. Mr. Price Dodgen, co-owner of the D and D Gravel Company, reported (oral communication, June 9, 1960) that a well on the Lyles ranch, half a mile south-southwest of the falls, penetrated asphalt at a depth of 80 feet, and that to the best of his knowledge wells drilled on the higher ground away from the Nueces River encountered asphalt at depths of 75 to 80 feet. At the outcrops seen along the Nueces, the overburden does not exceed 35 to 40 feet.

So far as known, no attempts have been made to use the sandstone rock asphalt at this locality. It is difficult to determine the size of the area of asphaltic rock because wide areas along the Nueces River are covered by alluvium, and the only good exposure is at Black Wax Falls; it appears to cover several square miles. The thickness of overburden ranges from 5 to 10 feet near the river to about 80 feet 1 mile or so away. The material in the river bed near the falls and for a short distance upstream could be worked easily as there is relatively little overburden.

The State Highway Department's laboratories have not tested the Nueces River asphaltic sandstone for road-surfacing material. It is the general opinion, however, that asphaltic sandstone has low stability and is not comparable in quality to asphaltic limestone, of which there are enormous reserves within the State. The chief reasons for the low stability are (1) inadequate bond between the asphalt and the small rounded sand grains which permits the paved surface to disintegrate relatively rapidly and (2) high ratio of asphalt to sand causes softness and excessive "bleeding" in hot weather.

The Oklahoma State Highway Department has had fair success by blending asphaltic sandstone with crushed limestone. The Black Wax Falls area is favorably situated for that type of operation. There are many thousand cubic yards of gravel in the beds of the Nueces River and along the river banks. The gravel was derived chiefly from the Comanche limestones of the Edwards Plateau and includes about 10 percent chert. The D and D Gravel Company operation is located within half a mile of Black Wax Falls. They have enormous gravel reserves and have been able to supply their market by screening to meet size specifications without crushing. Should that company desire to expand the number and types of their marketable products, their present operation is so situated that the gravel can be stripped, either screened or crushed, and blended with the asphaltic sandstone which (at least locally) directly underlies the gravel deposit.

Another possible use for the asphaltic

sandstone in the vicinity of the Nueces River is the production of tar for the chemical industry. No tests have been made to determine the amount of asphaltic tar that can be distilled from the sandstone, but tests in the Bureau of Economic Geology laboratory show that the asphaltic content ranges up to 14.2 percent asphalt. The sand may be marketable because there is very little clean sand along that part of the Nueces River.

Transportation and utility facilities are excellent. The Missouri Pacific right-of-way passes over the asphalt outcrop at Black Wax Falls. It is about 12 airline miles to the main line of the Southern Pacific, and the area is within half a mile of a paved road to Uvalde. A low voltage R.E.A. power line and a telephone line pass over the area, and it is less than 2 miles to the Central Power and Light Company's high voltage line. An old lignite mine (now abandoned), which was at one time operated for locomotive fuel and is reported to have 10 feet of lignite at a depth of 35 feet, is within 1 mile of the outcrop; and two beds of lignite, 20 inches and 32 inches thick, crop out along the Nueces River about 2 miles below the Black Wax Falls (*see* Section III, p. 88, and table 30, Nos. 60085 and 60086, respectively).

FLAGSTONE.—Flagstone, known geologically as the Boquillas flags, crops out over thousands of acres near Comstock and Langtry in southwestern Val Verde County and also across the county line in southeastern Terrell County. The flagstone is an impure, bedded argillaceous limestone that generally occurs in layers from ½ inch up to 3 to 4 inches thick and is commonly interbedded with layers of finely crystalline limestone up to 8 inches thick. Much of the flagstone is a buff or dull cream color, but locally, and especially in the basal part of the formation, the layers are intricately mottled with colorful bands and streaks of reddish brown and yellow. Generally, the flagstone slabs are about 2 to 3 inches thick and most of these can be split into sheets 1 to 1½ inches thick.

The flagstone has been locally quarried **on several ranches in the Langtry area, but** the most active quarrying operation at present is on the Schnaubert ranch about 10 miles northwest of Langtry (Pl. II, Loc. FS 5). The principal market is to truckers who buy loads of flagstone on contract or for door-to-door sales. The flags are marketed in east Texas, in cities along the Gulf coast, and as far north as Midland. The average production is 5 to 6 squares per week. Principal use is for walks, terraces, and patio floors. Some of the thicker limestone beds have been sold for dimension stone and riprap. The industry is small and the flagstone reserves are enormous.

BASALT.—Along the southern border of the Edwards Plateau 80 or more igneous rock masses have intruded Cretaceous rocks (Pl. I). Most of the intrusions form brownish-black hills that rise above the surrounding surface but others have little or no topographic expression. Most of the rock is basaltic. When fresh the basalt is generally black, fine grained, and hard; when crushed it produces a high-quality stone. However, because of its hardness it is expensive to crush. For many years the Southwest Stone Company has produced crushed stone from a basalt mass near Knippa (Pl. I). Their products are sold for railroad ballast, concrete aggregate, road stone, and riprap. Although many basaltic masses close to both truck and rail transportation facilities are available in this area, only one company is utilizing the material.

Basalt, frequently called trap rock, is a fine-grained, hard, dark, basic igneous rock. Basaltic rock occurs as shallow intrusive masses that moved upward along fractures but cooled beneath the earth's surface and were uncovered by later erosion, and as lava that was poured out and cooled on the earth's surface. The basalts in the area of this investigation are intrusions that occur in isolated masses along a narrow belt that extends from Travis County at the northeast, southwestward to Kinney County, a distance of more than 200 miles. The intrusions are not evenly distributed along the belt, and in some large areas, such as Bexar County, none have been mapped. In Medina and Bandera counties only three or four intrusions have been mapped; in Uvalde County, and to a lesser extent Kinney County, there are a large number of basaltic intrusions. Lonsdale (1927) mapped, studied, and described the igneous rocks of the Balcones fault zone in great detail.

The Southwest Stone Company operates a large basalt (trap rock) quarry on the north side of Chatfield Hill, just off the main line of the Southern Pacific Railroad at Knippa, Texas. The basalt occurs in a plug-like intrusion that forms a conical hill about one-fourth mile in diameter. The sedimentary layers which were intruded by the basalt are exposed only on the north side of the hill; elsewhere the intrusion is flanked by alluvium. The quarry face is 700 to 800 feet long and up to 115 feet high. A deep pit previously excavated in the northern side of the quarry is now filled with water. There are many thousand tons of basalt still in the quarry, and the Southwest Stone Company also owns the two basalt masses immediately north of the Southern Pacific tracks. In addition there are a score or more of basaltic bodies readily accessible by either rail or truck. The undeveloped basalt resources in the Uvalde-Kinney County area are enormous.

The Southwest Stone Company produced 65,000 tons of crushed basalt in 1959, which is approximately the average annual production during the past five years. Although expensive to crush, the basalt is hard, tough, very resistant to wear and is especially suited to certain construction uses. When crushed the basalt blocks are angular, do not roll, and rank high among the best of all materials for railroad ballast and for riprap. Its resistance to wear makes it an excellent material for road surfacing, and it makes a superior concrete aggregate, particularly when a heavy, dense concrete is desired.

Some basalts (trap rock) have been utilized for dimension stone, including monument stone, but so far as known the Uvalde-Kinney County stone has not been used for monument stone. Much of it would not be satisfactory because of joints and flaws. Locally, the basalt has been used as building stone for residences and other small structures, but the total amount used for building purposes is negligible.

The following analysis of the Knippa stone is taken from Nash (1918, p. 129).

	Percent
Specific gravity	3.15
Weight per cubic foot	196
Water absorption, lbs. per sq. ft.	0.39
Percent of wear	1.8
French coef. of wear	22.2
Hardness	17.5
Toughness	15
Cementing value	Good

Gulf Coastal Plain

Tertiary to Recent formations, including stream, beach, and bay deposits

The Tertiary to Recent formations of the Gulf Coastal Plain are predominantly clay and poorly consolidated soft sandstone; indurated sandstone occurs in some areas. Loose sand, caliche, and gravel are found on the divides along some streams, in terraces, and in stream channels. Massive hard stone that can be used for heavy riprap, dimension stone, or crushed stone is relatively rare. The northern tier of Coastal Plain counties have larger resources of the better consolidated materials than do the counties adjacent to the Gulf. Most outcrops of indurated and silicified sandstone, coarse gravel, and mixtures of sand, gravel, clay, and lime (caliche) have not been tested, but observation suggests that they may be used for some construction needs. Localities are shown on the accompanying maps (Pls. I, II, III), and the commodities are discussed by the county in which they occur.

ARANSAS COUNTY. — Naturally occurring building materials in Aransas County are limited. Oyster shell dredged from Aransas and Copano bays has been ground and used as aggregate and road stone, but there has been but little activity in Aransas County during the past year. Most of the shell used came from San Antonio Bay.

A bed of hard, resistant, coquina limestone, encountered during dredging operations by the L. W. Richardson Construction Company, occurs offshore in Redfish Bay (Pl. II, Loc. LS-1). The bed is reported to be about 6 inches to 6 feet thick (average 2 feet); it is overlain by 4 to 5 feet of sand and 1 to 2 feet of water.

Sand mixed with fine silt and mud is present in the bed of the Aransas River. To be used commercially, this material requires screening and/or washing to remove the silt and mud.

ATASCOSA COUNTY. — Atascosa County lies within the margin of an area characterized by sandstone formations, but most of the rock is poorly consolidated and not suitable for construction purposes. The principal exceptions occur in the eastern part of the county, east and northeast of Campbellton. Here some sandstone layers are sufficiently indurated to be suitable for production of crushed stone and riprap (Pl. II). Nash (1918, pp. 18–19) reported (1) a white porous limestone on hills adjacent to the San Antonio, Uvalde, and Gulf Railroad between Lenz and Campbellton; (2) a gray flaggy sandstone, 1 to 10 feet thick, extending for about 10 miles southeast from the junction of the old Falls City-Campbellton and Oakville-San Antonio roads; (3) a sandstone 40 feet thick southeast of Campbellton; (4) sandstone beds 12 to 15 feet thick along Atascosa Creek south of the old Whitsett ranchhouse; and (5) a sandstone conglomerate 2 miles northwest of Pleasanton.

Loose or slightly consolidated iron-stained sand deposits are widespread in the northern part of the county. Locally, these sands are free from iron stains or other impurities and are excellent construction sands. The Espey Silica Sand Company (Pl. II, Loc. 4) and West-Land Sand Company (Pl. II, Loc. 2) produce sand and gravel for construction purposes. In addition to production of common sand, shipments of blasting, hydraulic-fracturing, foundry, filter, and glass sand have been reported. Undetermined quantities of sand are present in bars along the Atascosa River.

BEE COUNTY.—Gray-white limestone crops out near the town of Mineral and also between Beeville and Orangedale community in central Bee County (Pl. II). This material has been crushed and used for concrete aggregate and as road stone. On the Rabe farm 1½ miles east of Tuleta (Pl. II, Loc. 1) a conglomeratic sandstone crops out in the bottom of a caliche pit. The material contains well-rounded limestone pebbles cemented with silica, is very hard, and is reported to be 60 feet thick in a nearby well. This material is suitable for riprap or aggregate. Hard sandstone crops out northeast of Beeville (Pl. II, Loc. 6) and is probably the same material as described above. A 5-acre tract at this locality is dotted with pits where the sandstone conglomerate was quarried and processed for riprap and aggregate. Calcareous sandstone is exposed along U. S. Highway 181 about 8.5 miles southeast of Skidmore (Pl. II, Loc. 4). Limestone conglomerate crops out in the hills along Farm Road 673 for a few miles northwest of Beeville, and a thin flint gravel caps some hills and ridge tops between Caesar and Monteola community in the northeastern part of the county.

BROOKS COUNTY. — Most of Brooks County is blanketed by dune sand deposits, and no indurated formations suitable for building materials are known. The dune sand is fine and little attempt has been made to investigate possible commercial application.

CALHOUN COUNTY.—Oyster shell has been dredged from shallow bays bordering the county by the Bauer Dredging Company and Smith Bros. Dredging Company, both of Port Lavaca. Heldenfels Bros. also dredged shell from adjacent bays.

DeWITT COUNTY.—There are only a few exposures of hard rock in DeWitt County, but there are several sand and gravel deposits that have been used for road construction purposes. Sand and gravel has been produced from a pit about 1 mile south of Thomason. Sand comprises about 38 percent of the deposit and screening is necessary. Once separated, the sand is a clean sharp sand satisfactory for cement aggregate. Nearby is a sand-clay deposit that may be suitable for road material. Sandstone crops out northwest of Yorktown (Pl. II, Loc. 3). Sand near the county line northwest of Cuero (Pl. II, Loc. 5) probably can be screened and washed to obtain a usable common sand. Sand and gravel is present in bars and terraces along the Guadalupe River, especially in the vicinity of Cuero.

DIMMIT COUNTY.—Soft, coarse, light-colored sand is exposed in an area about one-fourth mile wide and 3 miles long along Peña Creek in northwestern Dimmit County (Pl. II, Loc. 1). The sand is exposed in a pit about one-fourth mile below the U. S. Highway 277 crossing on Peña Creek. As taken from the pit, the sand is a good general purpose construction sand. Gravel is present on ridge tops bordering the Nueces River and both sand and gravel occur in terraces and bars in the river valley.

DUVAL COUNTY.—The Oakville sandstone crops out from northwestern Duval County northeastward across McMullen, Live Oak, Bee, Karnes, DeWitt, and Lavaca counties. The formation normally consists of fine- to coarse-grained, dirty gray to buff sandstone containing considerable clay; the sandstone layers are commonly interbedded with clay. The basal sandstone units resist erosion and form a prominent west-facing escarpment in northwestern Duval and south-central McMullen counties. Certain hills west and northwest of the escarpment, such as Atravasada, in Duval County, Dos Hermanos in east-central Webb County, and La Chusa, Mofield Hills, and Loma Alta Mesa in McMullen County, are capped by beds of thin-bedded to flaggy indurated basal Oakville sandstone (Bailey, 1926, Pl. I). Certain of the beds along the escarpment are quartzitic and very hard. Where silicified, the rock is suitable for production of crushed stone and riprap.

A short distance northwest of the Oakville escarpment are isolated groups of silica knobs composed of opal, chalcedony, and/or quartzitic sandstone. This material is very hard, brittle, and resistant to erosion. The silica knobs are small, the largest having an area of possibly half an acre, but some rise 60 feet above the plain and form prominent landmarks. Eagle Hill Knob (Pl. II, Loc. 1), Los Picachos (Pl. II, Loc. 2), Sarnosa and Las Parillas Hills (Pl. II) are among the better known knobs. If chemically stable, most of the siliceous rock is suitable for riprap or aggregate. Some of the siliceous rock might be suitable for abrasives. Quartzitic sandstone (Pl. II, Loc. 4), about 4 miles southwest of Freer, is also a possible source of riprap and aggregate.

Impure earthy limestone beds crop out near Sarroca Hill about 3 miles southeast of Freer (Pl. II, Loc. 6). This rock has been crushed and used for aggregate but its principal value is as road material. Similar deposits are found in the southern part of the county north of Hebbronville, near Realitos, and along the old Tilden road (now closed) 12 to 14 miles northwest of San Diego.

EDWARDS COUNTY.—The limestone building material resources of Edwards County are discussed under "carbonate rocks" (pp. 16, 31–32). In addition to limestone, there are gravel deposits on several of the high divides, within the upper part of the Nueces River drainage system, and along some creeks. For the most part, the gravel is a mixture of limestone and chert pebbles and cobbles.

FRIO COUNTY.—A bed, about 10 by 30 by 200 feet in size, of coarse, hard, iron-stained sandstone crops out in a hill near the crossing of Farm Road 140 and Black (Gaspar Flores) Creek about 8.9 miles east of Pearsall (Pl. II, Loc. 1). The rock appears suitable for aggregate or riprap. Nash (1918, p. 63) reported large quantities of gravel along the I.&G.N. Railroad about 2½ miles north of Pearsall. Gravel is found on divides along the Leona and Frio Rivers and sand is available from bars in the Frio River.

GOLIAD COUNTY.—Impure soft dirty sandstone mixed with clay occurs at several localities in Goliad County. Probably the best quality sandstone is about 5 miles southeast of Goliad (Pl. II, Loc. 5). The sand ranges from 10 to 15 feet in thickness and if washed can probably be used for general construction purposes. Small amounts of sand are available in bars along the San Antonio River.

GONZALES COUNTY.—A sand and gravel pit is located east of U. S. Highway 183 near the junction with Farm Road 1586 northwest of Gonzales, Texas. The deposit ranges from 3 to 4 feet up to 15 feet thick and crops out in an area of 6 to 8 acres. Farther southeast and approximately midway between the above locality and Gonzales, sand and gravel are exposed for a distance of 2 to 3 miles on each side of Highway 183. The material from both pits can be processed to produce aggregate and common sand. A fairly hard sandstone crops out about 4½ miles east of Smiley (Pl. II) and also along a belt extending about 4 miles toward the southwest. This material should produce a satisfactory aggregate; locally some of it has been used for building stone. Nash (1918, pp. 63–64) reported that a bed of fairly hard, gray sandstone crops out in the banks of Cattleman's Fork about 4½ miles southeast of Pilgrim and also caps a hill about 4 miles south of the same settlement. Considerable quantities of sand and gravel are available in bars and terraces along the Guadalupe and San Marcos Rivers.

GUADALUPE COUNTY.—The outcrop of the Wilcox group traverses Guadalupe County (Pl. IV). The unit normally consists of poorly indurated sandstone, loose sand, and clay, and much of the outcrop belt is blanketed by loose iron-stained sand. Sand exposures were examined along State Highway 123 about 6.5 miles north of the Guadalupe-Wilson County line (Pl. II, Loc. 2) and about 4 miles north of the same line (Pl. II, Loc. 3). The sand from either locality can be used for aggregate, and washing should improve the product considerably. A sand-gravel pit about 20 feet deep and 500 to 600 feet across, 14 miles southwest of Seguin (Pl. II, Loc. 9), has produced both sand and gravel. The Tiemann Sand and Gravel Company produced aggregate from the Guadalupe River near Seguin. Both sand and gravel are available in stream beds and terraces along the Guadalupe and San Marcos Rivers, but water held behind dams on the Guadalupe River makes some of the deposits inaccessible.

Nash (1918, p. 67) reported the results of tests made on two samples collected near Cibolo in the northwestern part of the county. One sample from the bank of Cibolo Creek contains rounded limestone fragments cemented by a calcareous sandy matrix and is suitable for road construction; probably this deposit can be screened to produce aggregate. The other sample from the bed of Cibolo Creek contains rounded limestone pebbles without sand or clay.

HIDALGO COUNTY.—The Crow Iron and Gravel Company is producing sand and three sizes of gravel from pits along U. S. Highway 83 a few miles east of Sullivan City (Pl. II, Loc. 1). Sand and gravel are produced at a nearby pit (Pl. II, Loc. 2) and sand is produced from pits a few miles toward the northwest (Pl. II, Loc. 3). Most of the sand and gravel occurs in bars and terraces along the Rio Grande. A limestone conglomerate from a locality northwest of Mission (Pl. II, Loc. 7) is crushed to make aggregate used in a "hot mix" by the State Highway Department. Dune sand covers much of the county. This material is generally too fine for most uses, but locally some of the deposit could be screened or screened and washed to produce building sand for the construction industry.

JACKSON COUNTY.—Quartz sand has been dredged from the Lavaca River near the headwaters of Lavaca Bay (Pl. II, Loc. 2) and sand or sand and gravel is present for several miles along the Lavaca River northwest of Edna (Pl. II, Loc. 4). Clean quartz sand occurs in a bar about 100 yards downstream from the junction of the Navidad River and Sandy Creek (Pl. II, Loc. 5). This locality is easily accessible from U. S. Highway 59 northeast of Edna. Sand is also exposed in a pit adjacent to Highway 59 about 2 miles southwest of Edna.

JIM HOGG COUNTY.—Dune sand blankets much of the surface in east-central Jim Hogg County, and the dunes are especially prominent along Farm Road 1017 south of Hebbronville. Analysis of a sample collected about 15 miles south of that town (Pl. II, Loc. 3) is given in table 43 (No. 60159). Similar deposits occur farther south toward La Gloria along the same highway. Quartzitic gravel that, if screened, can probably produce commercial gravel occurs along the dry creek bed 2 to 3 miles east of Hebbronville.

The Reynosa escarpment is a prominent topographic feature chiefly within southwestern Jim Hogg and Starr counties. Where the escarpment crosses the Jim Hogg–Starr County line, the trend is slightly east of south, and the ridge continues southward across Starr County, terminating near the Rio Grande immediately east of Rio Grande City. The rocks of the escarpment are predominantly conglomeratic and consist of flint and siliceous or manganese-stained limestone pebbles cemented with caliche. The bedding is irregular; in places the rock is silicified and very hard, but elsewhere it is tuffaceous and soft. There are also layers of coarse, limy sandstone, silicified sandstone, and soft tuffaceous limestone; some hills and ridges are capped by hard limestone and the intervening depressions are occupied by red and brown silty clays. A planetable map by Wilson (1932) indicates local well-indurated sandstone ledges, siliceous knobs, and chalcedony veins. Although most of the rock forming this escarpment is not suitable for common construction needs, the harder layers are suitable for riprap and aggregate.

JIM WELLS COUNTY.—The only building material known in Jim Wells County is a soft limestone that crops out along the railroad near Alford.

KARNES COUNTY.—Indurated and silicified sandstone ledges crop out at Tordilla Hill in the vicinity of Falls City in northwestern and north-central areas of Karnes County. At several of these localities the rock is suitable for riprap and aggregate. The more uniformly indurated beds in some quarries have been used locally for building stone. Sand and gravel from a pit in northeastern Karnes County have been used in concrete and for road materials (Pl. II, Loc. 7). Soft sandstone that could be crushed, screened, and perhaps used for concrete, crops out about 1 mile northwest of Hobson, on U. S. Highway 181 northwest of Karnes City; a similar deposit occurs along the banks of the San Antonio River one-half mile southeast of the same village.

KENEDY COUNTY.—Sand dunes, with minor amounts of beach sand and clay, blanket the surface of Kenedy County. Most of the dune sand is too fine for construction purposes, and no firmly consolidated rock outcrops are known.

KINNEY COUNTY.—The limestone and basalt deposits of Kinney County are discussed on pages 16, 21–22 under "Comanche limestones" and 'basalt." In addition, there are gravel deposits in Sycamore Creek at the western boundary of the county and also along other drainage channels.

KLEBERG COUNTY.—Caliche is the only building material reported from Kleberg County.

LA SALLE COUNTY.—A dirty, fossiliferous sandstone, 7 feet thick with 4 feet of overburden, is exposed for three-tenths of a mile along U. S. Highway 81, 3½ miles south of Gardendale (Pl. II, Loc. 1); the same formation crops out around Cotulla and is best exposed in a pit about 7 miles northeast of Los Angeles (Pl. II, Loc. 4); similar material was seen about 2 to 2½ miles northwest of Fowlerton (Pl. II, Loc. 5). All of the material requires crushing, screening, and washing to meet specifications for the construction industry.

LAVACA COUNTY.—Poorly indurated, clayey, sandstone crops out in several areas in Lavaca County, but not much of it is suitable for construction purposes. Exposures occur within a northeast-southwest belt through Hallettsville; the best material occurs in pits along Farm Road 1891 about 8 miles northwest of that town

(Pl. II, Loc. 3). Years ago a sandstone quarry was operated near Moulton in the northwestern part of the county.

LIVE OAK COUNTY.—The West Materials, Inc., operates a large sand and gravel pit 4.4 miles north of George West in Live Oak County. The company produces two sizes of sand and nine sizes of gravel which are used for concrete aggregate, filter material, and road construction. Sandstone crops out in a creek bed two miles southeast of Whitsett, and at one time this material was quarried and used for building stone (Pl. II, Loc. 1). Gravel is exposed on Lagarto Creek about one-half mile northwest of Lagarto. The gravel bed is about 3 feet thick. Fragments range from pea-size to 6 inches in diameter and consist of flint, chert, chalcedony, silicified wood, and sandstone.

MAVERICK COUNTY.—Gravel deposits are present on some of the hills and ridges on both sides of the Eagle Pass–Carrizo Springs road for a distance of 15 to 20 miles east of Eagle Pass. Similar deposits occur on hills along State Highway 76 toward La Pryor, State Highway 131 toward Brackettville, and U. S. Highway 277 toward Del Rio. These gravel accumulations range from scattered pebbles or thin veneers up to accumulations 10 to 12 feet thick. They consist of various kinds of rocks, but limestone and flint pebbles are predominant. Some of the deposits are quite firmly cemented by caliche and require crushing. Most of the material must be screened or screened and washed to produce satisfactory aggregate. Sand and gravel deposits mixed with variable amounts of silt and mud are present along the Rio Grande.

McMULLEN COUNTY.—The Hoover Construction Company of Pleasanton formerly operated gravel pits on the Gubbels ranch about 3 miles east of State Highway 173 and 2 miles north of San Miguel Creek. Gravel has been produced from a pit along Farm Road 63 about 2 miles east of the McMullen–La Salle County line west of Tilden, along Esperanzo Creek a few miles northeast of Fowlerton, and at the Wheeler ranch airfield about 2 miles north of Tilden. All of the deposits need processing, but materials from the latter locality will require extensive screening and washing to meet most construction specifications.

Sandstone, fairly well indurated, crops out 3¾ miles south of the old Crowther townsite and extends northward for about half a mile. Other outcrops of similar sandstone occur about 1½ miles southwest, 1½ miles southeast, and 8 miles south of the same town. A sandstone bed 5 to 10 feet thick crops out about 2 miles southeast of Tilden. All of the material at the above localities requires crushing, screening, and washing.

In southeastern McMullen County along the general northeastern trend of the Oakville escarpment in Duval County are a series of indurated and silicified ledges that form ridges, mesa caps, and knobs. Some of this rock is suitable for riprap and aggregate.

NUECES COUNTY. — Heldenfels Bros. produce building sand and some gravel (Pl. II, Loc. 3), and M. P. Wright, Jr., is producing sand and gravel (Pl. II, Loc. 5) from pits near the Nueces River northwest of Corpus Christi. Oyster shell (discussed on pp. 35–36, "carbonate rocks") was in part used for concrete aggregate and road material.

REAL COUNTY.—The limestones in Real County are discussed on pages 16, 31–32 under "Comanche limestones" and "carbonate rocks." In addition to limestones, gravel deposits blanket the tops of several divides and are found in drainage channels of the Nueces, West Nueces, Frio, and Dry Frio Rivers. The gravel consists chiefly of limestone and flint pebbles ranging up to 6 inches in size. It is clean and when screened to size makes a satisfactory aggregate. The gravel found on the divides is generally indurated and will require crushing.

REFUGIO COUNTY.—Except for oyster shell, very little building material is available in Refugio County.

SAN PATRICIO COUNTY.—The M. P. Wright, Jr., Company (Pl. II, Loc. 11) and the Sam Fordyce Company (Pl. II, Loc. 12) produce sand and gravel from pits along the Atascosa River northwest of Corpus Christi.

STARR COUNTY.—The Fordyce Sand and Gravel Company produces sand and four sizes of gravel at their plant west of Rio Grande City (Pl. II, Loc. 5). Sand and gravel are also available in bars and terraces at other localities along the Rio Grande. The Reynosa escarpment, a northwest-southeast belt of ridges and hills, traverses most of Starr County. Indurated sandstones, gravel beds, and some caliche along the escarpment are suitable for some sizes of riprap and can be crushed to produce aggregate. Wilson (1932) shows quartz veins and a silica knob a few miles northeast of Rio Grande City.

UVALDE COUNTY. — Limestone, asphaltic limestone, and basalt in Uvalde County are discussed on pages 16–22. There are extensive gravel deposits, consisting chiefly of limestone and flint pebbles, along the Blanco, Frio, Nueces, and Sabinal Rivers and in several of the larger creeks. There are many tons of material that could be crushed to produce high-grade aggregate. Gravel deposits, some of which are well indurated, cap the high ridges and divides along the principal drainage channels. Nash (1918, p. 130) described a gravel deposit 50 feet thick in the southwestern part of the county.

VAL VERDE COUNTY.—In addition to the limestone discussed elsewhere (pp. 16, 31–33), there are extensive gravel deposits along the Pecos and Devils Rivers and Sycamore and other creeks. Both sand and gravel occur in bars and terraces along the Rio Grande. Gravel, variable in thickness, loose to firmly indurated, is present on top of many hills and ridges in the county. In the past these commodities have been locally utilized chiefly for paving sand and gravel.

VICTORIA COUNTY.—The Fordyce Sand and Gravel Company (Pl. II, Loc. la-b), Heldenfels Bros. (Pl. II, Loc. 2), Gulf Materials Company, and the South Texas Construction Company have produced sand and gravel from bars and terraces along the Guadalupe River near Victoria. Deposits that appear to have commercial value occur both up and downstream from Victoria; a clean and fairly well-graded sand occurs near Nursery.

WEBB COUNTY.—Gravel is quite widely distributed in stream beds and along divides in Webb County. Some of these localities are: (1) on Webb Bluff near the Rio Grande about 3 miles south of the Webb-Maverick County line; (2) along San Lorenzo Creek a few miles farther toward the southeast; (3) capping a butte near the Rio Grande about 4 miles north of Palafax; (4) near the cannel coal mine, about 3 miles east of Santo Tomas; (5) capping ridges and in terraces along the Rio Grande near Laredo; and (6) in bars in the Rio Grande.

In the bottom of a caliche pit, on an unimproved road about 3 miles north of Oilton, is an undetermined thickness of sandy, siliceous conglomerate (Pl. II, Loc. 15) which is hard and could be used for riprap or aggregate. Large unfractured blocks of the conglomerate have possibilities as an attractive building stone. Nash (1918, p. 135) reported a similar material along the I.&G.N. Railroad about 12 miles north of Laredo. A sandy bentonitic gravel (Pl. II, Loc. 14) crops out along U. S. Highway 59 about 6 miles southwest of the junction with Farm Road 2050.

WILLACY COUNTY.—No important building materials are known in Willacy County.

ZAPATA COUNTY.—Sand and gravel are present in certain bars along the Rio Grande.

ZAVALA COUNTY.—The D and D Gravel Company operates a large screening plant near the Uvalde-Zavala County line (Pl. II, Loc. 2). Sand and sandstone deposits occur on the Brundage property along the Nueces River in north-central Zavala County (Pl. II, Loc. 10, 11, 12). Sample from locality 10 is a clean, light-colored quartz sand taken from the side of a pit about 5 feet below the surface. Sample from locality 11 is from an outcrop about 20 feet west of the pit at locality 10. The sand from both of these localities is good construction material; analyses of both samples are included in table 43 (Nos.

60129 and 60130). The sample from locality 12 is an indurated, iron-stained sandstone that overlies the material at localities 10 and 11; it was collected about 150 feet west of locality 10. Here the sandstone is very hard, heavily iron-stained, and suitable for riprap or aggregate. The three samples were taken within an area of only a few acres, but the outcrop, especially the indurated sandstone unit, is traceable for about three-fourths of a mile to the southwest and 5 or 6 miles toward the northeast.

Sand deposits on the Glen Smith ranch along the Leona River near the Zavala-Uvalde County line were examined, sampled, and analyzed (Pl. II, Loc. 20) ; analysis is given in table 43 (No. 60133). Clean quartz sand is best exposed in a pit about 200 to 250 feet long and 100 feet wide with average depth of 8 feet. An area of about 20 acres has been drilled and the sand body is estimated to be 60 to 70 feet thick. The sand body, which is now being exploited for general construction purposes, is probably much larger than the 20 acres that were explored during the drilling project.

Asphaltic sandstone that crops out along the Nueces River adjacent to the Zavala County line is discussed on pages 19–21. Gravel deposits suitable for aggregate were seen at several localities along the Nueces River.

Caliche

As previously stated, the term caliche is loosely applied to most any type of rock that when crushed, wetted, and rolled, will rebond to form a smooth relatively stable and hard surface. According to this loose usage, caliche may be (1) soft, earthy, partially weathered limestone; (2) marl, or calcareous clay; (3) a limestone or flint gravel with enough clay and lime to pack around the pebbles and cause them to adhere; (4) sand and gravel with enough calcium carbonate to cause the fragments to bond; (5) a shaly sandstone with clay and calcareous cement; or (6) a combination of almost any of the above ingredients. It is possible to blend two or more of the ingredients to obtain satisfactory proportions in the mix.

Caliche containing a satisfactory combination of the above rock and mineral ingredients is sought by contractors for use as road material, and caliche borrow pits are common along most highways. Stretches of some roads, such as U. S. Highway 90 (where it crosses western Uvalde, Kinney, and parts of Val Verde counties), cross formations which are relatively soft limestone so that the road base can be constructed merely by grading, watering, and rolling the native rock. In areas where highways cross clay formations, or where cuts are made through massive rock, the surface is blanketed with a layer of caliche before the paved surface is applied.

Plate III shows the location of pits from which road builders have obtained caliche, paving sand, and gravel. Most of the locations were furnished by the State Highway Department's Resident District Engineers, but some were added during the field investigation. The black dots indicate localities where other materials suitable for road building purposes are available. The map shows abundant material suitable for road building in most counties except those bordering the Gulf of Mexico and in the lower Rio Grande Valley. In those counties the most readily available road building material is oyster shell dredged from shallow bays.

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CARBONATE ROCKS

LIMESTONE

Carbonate rocks, which in the area of this investigation are chiefly limestone, crop out principally in the northwestern part of the area in Edwards, Kinney, Real, Uvalde, and Val Verde counties. The limestone varies widely in its physical properties and chemical composition, but some formations contain rock suitable for commercial utilization.

The use of lime, produced by the burning of limestone, goes back to antiquity, and mortar was used widely in Biblical times. The cement made by mixing volcanic ash with lime was a basic construction material when Pompeii was built. The Romans built and surfaced many miles of their ancient roads with limestone, and crushed limestone is used as the foundation base for hundreds of thousands of miles of modern roads. Many limestones are quarried for dimension stone. For centuries houses and other structures have been built with limestone, and eastern United States is dotted with abandoned limestone quarries and ruins of old lime kilns which were operated during the colonial period.

In the eighteenth century an argillaceous limestone in England was calcined and found to be the natural raw material for a new industrial cement. Rock of similar composition was sought in the United States and found in the Lehigh Valley of northern Pennsylvania. It was subsequently learned that the same cement, Portland cement, could be produced by blending limestone and shale or clay, and the industry has since spread throughout the world. Gillson (1960, p. 124) has reported that the carbonate ingredient for Portland cement should not be more than 5 percent $MgCO_3$, but the $CaCO_3$ content may be as low as 65 percent. For the manufacture of most lime, a high-calcium limestone is needed so that beds averaging 95 percent $CaCO_3$ or more are sought in the lime industry. For some lime uses the MgO content is not so important and "magnesian limes" can be made from dolomites. For flux stone used in metallurgical operations the carbonate rock must be low in silica, particularly for use in open hearths, and many large quarries have been operated for that purpose. About 70 percent of the total limestone quarried is produced for road metal or aggregate and for use as agricultural stone. Agricultural limestone is ground and placed on fields partly as a fertilizer and partly to neutralize acidity. The chemical composition is not important for "Agstone," and for road construction purposes the physical properties are more important than chemical composition.

Developments in modern chemistry have stimulated new uses for limestone and for the lime and carbon dioxide from which the limestone is formed. Lime and coke are used to make calcium carbide which in turn is used in the manufacture of acetylene. Soda ash used in glass manufacturing and in many chemical products is made by a reaction utilizing salt and limestone.

Gillson (1960, pp. 144–145) has divided the carbonate rocks into five main groups, based on their chemical composition:

1. High-calcium limestone with over 95 percent $CaCO_3$. Such limestone is suitable for the production of lime, but most limestone quarried for this purpose analyzes higher than 97 percent $CaCO_3$. Oyster and other shell deposits also belong to this group of high-calcium carbonate materials.

2. Cement rock. There are five different types of Portland cement rock, designated by the American Society for Testing Materials as Type I to V. Following Blanks and Kennedy (1955), the average analyses of the raw materials in these five types are:

	Type I Standard	Type II Moderate heat	Type III High early strength	Type IV Low heat	Type V Sulfate resistant
SiO_2	14.1	14.7	13.7	16.3	12.4
Al_2O_3	4.2	3.2	3.6	3.3	1.6
Fe_2O_3	1.6	2.6	2.0	3.0	1.0
$CaCO_3$	75.8	74.7	77.3	72.5	76.0
$MgCO_3$	3.5	4.2	3.0	4.2	3.5
Alkalies	0.9	0.6	0.4	0.7	0.5

3. Dolomite for flux and magnesian limes. Since the critical deleterious impurities are silica, sulfur, and phosphate, for which tolerances are very low, stone for these purposes must be very carefully selected.

4. Stone for concrete aggregate, dimension stone, and miscellaneous purposes. The requirements for aggregate and dimension stone are largely physical rather than chemical but the absence of chert and pyrite nodules is important. Chert reacts with free alkalies in the cement to form sodium silicate, which is soluble in water. Pyrite oxidizes to form limonite, which produces brown pits or streaks on the faces of buildings made of native stone or in cement with stone aggregate containing pyrite.

5. Stone for road metal, railroad ballast, riprap, and other bulk uses. The specifications for such stone are physical rather than chemical. Some selective quarrying is possible; screening and heavy media separation processes are practicable and are used at some quarries to separate shale and other undesirable materials.

The United States Bureau of Mines has published several Information Circulars on the use of limestone and dolomite (Hatmaker, 1931; Bowles, 1956; Bowles and Jensen, 1941). These can be found in most geological libraries throughout the State and may be available by purchase from the Superintendent of Public Documents, Washington, D. C. The Minerals Yearbook, published annually by the U. S. Bureau of Mines, lists uses for limestone and dolomite. The following amounts of crushed or broken limestone were sold or used by producers in Texas in 1959 (Key, Holmes, and Jensen, 1960, pp. 1012–1016):

	Short tons	Value
Riprap	$ 180,997	$ 271,832
Fluxing stone	467,799	535,736
Concrete and roadstone	20,165,057	17,781,324
Railroad ballast	752,303	652,148
Agriculture	98,842	101,229
Miscellaneous	7,426,416	9,615,526
Total	$29,091,414	$28,957,795

Tests made by the Bureau of Economic Geology's Mineral Technology Laboratory of samples collected in the northwestern counties of this area show that some of the limestone is suitable for industrial utilization in at least four of the five chemical groups designated by Gillson (1960). These include: (1) high-calcium limestone, (2) cement rock, (3) stone for concrete aggregate, dimension stone, and miscellaneous purposes, and (4) road metal, railroad ballast, riprap, and other bulk purposes.

Analyses of limestone samples collected during this study are given in table 2; the locations from which the samples were taken are shown on Plate II.

It will be noted from table 2 that 10 of the Edwards limestone samples and 8 of the Georgetown limestone samples tested 97 or more percent of calcium carbonate ($CaCO_3$), which qualifies the rock from those specific localities as potential sources for high-calcium carbonate limestone. Several additional samples tested 95 percent calcium carbonate or fall just below that limit. Other deposits of high-calcium limestone can probably be found by careful field study. Practically all of the Edwards, Georgetown, and Buda limestone units are suitable for the manufacture of cement if the limestone is blended with a clay, such as the Del Rio or some of the younger shale formations. All of the massive limestone layers are suitable for the production of crushed stone, concrete aggregate, road metal, riprap, railroad ballast, and miscellaneous bulk purposes; the available resources for these more general uses are unlimited.

ARAGONITE

Bailey (1926, p. 42) reported creamy white, silky, fibrous aragonite, partially recrystallized into calcite, in veins near Calliham in eastern McMullen County. The aragonite veins are in shale and locally attain a thickness of 10 or more feet. The veins parallel bedding in shale and the aragonite fibers and crystals are perpendicular to the vein walls. A hill about half a mile west of Calliham is capped by a 10 to 15-foot thickness of the aragonite, which is so plentiful at this locality that early road builders used the material to fill mudholes. Veins of similar material crop out in the lower hill slopes and in nearby hills. Since the aragonite veins parallel the bedding, which is quite flat in that vicinity, the deposits are found only on some hilltops or in the slopes of surrounding hills.

Aragonite also crops out about 3 miles west of Calliham, where there are three beds 10 to 12 inches thick, separated by 5-foot layers of clay. The outcrop is not continuously exposed, but nodules of aragonite float occur in a belt half a mile or more in length. This deposit is no doubt related in origin to the deposit immediately west of Calliham, but the aragonite bodies probably are not connected.

A bed of aragonite 16 to 18 inches thick crops out near the abandoned townsite of Crowther, which is on the Jambers ranch, in northeastern McMullen County. Near the old townsite the beds are quite flat, and although the aragonite bed is not more than 18 inches thick, it forms a band 10 to 20 feet wide that can be traced across country for at least 3 miles.

The aragonite is a high-calcium carbonate mineral but the deposits are very small and probably not commercially important. Analysis No. 60103 of table 2 (Pl. II, Loc. 6) shows a calcium carbonate content of 97.6 percent.

CALICHE

The term caliche as used herein applies to a secondary deposit of calcium carbonate containing impurities of sand, clay, and locally gravel that generally occurs at the surface or from a few inches to a few feet below the surface. Caliche occurs in layers similar to limestone, as rounded pebbles or boulders, and as nodules deposited in sedimentary rocks by percolating ground water. The writer wishes to emphasize that the term caliche as used in this chapter on carbonate rocks applies only to a secondary calcium carbonate deposit with rock impurities and differs from the usage of the same term in the chapter on building materials, where the term caliche is loosely applied to most any kind of weathered rock material that can be used for road-building purposes.

Caliche deposits are present in several of the south Texas counties included in the area of this report, but most have little or no economic value as a carbonate rock. The most extensive caliche accumulations are in a formation that overlaps the older rocks and caps plateaus, buttes, ridges, and isolated hills. Price (1933, p. 490), who mapped the caliche-bearing formation, has shown that the largest single caliche mass caps the Reynosa Plateau, an area that extends almost continuously from south-central Hidalgo County north-northeastward across Hidalgo and parts of Starr, Zapata, Brooks, Jim Hogg, Webb, Duval, McMullen, and Live Oak counties to the Nueces River valley. Northeast from the Nueces River valley the caliche belt is broken by cross drainage, but there are fairly conspicuous outcrops on some hills and ridges in Bee, Karnes, Goliad, and DeWitt counties northeastward to near the Guadalupe River; isolated caliche masses are found in San Patricio, Nueces, and Kleberg counties along the coast and also in some of the counties toward the northwest.

Among the several writers who have published on the caliche deposits of the Texas Coastal Plain are Hawker (1927), Price (1933, 1940, 1941, and 1949), Sayre (1937), Trowbridge (1932), and Weeks (1933). A great deal of data regarding the origin, composition, characteristics, thickness, and distribution of the caliche deposits in south Texas is already available in the literature, and no attempt was made to map the deposits during this study.

At many localities the caliche blanket consists of a dense, hard, resistant, whitish layer of relatively pure calcium carbonate, 1 to a few inches thick, that grades downward into softer, less pure calcium carbonate, and finally into calcareous sand or clay. The zone that shows a concentration of calcium carbonate greater than the normal calcium carbonate content of the underlying bedrock is classed as caliche. This caliche zone, variable in thickness, is normally only about 1 to 3 feet thick, and

TABLE 2. *Chemical properties of limestone in south Texas area.*

Formation	Field Sample No.	Mineral Technology Laboratory No.	Neutralization value as percent $CaCO_3$ equivalent	CaO by flame *Percent*	MgO by difference *Percent*	CO_2 by neutralization *Percent*	$CaCO_3$ plus MgO_3 *Percent*	Moisture H_2O *Percent*	Ignition loss 450°–1050° C. *Percent*	Ignition loss 105°–1050° C. *Percent*
				EDWARDS COUNTY						
Edwards (?)	1	60205	98.3	52.1	2.1	43.2	97.4	0.25	42.47	43.07
Georgetown	2	60206	99.2	54.6	0.6	43.6	98.8	0.03	43.52	43.76
Glen Rose (?)	3-B	60207	75.8	29.7	9.1	33.2	72.0	1.58	33.63	38.43
Edwards	4	60208	99.8	41.5	10.3	43.8	95.6	0.08	43.17	43.76
Georgetown	5	60209	100.0	55.5	0.4	43.9	99.8	0.03	43.60	43.73
Georgetown	6	60210	98.7	54.6	0.5	43.4	98.5	0.10	43.22	43.62
Georgetown	7	60211	99.5	53.5	0.6	42.5	96.6	0.17	42.13	42.82
Georgetown	8	60212	99.1	53.4	1.7	43.6	98.7	0.03	43.54	43.78
				KINNEY COUNTY						
Edwards (?)	1-A	60213	98.1	54.4	0.5	43.2	98.1	0.05	42.92	43.31
Edwards (?)	1-B	60214	97.1	54.0	0.4	42.8	97.2	0.06	42.58	42.97
Edwards	2	60215	97.1	54.9	0.00	42.7	97.6	0.07	42.60	42.86
				REAL COUNTY						
Edwards	4	60221	99.1	40.9	10.5	43.5	94.9	0.12	43.31	43.82
Georgetown (?)	5	60222	99.5	55.0	0.6	43.7	99.3	0.09	43.54	43.69
Glen Rose (?)	6	60223	76.6	38.6	3.1	33.7	75.4	1.60	34.39	38.64
Edwards (?)	7	60224	98.7	54.7	0.5	43.4	98.6	0.09	43.15	43.35
				UVALDE COUNTY						
Edwards	23	60225	93.2	50.8	1.1	41.0	92.9	0.45	41.17	41.46
Edwards	24	60226	98.4	55.0	0.1	43.2	98.3	0.17	43.20	43.20
Edwards	25	60227	90.7	31.5	13.8	39.8	85.1	0.22	39.74	39.97
Edwards	26	60228	99.8	48.9	5.0	43.99	97.8	0.23	43.69	43.79
Glen Rose (?)	27	60229	84.6	31.4	11.5	37.2	80.1	1.10	38.23	38.96
Edwards (?)	28	60230	92.2	48.6	2.1	40.5	91.2	0.45	40.45	41.25
Glen Rose	29	60231	77.6	39.6	2.9	34.2	76.7	1.27	34.52	35.71
Edwards	30-A	60232	97.4	53.1	1.0	42.8	96.9	0.15	42.83	43.01
				VAL VERDE COUNTY						
Edwards (?)	7	60233	90.0	49.2	0.8	39.5	89.5	0.20	39.56	39.99
Georgetown (?)	8	60234	94.5	52.8	10.0	41.5	94.3	0.95	41.18	41.44
Georgetown	9	60235	97.5	52.6	1.6	42.9	97.1	0.25	42.69	49.94
Buda	10-B	60237	94.4	51.7	0.8	41.5	94.0	0.54	41.28	41.77
Georgetown	11	60238	96.4	53.7	0.3	42.4	96.4	0.28	42.18	42.65
Buda	12	60239	94.4	51.7	0.8	41.5	94.0	0.32	41.19	41.64
Del Rio	13	60240	33.5	17.4	1.0	14.17	33.1	......	....	....
Georgetown	14-A	60241	99.1	56.2	0.0	43.6	99.8	0.16	43.42	43.57
Buda	14-C	60243	91.7	50.5	0.7	40.4	91.6	0.50	40.51	41.00
				McMULLEN COUNTY						
	6	60103	98.7	55.3	0.0	43.4	98.7	0.12	43.08	43.37

generally the lower part contains many impurities. Rarely does the caliche zone exceed 10 feet in thickness but Hawker (1927) described 20 feet of caliche in Hidalgo County.

Weeks (1933) has reported that at some localities the upper few feet of the caliche-bearing formation is so thoroughly impregnated with calcium carbonate that the caliche deposit looks similar to limestone, but that pockets of sand or clay are commonly found in the caliche. In many places hard calcium carbonate (caliche) nodules are surrounded by clay or sandy clay. The caliche nodules range in size from less than one-eighth inch to several inches. In some deposits the pellets and cobbles are loosely cemented with calcium carbonate and in others the cement is hard; when the rock is broken the outline of the cobbles can be seen. At some localities gravel beds are cemented with calcium carbonate forming a caliche conglomerate; in others the caliche beds comprise subangular fragments of impure calcium carbonate probably derived from previously existing caliche beds.

Sayre (1937) reported that most of the caliche in Duval County is a hard, resistant, whitish layer of calcium carbonate that grades downward into the underlying formation, and that the base is very irregular. The upper surface is gently undulating and in places has pothole-like depressions. At some localities the caliche is present only as a nodular layer in the soil, but as a whole the caliche deposit forms a very conspicuous member of the rock formation within Duval County.

Most writers have noted that the caliche mantle conforms roughly to the contours of the land, and that it is exposed on both slopes and hills; this commonly leads to an exaggerated idea of its thickness. Also there are frequently long stalactite-like fingers, stringers, or columns extending downward along joints or fissures in the underlying formation that make it difficult to determine true thickness.

Price (1933), Weeks (1933), and others have shown that the caliche deposits are widespread and that the geology of the deposits is complex. Probably the thickest deposits are in central Hidalgo County, but none of the caliche deposits seen appear favorable for commercial production of high-calcium carbonate lime.

OYSTER SHELL

Oyster shells are found in large quantities making up reefs in shallow sea water. Being composed of very pure calcium carbonate, the shells are used in the manufacture of lime, cement, chemicals, concrete aggregate, poultry grit, and road materials. The oyster shell dredging and processing industry is large and active along the Gulf of Mexico in a belt that extends from New Orleans, Louisiana, westward to Corpus Christi, Texas.

In Texas, the oyster shell dredging operations are regulated under permit from the Game and Fish Commision (J. H. Marshall, oral communication, Jan. 5, 1961) and most dredging companies have permits to operate in several areas. Some of the larger dredging companies have active operations in more than one bay, and others move their location from time-to-time depending upon their current market. The State's total oyster shell production for the period September 1, 1959 to August 31, 1960 (Texas' fiscal year), was approximately 11,500,000 cubic yards. Approximately 74 percent of the total production came from the Galveston-Trinity Bays area and to a limited extent from Sabine Lake. The remaining 26 percent of oyster shell production came from bays in the Corpus Christi area.

Most of the oyster shell produced in the Corpus Christi area is dredged from four bays by six dredging companies. A breakdown of the approximate percentage of total cubic yardage produced from each bay follows.

Bay	Approximate percentage of total cubic yards
Lavaca	4.0
Matagorda	3.0
Nueces	10.0
San Antonio	9.0
Total	26.0

Small amounts of oyster shell have also been dredged from Haynes and Copano Bays, but at the time of writing this report both projects are, at least temporarily, abandoned. Oyster shell, in variable amounts, is known to be present in other bays, but no large-scale production has been attempted chiefly because of depth to the oyster shell reefs.

In the Corpus Christi area, the principal shell production is processed for utilization in the manufacture of lime, cement, concrete aggregate, road stone, and chemicals. During 1960 the principal dredging operations in Lavaca Bay were by the Bower Dredging Company and Heldenfels Bros.; in Matagorda Bay by the Matagorda Shell Company and Smith Bros. Dredging Company; in Nueces Bay by the Corpus Christi Shell Company, General Dredging Company, Heldenfels Bros., and Matagorda Shell Company; in San Antonio Bay by the Matagorda Shell Company and Smith Bros. Dredging Company. Much of the oyster shell produced by these companies was utilized in the preparation of concrete aggregate and road stone. Netzeband and Girard (1960) reported specifically that the Alcoa Company manufactured lime from shell for use in their alumina plant in Calhoun County; Portland and masonry cements were manufactured from shell and local clay at the Corpus Christi plant of the Halliburton Portland Cement Company; and lime for industrial, chemical, and building purposes was manufactured from shell by the Chemical Division of the Pittsburgh Plate Glass Company.

Accurate estimates are not available of the oyster shell reserves in the Corpus Christi bay area. The annual production has increased during the past few years. Improved equipment has enabled the dredges to work at increasingly greater depths; the average depth of present dredging activities is about 28 to 30 feet. No doubt there are extensive shell deposits at greater depths in some of the areas that have already been dredged at shallow depths. This is especially true in Aransas, Corpus Christi, and Baffin Bays. Oyster shell is also present in Copano Bay, where small quantities of shell have been recovered, but little information is available as to the extent, thickness, and depth of the deposits. A few dredge loads of shell were produced from Haynes Bay, but the operation was soon abandoned. Shell deposits are probably present in Espiritu Santo Bay but no information as to extent, depth, thickness, or quality of the deposits is available to the writer. The Texas Game and Fish Commission has in progress a project to study and map the oyster shell deposits along the Texas Gulf Coastal area, but field work, as well as preparation of the report, is incomplete. That report will include maps of the bay areas showing location of oyster shell reefs, thickness of the shell deposit, depth of water over the reef, and an estimate of the cubic yardage in each deposit.

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CELESTITE

OCCURRENCE AND TYPES OF DEPOSITS

The known celestite deposits of Texas are restricted to sedimentary rocks of Cretaceous and Permian age. Three types of deposits have been recognized: (1) nodular deposits, (2) cave deposits, and (3) blanket or bedded deposits. All the known celestite deposits within the area of this investigation are in small caves or sinks in massive Cretaceous limestone; they are small and probably have no significant commercial potential.

REAL COUNTY.—Evans (1945, pp. 114–115) described a small celestite cave deposit in Real County. The cave, on the Miller ranch about 13 miles west and 5 miles south of the junction of U. S. Highway 83 and State Highway 41, is in massive Cretaceous limestone about 10 to 15 feet below the present surface. The cavern is about 25 feet long, 14 feet wide, and 5 feet high with a narrow passage extending about 40 feet beyond the main opening. The celestite occurs as a crystalline mass from 1 to 2½ feet thick on the west and south walls of the cave. Calcareous dripstone forms encrustations over part of the celestite and the cave floor is covered with several feet of bat guano. About 70 tons of high-grade celestite were produced in 1943. There has not been any mining activity since that date.

VAL VERDE–TERRELL COUNTIES.—Celestite crops out on the Andy White ranch, just east of the Val Verde–Terrell County line about 11 miles west-southwest of Pandale and can be traced for a quarter of a mile (Pl. II, Loc. 3, and fig. 6). The celestite body is mostly covered, but small exposures suggest a tabular body 2 to 2½ feet thick. The origin of the mass is not clear but it probably was deposited in a cave or collapsed structure. There has not been any mining or exploratory activity. The deposit is probably small and not commercially important.

Since there are many small caves, open solution cracks and fissures, and a few sinks in the massive Cretaceous limestones of the Edwards Plateau, additional deposits may be found within the region.

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CLAY MATERIALS

DEFINITIONS, PROPERTIES, AND INDUSTRIAL USES

The term clay is used both as a rock compositional term and a particle-size term. As a compositional term, clay is a general term because there are many different clay minerals and clays display a wide range of physical properties. As a particle-size term, clay designates the smallest grain-size range. Soil investigators and mineralogists generally use 2 microns as the maximum clay particle size, but the Wentworth (1922) scale defines clay as the material finer than approximately 4 microns. Grim (1953) used the term clay material for any natural, fine-grained, earthy, argillaceous material and included clay, shale, or argillite, and argillaceous soils. Grim's definition probably best applies to most of the materials found in the Gulf Coastal Plain area of this report, because most of the clay materials have been picked up by streams, rolled about, reworked, redeposited several times, and include a wide variety of minerals derived from various formations. Murray (1960, pp. 259–284) prepared an excellent report on clays, and much of the general data in this chapter is taken from his paper.

Clay minerals are composed of hydrous aluminum, magnesium, and iron silicate groups that may contain calcium, potassium, and other ions. The major clay mineral groups include kaolinite, montmorillonite, illite, and chlorite, with various mineral species within each group. The clay minerals present control the physical characteristics of a particular clay. Organic material, carbonate, or other impurities commonly alter the basic clay mineral characteristics and have an important influence upon the properties of a clay and thus upon its possible commercial utilization. For example, calcareous material and pyrite are detrimental in ceramic clays, and quartz or other abrasives are detrimental in kaolins used as coating pigments in the paper industry. A small amount of organic material might have an important coloring effect in some products; certain mineral salts flocculate clays so that dispersion, as is necessary in some industrial uses, becomes difficult. Murray (1960) discussed the procedures and testing equipment used to analyze clays to determine commercial potential.

Structural Clay Products

Structural clay products include brick, drain tile, sewer pipe, conduit tile, glazed tile, terra cotta, and other items. The properties of clays used in the structural clay products industry vary in different parts of the country. The important parameters are plasticity, green strength, dry strength, drying and firing shrinkage, vitrification range, and fired color. These properties depend on the composition of the clay and the grain size.

Clay becomes plastic when mixed with varying proportions of water and range from highly plastic ("fat" clay) to only slightly plastic ("lean" clay). Particle size, shape, type of clay minerals, soluble salts and absorbed ions, organic matter, and the amount and type of non-clay minerals are all believed to affect the plastic properties.

The green and dry strengths of clay are very important because most types of structural clay products must be worked before firing. The green strength is closely related to the plasticity of the clay; the dry strength is determined by measuring tensile, compressive, and shearing strength. Clay strength depends on the proportion of fine particles present, the shape of the particles, the degree of hydration of the colloidal fraction before the sample is prepared, the way in which the test sample is formed, and the extent of drying before testing.

Shrinkage, both drying and firing, is another important property of the clays that are used for structural clay products. Drying shrinkage depends upon the water content, character of the clay minerals, and the amount of colloidal material. Drying shrinkage is high in most very plastic clays and produces cracking and warping; it is low in low-plasticity clays. The presence of montmorillonite, a highly hydrated fine-grained clay, in relatively large amounts causes excessive shrinkage, cracking, and slow drying. Firing shrinkage depends on the volatile substances present, the type of crystalline phase changes, the dehydration characteristics of the clay minerals, and the viscous and surface tension properties.

The temperature range of vitrification (glass formation) is very short for some clays. Illites, montmorillonites, and chlorites show evidence of vitrification much earlier than do kaolins. Minerals such as calcite, quartz, and feldspar may act as a flux and lower the vitrification temperature.

Iron is primarily responsible for the color in structural clay products. The color is influenced by the state of oxidation and division of the iron, the firing temperature and degree of vitrification, the proportion of alumina, lime, and magnesia in the clay material, and the composition of the gases present during burning.

Clay and shale used in the structural clay products industry are in general not as pure or as high grade as clays used in other industries. In general, underclays, a layer of clay beneath a coal seam, are best suited for glazed tile and some grades of sewer pipe and brick. Shales and impure clays are used for common brick and drain tile.

Most of the south Texas clay has a high lime content, which is undesirable for the manufacture of most high ceramic products. This problem has been partially overcome by blending ingredients and carefully regulating firing procedures; structural clay products are manufactured from some lime-rich clays. The analyses in table 3 (in pocket) show the high lime content. Nevertheless the clay is used for the manufacture of common brick and tile and the Texas Coastal Plain has enormous resources of high-lime clay materials. The more successful operations are near the larger centers of population or adjacent to good transportation facilities, because structural clay products, especially common brick and tile, are heavy and generally not transported for long distances. Some producers have successfully operated for many years; others have ceased activity due to increased transportation and labor costs, changing market conditions, or exhaustion of suitable clay. There are relatively few localities where the source of raw material was depleted. The county production of the brick and tile industry is summarized in the following pages. Analyses of many clays in the area of this investigation are contained in tables **3–15 (in pocket; and on pp. 41, 44, 46–48,** 51–52, 60–66).

Common Brick and Tile

ATASCOSA COUNTY.—J. W. Madden formerly owned a brick plant about 1½ miles north of Jourdanton that produced brick from a clay in the Cook Mountain formation. The operation was abandoned several years ago, and there has been no activity during recent years. The Cook Mountain formation crops out in a band that extends across the central part of Atascosa County, northeastward across Wilson and Gonzales counties, southwest and south into Frio, Zavala, La Salle, and Webb counties. The only known locality where brick is now being manufactured from clay materials in the Cook Mountain is at Laredo.

King (1940, pp. 139–142) reported on a clay deposit on the J. W. Miller place 1½ miles east of the Poteet road and 2 miles south of where that road crosses the San Antonio Southern Railroad tracks in northern Atascosa County. The deposit lies within the Carrizo sandstone and the surface is largely covered with reworked and drifting sand. The U. S. Geological Survey drilled test holes through 5 to 18 feet of overburden and found that the clay deposit ranged from 7 to 23 feet in thickness. The clay, which has been used in the pottery industry, has high plasticity, medium hardness, and very satisfactory handling properties except for the high water of plasticity and the consequent high drying shrinkage. Results of tests made on this material are shown in table 4 (King, 1940, pp. 140–141).

D. L. Mullen, Texas Mining and Milling Company, reported (oral communication, July 1960) that his company has blocked 98.2 acres of clay on the Miller ranch, Palo Alto–Pleasanton road, about 16 miles south of San Antonio. The area was core drilled and holes were drilled to a depth of about 30 feet and bottomed in clay. Results of tests are given in table 3 (No. 60117).

CAMERON COUNTY.—The alluvial, beach sand, and terrace deposits that underlie most of the surface of Cameron County in general do not contain clays suitable for the manufacture of structural clay products, but certain beds and lenses can be used for the manufacture of common brick or tile and adobe brick. The Anderson Brick Company formerly operated a plant at Olmito. Samples from this pit were not available but samples from a clay near Olmito were obtained (Pl. II, Loc. 7, and table 3, No. 60252).

GOLIAD COUNTY.—About 1890, river silt (Pl. II, Loc. 2) and clay from the Goliad formation were blended and used for making bricks near Goliad. Judging from the broken bricks at the old kiln site, the products were not of high quality, and according to local reports production ceased 50 or more years ago. Clay samples from Lagarto clay (Pl. II, Loc. 1), Goliad sand (Pl. II, Loc. 2, 3), and Lissie clay (Pl. II, Loc. 4) were analyzed (Table 3, Nos. 60322, 60323, 60324, and 60325).

GONZALES COUNTY.—The Sunset Brick and Tile Company produces brick from a blend of flood-plain silt and clay at their Gonzales plant which is in the southwest corner of Gonzales; the pit is on the Guadalupe River flood plain 0.2 to 0.3 mile south of the plant. The alluvial material, which is hauled to the plant, is a soft, crumbly, nonstratified, pale yellowish-brown, very calcareous, silty clay that is blended with clay from the Yegua formation. Clay materials at several localities within the outcrop belts of the Cook Mountain and Yegua formations appear satisfactory for producing common brick and tile.

GUADALUPE COUNTY. — The Acme Brick and Tile Company (until March 1961, the Fraser Brick and Tile Company) has a brick plant near McQueeney, Guadalupe County. The plant is about 0.8 mile south of Farm Road 78 as measured from the west end of the Guadalupe River bridge (Pl. II, Loc. 1). The company uses a light to medium-gray calcareous clay, interbedded with siltstone, from the Nacatoch formation of the Navarro group, which is the oldest formation now being used for brick production in the south Texas area. Although there are clays suitable for producing brick or tile at several localities, this is the only current operation in the county. Results of tests on samples from the Corsicana unit of the Navarro group (Pl. II, Loc. 6, 8) are included in table 3 (Nos. 60192 and 60194).

HIDALGO COUNTY.—The Valley Brick and Tile Company's Mission plant is on the east side of Highway 1016, 3.5 miles south of the junction with U. S. Highway 83, south of Mission, Hidalgo County. The raw material is a part of the Recent Rio Grande deposits. A lower sand and upper clay are blended and fired to produce a tan brick marketed as "Mission Brick." The upper clay is a soft, slightly coherent, very pale, yellowish-orange, nonbedded calcareous clay about 15 feet thick (Pl. II, Loc. 6-B). The lower sand is friable, pale yellowish-brown, very fine-grained silt with subangular quartz and black heavy mineral grains. Although deposits of this type commonly vary in composition and texture within short distances, there appear to be many acres of similar material along the lower Rio Grande Valley. Analysis of material from this locality is given in table 3 (No. 60262).

JACKSON COUNTY.—The Lolita Brick and Tile Company once operated a brick plant at Lolita, Jackson County. The material used was red calcareous clay from the Beaumont formation taken from a pit about 3 miles north of Lolita (Pl. II, Loc. 3). Although no brick is being made in

TABLE 4. *Tests of clay from the Miller farm, northern Atascosa County, Texas* (Bureau of Industrial Chemistry, The University of Texas).

PRELIMINARY TESTS

Depth in feet	Raw color	Shrinkage percent Drying	Shrinkage percent Firing	Fired color	Fired condition	Univ. Texas Lab. No.
Clay pile at pit	Light gray	9.0	4.0	Buff	Very good	23
G.S. test hole 52						
5–7	Gray	8.5	3.0	Buff	Very good	108
7–9	Gray	7.5	4.5	Buff	Very good	109
9–11	Gray	8.5	4.5	Buff	Very good	110
11–12	Gray	5.0	5.0	Dark buff	Good	111
12–13	Red and gray	5.5	2.0	Red	Good	112
G.S. test hole 66						
8½–10	Light olive	8.5	4.0	Dark buff	Very good	129
10–12	Blue-gray	8.0	3.5	Light red	Very good	130
12–14	Blue-gray	8.5	4.0	Light red	Very good	131
14–17	Brown	7.5	5.0	Red	Very good	132
17–20	Blue-gray	8.0	4.0	Buff	Very good	133
20–23	Blue-gray	8.5	5.5	Light buff	Very good	134

COMPLETE TESTS

Sample No.	U.T. 108–110	U.T. 130–132	U.T. 133–134
Dry color	Gray	Blue-gray	Blue-gray
Hardness	Medium	Soft	Medium
Plasticity	High	High	High
Shrinkage water	14.4	14.3	14.6
Pure water	10.6	9.9	10.6
Water of plasticity	25.0	24.2	25.2
Drying shrinkage	28.8	27.5	28.9
Cone 010			
Color	Buff	Light red	Flesh
Condition	Steel hard	Steel hard	Steel hard
Shrinkage	2.8	2.3	2.9
Porosity	26.2	21.8	21.7
Cone 08			
Color	Buff	Light red	Flesh
Condition	Steel hard	Steel hard	Steel hard
Shrinkage	5.6	3.1	5.6
Porosity	23.8	19.8	19.6
Cone 06			
Color	Buff	Light red	Buff
Condition	Steel hard	Steel hard	Steel hard
Shrinkage	8.4	4.0	13.2
Porosity	19.0	9.4	20.5
Cone 04			
Color	Buff	Light red	Buff
Condition	Steel hard	Cracked	Steel hard
Shrinkage	9.6	1.3	14.0
Porosity	15.9	9.9	12.4
Cone 02			
Color	Buff	Light red	Buff
Condition	Steel hard	Bloated	Steel hard
Shrinkage	12.5	0.4	18.2
Porosity	9.6	7.0	3.3
Cone 1			
Color	Gray-green	Brown	Gray-buff
Condition	Incipient vitrification	Bloated	Bloated vitrified
Shrinkage	12.7	– 24.1	1.8
Porosity	4.0	7.0	5.5
Cone 3			
Color	Gray-green	Brown	Gray-buff
Condition	Incipient vitrification	Incipient vitrification	Bloated vitrified
Shrinkage	14.9	– 13.4	19.5
Porosity	5.7	1.9	0.6
Cone 5			
Color	Gray-green	Green-brown	Gray-buff
Condition	Vitrified	Bloated vitrified	Vitrified cracks
Shrinkage	12.5	– 19.6	11.3
Porosity	5.0	6.6	1.9

Jackson County at this time, materials similar to those used at Lolita are present at other localities within the Beaumont formation, which crops out over most of the southern two-thirds of the county.

MEDINA COUNTY.—The D'Hanis Brick and Tile Company has a large plant at D'Hanis, Medina County (Pl. II, Loc. 1). This company produces large quantities of brick and tile from clays in the Escondido formation.

At the D'Hanis pit three principal clay beds are separated by thin layers of limestone, and limestone stringers are numerous within the clay beds. The limestone is discarded in the pit. The upper clay layer contains considerable sand; materials from the three clay layers are blended in order to obtain a proper mix.

The outcrop band of the Escondido extends westward from D'Hanis across southern Uvalde and northern Zavala counties; thence the outcrop turns southward across Maverick County and extends east and southeast of Eagle Pass. There are several localities along the Escondido outcrop where clays are available that appear to be satisfactory for the production of common brick or tile. Limestone in beds, stringers, and veins is common throughout the formation. Localities where the limestone content is high should be avoided. Localities 8, 9, and 11, Maverick County (Pl. II), are in the Escondido and locality 10 is in the Olmos; samples A, B, C, and D, locality 1, are from the pit at D'Hanis. Analyses from these samples are given in table 3 (Nos. 60217, 60218, 60219, and 60220).

STARR COUNTY.—The Valley Brick and Tile Company's Rio Grande City plant is on the northwest side of the Missouri Pacific Railroad tracks and Farm Road 1430, 0.4 mile southeast of the junction of Highway 1430 with Highway 83, and about 5.4 miles southeast of Rio Grande City. The company has opened several pits in the area and is producing raw materials for brick and tile, bloated clay for lightweight aggregate, clay carrier for insecticides, and pozzolanic material. Clay for brick and tile production is obtained from the Summers pit (Pl. II, Loc. 1), the Wood pasture pit (Pl. II, Loc. 2-A), the La Puerta pit (Pl. II, Loc. 2-B), all southeast of Rio Grande City; material for the manufacture of a dry-pressed brick is obtained from pits northwest of Rio Grande City (Pl. II, Loc. 4). A bloating clay used for experimental production of lightweight aggregate (Pl. II, Loc. 3) and volcanic ash used as pozzolanic material and as a diluent for insecticides (sold under the trade name of "Vol Dust") are also obtained southeast of Rio Grande City (Pl. II, Loc. 8). Analyses of samples from these localities are included in table 3 (Nos. 60199, 60200, 60201, 60202, and 60203).

The clays are hard, brittle, and massive with highly irregular joints and fractures, and contain some quartz grains and glass shards; colors range from pale green and pinkish orange to red. Bailey (1926) mapped the deposits as part of the Oakville formation, which has also been sampled at other localities including DeWitt (Pl. II, Loc. 2 and 4), Duval (Pl. II, Loc. 3), Lavaca (Pl. II, Loc. 2 and 5), and Live Oak (Pl. II, Loc. 12 and 13) counties. (*See* table 3.)

The material used for additive in pozzolan cement and as an insecticide diluent (Pl. II, Loc. 8) is an impure pinkish-gray volcanic ash that is soft and friable and contains some quartz, feldspar, glass shards, and a black mineral. Bailey (1926) reported that the volcanic ash beds are part of the Oakville. Petrographic analysis made by Cader A. Shelby, of the Bureau of Economic Geology, shows that the rock is a tuff composed chiefly of montmorillonitic (benzene test) clay with numerous shards of partly devitrified rhyolitic glass ($n = 1.498$),[2] silt-size quartz (approximately 20%), and a trace of plagioclase. Major accessory mineral is magnetite. Minor accessory minerals are ilmenite, leucoxene, biotite (hexagonal flakes), and zircon.

WEBB COUNTY.—The Laredo Brick and Tile Company operates a brick plant on the west side of the Missouri Pacific Railroad tracks in northwestern Laredo,

[2] Index range of volcanic glass, $n = 1.48–1.51$.

Webb County. The company manufactures brick and tile from a material blended from two pits. Pit No. 1 (Pl. II, Loc. 18) is located east of the junction of U. S. Highway 83 and State Highway 359 and half a mile north of the junction of State 359 with Loop 20. This pit produces firm, strongly coherent, pale yellowish-brown, laminated, gypsiferous, limonitic-stained clay from the Cook Mountain formation. The clay is blended with silt obtained from alluvial deposits at pit No. 2 on the south bank of Chacon Creek, 0.2 mile east of U. S. Highway 83 from south end of bridge over Chacon Creek, and 0.7 mile south of the junction of U. S. Highway 83 and State 359 (Pl. II, Loc. 17). The alluvial material is a soft, friable, unstratified, yellowish-gray, calcareous, argillaceous silt that contains traces of a black heavy mineral and limonite stains. There appear to be many acres of similar silt along the Rio Grande Valley both above and below Laredo.

The Cook Mountain crops out in a north-south belt that extends from near Falcon Dam in Zapata County northward into La Salle, Zavala, and Frio counties, and thence northeastward across Atascosa and Gonzales counties. The city of Laredo is situated near the center of the exposure. There is a large tonnage of clay similar to the material now being used by the Laredo Brick and Tile Company along this outcrop belt, but the only other operation in which Cook Mountain clays have been utilized for brick and tile production was at Gonzales. Analyses from the Cook Mountain clay in Atascosa, La Salle, Webb, and Zapata counties are included in table 3 (Min. Tech. Lab. Nos. 60087; 60161, 60162; 60164, 60165, 60169, 60177; and 60179).

The following information on clay resources in the Laredo area was reported by E. J. Dryden, Jr. (1959). Three clay beds crop out near the Dolores cannel coal mine and in the area immediately adjacent. The upper bed is approximately 20 feet thick and is overlain by sandstone; the second bed, approximately 30 feet thick, crops out on the slope beneath sand and gravel; while the third clay bed, separated by a 4-foot layer of coal from the second clay, is approximately 40 feet thick and is underlain by coal. Clay also underlies the second coal layer. In the immediate area of Laredo and east of that city several clay deposits occur. The natural mixture of clay and sand from the Chacon Creek locality is used in the manufacture of brick. Farther east at Chavana's ranch is a clay which is used to temper other clay mixes for color to make a light cream to tan shade. Still farther east, in an area known as "Bruni Pasture" and "Edwards Pasture" are dark gray and deep brown clays which are used to color brick a deep red. This clay is too "fat" to be used without blending. Both of these deposits are close to highway, rail, and gas lines.

East of Laredo in the Killiam ranch and Reiser area is a clay which burns to a light cream and tan; some of it is very fine in texture and is suitable for face brick. A brick plant was at one time located at Reiser but is now abandoned.

South of Laredo are other clay deposits of color, texture, and composition similar to those east of Laredo; no samples were tested from these deposits. Analyses given in table 5 are taken from Dryden (1959, pp. 98–100).

The above tests indicate that the commercial use of these two clays would be limited to the manufacture of brick, roof tile, flower pots, sewer pipe, drain tile, etc. The low fusion temperatures eliminate these clays for materials that are required to stand high temperatures.

Refractory, Whiteware, Pottery or Stoneware, and Porcelain Clays

Refractory clays, or refractories, are materials that retain their physical shape and chemical identity at high temperature. Such clays are suitable for the construction of furnace linings. The refractory material must be able to withstand thermal shock resulting from rapid heating or cooling and other stresses induced by temperature change, pressure from weight of furnace parts or contents, mechanical wear resulting from the movement of furnace con-

TABLE 5. *Analyses and tests on clay from near Dolores cannel coal mine, Maverick County, Texas* (Louis G. Robinson Laboratories).

	Gray clay	Red clay
LAB. No. 99918 (July 29, 1955)—		
Chemical analysis, percent—		
Combined water	9.08	11.70
Silica (SiO_2)	49.81	61.13
Alumina (Al_2O_3)	19.22	18.15
Iron oxide (Fe_2O_3)	4.50	3.50
Calcium oxide (CaO)	10.00	5.00
Magnesia (MgO)	Trace	Trace
Sodium oxide (Na_2O)	Trace	Trace
Potassium oxide (K_2O)	Trace	Trace
Titanium oxide (TiO_2)	0.15	0.10
Vitrification temperature oxidizing atmosphere	2027° F Cone 1	2300° F Cone 10
Fusion temperature	2300° F Cone 10	2408° F Cone 11
Color at vitrification temperature oxidizing	Brown	Dark red
LAB. No. 1323 (Feb. 20, 1956)—		
Chemical analysis, percent—		
Silica (SiO_2)		56.25
Iron oxide (Fe_2O_3)		2.90
Alumina (Al_2O_3)		25.59
Calcium oxide (CaO)		0.80
Magnesium oxide (MgO)		None
Sodium oxide (Na_2O)		0.50
Titanium oxide (TiO_2)		Trace
Potassium oxide (K_2O)		0.16
Loss on ignition		13.80
LAB. No. 1431 (March 7, 1956)—		
Vitrification temperature		2080° F
Fusion		2296° F
LAB. No. 480 (Oct. 31, 1955)—		
Chemical analysis, percent—		
Silica (SiO_2)		66.0
Alumina (Al_2O_3)		12.70
Iron oxide (Fe_2O_3)		1.00
Calcium oxide (CaO)		6.12
Magnesium oxide (MgO)		Trace
Potassium oxide (K_2O)		0.08
Sodium oxide (Na_2O)		0.10
Titanium oxide (TiO_2)		Trace
Loss on ignition		14.00

tents, and chemical attack by heated solids, liquids, or gases.

All clays that have a fusion point of Cone 19 or higher are considered a refractory. Refractory clays are predominantly kaolins. The most widely used material for manufacture of refractories is fire clay, which is generally found beneath coal seams. The fire clay is used to manufacture insulating fire brick, high-temperature cement, ramming mixtures, plastic fire brick and other materials.

Whitewares are usually made by blending china clay or ball clay with feldspar and silica. China clay is composed of kaolinite; ball clay generally contains some montmorillonite and organic impurities in addition to kaolinite; it is finer grained than china clay and highly plastic. Suitable clays fire white or cream white.

Pottery or stoneware is made from many different types of clay but usually from fire clay. The better grade products are made from clays that are at least semirefractory, of dense-burning character, good plasticity, high strength, and low shrinkage; it is not necessary that the clays burn white.

The demand for materials suitable for the production of porcelainware has increased during recent years due largely to expansion of the electronics industry. Ball clay and china clay of high purity and adequate plasticity blended with feldspar and silica are the basic ingredients for porcelainware. Shrinkage and distortion must be kept to a minimum in high-grade porcelains; electrical properties such as conductivity, dielectric content, power factor, and power loss are also very important (Bloor, 1953).

Few raw materials suitable for the manufacture of most high-grade refractories, whiteware, and porcelain products are present in south Texas. Most of the known large raw material deposits are of inferior quality.

Kaolin and Associated Fire Clay

LEAKEY KAOLIN DEPOSIT.—The Leakey kaolin deposit, in Real County, has been known for more than 70 years. The deposit, owned by F. Clay McGaughy of San Antonio, is in section 71, block 3, T.W.N.G. RR. survey about 5 airline miles northwest of Leakey (Pl. II, Loc. 1, 2, 3). Sporadic attempts have been made to develop and market the kaolin, but all have been unsuccessful.

Shortly after discovery, small amounts of the Leakey kaolin were shipped to Dallas under the misapprehension that it was talc. About 1912 a crushing plant was installed and 300 to 400 tons were shipped to eastern markets for use in the ceramic industry. Later, the deposit was explored, sampled, and tested by Schoch (1931, pp. 140–161) and Robbins (1932). There has been no activity in recent years, but sample shipments to several ceramic firms have been made by the present owner. A few analyses are included in tables 6 and 7.

The kaolin body occurs in a shallow draw between two slight elevations on an arm of the Edwards Plateau about 600 feet above the Frio River. The surface rock is the Edwards limestone, which caps extensive areas of the Plateau. The depression in which the kaolin is found appears to be a solution cavity in the Edwards limestone and includes two pits, walled by undisturbed massive limestone, that are referred to as the north and south caves.

The north cave (pit), as it is locally known, has an elliptical shape, with dimensions of approximately 475 feet in north-south direction and 350 feet in east-west direction. Robbins (1932, p. 4) found the maximum depth to be 103 feet at a point north of the center. Core drilling showed the kaolin deposit to be a crescent-shaped body occupying the northern and eastern sides of the pit and filling approximately one-third of the depression. Much of the remainder of the pit, especially the western and southern sides, is filled with fire clay and sand. The kaolin crops out or is at shallow depths adjacent to the north and east walls of the pit. The upper surface of the kaolin appears to slope southwest and is covered by a heavy chert conglomerate up to 20 feet thick, which is locally mixed with iron-stained sand. On the west side of the pit, the cobbles in the conglomerate are smaller and mixed with larger quantities of sand and are overlain by a fine sand up to 60 feet thick (Robbins, 1932, p. 5); southwestward the sand grades into fire clay with a maximum thickness of 55 feet.

The south cave (pit) is also outlined by bedded limestone and is larger than the north cave, being about 300 feet wide from east to west and almost 1,000 feet long. It is separated from the north cave by a limestone wall about 30 to 70 feet thick. A maximum depth of 142 feet was reached in a core hole near the north end of the pit (Robbins, 1932, p. 5). Kaolin was not encountered in this core hole, but Schoch (1931, p. 145) reported 10 feet of pure white kaolin at a depth of 62 feet in one of the shafts excavated in the northwestern corner of the south cave. The south cave has not been as thoroughly tested as the north cave and the tests do not exclude the possibility that a sizable kaolin body may exist.

Of the 14 core holes drilled on the property, Robbins (1932) reported kaolin in eight, in which the clay ranged from 8 to 62 feet thick. Most holes indicate that the kaolin is lenticular and contains stringers of sand, sand and gravel, sandy clay, sandy fire clay, and chert boulders in bodies from 1 to 7 feet thick. The total thickness of the deposit in the eight holes in which kaolin was encountered is 8, 20, 17, 13, 58, 62, and 25 feet; detailed logs of the core holes are on file at the Bureau of Economic Geology. Robbins (1932, p. 7) reported that about 95 percent of the kaolin is discolored; prevailing colors are shades of pink, red, and yellow, but some of the cores showed gray, blue, and black stains. Most of the stains are along or adjacent to shrinkage cracks, but certain specks are probably due to decomposition of isolated mineral grains embedded within the kaolin.

Schoch (1931, pp. 148–149) reported that the kaolin obtained from the north cave deposit varies from a dense, hard mass to a soft, tallow-like mass with pseudocrystalline appearance, and that the middle of the kaolin body is dense, flinty, and remarkably free from coloring materials. Toward the top, the kaolin is interspersed with a mixture of sand and kaolin that is bluish in color. The hard flinty kaolin is stained with many spots of red iron oxide.

Schoch (1931, pp. 149–150) tested some of the pure white kaolin by grinding in an "edgerunner" mill and made two series of bricklets: in one, water was added to the material to form a stiff mud (water required was about 40 percent by weight of dry kaolin) ; the other was "dry-pressed," with only enough water to make the kaolin cohere. On drying, the bricklets shrank an average of 11.77 percent of their volume. The results of tests made by Schoch (1931, p. 150) are given in table 6.

The kaolin has a melting point of about 1,800 degrees Centigrade, Cone 33. The burned bricklets showed fine surface cracks but remained intact. Some of the burned bricklets were heated to redness, dropped into water, and then replaced in the red-hot furnace; they withstood such treatment an indefinite number of times without cracking.

Calculated tonnage of the kaolin deposit based on the core-drill survey directed by Robbins (1932, pp. 10–11) and on maps, cross sections, and other data prepared by him is estimated at 180,216 tons. Robbins (1932, p. 10) further estimated that 70 percent of the kaolin is recoverable.

The best grades of pure white Leakey kaolin are suitable for making fine china but pure white material occurs in small amounts and is not typical of the deposit. According to Robbins' estimate, about 95 percent of the kaolin is iron stained and the iron must be removed before the kaolin can be utilized for the manufacture of high-grade porcelainware or fine china. If the iron cannot be satisfactorily removed, the deposit remains as a potential source of clay for the manufacture of fire brick and other refractories (table 3, Nos. 60122–60126).

Detailed information on mineralogy and physical properties of the Leakey clay is contained in some unpublished reports and may be secured from the owner, F. Clay McGaughy, San Antonio, Texas.

Schoch (1931, p. 160) also reported kaolin on section 6, block F, G.H.&S.A.

TABLE 6. *Tests of the Leakey kaolin, Real County, Texas.*

Test Piece No.	Cone "down"	Temperature at which piece was removed *Degrees C.*	Dry volume	Volume burned	Percent fire shrinkage	Percent porosity	Color and hardness
			STIFF MUD SERIES				
L 1	4	1210	37.9	28.2	25.6	45.6	White
					Av. 27.5	44.0	
L 2	.	.	37.9	26.75	29.4	42.5	
L 3	6	1250	37.9	24.9	34.3	38.7	White
					Av. 35.57	37.4	
L 4	.	....	37.6	23.75	36.85	36.2	
L 5	8	1290	37.6	22.4	40.45	32.6	White,
					Av. 40.67	32.1	Very
L 6	...	....	38.0	22.45	40.9	31.6	hard
L 7	12	1370	37.9	21.65	42.9	29.5	White,
					Av. 42.45	30.0	Steel
L 8	....	....	38.3	22.2	42.0	30.4	Hard
L 9	....	1400	38.3	20.7	45.9	25.6	White
					Av. 46.05	25.2	
L 10	....	....	38.0	20.45	46.2	24.9	
			DRY PRESSED SERIES				
L 1	4	1210	28.5	25.6	10.2	43.9	White,
					Av. 11.65	41.83	Very
L 2	....	.	28.1	24.4	13.1	39.75	hard
L 3	6	1250	28.2	22.75	18.6	36.7	White,
					Av. 20.15	35.4	Steel
L 4	....	....	28.3	22.15	21.7	34.1	Hard
L 5	8	1290	26.4	19.5	26.2	28.2	White,
					Av. 26.5	28.4	Steel
L 6	....	....	27.2	19.9	26.8	28.6	Hard
L 7	12	1370	30.2	17.7	41.4	27.1	White,
					Av. 42.0	26.6	Steel
L 8	....	....	31.7	18.2	42.6	26.1	Hard
L 9	....	1400	32.6	17.65	45.8	21.5	White,
					Av. 45.8	20.85	Steel
L 10	....	....	30.2	16.35	45.8	20.2	Hard

RR. survey, about 1½ miles southwest of the Leakey kaolin deposit. The outcrop is in the bank of a draw, and other masses are exposed in prospect pits. None of the deposits appear to be more than 10 feet thick and the clay is stained by iron oxide or mixed with sand. There has not been enough prospecting to determine the lateral extent of the deposits but they might be utilized in conjunction with the Leakey deposit.

Kaolin deposits were also reported from a locality along the Cedar Creek road about 12 miles northwest of Leakey and from the Hebe ranch about 25 miles north of Leakey. These deposits were not visited by the writer, but judging from the data available they are probably small.

LEAKEY FIRE CLAY DEPOSIT—Fire clay is present in both the north and south caves at the Leakey kaolin deposit. The fire clay was penetrated in two of the core holes in the north cave and showed thicknesses of 28 and 55 feet (Robbins, 1932) ; it was also encountered in several of the shafts (Schoch, 1931, pp. 145, 151–152, 155). Schoch stated that the fire clay is of suitable grade for the manufacture of fire brick or other refactory ware and estimated about 288,700 tons in the north cave and a substantial tonnage in the south cave. Other tests by Schoch showed that when the fire clay is burned at 1,280 degrees Centigrade it forms a porous mass, the bricklets show no cracks, and the total shrinkage is low. Schoch concluded that ordinary or medium-grade porcelainware could be made from the clay merely by adding feldspar or some other fluxing material. Results of tests conducted by Schoch (1931, p. 152) to determine the possible value of the fire clay for ceramic purposes are given in table 7.

SILVER MINE PASS DEPOSIT.—Kaolin has also been reported from Silver Mine Pass about 22 miles north of Uvalde and about 1½ miles southwest of the Concan road junction. The prospect workings are at the top of the pass about 100 yards north of the highway and the dump can be seen from the road (Flawn and Anderson, 1951).

The "kaolin" or calcareous clay is exposed in old prospect workings within a lenticular area about 300 feet long and 150 feet wide. The clay is a white or light brown calcareous clay locally stained red or brown with iron oxides. Black dendrites of manganese oxide occur in irregular cracks, and chert fragments, commonly broken nodules, are present in the clay. As seen in the workings, the clay occurs in a wedge-shaped body that is about 4 feet thick in the Old Spanish Shaft and thins to about 1 foot in the middle pit and is about 60 feet thick toward the southwest. There is no indication of any substantial tonnage.

OTHER DEPOSITS

KARNES COUNTY.—King (1940, p. 147) reported on white clay beds, prob-

TABLE 7. *Tests of the Leakey fire clays, Real County, Texas.*

Test Piece No.	Temperature of test cone	Temperature *Degrees C.*	Fire shrinkage Percent of dry volume	Percent porosity	Hardness	Color
L 1	08	990	2.96	33.9	Medium	White with slight cream tint
L 2	08	990	3.7	33.4		
L 3	06	1030	3.97	34.0		
L 4	06	1030	4.18	33.6		
L 5	04	1070	3.17	33.4		
L 6	04	1070	3.98	33.8		
L 7	02	1110	4.21	33.8		
L 8	02	1110	4.2	33.8		
L 9	1	1150	5.16	33.9		
L10	1	1150	5.44	32.9		
L11	3	1190	6.9	31.3	Hard	
L12	3	1190	6.62	32.0		
L13	5	1230	7.7	30.6		
L14	5	1230	7.95	31.0		
L15	8	1290	9.85	29.2	Very hard	
L16	8	1290	9.85	29.0		

ably in the lower part of the Jackson, that crop out on the old Kaspzik farm, half a mile north of Cestahowa Village, about 5 miles northeast of Falls City, Karnes County; his included analysis of sample U.T. 100, made by the Bureau of Industrial Chemistry, The University of Texas, is: raw color, white; shrinkage on drying, 8.5 percent; on firing, 16.0 percent; fired color, cream; fired condition, brittle. The sample collected by King was also tested for its bleaching properties (p. 107). A similar clay was also sampled at localities about 2½ and 6½ miles east of Pawelekville (Pl. II, Loc. 5, 6).

LA SALLE COUNTY.—King (1940, p. 143) reported a kaolin-like deposit in roadside cuts and ditches near the village of Los Angeles, La Salle County, between Cotulla and Fowlerton. The material is white, massive, and fairly soft when fresh but sufficiently hard on drying and exposure to have a conchoidal fracture. King reported that tests made by the Bureau of Industrial Chemistry, The University of Texas (sample U.T. 103), showed raw color, white; shrinkage on drying, 2.0 percent; on firing, 1.5 percent; fired color, cream; fired condition, good.

McMULLEN COUNTY.—King (1940, p. 143) reported on kaolin prospects in the

TABLE 8. *Tests on sample of clay from Franklin ranch, about 15 miles south of Christine, McMullen County, Texas* (Bureau of Industrial Chemistry, The University of Texas).

SAMPLE U. T. 102

Cone 010	
Color	Light buff
Condition	Very hard
Shrinkage	0.0
Porosity	41.2
Cone 08	
Color	Buff
Condition	Very hard
Shrinkage	1.0
Porosity	34.1
Cone 06	
Color	Buff
Condition	Very hard
Shrinkage	1.9
Porosity	35.5
Cone 04	
Color	Buff
Condition	Very hard
Shrinkage	1.7
Porosity	35.1
Cone 02	
Color	Light buff
Condition	Very hard
Shrinkage	1.8
Porosity	37.0
Cone 1	
Color	Light buff
Condition	Very hard
Shrinkage	2.6
Porosity	36.5
Cone 3	
Color	Light buff
Condition	Very hard
Shrinkage	3.0
Porosity	36.8
Cone 5	
Color	Light buff
Condition	Very hard
Shrinkage	2.9
Porosity	37.2

Chemical Analysis**

	Sample 1	Sample 2
SiO_2	73.05	71.15
Al_2O_3	9.27	10.68
Fe_2O_3	2.42	1.78
CaO	2.83	5.66
MgO	1.85	1.41
Na_2O	3.28	1.33
TiO_2	0.0	0.0
CO_2 and H_2O	6.38	7.94
Totals	100.65	101.03

**

1, as received.

2, washed to remove 20 percent of heavy matter.

Yegua formation on the Kuykendall and Franklin ranches in McMullen County. The Kuykendall prospect, about 10 miles northeast of Fowlerton, is exposed in a small gulley, and prospect pits extend over a considerable area. The rock is cream-colored and soft when fresh but turns white and hard on exposure; it is laminated and cross-bedded but breaks with conchoidal fracture across the bedding. Tests made by the Bureau of Industrial Chemistry of The University of Texas gave the following information for sample U.T. 101 (King, 1940, p. 143) : raw color, white; very hard; shrinkage on drying, 2.0 percent; on firing, 3.0 percent; fired color, cream; fired condition, fair.

The Franklin ranch joins the Kuykendall ranch on the northeast, and a similar deposit has been prospected about 1½ miles east of the Franklin ranch headquarters, about 15 miles south of Christine. King (1940, p. 144) reported that preliminary tests by the Bureau of Industrial Chemistry (sample U.T. 102) show raw color, white; shrinkage on drying, 7.0 percent; on firing, 4.5 percent; fired color, cream; fired condition, good. Complete tests showed dry color, white; very hard; plasticity, medium to low; shrinkage water, 17.3 percent; pore water, 19.3 percent; water of plasticity, 36.8 percent; drying shrinkage, 30.6. Additional detailed information on this clay deposit is given in table 8 (King, 1940, p. 145).

The Kuykendall (Pl. II, Loc. 3) and Franklin (Pl. II, Loc. 1) ranch deposits were sampled during the current investigation, and analysis data appear in table 3. Limited production has been reported from the Franklin deposit during recent years. Apparently the raw clay was trucked to Corpus Christi for processing, but the project was abandoned because of transportation costs. D. L. Mullen reported (oral communication, July 1960) that he had made limited shipments of clay from a deposit in McMullen County to one of the major oil companies, but he did not know what utilization, if any, was made of it.

A similar clay deposit is also present on the Jambers ranch about 2 miles north of Crowther (Pl. II, Loc. 5). A clay deposit on the John Dunn ranch, about 7 miles west of Tilden (Pl. II, Loc. 2), is exposed intermittently over an area about 1½ miles long and 100 to 200 feet wide; it is probably present in a much larger area beneath about 10 feet of overburden. The clay is a white kaolin-like material, very similar to the deposit on the Kuykendall ranch and is probably a continuation of that deposit. The clay is best exposed in three borrow pits, which were excavated for road material by the highway department.

WEBB COUNTY.—Clay from pits in the Jackson about 3½ miles west of Aquilares, Webb County (Pl. II, Loc. 16) was used by the Calto Brick Company about 30 years ago for the manufacture of refractory brick. The deposit is about 20 feet thick with 4 feet of overburden and covers an area of about 150 acres. It has not been utilized during recent years.

Lightweight Aggregate

The production and consumption of manufactured lightweight aggregate from clay and shale are rapidly increasing, and several trade-name products are now on the market. The raw clay or shale is heated rapidly in a rotary kiln or sintering machine to a temperature between incipient and complete fusion for the material. At this temperature gas is released but cannot escape because melting has developed a viscous molten jacket around the particle. As a result the clay masses expand or bloat to form light vesicular particles. Shales and clays containing either illites, montmorillonites, or chlorite-vermiculite minerals are the most promising sources of lightweight aggregate (Riley, 1951). The presence of large amounts of kaolinite in the clay will cause the material to be too refractory for economic use.

GOLIAD COUNTY. — Calcareous clay from about 2 miles west of Goliad (Pl. II, Loc. 2) bloated when fired at 2,000 degrees Fahrenheit (table 3, No. 60323). This is the site of some old kilns where, about 1890, common brick was produced from a blend of clay and river silt.

This material should be further tested for expanded aggregate.

MAVERICK COUNTY.—Clay from near the Rio Grande at the mouth of Rosita Creek (Pl. II, Loc. 8) bloated when fired at 2,000 degrees Fahrenheit (table 3, No. 60146). The amount of bloating was inadequate for a lightweight aggregate but was satisfactory for aggregate where lightweight materials are not specified. Further testing at various temperatures is recommended.

NUECES COUNTY.—In 1959 the Robstown Clay Products Company began producing aggregate from local clays at their Robstown plant, Nueces County (Pl. II, Loc. 15). The clay, 18 to 20 feet thick, is encountered beneath 5 to 6 feet overburden of black soil. A sand and sandy clay bed, 4 to 5 feet thick, is beneath the clay and there is more clay at a greater depth that has not been tested. The clay is dried, ground, and passed through a rotary kiln. In March 1961, the company was producing three sizes of aggregate which at that time was sold chiefly for manufacture of concrete blocks.

Pellets made from clay occurring about 8 miles south of Robstown (Pl. II, Loc. 10) bloated to a density of less than 50 pounds per cubic foot when heated for 10 minutes at 2,200 degrees Fahrenheit (table 3, No. 60293). Clays from this locality should be further tested as a raw materials source for producing lightweight aggregate.

SAN PATRICIO COUNTY.—Pellets from clay cropping out about 4 miles southeast of Mathis (Pl. II, Loc. 1) bloated to a density of 50 pounds per cubic foot when heated 10 minutes at 2,200 degrees Fahrenheit (table 3, No. 60182). Further testing is recommended to determine if the raw material is suitable for commercial production of lightweight aggregate.

STARR COUNTY.—Pellets from clay occurring about 5 miles southeast of Rio Grande City (Pl. II, Loc. 3) bloated to a density of 50 pounds per cubic foot when heated 10 minutes at 2,200 degrees Fahrenheit. This pit is owned by the Valley Brick and Tile Company which has been experimentally testing the materials with the thought of producing lightweight aggregate. There is little overburden in the immediate vicinity of the pit, but the clay is mixed with sand and gravel which would necessitate wasting the undesirable material (table 3, No. 60202).

Bonding Clays in Foundry Sands

Clays are employed in foundries to bind sand into molds in which metals are cast. Natural sand and clay mixtures, used for this purpose, are called naturally bonded sands. Recently custom mixtures of sand and clay, called processed molding sand, have become popular because by using mixtures of clean sand and specific types of clay the properties of the material (green, dry, hot strength, permeability, flowability, and plasticity) can be more closely controlled.

The bonding clays used in foundries are bentonites and fire clays. The southern bentonites from Mississippi, Louisiana, and Texas are largely calcium montmorillonite and they give an exceptionally high green strength to the molds. Fire clays which are composed mainly of kaolinite with some illite are used in the north-central states, but it requires two to three times as much fire clay to equal the strength qualities of the bentonites. Grim and Rowland (1940) showed that the mineralogy of the clay material used to bond the foundry sand controls the physical characteristics of the sand; with more clay the surface of the metal casing tends to be smoother.

FRIO COUNTY.—An iron-stained sandy clay reported to have been used several years ago as a bonding clay occurs in the Mount Selman formation and crops out along U. S. Highway 81 about 4.4 miles south of Pearsall, in Frio County (Pl. II, Loc. 2). A pit about 10 feet deep exposes but does not extend through the deposit. There are outcrops at the nearby airstrip and the material covers at least 10 acres. Analysis of a sample taken from the pit is included in table 43 (No. 60115), in pocket.

Bleaching Clays and Absorbents

The term bleaching clay as used in the

oil industry refers to clays that in their natural state, or after chemical or physical activation, have the capacity for absorbing coloring matter from oil. Three common types are fuller's earth, activated clays, and activated bauxite. Clays used to absorb oils, insecticides, alkaloids, vitamins, carbohydrates, and other materials are called absorbing clays.

Fuller's earth is a naturally active bentonitic clay that has the capacity to absorb coloring material from oil. The activity of some bentonites that have low natural activity can be increased by acid treatment so that they may have several times the bleaching capacity of the best fuller's earth. Activated bauxite is produced by calcining because in its natural state bauxite has very little activity. Kaolin has also been used as a decolorizing agent.

Fuller's earth is characterized by lack of plasticity, high water content, and a tendency to be strongly absorptive when dry. Acid-activated clays differ from fuller's earth in that they generally have a waxy appearance and slake or rapidly disintegrate in water.

Bentonite is a clay formed through alteration of or hydrothermal alteration of volcanic ash and is composed primarily of montmorillonite minerals. Acid-activated clays are usually prepared from nonswelling bentonite. Activated clay is prepared in both granular and powdered form and used predominantly in refining and decolorizing mineral and vegetable oils, fats, and waxes. Two methods are employed: (1) *percolation,* in which the oil passes through a bed of clay granules, and (2) *contact,* in which pulverized clay and oil are agitated together. In the latter process the clay is removed from the oil by filtration. The bleaching action in decolorizing oils is highly involved and not completely understood. It is not a simple straining or filtering action but appears to be selective absorption of color bodies and impurities by the clay. Factors that are known to affect the absorptive capacity include particle size, surface character, atomic structure, chemical and mineral composition.

In general, the south Texas bleaching clays are of lower quality than the bleaching clays produced east of the Mississippi River, but the area is favorably located with respect to market and thus enjoys a freight advantage.

SAN ANTONIO AREA.—King reported on bleaching clays of the San Antonio area, including in part clay deposits in the area of this present study. Data in table 9 are taken from King's work (1940, p. 150), and results of chemical and physical tests on certain samples are included in table 10 (King, 1940, pp. 175–178).

ATASCOSA COUNTY

Witherspoon ranch deposit. — King (1940, p. 178) reported that the clay in this deposit is a white, porcelain-like material

TABLE 9. *Details on bleaching clay deposits in San Antonio area.*

County	Location of deposit	Producer, owner, or lessee	Stratigraphic position	Status of operation
Atascosa	Halfway between Campbellton and Christine	Witherspoon ranch, J. R. Martin, lessee	Jackson group	Production several years ago; to be reopened
Gonzales	2.6 miles east and 5.6 miles south of Waelder	Bennett and Clark	Jackson group	Operated in 1934
Gonzales[a]	6.5 miles south of Gonzales	Earthen Products Company	Jackson group	Operated in 1934
Karnes	Cestahowa, 5 miles northeast of Falls City	Kaspzik farm, J. R. Martin, lessee	Jackson group	Prospect
Karnes	Conquista Crossing, 4 miles west of Falls City	None	Jackson group	Said to have produced years ago

[a] Clay is naturally active but not activeable.

TABLE 10. *Data on tests of bleaching clays in San Antonio area.*

Deposit	Sample	Raw G	Raw Y	Raw R	Raw B	Acid-treated G	Acid-treated Y	Acid-treated R	Acid-treated B	Acid removal Fe	Acid removal Al	Acid removal Ca	Off (percent)
Witherspoon		0.5	0.7	0.8	0.9	0.5	0.7	0.9	1.1	3	5	2	30
Waelder	Bed being worked	0.7	0.9	1.0	1.1	0.8	1.0	1.2	1.4	5	4	1	25
	Overburden	0.6	0.8	0.9	1.0	0.6	0.7	0.8	0.9	5	4	1	20
Gonzales	G-1	0.9	1.2	1.4	1.8	1.0	1.2	1.4	1.7	Tr.	6	4	15
	G-1a	....	....	....	....	0.4	0.5	0.7	1.0	Tr.	6	4	15
	G-2	0.4	0.5	0.6	0.8	1.1	1.5	1.8	1.8	4	5	1	25
	G-3	0.5	0.6	0.7	0.8	1.2	1.5	1.8	2.1	2	5	3	30
Cestahowa		0.4	0.6	0.7	0.8	0.6	0.7	0.8	0.9	0	7	3	15

Abbreviations: G=green; Y=yellow; R=red; B=black; Fe=iron; Al=aluminum; Ca=calcium.

with faint bedding. About 6 feet is exposed in a pit; overburden is about 3 feet.

McCammon (1942) studied the clays in Atascosa County and reported on several gypsiferous iron-stained, bentonitic clay deposits. About half a mile south of the Black Hills School in the eastern part of the county about 8½ feet of bentonitic clay occurs at a depth of 3½ feet. A bentonitic bed 8 feet thick below 3 feet of overburden was reported about 6 miles southwest of Jourdanton. Ten feet of clay beneath 5½ feet of overburden was reported from a locality half a mile southwest of the old Hitchcock School. Bentonitic clay was penetrated during exploration on the Guy Smith ranch 4½ airline miles southwest of McCoy and on the Harrison-Abercrombie ranch 1½ miles west of Metate Creek on the Campbellton-Christine road. The Smith deposit is a rectangular body about 450 by 730 feet in area, and the clay mass is 3½ to 4 feet thick at a depth of 1 to 15 feet. The Harrison-Abercrombie deposit is about 250 feet wide, 2,500 feet long, and 5 feet thick. Logs from these localities are included in McCammon's report (1942, pp. 7–9).

GONZALES COUNTY

Waelder deposit.—King (1940, p. 175) reported that the workable bed in this deposit comprised 3 feet of waxy, gray-brown, laminated clay underlying 2 to 10 feet of waxy, gray, brittle clay, somewhat lighter colored than the clay that was being utilized. Chelf (1942, pp. 6–7) stated that the first pit opened near Waelder was by the Bennett and Clark Company on the J. L. Johnson land, 2.5 miles east and 5.5 miles south of the town. The workings are on a northeastward-sloping hillside, and mining has proceeded down dip and along the strike of the beds. Near the outcrop, overburden was thin, but in later down-dip operations as much as 12 feet was removed.

The mined clay occurs in a 2.5- to 3-foot stratum and is brown when fresh. Grayish-brown overlying and underlying beds are like the commercial material. Other pits in this area have recently been opened in beds equivalent in age to those in the Hell's Gate pits. These recently mined clays are of the same quality as the other Wellborn clays. Little prospecting has been done in this area of the county.

Gonzales deposit.—King (1940, p. 175) reported that this deposit was first opened in 1906 for the production of china clay. In 1934 the deposit was exploited for bleaching clay. The clay is white or bluish white with an opaline appearance when wet; it dries with a porcelain-like texture. The thickness range is 5 to 14 feet, with 15 to 20 feet of overburden. Similar deposits occur on the Oscar Dubois [DuBose] farm about 1 mile toward the west, and King (p. 176) reported that the producing bed had been traced by auger holes along the strike for several miles both northeast and southwest.

Much of the following data on bleaching clays in Gonzales County are from Chelf (1942, pp. 5–9).

Bentonite in the Mount Tabor member of the Cook Mountain formation.—Bentonite occurs on the A. M. and M. D. Lindemann farm one-fourth of a mile north of Cost on a small stream known as Lindemann Slough. In a 45-foot sequence of dark chocolate-colored shale, gray shale, and sand, there is a 20- to 24-inch stratum of drab-green bentonite which contains abundant biotite. The upper 12 to 14 inches is waxy clay, uniform in grain, soapy, and disintegrates readily upon drying. This bed can be traced laterally for more than a hundred yards along the exposure, but recent slumping has partly covered the outcrop.

Bentonite in the Yegua formation.—Bentonite occurs in the Yegua formation on the Hunter Cook farm about three-fourths of a mile north of State Highway 183, 6 miles southwest of Gonzales. In a test pit, 9 feet of bentonite containing thin seams of ash occurs beneath 9½ feet of brown glauconitic carbonaceous sandstone. The bentonite is a light gray soapy variety, somewhat gritty because of included ash. The overlying sandstone is cross-bedded and carries numerous well-preserved leaf and stem imprints, as well as occasional seeds. This rich-colored brown stone has been used locally for chimneys; in recent years the State Highway Department used this rock to build part of the retaining walls on the south bank of Guadalupe River at the bridge south of Gonzales.

Bentonite in the Jackson group.—The principal bentonite beds in Gonzales County are in the Jackson group and have been known locally for many years; beds in the Caddell and McElroy formations are currently being mined. Beds of possible commercial importance in the upper part of the Jackson group were discovered by Chelf. Jackson bentonites include white, cream, and pink varieties which have a kaolin-like appearance when dry. Production has been largely from the Hell's Gate area, 6 miles south of Gonzales; the Kent DuBose land, 7 miles southeast of Gonzales on the Shiner road; and the Bennett and Clark pit, 6½ miles southeast of Waelder on the Waelder-Moulton road.

Hell's Gate deposit.—Six miles south of Gonzales on the east side of State Highway 29 on the Lou DuBose and Oscar DuBose tracts, a series of abandoned pits extends for approximately 1.6 miles from the highway to the bluff known as Hell's Gate on Guadalupe River. This is perhaps the best known bentonite occurrence in the county and was formerly worked by the Coen Company and later by the Earthen Products Company. Practically all of the available clay has now been extracted. The cream-colored bentonite occurs as a long and narrow wedge-shaped bed in the Wellborn formation less than an inch thick on the outcrop and gradually increasing down dip to a maximum thickness of 4 feet where it suddenly terminates at an intra-formational unconformity. This unconformity is also present approximately 2 miles northeast in other clay pits on the Kent DuBose tract. The bentonite and associated chocolate-colored shale exhibit a much greater dip than the underlying Wellborn sandstone and shale. At the down-dip side of the pit as much as 25 feet of overburden was removed to extract approximately 4 feet of clay. The clay on the up-dip side of the old pits is heavily impregnated with limonite, but in the thicker down-dip section it is relatively free of included matter. Iron occurs only between bedding planes and joints and is of no serious consequence. Bentonite in the lower part of the section is soft, somewhat mealy, and grades into, or sometimes rapidly changes to, a bedded, hard, conchoidally fracturing material. The harder stratum is generally overlain by a clay somewhat like the lower bed. The more indurated part of the stratum has been mined. Tests on clays from these deposits made by P. G. Nutting, of the United States Geological Survey, indicated that they are naturally active but not activable. The following comments are taken from Nutting's report (King, 1940, p. 177):

> The sample from the pit being worked by the Earthen Products Company south of Gonzales is a fairly good fuller's earth and is not increased in bleaching power by acid treatment. It is chemically exceedingly tough, so we gave it a longer leach which halved the bleaching power. The material appears to have been pure bentonite, high in calcium. The underlying bentonite is nearly normal, but a little too much leached to be of commercial interest.[3]

[3] Practically all of the clay has been used since King's investigation.

Kent DuBose deposit.—Mines on the Kent DuBose land are located approximately 6.5 miles southeast of Gonzales on the east side of State Highway 183. These pits are in the Wellborn formation in an eastern extension of the Hell's Gate beds.

Mining extends northeast from the highway for approximately 1 mile. The clay is recovered from the outcrop down dip until the thickness of overburden makes the operation uneconomical. Because of the relatively steep dip, operations are confined to a relatively narrow strip along the strike. A large area was mined near the highway where the favorable hill slope made the clay available at shallow depths. In the pits that are worked at present, 15 feet of overburden is removed for approximately 15 inches of clay.

In recent pits the bed being mined lies beneath 15 feet of gray to chocolate-colored shale. The central hard stratum of mined clay is a delicate flesh-pink variety, somewhat opaline in appearance when fresh, which breaks into large flattened rectangular blocks. Limonite adheres to the clay along bedding planes and is present in the oblique cracks developed in the clay. This is largely removed with steel brushes before shipment.

Kennard deposit.—Pits have recently been opened on the Kennard tract immediately across State Highway 183 and south of the Kent Dubose mines in beds which are extensions of those in the DuBose and Hell's Gate pits.

The mined stratum is pink in the pit near the highway, but soapy white and grayish-blue clays are also present in the same pit. The clay is like that of the Kent DuBose mines. This tract, although not large, contains a fair quantity of clay.

Reed ranch deposit.—The Reed area is located approximately 8 miles southeast of Gonzales and 1 mile south of the Gonzales-Shiner highway. The deposits are approximately southwest of the Kent DuBose and Kennard pits. The outcrop of the bentonite strikes N. 60° and is easily traced because a small stream follows the outcrop. The minable part of this bed in the area drilled varies from 12 to 16 inches in thickness. The Reed ranch bentonite is hard, brittle, white to pinkish-colored and has a conchoidal fracture. The fresh clay has a soapy, waxy texture and can be cut into thin shavings like soap. It is relatively pure, the main contaminant being thin layers of limonite along the bedding planes.

Hinton farm deposit.—A stratum of soapy white bleaching clay from 6 to 8 inches in thickness is located on the J. R. Hinton farm, 8 miles south of Gonzales in a highly gullied area immediately below the DuBose cemetery. Here beds of cross-bedded sandstone, ash, and clay dip gently to the northwest. Although the stratum of hard clay is thin, there is little overburden.

Oscar DuBose deposit.—A brownish-red to chocolate-colored fatty bentonitic clay is mined from a pit on the Oscar DuBose farm near State Highway 29, 9.5 miles south of Gonzales. This clay is similar in appearance to that in the old Bennett and Clark pit near Waelder. Clay from this pit was used by the Milwhite Company. The producing beds grade laterally into sands and ashy clays.

Terryville deposit.—A large bentonite deposit is located in the vicinity of Terryville, southwest of Gonzales. Exploration along the outcrop proved the existence of a thin but persistent bed of clay covering many acres. The clay lies in a long narrow basin on top of sandstone which in part is highly cross-bedded and quartzitic. The clay is overlain by volcanic ash which attains a maximum thickness of 21 feet.

Drill holes penetrated volcanic ash, partially altered ash, and hard bentonite. This sequence apparently lies on an eroded surface on the quartzitic sandstone. The clay is white to cream colored, very hard and brittle, breaks into rectangular blocks, and has good conchoidal fracture; the best bleaching clay is 1 to 1.5 feet thick. Due to the hardness of this material, it does not disintegrate as rapidly as other clays in the county.

The best exposures of clay are on the Terryville State School land and the Joe Dunning tract, but the clay is also exposed on the Robert Nelson and Will Brassfield farms. The quality of the clay, the available quantity, and relatively shallow overburden make the Terryville clay one of the most promising deposits examined.

Guy Moore deposit.—A bed of white brittle bentonite about 1 foot thick occurs on the Guy Moore farm near Terryville. The exposure, about 250 yards from the Guy Moore house, is in a new channel of a small stream formed by the stream's cutting around an earth dam. Preliminary testing by Chelf showed that several carloads were available; prospecting would probably indicate additional tonnage. At the outcrop there is about 3 feet of overburden but this thickens rapidly down dip.

GUADALUPE COUNTY.—Tests of a clay sample (table 3, No. 60194) from near York Creek, about 12 miles north of Seguin, indicate that the clay has medium capacity as an oil decolorizer and is a potential source for drilling mud (Pl. II, Loc. 8).

KARNES COUNTY.—Tests of clay from a deposit about 3 miles southwest of Gillett (Pl. II, Loc. 6), collected in this present investigation, showed a high oil-decolorizing capacity after acid-activation (table 3, No. 60326). As a bleaching clay, the sample tested 117 percent as compared with the American Oil Chemists Society official activated earth; and when calcined the oil-absorbing capacity is 84 percent (commercial oil-absorbing floor sweep is 110 percent). Clay from about 4½ miles northeast of Falls City (Pl. II, Loc. 2) has an oil-decolorizing capacity of 50 percent as compared with the American Oil Chemists Society official activated earth (table 3, No. 60197) ; and an oil-absorbing capacity of 101 percent when calcined at 450 degrees Centigrade. Further testing of the clay at both localities is recommended.

Cestahowa deposit.—King (1940, p. 177) reported white clay, possibly of commercial interest, on the Kaspzik farm about 5 miles northeast of Falls City. The clay is 4 to 5 feet thick, soft and soapy when fresh, but hard and porcelanic when dry.

Conquista Crossing deposit.—During the Civil War a sugar mill was located at Falls City because of the availability of fuller's earth at Conquista Crossing for bleaching the sugar (King, 1940, p. 178). King did not sample or test the deposit; he was told by J. R. Martin that the clays at Conquista Crossing are inferior bleaching clays but might be suitable for the ceramic industry.

WEBB COUNTY.—After acid activation, clay from about 10 miles northwest of Mirando City (Pl. II, Loc. 16) showed an oil-decolorizing capacity of 62 percent as compared with the American Oil Chemists Society official activated earth (table 3, No. 60175). This clay is also a potential source of drilling mud and should be further tested for both industrial uses. Fair to medium oil-decolorizing capacities were obtained from clay samples collected near the Rio Grande (Pl. II, Loc. 6); northeast of Laredo (Pl. II, Loc. 8); and east of Laredo (Pl. II, Loc. 10). Details of the tests are shown in table 3 (Nos. 60167, 60169, and 60171).

ZAPATA COUNTY.—Clay with an oil-decolorizing capacity of 62 percent, compared with the American Oil Chemists Society official activated earth, was collected near Bustamante (Pl. II, Loc. 1). Clay with fair oil-decolorizing capacity was collected from a locality about 4 miles northwest of Zapata (Pl. II, Loc. 3). For detailed analyses, see table 3, Nos. 60178 and 60180.

Mineral Fillers and Pigments

Clays are employed as fillers and pigments in paper, paints, plastics, rubber, pesticides, fertilizers, textiles, linoleum and other floor coverings, adhesives, medicines, and many other products. Most of the domestic clays used in these industries are sedimentary kaolins from the southeastern United States, principally from Georgia, South Carolina, and Florida. The only clay known in the area of study that might be suitable is the Leakey kaolin in Real County (Pl. II, Loc. 1–3).

Catalysts

The use of catalysts in the petroleum industry has undergone a tremendous expansion in recent years, and the manufacture of cracking catalysts is a major industry. The cracking process involves the passing of oil at a temperature range of about 425 to 500 degrees Centigrade over the catalyst where a residue commonly called "coke" is deposited. In general, 0.5 to 1.5 tons of catalyst are circulated per barrel of crude oil (Milliken, Oblad and Mills, 1955). Circulation, temperature changes, and exposure to various organic compounds and steam require that the catalyst have a high degree of physical and chemical stability.

The industrial use of clays as catalysts started about 1931. The clay minerals used as cracking catalysts are montmorillonite, halloysite, and kaolinite. Very few montmorillonite clays yield satisfactory catalysts; in general, the sub-bentonites have yielded the best results. The montmorillonite is treated with acid to remove part of the basic components in the clay and thus increase the catalytic activity, but there is no simple physical or chemical test to determine whether or not the montmorillonite will respond to acid treatment and produce a suitable catalyst. Halloysite and kaolinite are activated by acid treatment and then calcined. The surface area of the catalyst produced from kaolinite and halloysite is lower than that of a montmorillonite catalyst.

Several of the important bentonites and sub-bentonite deposits in south Texas have been discussed under bleaching clays, but their suitability as catalysts is not known. Tests to determine the catalytic value of the Leakey kaolin and the kaolin-like clays in McMullen County have not been attempted.

Halloysite occurs at Cedro Hill, in west-central Duval County southwest of Freer (Pl. II, Loc. 7). The following description is taken from Sayre (1937, p. 74). Cedro Hill, about 25 feet high, is made up of light-gray to white tuffaceous clay or clayey tuff, which grades westward into a thoroughly indurated gray tuffaceous sandstone. At the base of the east side of the hill is a sandy conglomerate composed largely of fragments of chalcedony and igneous rock firmly cemented with blue translucent chalcedony. The east side of the hill is formed by a dike-like body of dense, fine-grained, massive, white halloysite which breaks with a conchoidal fracture. The dike-like mass is about 25 feet high, 15 feet wide, 50 feet long, and trends N. 10° E. The halloysite mass is terminated on the south by a vein of reddish-brown opal from 1 foot to several feet thick that trends west-northwest. North of the halloysite dike is a vein of fibrous calcite from a few inches to 10 feet in width, which trends east-northeast and extends with one interruption for a distance of 800 feet east of the ranch road that passes near the base of the hill. Sayre (1937, p. 74) included a sketch showing these relationships. Halloysite-like material also crops out about 1½ miles northeast of Cedro Hill (Pl. II, Loc. 9). This deposit is also a vein or dike-like mass at the base of a silica knob; the material is siliceous. The strike is approximately the same as that of the mass at Cedro Hill.

Drilling Muds

The rotary method is now the most widely employed system for drilling deep wells. A drilling fluid or mud is circulated in the hole at all times while the drilling is in progress to (1) remove the drill cuttings from the hole, (2) form a filter cake on the wall of the drill hole and prevent water in the rock formations from entering the hole, (3) cool and lubricate the bit, and (4) prevent blowouts.

Common drilling mud consists of water to which clay is added to increase viscosity and shearing strength and impart thixotrophy; the resulting substance is fluid when agitated and gelatinous when static. Only certain clays will impart these characteristics to the mud. The most widely used clays are the bentonites; attapulgite is in demand in some areas because it does not flocculate in salt water. Illites and kaolinites are not used for drilling muds because they are not thixotropic.

In the area of this investigation, the principal bentonites occur within the Jackson group and Frio and Catahoula formations. The best and most extensive bentonite deposits are in Karnes and Gonzales counties and are generally found in the lower part of a volcanic ash sequence (Pl. II).

Netzeband and Girard (1960) reported that the Texas bentonitic clay production in 1959 increased 10 percent over the 1958 production, with Angelina, Walker, and Gonzales counties as the principal producers. Nearly 80 percent of the bentonitic clay produced was used for preparation of drilling muds; the remaining 20 percent was used for filtering and bleaching media. In Gonzales County the Baroid Division of the National Lead Company and the Southern Clay Products Company mined bentonitic clays from open pits and processed the raw clay materials.

GONZALES COUNTY.—In Gonzales County the bentonitic clays are found predominantly in the clays of the Jackson group, the Catahoula formation, and to a limited extent in the Cook Mountain formation. They have a rather wide range in physical characteristics, and changes occur between adjacent pits within the same formation.

Colors include white, gray white, light and dark cream, pink, olive gray, light and dark gray, dusty yellow, greenish yellow; the light shades are commonly stained yellow or yellowish brown along the bedding plane and fractures. Some of the clay is hard with conchoidal fracture. Some is hard and waxy and some is soft; the hardness varies at different levels within the same deposit.

Several of the largest bentonitic clay deposits in Gonzales County were discussed by Chelf (1942) (*see also* pp. 52–55). Subsequent to Chelf's report, W. S. Rogers, Southern Clay Products, Inc., Gonzales, Texas (1946–1947) directed an exploration program throughout the county to locate unexploited bentonite deposits at shallow depth. Mr. Rogers graciously made his notes available to the writer. Harris (1961) mapped the southern part of Gonzales County and studied the bentonites. Studies by Rogers and Harris have produced the following data on bentonitic clays of Gonzales County.

Along U. S. Highway 90-A toward Shiner, about 7 to 8 miles east of the Gonzales County Courthouse and about 114 miles west of the Peach Creek bridge, pits have been excavated in bentonitic clay beds on both sides of the highway. The pit on the northern side of the road is the Kent DuBose pit described by Chelf (1942) and is now under lease to Jim Abercrombie. Harris (1961) reported that 50 to 100 acres of bentonite with an average thickness of 4 feet and less than 30 feet of overburden are available for mining at this locality. The pit south of U. S. Highway 90-A (Chelf's Kennard pit) is now under lease to Southern Clay Products, Inc. Here about 5 feet of bentonite underlies an area of approximately 100 acres. Test borings in the area surrounding the pits indicate 2 to 3 feet, locally as much as 6 feet, of bentonite beneath 30 feet of overburden (Rogers, 1946–1947).

Bentonite has been mined on the Reed ranch about 1 mile southwest of the Kennard pits (Chelf, 1942). This deposit, also leased by Southern Clay Products, Inc., is crossed by an improved gravel road that turns south off U. S. Highway 90-A about 6 miles from the Gonzales County Courthouse. Exploratory drilling indicates bentonite beds 3 to 4 feet thick, maximum thickness to 5 feet, beneath an overburden of 20 to 30 feet thick over an area of 200 to 300 acres. The Helms deposit, south of Highway 90-A and about 1¾ miles west of the DuBose-Kennard pits, is also leased to Southern Clay Products, Inc.; in this area 3 to 5 feet of bentonite occurs beneath 5 to 6 feet of overburden. About 2 miles north of the junction of Highway 90-A with Farm Road 443, and along a country road southeast of Dilworth toward Sunset School, 2½ feet of bentonite crops out in a wash; the overburden is about 20 feet thick.

The Hell's Gate deposit, described by Chelf (1942), has been previously discussed (p. 53). About 2½ miles farther south, bentonite crops out on both sides of U. S. Highway 183; and still farther southeast, near the Hamon triangulation station, a narrow bentonitic bed extends from the country road east of Highway 183 northeastward to the Guadalupe River. Here exploratory drilling demonstrated 12 feet of bentonite beneath 10 to 15 feet of overburden in an area of about 200 acres (Rogers, 1946–1947).

In the vicinity of the Terryville School, on the Cheapside road west of U. S. Highway 183 and southeast of Gonzales, bentonitic clay beds 1 to 5 feet thick, average 2 to 2½ feet, occur beneath 8 to 12 feet of overburden (maximum is 27 feet) (Chelf, 1942; Rogers, 1946–1947). The clay extends from 1 to 1½ miles southwest of the school land.

Bentonite 1 to 2 feet thick occurs at a dozen or more localities along the Gonzales-Pilgrim road (Rogers, 1946–1947). About half a mile north of Pilgrim, 6 feet of bentonite was encountered at a depth of 25 feet; 4 feet of bentonite with 12 feet of overburden was encountered 3 miles north; and 2 feet of bentonite with up to 23 feet of overburden was encountered in exploratory holes 1½ miles west of that town.

Bentonitic clay has been mined and shipped from an exposure in a creek bed about 200 yards east of the store on U. S. Highway 87 at Sample. This clay crops out for about one-fourth mile along the stream and also for a similar distance along Highway 87 northeast of the store.

Bentonitic clay beds 1 to 6½ feet thick with 7 to 18 feet of overburden were encountered in test holes along the road between Forest Home School and Smiley, and bentonite crops out along a branch of Sandy Creek about half a mile east of Forest Home School (Rogers, 1946–1947). The thickest deposit is about 2 to 2¼ miles north of the school where overburden is 11 feet thick. Bentonite also crops out about 2 miles south of Rocky School, 10 miles south of Smiley, where three beds about 2 feet thick are exposed. Thin bentonite beds occur on the west side of Farm Road 108 about 5 miles southeast of Smiley.

On the Harry W. Schieberle property, immediately east of State Highway 95 and about half a mile east of Cost, 11½ feet of bentonitic clay with only 5 feet of overburden is exposed in an abandoned pit and similar thicknesses were penetrated in test holes (Rogers, 1946–1947). Other test holes in the surrounding area encountered 1½ to 2 feet of bentonitic clay with 15 to 40 feet of overburden. One hole penetrated 4 feet of clay at a depth of 46 feet. On the John Hassman farm southwest of Cost and near the intersection of State Highway 97 and Farm Road 1297, about 1½ to 2 feet of bentonite is exposed in a narrow area about three-fourths of a mile long. Exploratory drilling in the vicinity and on the nearby McNabb farm indicated 1½ to 2 feet of bentonitic clay beneath 8 to 16 feet of overburden.

Near the Nickel community on Farm Road 532 east of Gonzales toward Moulton, bentonitic clay has been mined from at least four pits. Southern Clay Products, Inc., has a mining operation about half a mile south of that community. Bentonitic clay is also present along the country road, east of State Highway 97, between Saturn Church and Hickston, northeast of Gonzales.

Bentonitic clay is exposed in abandoned pits near the western limits of Waelder; at the Farm Road 1680 crossing on Baldridge Creek, east of Waelder; and still farther east near where Highway 1680 crosses Peach Creek. At the Peach Creek locality about 4 to 5 feet of bentonitic clay is exposed beneath about 25 feet of overburden. It is reported that up to 15 feet of bentonite was excavated in some of the older workings. Still farther east between Bear and Salt branches of Peach Creek, 2½ to 3 feet of bentonitic clay was extracted from the old Bennett and Clark pit on each side of Highway 1680. Immediately adjacent to the Gonzales-Lavaca County line about 1 mile southwest of Highway 1680, bentonitic clay has been excavated from two abandoned pits. South of U. S. Highway 90, and about 1 mile south of where that highway crosses the Gonzales-Fayette County line, 2 feet of bentonite is exposed in an abandoned pit.

ATASCOSA COUNTY.—In addition to the information on bentonites in Gonzales County, Rogers (1946–1947) reported bentonitic clay about 1 mile west of

Campbellton in Atascosa County. The clay crops out along the gravel road that intersects U. S. Highway 281 about half a mile northwest of Campbellton and extends southwestward to the San Miguel oil field. The bentonite is about 5 feet thick with 4 feet of overburden. Farther southwest along this same road, about 9 miles from Campbellton, 4 feet of bentonitic clay beneath 4 feet of overburden was encountered in an auger hole in the bottom of a small pit. Hard bentonitic clay, about 4 feet thick, occurs along Farm Road 99 about midway between Fashing and the Atascosa-Karnes County line.

BEE COUNTY.—Tests from a bentonitic clay about 5 miles northwest of Pettus (Pl. II, Loc. 2) show that the material is capable of yielding 53 barrels of 15-centipoise drilling mud per ton of clay when treated with sodium carbonate (table 3, No. 60310). The sample also shows a capacity for bleaching, and it is recommended that this material be further tested to determine its potential value as a commercial source of drilling mud and/or bleaching clay.

JIM HOGG COUNTY.—A clay sample from northwestern Jim Hogg County (Pl. II, Loc. 5) when treated with sodium carbonate yielded 60 barrels of 15-centipoise drilling mud (table 3, No. 60160). If the chemical treatment is varied, it is possible that the yield can be improved. Further testing with specialized equipment is suggested.

KARNES COUNTY.—Rogers (1946–1947) reported that 168 test holes were drilled along county roads and highways radiating from the village of Gillett in northwestern Karnes County. Most of the clays encountered were hard, brittle, earthy, and reacted slowly when tested. A few small deposits may have commercial value. North of Gillett about three-fourths of a mile from where the old county road intersects State Highway 80 a cream-colored clay 5 feet thick crops out over an area 300 to 400 feet wide and 1,000 feet long (possibly 6 to 8 acres). Another deposit of similar size underlies the Patton homestead and service station, and a third with about the same dimensions crops out along Eclato Creek on the Patton property. About 2 miles south of Gillett an east-west country road crosses Eclato Creek and along that road east of the creek a fourth deposit of similar clay was observed.

Rogers (1946–1947) reported that 15 feet of pure white bentonite crops out in a test pit along the banks of a dry wash about half a mile west of the general store at Czestochowa, north of Karnes City, north-central Karnes County. Also in north-central Karnes County, there are small deposits of bentonite about one-fourth mile south of Harmony School and about one-fourth mile west of Jolly Land School. Bentonite is exposed along a country road to Mound Creek School about 1 mile south of Gillett and about 5 miles east of Highway 80.

LA SALLE COUNTY.—Tests on a clay sample from northeast of Cotulla (Pl. II, Loc. 7) showed a yield of 68 barrels of 15-centipoise drilling mud after chemical treatment of the clay (table 3, No. 60162). Varying the chemical treatment of the clay may improve quality of product, and further testing is suggested.

LIVE OAK COUNTY.—Clay from east-northeast of Oakville (Pl. II, Loc. 12) showed a test yield of 53 barrels of 15-centipoise drilling mud and 56 barrels after chemical treatment (table 3, No. 60141). A sample from locality 13 showed a yield of 55 barrels following chemical treatment (table 3, No. 60142). Clay from localities 12 and 13 was used locally for drilling mud during a short period ending about 1930. The drilling mud was reported to be of low quality and there has been no recent utilization. The clay covers an area of several acres and is best exposed in the old pits, where it is about 6 feet thick (Pl. II, Loc. 12, 13).

Rogers (1946–1947) reported a bentonite pit on the Martinez farm in the northeastern part of the county along the road to Mineral. The bentonite is low quality and has not been utilized in recent years.

McMULLEN COUNTY.—Drilling mud tests were made from clay at localities 1, 2, 3, and 5 (Pl. II) but all gave a low yield and probably are not commercial sources of drilling mud (table 3, Nos. 60094, 60098, 60101, 60102, 60120, and 60121).

NUECES COUNTY.—Clay occurring southwest of Corpus Christi (Pl. II, Loc. 13) after treatment with sodium carbonate yielded 54 barrels of 15-centipoise drilling mud per ton of clay (table 3, No. 60296). The yield per ton of clay may be improved by varying the chemical treatment and further testing is suggested.

REFUGIO COUNTY.—A clay sample from near Refugio (Pl. II, Loc. 2) yielded 58 barrels of 15-centipoise drilling mud per ton after chemical treatment (table 3, No. 60341). Variation of the chemical treatment may improve the yield and additional testing is suggested.

SAN PATRICIO COUNTY.—Clay that appears to be a source of premium drilling mud was obtained about 4 miles southwest of Mathis (Pl. II, Loc. 1). The air-dried clay yielded 47 barrels of 15-centipoise drilling mud per ton; when the clay was chemically treated the yield of drilling mud was increased to 66 barrels per ton (table 3, No. 60182). Tests were also made from clay at localities 3, 9, and 10 (Pl. II) which yielded only about 49 barrels of 15-centipoise drilling mud per ton after chemical treatment (table 3, Nos. 60298, 60304, and 60305). Further testing of the clay especially from locality 1 is recommended.

WEBB COUNTY.—Tests on a clay from about 10 miles northwest of Mirando City (Pl. II, Loc. 16) indicate a premium drilling mud. Tests of air-dried samples yielded 55 barrels of 15-centipoise drilling mud per ton of clay and after chemical treatment the yield was increased to 66 barrels (table 3, No. 60175). The clay is also a potential bleaching clay after acid activation. Another clay sample from an outcrop along Chacon Creek, about 5 miles northeast of Laredo (Pl. II, Loc. 8), yielded 55 barrels of 15-centipoise drilling mud per ton after chemical treatment (table 3, No. 60169). Further testing is recommended for the clay from both localities.

At Ten Mile Hill, on U. S. Highway 59

TABLE 11. *Ceramic tests of clays from miscellaneous localities in south Texas area.*[a]

Sample No.	Water of plasticity	Air shrinkage	Average tensile strength	Plasticity	Slaking	Texture	Cone 05 Shrinkage	Cone 05 Absorption	Cone 03 Shrinkage	Cone 03 Absorption	Cone 1 Shrinkage	Cone 1 Absorption	Cone 3 Shrinkage	Cone 3 Absorption	Cone 5 Shrinkage	Cone 5 Absorption	Cone 9 Shrinkage	Cone 9 Absorption	Cone 14 Shrinkage	Cone 14 Absorption	Vis. at Cone
802	24.2	10.1	167	G	Sl	....	3.0	4.7	......	......	......	......	......	......	......	......	......	......	......	......	....
803	23.1	9.6	202	G	Sl	....	5.0	2.0	6.0	0.0	......	......	......	......	......	......	......	......	......	......	....
804	23.1	8.0	301	Fa	VSl	....	4.3	8.2	5.3	7.0	5.0	6.5	5.6	7.2	5.6	5.8	6.0	4.2	......	......	14
805	23.1	9.1	258	H	Sl	....	4.0	8.8	5.4	7.0	6.0	6.7	6.0	7.0	6.2	6.6	......	......	......	......	....
806	17.6	4.7	149	L	Fst	C	—1.0	19.3	0.3	18.6	4.3	8.3	5.6	3.7	......	......	......	......	......	......	7
813	17.6	6.0	301	L	Fst	C	—1.3	......	0.0	......	—1.0	......	2.3	......	3.4	......	......	......	......	......	....
816	19.8	8.3	357	Fa	Fst	M	1.0	23.1	1.3	22.7	0.3	22.1	0.3	21.7	1.6	14.1	......	......	......	......	7
817	19.8	6.5	266	G	Sl	C	0.7	26.5	0.0	26.3	0.0	26.5	1.7	24.5	0.7	22.4	......	......	......	......	7
818	29.7	9.6	20	L	Sl	C	1.4	16.0	2.0	15.0	1.3	14.6	1.6	13.8	5.7	4.6	......	......	......	......	9
820	35.2	10.6	15	L	Sl	F	6.4	13.7	7.7	12.2	6.7	13.4	7.0	12.1	7.0	12.9	8.3	8.6	12.0*	1.8	....
833	44.0	6.9	159	VL	Sl	....	5	32.8	6	29.9	10	20.5	13.3	13.5	13.7	10.7	14.7	8.6	......	......	35

* Dry press.

Abbreviations: C=coarse; F=fine; Fa=fair; Fst=fast; G=good; H=high; L=low; M=medium; Sl=slow; V=very.

[a] Potter, A. D., and McKnight, David, Jr. (1931) The clays and the ceramic industries of Texas: Univ. Texas Bull. 3120, pp. 167–175.

about 10 miles east of Laredo, Rogers (1946–1947) reported 1 to 2 feet of bentonite in a road cut. Similar exposures occur along the Ten Mile Hill escarpment for several miles toward the south and also farther northeast in the vicinity of northwestern Duval County.

ZAPATA COUNTY.—Clay samples from near Bustamante (Pl. II, Loc. 1) and about 4 miles southeast of Zapata (Pl. II, Loc. 2) after chemical treatment yielded 49 barrels of 15-centipoise per ton drilling mud (table 3, Nos. 60178 and 60179). Sample No. 60178 responded favorably as a bleaching clay.

Further testing is suggested for the clay at both localities.

Cement

Large quantities of clay and shale are used as a source of alumina and silica in cement manufacturing. Most common clay or shale is satisfactory. The Halliburton Portland Cement Company at Corpus Christi blends local clay and oyster shell. Many thousands of acres of clay suitable for this purpose are available within the area of this report.

Miscellaneous Uses

In the southwest and western part of this area large tonnages of clays are used in the manufacture of adobe brick for construction of homes and buildings. Specifications for the clay are not strict. Highly bentonitic varieties are the least desirable. Small adobe brick plants operate at Laredo, Eagle Pass, and Del Rio, and many individuals make adobe brick from local materials. There are no production figures available on the tonnage of clay used but adobe brick making is an important activity in the Southwest.

Recently bentonite products marketed under trade names have been used to seal irrigation ditches, earthen dams, and rock fractures. Bentonite is also used as a coagulant in clarification of liquids, as a thickener in wet-mash poultry and stock feeds, and as a suspending agent in detergents.

Attapulgite is used as an absorbent for removing water and oil from commercial and industrial floors, as a catalyst support, to purify and clarify water, as a thermal insulation, as a dessicant, and in the preparation of spot removers for rugs, clothes, and wallpaper.

Halloysite is used in the production of alum and could be used as a bonding agent for foundry sands.

LOCALITIES AND NOTES ON SAMPLES, TABLE 11

802, 803, 804, and 805. Shales associated with coal from near Laredo, Webb County. 802 and 803 are shales found below and between coal seams near Minera, 804 is shale found below lower coal seam at Cannel, and 805 is a weathered sample from the same source as 804. All are of good plasticity and high drying shrinkage. They burn to a buff color, with the exception of the weathered sample, which has a light color at lower temperatures and brown color above Cone 1. All are suitable to the manufacture of buff brick, preferably by the dry press process.

806. From brick yard at Laredo, Webb County. A sandy calcareous clay used for making common brick by the soft mud process. It burns first to a buff, which at cone 1 takes a brownish shade.

813. From near Seguin, Guadalupe County. A highly calcareous clay used for common brick. It burns to a dirty gray-brown color.

816 and 817. From the bank of the Guadalupe River near Gonzales, Gonzales County. Upper and lower layers from this deposit are represented by these two samples. The deposit is a calcareous river silt, the upper layer being green and the lower brown. The top layer is more plastic but has tender drying and burning properties. The lower is less plastic but more plentiful and has better drying and burning strength. A mixture of the two is used to advantage in the manufacture of common brick. Both clays burn buff.

818. From 6 miles southeast of Gonzales, Gonzales County. A sandy grayish-brown clay of low plasticity and high air shrinkage. Its strength is low, and it has very tender properties, making it of very doubtful value. It burns buff and begins to become viscous and to blister at Cone 9.

819 and 820. From one-fourth mile northeast of the source of sample 818. A dense fine-grained soapy-looking clay, of low plasticity and tender drying properties. It would burn white but for the contamination of limonite in all the crevices. This might be partly removed on washing, but it is doubtful that a high-grade material approximating a kaolin could be thus produced.

833. Sample of Leakey kaolin from west of Leakey, Real County.

TABLE 12. *Chemical analyses and results of ceramic tests on clay and shale samples from miscellaneous localities in south Texas area* (Bureau of Industrial Chemistry, The University of Texas).[a]

CHEMICAL ANALYSES (J. E. Stullken, analyst)

Lab. No.	SiO_2	Al_2O_3 and Fe_2O_3		Na_2O and K_2O	CaO	MgO	SO_3	H_2O	CO_2	TiO_2
C1334	66	26	......	......	1	some	some	......	......	......
C1366										
"A"	44.30	39.71	0.29	......	0.66	0.0	......	14.90	......	0.50
"B"	41.73	36.55	5.12	..	0.66	0.0	......	14.90	......	0.50
C1367	44.95	39.61	0.94	1.63	0.42	......	......	14.91	......	tr.
C1368	45.12	27.14	1.13	1.26	0.64	......	......	14.73	......	tr.
C1441	41.76	39.00	1.14	1.54	0.80	0.17	......	16.60	......	0.0
C1442	58.46	26.95	2.12	1.43	0.80	0.22	......	10.21	......	1.5
C1443	58.83	17.28	13.72	1.41	0.53	0.19	......	6.60	......	1.2
C1511	70.50	17.44	1.99	1.99	1.04	......	......	7.31	......	......
C1814	75.45	10.86	2.49	2.82	2.19	0.0	......	7.54	......	......
C1816	78.15	14.61	......	1.75	0.82	......	......	5.05	......	......

RESULTS OF CERAMIC TESTS

C1521, stiff mud bricklets containing different proportions of grog burned to Cone 08:

Pct. of grog used	5%	10%	15%	25%	35%	50%
Color						light slate
Hardness	med.	med.	med.	soft	soft	tender
Fire shrinkage	0.4	1.7	0.8	1.1	0	1.8
Porosity	23.7	23.0	23.8	26.7	27.3	29.7

Best surface obtained with 15% mixture.

C1814, burning trial with dry press bricklets:

Cone	010	08	06	04	02	1	3	5
Temperature	950	990	1030	1070	1110	1150	1190	1230
Color	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff
Hardness	med.	med.	med.	med.	hard	very hard	steel hard	steel hard
Fire shrinkage	13.2	17.3	19.6	21.6	23.6	25.9	30.2	33.8
Porosity	37.9	32.7	29.2	28.2	26.5	24.6	21.5	17.1

C1814, burning trial on bricklets made of 40% raw clay and 60% grog:

Cone	010	08	06	04	02	1	3	5
Temperature	950	990	1030	1070	1110	1150	1190	1230
Color	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff	lt. buff
Hardness	med.	med.	med.	med.	med.	med.	med.	hard
Fire shrinkage	1.4	3.1	4.8	9.1	10.0	12.1	14.8	16.1
Porosity	39.9	39.1	37.0	34.8	33.8	33.3	32.0	31.0

C2097, Red, siliceous clay. Plasticity—low; water of plasticity, 21.8%; drying shrinkage, 15.4%. Burning trial on stiff mud bricklets:

Cone	08	06	04	1
Temperature	990	1030	1070	1150
Color	red	red	red	dark red
Hardness	very soft	very soft	very soft	very soft
Fire shrinkage	–4.1	–4.0	–4.4	–3.5
Porosity	25.6	27.2	27.9	....

C2162, plasticity—good; drying properties—good; water of plasticity, 28%; drying shrinkage, 25.8%. Burning trial on stiff mud bricklets:

Cone	010	08	06	04	02	1	3	5
Temperature	950	990	1030	1070	1110	1150	1190	1230
Color	salmon	salmon	salmon	lt. red	red	red	red	dk. red
Hardness	med.	hard	very hard	steel hard		vitrified		
Fire shrinkage	1.6	3.3	8.3	24.0	25.4	25.5	25.6	24.8
Porosity	31.8	31.0	26.7	7.0	0.6	0.4	0.1	0.2

C2162, burning trial on dry press bricklets:

Cone	010	08	06	04	02	1	3	5
Temperature	950	990	1030	1070	1110	1150	1190	1230
Color	salmon	salmon	salmon	lt. red	red	red	red	choc.
Hardness	soft	med.	med.	steel hard	steel hard	steel hard	cracked	
Fire shrinkage	0.3	2.3	6.2	20.6	25.0	26.4	....	....
Porosity	35.4	35.0	32.8	19.5	14.5	11.7	....	....

C2635, plasticity—medium; drying properties—good; water of plasticity, 7.6%; drying shrinkage, 29.1%. Burning trial on stiff mud bricklets:

Cone	010	08	06	04	02	1	3	5
Temperature	950	990	1030	1070	1110	1150	1190	1230
Color	lt. red	lt. red	lt. red	very lt. red	very lt. red	very lt. red	very lt. red	
Hardness	med.	med.	hard	hard	steel hard	steel hard	vitrified	fused
Fire shrinkage	0.4	0.2	0.2	-0.7	6.8	14.0	-2.3	....
Porosity	13.4	14.0	14.0	14.0	20.0	3.7	0.8	....

[a] Potter, A. D., and McKnight, David, Jr. (1931) The clays and the ceramic industries of Texas: Univ. Texas Bull. 3120, pp. 176–195.

LOCALITIES AND NOTES ON SAMPLES, TABLE 12

C1334. Near Moore Station, Frio County. Chemical analysis indicated that this might prove to be a good brick or pottery clay, but no ceramic tests were made. December 6, 1920.

C1366. Near Leakey, Real County. Two samples of the Leakey kaolin. Sample "A" is of a flesh color and analysis shows it to be of such purity as to be probably a true kaolin. Sample "B" is of a blue color and is found to contain too much iron to be classed as a kaolin. It is probably from one of those portions of the deposit which have been contaminated by adjoining strata. December 15, 1920.

C1367. Near Leakey, Real County. Leakey kaolin, described as being white and compact. The analysis shows it to be very pure. December 18, 1920.

C1368. Near Leakey, Real County. Leakey kaolin, described as dull white in color. December 18, 1920.

C1441, C1442, C1443. Near Leakey, Real County, described respectively as white, dull stone, and blue stone color. Sample C1443 contains a great deal of iron, in which respect, as well as in color, it seems to resemble sample C1366 "B" and likewise cannot be classed as a kaolin. Samples C1441 and C1442 compare favorably with other samples of true kaolin from that vicinity. March 23, 1921.

C1511. Near Leakey, Real County. This kaolin sample shows about the same composition as others discussed above. July 9, 1921.

C1521. From Taft, San Patricio County. This clay was tried out with various portions of grog in order to find what proportions could be used to produce a good brick. The grog used was composed of ground portions of the previously burned clay, and the raw clay-grog mixtures were burned to Cone 08. Best results were obtained with a mixture of 15% grog and 85% raw clay. August 13, 1921.

C1814. Franklin ranch, northern part of McMullen County. This sample was submitted as a kaolin, but the high percentage of fluxes shown by the chemical analysis and the fact that it burns buff show that it cannot be classed as such. It has extremely high plasticity and high drying shrinkage. The plasticity was so high that as much as 75% of non-plastic material could be added and the mixture still be worked. The clay burns to a hard buff body and will make a good face brick by either the stiff mud or the dry press process. For the stiff mud process, inert grog or sand must be added to reduce the drying shrinkage. October 26, 1922.

C1816. McMullen County. This sample, evidently from a source the same as, or near to, sample C1814, was also tested for kaolin. Iron was not determined, but the lime and alkali contents are somewhat lower than in sample C1814, and in this respect it appears a little more favorable from the standpoint of kaolin. No ceramic tests were made; hence there is not enough evidence to class the sample as a kaolin. November 7, 1922.

C2097. Half a mile from Dilley, Frio County. A red siliceous clay of low plasticity. It was made into bricklets with 21.8% water and showed a shrinkage of 15.4% on drying. The bricklets burned to a dark red at Cone 1 but never attained much strength. They showed the characteristic burning expansion of siliceous clays. No chemical analysis was made. February 1, 1924.

C2162. Land of Joe Vanham, half a mile from Uvalde, Uvalde County. No chemical analysis. Ceramic tests were made on both stiff mud and dry press bricklets. The dry press bricklets became steel hard at Cone 04, but the structure was only of moderate strength. At Cone 3 the bricklets cracked badly. The stiff mud process worked much better. The clay was made up with 28% water, showing good plasticity and good drying behavior in spite of the high drying shrinkage (25.8%). The clay burns to a dark red, becoming steel hard at Cone 04 and vitrifying at Cone 02. It would make a light red common brick if burned up to Cone 04 or a dark red vitrified brick if burned to Cone 02 or higher. May 15, 1924.

C2635. Land of A. M. Bruni, Webb County. No chemical analysis. The clay was made up into stiff mud bricklets, showing medium plasticity and good drying behavior in spite of the drying shrinkage of 29.1%. It burns to a light red and will make a good grade of common brick of medium hardness burned at Cone 010. A semi-dry process may be used. April 10, 1926.

TABLE 13. *Preliminary ceramic tests made for San Antonio and Aransas Pass Railway [Southern Pacific]* (A. D. Potter, analyst; Bureau of Industrial Chemistry, The University of Texas).[a]

Sample No.	Plasticity	Behavior of dry press bricklets	Drying behavior of stiff mud bricklets	Linear shrinkage %	Burning behavior	Burned color	Hardness	Ring	Promising for
Yo-1	very low	none made	good	4	good	red	soft	very dead	too siliceous for brick
Yo-2	low	none made	good	8	good	red	soft	very dead	no good, warps on firing
Yo-3	very low	none made	good	1	good	red	soft	very dead	too siliceous
Kc-1	low	cracked	good	4	good	light red	soft	fair	common brick
Kc-2	low	cracked	good	8.5		light red	soft	fair	common brick
Kc-3	good	good	bad	12	fair	light red	medium	fair	common brick
Kc-4	good	good	bad	16	fair	buff	medium	fair	common brick
Kc-5	low	good	good	6	good	light red	soft	dead	common brick
Ma-1	fair	none made	good	4	good	buff	medium	low	common brick
Ma-2	fair	bad	good	7	fair	red	soft	dead	common brick
Ma-3	low	bad	good	4	fair	red	soft	dead	common brick
Pl-1	good	good	good	10	good	buff	medium	good	face brick
Pl-2	good	good	good	10.5	fair	buff	hard	good	face brick
Pl-3	medium	good	good	10	good	buff	very hard	good	face brick
Pl-4	good	good	good	10	cracked	buff	hard	medium	face brick (?)
Pl-5	good	good	cracked	14	cracked	light red	hard	medium	common brick
Pl-6	good	bad	cracked	11	good	light red	medium	medium	common brick
Pl-7	good	bad	good	12	good	light red	hard	good	not promising (scums)
Pl-8	good	good	good	11	good	red	very hard	good	face brick, tile
CC-1	good	good	good	11	good	light buff	very hard	good	face brick
CC-2	fair	bad	good	9	good	buff	medium	good	face brick
CC-3	medium	bad	good	10	good	buff	medium	good	face brick
CC-4	good	good	good	11	bad	buff	hard	good	face brick
CC-5	medium	good	good	12	good	light buff	hard	good	face brick
CC-6	good	good	good	11.5	good	buff	medium	good	face brick
CC-7	good	bad	good	9	good	very light	hard	good	face brick
RP-1	low	bad	good	3.5	good	red	soft	low	common brick
RP-2	good	good	good	12	good	red	hard	fair	common brick
RP-3	good	good	good	13.5	good	red	hard	good	paving brick
RP-4	medium	bad	good	9	good	buff	hard	fair	face brick
RP-5	low	bad	good	4	bad	white, blue flash	slaked	none	no good, lime
RP-6	low	bad	good	6	good	red	soft	dead	common brick

Go-1	medium	good	bad	14	bad	....	....	....	not promising
Go-2	fair	good	good	8	fair	red	hard	fair	common brick
Go-3	good	good	tender	11	fair	red	hard	good	common brick
Go-4	low	good	good	7	good	light yellow	medium	fair	face brick
Go-5	fair	good	good	12	fair	red	very hard	good	common brick
Fc-1	fair	good	good	8	good	red	very hard	good	tile
Fc-2	low	good	good	10	good	red	medium	fair	common brick
Fc-3	medium	good	good	10	good	pink	very hard	good	face brick
AP-1	medium	bad	good	4	bad	light yellow	very soft	dead	common brick
AP-2	medium	bad	good	6	good	cream	hard	medium	face brick

[a] Potter, A. D., and McKnight, David, Jr. (1931) The clays and the ceramic industries of Texas: Univ. Texas Bull. 3120, p. 198 and Table V.

LOCALITIES AND NOTES ON SAMPLES, TABLE 13

AP-1 and AP-2, Aransas Pass, San Patricio County. These two samples of calcareous clay were also analyzed chemically to determine their fitness for use as raw materials for cement. The analyses were:

	AP-1	AP-2
SiO_2	44.91%	50.60%
Fe_2O_3 and Al_2O_3	6.50	12.75
CaO	17.37	13.66

Neither of these is suitable for cement manufacture. AP-1 is entirely too low in alumina. AP-2 has about the correct alumina ratio, but the silica is rather high, and if lime were added the alumina ratio would decrease and would then be too low.

CC-1 to CC-7, inclusive, Corpus Christi, Nueces County. Numbers 1, 2, and 3 are from Weil Brothers; 4, 5, and 6 from H. M. Baker; and 7 from Robert Toenisch.

FC-1 to FC-3, inclusive, Falls City, Karnes County.

Go-1 to Go-5, inclusive, Gonzales, Gonzales County.

Kc-1 to Kc-5, inclusive, Karnes City, Karnes County.

Ma-1 to Ma-3, inclusive, from C. B. McAnally, Mathis, San Patricio County.

Pl-1 to Pl-8, inclusive, Portland, San Patricio County.

RP-1 to RP-6, inclusive, Rockport, Aransas County. Sample RP-4 was found to fuse at Cone 5 and sample RP-3 to begin to fuse at Cone 5 but not be completely down until Cone 8.

Yo-1 to Yo-3, inclusive, Yoakum, Lavaca County.

TABLE 14. *Chemical analyses of miscellaneous rocks and minerals from localities in the south Texas area.*[a]

Number	SiO_2	Al_2O_3	Iron oxide	MnO	CaO	MgO	K_2O	Na_2O	CO_2	P_2O_5	SO_3	TiO_2	H_2O	Organic matter	Total
77	98.80	1.00	......	......	......	......	......	......	......	......	......	......	0.48	......	100.28
82	76.00	12.88	1.92	......	4.53	0.66	......	......	0.30	......	3.57	......	0.00	......	99.86
83	61.36	10.61	3.39	......	6.95	0.92	......	......	4.10	......	0.82	......	10.46	......	98.61
84	58.60	11.04	1.92	......	12.11	0.88	......	......	5.80	......	0.63	......	7.16	......	98.14
85	39.16	5.24	2.14	......	25.41	Trace	......	......	19.49	......	0.96	......	5.87	......	98.27
86	52.50	1.41	3.75	......	21.05	Trace	......	......	15.75	......	1.23	......	3.65	......	99.34
161	73.16	13.86	1.44	......	3.14	1.61	Trace	0.23	......	......	......	0.70	5.15	......	99.29
162	74.82	13.61	0.72	......	1.69	2.02	Trace	0.27	......	......	......	0.39	5.67	......	98.19
163	37.05	8.13	1.80	......	2.23	0.08	0.47	Trace	22.12	......	......	0.47	2.64	......	99.82
164	41.20	6.50	1.98	......	1.62	0.14	0.43	0.09	20.63	......	......	0.43	2.28	......	99.27
165	75.41	12.49	0.72	......	1.82	1.80	0.29	0.56	......	......	......	0.19	5.93	......	99.21
166	57.78	17.11	Trace	......	2.70	1.86	1.12		......	......	......	none	19.85	......	100.42
167	76.00	11.36	0.72	......	1.96	1.58	0.58	0.86	......	......	......	Trace	6.20	......	99.26
174	72.30	19.33	2.47	......	Trace	0.50	4.44			......	......	none	none	......	99.04
175	18.62	3.23	1.26	......	41.30	0.42	......	......	32.50	......	......	......	2.42	......	99.75
221	67.20	13.50	......	......	2.00	......	1.16	0.11	1.65	......	0.75	......	......	13.25	99.72
222	51.12	11.04	4.10	......	14.24	0.90	0.40	1.59	10.62	......	......	0.95	4.00	......	98.97
283	60.41	22.43	1.90	......	0.44	0.61	0.45	0.24	......	......	......	1.30	6.00	6.50	100.28
284	59.03	11.19	2.77	......	12.16	0.80	Trace	0.18	9.60	......	......	1.05	2.10	......	98.88
285	63.00	23.00	2.50	......	Trace	1.10	1.70	0.30	......	......	......	1.30	......	......	97.70
286	63.43	23.42	1.15	......	0.45	1.23	0.07	0.26	......	......	......	1.13	......	0.40	98.54
287	57.00	22.20	2.10	......	0.25	Trace	Trace	0.21	......	......	......	1.31	16.65		99.72
288	58.22	21.10	1.85	......	1.08	0.10	0.05	0.18	......	......	......	1.48	14.42		98.48

KAOLIN

Number	Silica	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2	H_2O (comb.)	H_2O (Hyg.)	Total
1092	45.50	32.23	0.60	......	......	......	......	......	12.50	6.42	98.26
1093	48.41	43.17	......	0.38	0.10	1.78		......	6.05	......	99.89
1094	45.04	32.99	2.73	......	......	......	......	1.80	8.23	4.97	98.45
1095	45.52	42.30	......	Trace	......	......	......	......	13.92	......	100.74
1096	45.00	33.50	1.50	1.00	0.30	......	......	......	18.20	......	99.50

[a] Schoch, E. P. (1918) Chemical analyses of Texas rocks and minerals: Univ. Texas Bull. 1814, pp. 22–36, 171–175, 182.

LOCALITIES AND NOTES ON SAMPLES, TABLE 14

77. Atascosa County. Alluvium from San Antonio, Uvalde and Gulf Railway, north of Pleasanton. Marked "Atascosa River sand."
82. La Salle County. Alluvium (adobe) from Dobson. Proposed to be used for ballast.
83. Live Oak County. Alluvium (adobe) from Fant City. Labelled "adobe shale." Has given good service as ballast.
84. Live Oak County. Alluvium (adobe) from Fant City. Proposed to be used as ballast.
85. San Patricio County. Alluvium (adobe) from near Mathis.
86. San Patricio County. Alluvium (adobe) from near Mathis. Proposed to be used as ballast.

Samples 82–86 sent in by E. R. Breaker, Chief Engineer of the S.A.U.&G. Ry., Pleasanton, Texas.

161. 162. Gonzales County. Clay (Eocene Tertiary) from Harwood property, 6 miles southeast of Gonzales.
163. 164. Gonzales County. Calcareous clay (Eocene Tertiary) from near Gonzales.
165. Gonzales County. White clay from Harwood property, 6 miles southeast of Gonzales.
166. 167. Gonzales County. Clay from Sunset Brick and Tile Company, Gonzales.
174. Guadalupe County. Sandy brick clay from Morrison.
175. Guadalupe County. Calcareous brick clay from Seguin.
221. McMullen County. White clay (siliceous sinter, Eocene Tertiary) from 12 miles north of Tilden.
222. Medina County. Calcareous brick clay (Upper Cretaceous) from D'Hanis.
283. Webb County. Buff-burning, semi-refractory clay from Minera. Vitrified at Cone 12.
284. Webb County. Calcareous brick clay (Eocene Tertiary) from Laredo.
285. Webb County. Shale from under coal at Minera, near Laredo.
286. Webb County. Shale beneath coal at Minera.
287. Webb County. Shale under lower or San Pedro seam at Cannel, near Laredo.
288. Webb County. Weathered shale from the lower or San Pedro seam at Cannel. Used for dry pressed bricks at Laredo.

KAOLIN

1092. Edwards [Real] County. Cleaned and ground kaolin from the mill at Godbold's house, near Leakey.
1093. Edwards [Real] County.
1094. Edwards [Real] County. Ground but not cleaned kaolin from mill at Godbold's house, near Leakey.
1095. Uvalde County. From Thornton's ranch, 15 miles north of Uvalde, from hole alongside creek in arroyo.
1096. Uvalde County. From 15 miles north of Sabinal on Big Blanco Creek. Received from Russell Myrick, San Antonio.

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COALS

ORIGIN AND RANK

Coals were among the first of the natural resources to attract the attention of the early Texas settlers. Stenzel (1946, p. 197) reported small-scale coal production as early as 1819. Coals are formed from accumulated plant remains in special depositional environments and are subjected to specific geologic processes. The rank of the coal depends on the composition of the plant material and heat and pressure to which it was subjected through burial, lithification, and other geologic processes.

The lowest grade of coal is peat, in which the plant remains can be normally separated into individual strands and identified. Peat has very low specific gravity, high porosity, and high water content.

Lignite, a higher rank coal than peat, is a dark brown material, commonly called "brown coal." It contains fragments of leaves, twigs, roots, and sporadic fragments of tree trunks. In addition, there is a considerable amount of earthy to dense organic materials that cannot be identified without the aid of a microscope. Variable amounts of inorganic impurities are disseminated through the lignite or occur as thin clay beds or partings between layers of lignite. Most lignites are soft and crumbly, with low specific gravity, high primary porosity, and high moisture content.

Bituminous coal is brownish black to deep black, has considerable luster (locally glassy on fresh breaks), is considerably more coherent and harder than lignite, and has lower porosity and water content. Plant structures are rarely visible without the aid of a microscope. Cannel coal, a special bituminous variety, is distinguished from normal bituminous coal by its dull waxy luster and lesser hardness. Cannel coal is rich in volatile constituents and burns with a vivid flame for unusually long periods.

Baker (1935, p. 307) has shown that volatile substances calculated on an ash-, moisture-, sulfur-free basis amount to more than one-half the composition of lignite and that for bituminous coals the volatile substances range from 46 or 47 to 25 percent. Flynn (1949, p. 2) has shown the B.T.U. value of American bituminous coals, on nation-wide basis, as follows:

	B.T.U.
Low-volatile bituminous	14,200
Medium-volatile bituminous	14,000
High-volatile bituminous	12,900
Sub-bituminous	9,550
Lignite	7,000

Flynn (1949, p. 9) also showed that Texas lignites have a B.T.U. range of 7,630 to 8,090, and that the average B.T.U. value is 7,860.

Coal seams are layered accumulations of plant remains that accumulated in a unique environment. It is believed that the type of environment necessary for extensive deposition and preservation of plant material was a subsiding, low, flat, swampy land surface with a lush vegetation cover, and without contamination by sand or mud from major streams. The thickness of the accumulated plant material and resulting coal seam depended on the rate of plant debris accumulation, the amount of subsidence, and the length of time the environment persisted. Conditions favorable for the formation of coal in the south Texas Coastal Plain were limited. There are widespread carbonaceous shale accumulations and numerous small, thin lignite deposits. Some lignite beds in the Wilcox and Yegua formations (Pl. IV) may have commercial values. There are cannel coal deposits in Webb County and bituminous coals in Maverick County.

Cannel Coal

WEBB COUNTY.—Several of the early reports on the geology of Texas mention and describe the cannel coal in Webb County, Texas. Ashley (1919, pp. 251–

270) made the most complete study and his report includes discussions of the geology, mining methods, analyses, and physical and chemical properties of the coal. The coal is probably the largest cannel coal deposit of bituminous rank in the United States, or perhaps in the world; it is a low-moisture coal, resists weathering during shipment and storage, is almost as hard as anthracite, is of uniform quality, and could be sold on a dry basis under a guarantee of 12,500 B.T.U.

There are two principal cannel coal beds in the Webb County area, the Santo Tomas coal above and the San Pedro coal below, separated by about 90 feet of sandstone and shale (Mount Selman formation). Lonsdale and Day (1937) showed that the Santo Tomas coal does not crop out north of Palafox and the San Pedro coal does not crop out south of that community. Lonsdale's map shows the distribution of the coal outcrops and the location of the old mines (Pl. IV).

The rocks in west-central Webb County dip gently toward the east-southeast. Thus the depth of the coal beds below the surface increases southeastward toward the Gulf of Mexico. The Santo Tomas coal crops out about 50 to 75 feet above water level in the breaks of the Rio Grande near the mouth of Espadilla Creek. Coal blossom can be seen at other points between Dolores and Artellaro Creek. The early settlers mined the surface outcrops but later all the mining was from shafts. The old mine shafts are all east or slightly southeast of the outcrop. The Santo Tomas coal is 165 feet below the surface in the Santo Tomas mine, 50 feet in the Darwin mine, and 110 feet in the Dolores mine. The San Pedro coal is 140 feet deep in the Darwin mine, 200 feet in the Dolores mine, and appears to be absent in the vicinity of the Santo Tomas mine.

The Santo Tomas coal bed is generally about 24 to 36 inches thick and at most localities has a 2-inch parting near the middle. This thickness does not include some 2 to 14 inches of bony coal at the base. From 14 inches to 20 feet above the Santo Tomas coal is a thin persistent coal seam ("rider") generally about 6 to 12 inches thick. At most localities the "rider" is bony coal, but locally it is of good grade. Clay and brown shale generally separate the "rider" from the Santo Tomas coal.

The San Pedro coal consists of two benches but only the upper bench was mined. It averages about 24 inches thick and is generally more cannel-like than the Santo Tomas bed. The San Pedro coal is the more irregular of the two coal beds and pinches and swells laterally. These irregularities were especially prominent in the Old Dolores mine.

The Webb County coal is a bright glossy black, almost pitchy, and has a more brilliant luster than most cannel coals. It is firm and yields 75 to 80 percent of lump as mined and screened over 1¼-inch bars. As dug in the mine it is as hard or harder than the average bituminous coal and approaches splint coal in this respect. It can be shipped in open cars without appreciable deterioration; when free of sulfur it can be stored and will remain in good condition for months. If much pyrite is left in the stored coal, the percentage of slack will be substantial by the end of a year. When fresh, the coal does not split readily with the bedding but has a strong vertical cleavage in one direction and tends to break with a vertical face. Where the beds are deeply weathered or have a high ash content, the coal tends to split into paper-thin sheets parallel to the bedding.

Ashley showed the Webb County cannel coal to be high in volatile matter and low in moisture but high in ash, sulfur, and nitrogen content. The analyses in table 16 are from Ashley (1919, pp. 257–258).

On distillation at high temperatures the Webb County cannel coal yields a higher percentage of gas than does ordinary bituminous coal. Tests made by Phillips and Worrell (1913) and reprinted by Ashley (1919, p. 20) and by Baker (1935, p. 327) are contained in table 17.

Tests of the Santo Tomas coal by low-temperature distillation by the U. S. Bureau of Mines, as published by Ashley

(1919, p. 260), gave the following results:

Oil—	
Gallons per ton	52.2
Percent by weight of coal	20.2
Specific gravity at $\frac{60°F.}{60}$	0.938
Non liquid at 60°F.	
Gas—	
Cubic feet per ton, collected over water, at 0°C. and 760 millimeters pressure	5,672
Water—	
Percent by weight of coal condensed	9.5
Loss in distillation—	
Percent by weight	44.3
Ammonia—	
Not determined.	

The yield of 52.2 gallons of oil per ton (table 17) may be compared with 50.4 and 37.3 gallons of oil obtained by using the same testing methods on two samples of coal from Cannelton, Pennsylvania. The Webb County cannel coal yields a higher proportion of oil when distilled at low temperatures and more gas at high temperatures than does the average bituminous coal. The oil is satisfactory for fuel oil and probably for flotation processes, and other uses. The low temperature at which the oil is driven off in the distillation process suggests that catalytic cracking will be necessary to produce commercial gasoline and related products. With proper treatment large quantities of both lubricating oils and gasoline could be distilled from the coal. Because it yields a high percentage of volatile materials, including several unsaturated hydrocarbons, the future utilization of the coal will probably be as a chemical raw material rather than as a fuel.

The reserves of the Webb County cannel coal have not been determined. The western limit is the outcrop shown on the accompanying map (Pl. IV). The coal extends eastward to some point beyond the mines, for all mines were in the coal at the time of their abandonment. The dip of the rocks indicates that the depth to the coal increases toward the east and southeast. There is a limit below which the coal cannot be economically mined. The log of the Central Power and Light Company's well at Laredo (Lonsdale and Day, 1937, p. 78) shows a 10-foot zone of hard sand and lignite at a depth of 1,665 to 1,675 feet but no cannel coal. This suggests that the cannel coal thins and pinches out between the mines and Laredo. Logs of old wells drilled east of the coal mines show no record of coal. Possibly the records at shallow depths were not accurately kept because there was no interest in the coal or possibly the coal beds pinch out and disappear a few miles east of the old mines.

Northward along strike the cannel coal beds thin, split into layers, and eventually disappear. The northernmost outcrop recognized by Lonsdale and Day (1937) is about 10 miles south of the Webb-Dimmit County line (Pl. IV). In southwestern Dimmit County a cannel-like coal bed crops out in the upper reaches of El Moro Creek about 1 mile southeast of Dentonia. An abandoned mine shaft is nearby. Mr. Herbert Ward of Catarina reported (oral communication, July 1960) that coal was encountered at a shallow depth, but that to the best of his knowledge there was no mining. This outcrop and abandoned mine are near the upper contact of the upper clay and Bigford sandstone members of the Mount Selman formation and along the strike of the cannel coal mapped by Lonsdale and Day (1937) in Webb County. Farther northeast along the strike, coal crops out again about 13 miles east-southeast of Carrizo Springs near the contact of these two units where they cross the Nueces River. Coal outcrops have also been recorded at about the same stratigraphic interval near Espantosa Lake about 8 miles northwest of Carrizo Springs. These isolated coal exposures in Dimmit County do not indicate a continuous outcrop that joins the cannel coal in Webb County, but more likely represent local accumulations of the same age that were deposited along the irregular margins of the depositional basin.

There is not much subsurface data available on cannel coal in northern Webb or southern Dimmit counties. The log of Windsor Oil Company No. 1 Lamesa Land and Cattle Company about 9 miles north-

TABLE 16. *Analyses of cannel coal, Webb County, Texas.*

Mine or locality	Coal bed	Condition*	Proximate					Ultimate				Heating value B.T.U.'s
			Moisture	Volatile material	Fixed carbon	Ash	Sulfur	Carbon	Hydrogen	Oxygen	Nitrogen	
Santo Tomas(?)	Santo Tomas	?	2.5	51.0	39.0	7.3	1.5	......	......	......	......	....
25 miles NW of Santo Tomas	Santo Tomas	?	2.3	42.6	37.5	16.5	0.8	......	......	......	......	....
Santo Tomas	Santo Tomas, upper bench	?	2.2	48.6	36.1	12.9	......	......	......	......	......	....
Santo Tomas	Santo Tomas, lower bench	?	2.6	45.6	39.9	11.7	......	......	......	......	......	....
Darwin	San Pedro, upper bench	?	2.7	49.9	37.7	9.7	......	......	......	......	......	....
Darwin	San Pedro, upper part, lower bench	?	2.0	48.3	33.1	16.5	......	......	......	......	......	....
Darwin	San Pedro, lower part, lower bench	?	2.3	49.3	38.0	10.2	......	......	......	......	......	....
Santo Tomas	Santo Tomas	A	4.0	47.9	38.8	9.0	2.4	66.7	5.3	10.8	1.4	11,050
		C	......	50.0	40.5	9.4	2.5	69.5	5.5	11.3	1.5	12,570
Darwin	San Pedro	A	3.4	48.8	36.6	11.0	2.0	66.6	5.6	7.4	3.6	12,040
		C	......	50.7	37.9	11.3	2.1	69.0	5.9	7.7	3.7	12,470
Santo Tomas	Santo Tomas	C	......	47.5	39.1	13.3	2.0	......	......	......	......	12,470
San Jose	Santo Tomas	A	2.3	52.7	37.1	7.8	2.2	69.4	5.5	9.0	2.9	12,320
		C	......	54.0	37.9	8.0	2.2	71.0	5.6	10.0	3.0	12,600
San Jose	?	A	3.9	43.6	36.1	16.2	4.1	......	......	......	......	11,580
		C	......	45.4	37.6	16.9	4.3	......	......	......	......	12,070
Llave prospect	San Pedro	A	3.0	48.8	39.5	8.6	3.5	......	......	......	......	13,110
		C	......	50.3	40.7	8.9	3.6	......	......	......	......	13,510
Santo Tomas	Santo Tomas	A	4.0	45.5	37.6	12.8	1.9	......	......	......	......	12,000
		C	......	47.3	39.1	13.3	2.0	......	......	......	......	12,470
?	Santo Tomas	A	2.6	46.4	38.9	11.9	2.3	......	......	......	......	12,340
		C	......	47.7	40.0	12.3	2.4	......	......	......	......	12,660
Santo Tomas	Santo Tomas	A	2.5	45.2	29.2	22.9	2.4	......	......	......	......	10,920
		C	......	46.9	30.0	23.6	2.5	......	......	......	......	11,190
Darwin	?	C	......	54.0	37.9	8.0	2.2	71.0	5.6	10.0	3.0	12,600
Santo Tomas	Santo Tomas	C	......	50.4	38.1	11.4	3.0	66.0	5 7	12.1	2.5	11,700

Cannel (Darwin), San Jose	San Pedro	A	4.4	40.6	34.1	19.5	2.6	......	......	......	......	10,890
and No. 3, average of 10		C	......	42.5	36.8	20.5	2.8	......	......	......	......	11,400
analyses run of mine		D	......	53.5	46.3	......	3.5	......	......	......	......	14,350
Santo Tomas, average of 12	Santo Tomas	A	3.8	42.8	35.5	17.6	1.4	......	......	......	......	11,400
analyses, 4-inch lump		C	......	44.6	37.0	18.3	1.5	......	......	......	......	11,850
		D	......	54.6	45.3	......	1.9	......	......	......	......	14,510
Santo Tomas, average of 3	Santo Tomas	A	4.2	42.8	37.2	15.9	1.9	......	......	......	......	11,500
analyses, lump		C	......	44.6	38.8	16.5	2.0	......	......	......	......	12,060
		D	......	53.4	45.7	......	2.5	......	......	......	......	14,440
Santo Tomas, average of 5	Santo Tomas	A	3.9	44.5	36.9	14.4	1.7	......	......	......	......	11,870
analyses, lump over		C	......	46.4	38.4	15.0	1.8	......	......	......	......	12,360
3-inch screen		D	......	54.5	42.2	......	2.2	......	......	......	......	14,560
Santo Tomas, shaft No. 1,	Santo Tomas	A	4.4	42.2	33.6	17.7	1.7	......	......	......	......	11,230
mine sample		C	......	46.2	35.2	18.5	1.7	......	......	......	......	11,750
		D	......	56.7	43.2	......	2.1	......	......	......	......	14,420
Dolores shaft, mine sample	Santo Tomas	A	4.4	46.0	30.5	19.0	2.0	59.3	5.7	12.6	1.1	11,070
		C	......	48.1	31.9	19.8	2.1	64.0	5.5	9.1	1.2	11,580
		D	......	60.1	39.8	......	2.7	77.4	6.8	11.4	1.5	14,450
Dolores shaft, mine sample	San Pedro	A	3.9	48.8	34.9	12.2	1.9	65.5	6.2	12.7	1.2	12,230
		C	......	50.9	36.4	12.8	2.0	68.3	6.0	9.5	1.3	12,740
		D	......	58.3	41.6	......	2.3	78.2	6.9	10.9	1.5	14,600
Hunt, mine sample,	....	A	3.6	31.6	20.9	43.7	1.3	38.9	4.3	10.8	0.6	7,230
30 feet in weathered		C	......	32.8	21.7	45.4	1.4	40.4	4.1	7.9	0.6	7,510
		D	......	60.1	39.8	......	2.5	74.1	7.5	14.5	1.2	13,760

* A, Sample as received; C, moisture free; D, moisture and ash free.

west of the Santo Tomas mine (Pl. IV) shows 18 feet of lignite at a depth of 340 feet. Although the lignite is reported to be in the Mount Selman formation, the rank and thickness of coal and the depth to the coal do not suggest a correlation with the Webb County cannel coal. Lonsdale and Day (1937, p. 74) reported that deep wells drilled in northwestern Webb County did not encounter cannel coal and gave no evidence that the beds extend in that direction. Probably the only workable deposits in Webb County are in the immediate vicinity of the old mines. Any new exploration program should determine the (1) depth to and lateral extent of the available coal, (2) the number and thickness of coal beds, (3) the grade of coal, and (4) tonnage available for strip or underground mining. Available information indicates that the Santo Tomas coal bed ranges from 24 to 36 inches and that the San Pedro coal is generally about 24 inches thick. The chief difficulties encountered during the past mining operations were high costs due to the thinness of the coal beds and the poor roof conditions.

Bituminous Coal

MAVERICK COUNTY.—High-grade coal has been mined for years in the Sabinas basin of Mexico, which flanks the Sierra Madre Oriental on the east (Baker, 1935, pp. 316–318). The rocks are locally highly deformed and the associated coal is hard with anthracite luster and a low ash content. Except for the true anthracite of Pennsylvania, the Sabinas basin coal is probably the best coal in North America. The same formations that contain the coal in the Sabinas basin crop out in the Eagle Pass–Piedras Negras basin in Maverick County, Texas, and in the adjacent part of the Mexican State of Coahuila. Here the coal-forming plant debris was probably deposited closer to the margin of the basin and was mixed with larger quantities of mud. The Maverick County coal is therefore lower in rank and quality and contains more inorganic impurities than the Sabinas basin coal.

The coal beds occur in the Olmos formation, which crops out in a belt about 4 miles wide from about 5 miles below Eagle Pass to about 1 mile above the mouth of Elm Creek northwest of Eagle Pass and north for about 8 miles or more along the valley of Elm Creek (Pl. IV). The coal is preserved in the rim of a syncline the axis of which is located about 10 miles east-

TABLE 17. *Data on Santo Tomas cannel coal.*

GAS DISTILLATION TESTS

		Darwin Mine	Santo Tomas Mine 1	Santo Tomas Mine 2
Yield of gas per ton	cubic feet	7,320	6,660	7,147
Composition of gas—				
Illuminate	percent	5.5	5.4	5.4
Carbon monoxide	percent	2.1	11.8	6.6
Hydrogen	percent	42.0	40.0	43.6
Methane	percent	43.9	39.0	36.2
Nitrogen	percent	6.5	3.5	8.2
Specific gravity		0.385	0.428	0.424
Candlepower		16.0	6.5	15.4
Heating value per cubic foot—				
Observed	British thermal units	687	724	702
Calculated	British thermal units	630	702	667

COMPOSITION AND CHARACTER OF RESIDUAL FROM GAS DISTILLATION TESTS

		Darwin Mine	Santo Tomas Mine
Volatile combustible matter	percent	3.51	8.11
Fixed carbon	percent	78.31	73.63
Ash	percent	18.18	18.26
Sulfur	percent	2.01	1.35
Heating value per pound	British thermal units	12,050	11,664
Yield	percent	61.25	62.5
Character of coke		Fair	Fair

northeast of Eagle Pass. Flanking the syncline on the northeast is the more prominent Chittim anticline. North of Eagle Pass the formation crops out east and southeast around the nose of the anticline and the youngest formations involved in the folding are covered in part by the overlap of younger rocks. Thin coal beds and carbonaceous shale occur throughout the Olmos formation, but the only minable coal known crops out along the Rio Grande above the mouth of Elm Creek and in Elm Creek north and northeast of the old mines.

The Hartz mine, or old mine tunnel (a hillside adit), was probably the first coal mining activity in the Eagle Pass area (Pl. IV). Dumble (1889, p. 74) reported extensive working at the time of his investigation in 1888. Vaughan (1900, p. 60) reported that the mine was abandoned prior to 1900. The Dolch mine began coal shipments in January 1899 (Vaughan, 1900, p. 60). This property was later operated by the Rio Bravo Coal Company and finally by the International Coal Company. It was the last mine to operate in the area, closing about 1927. The Maverick County Coal Company, later known as the Olmos Mining Company, opened their shaft in 1895. There are at least three separate shafts connected by drifts, and the old dump is still visible along the highway near the junction of Farm Road 1588 with U. S. Highway 277. According to some local reports, the coal was nearly depleted when the mine closed in 1925. The Lamar mine, operated by L. M. Lamar (information from Eagle Pass Chamber of Commerce file), consolidated several of the Eagle Pass mining activities in 1907. Lamar built a large washing plant and used water from Elm Creek to remove the bone, shale, and other impurities from the coal. The Lamar mine and washing plant was probably the biggest operation in the area; it closed in 1925. It is reported that the Lamar mine produced from three beds and that washing improved the grade of coal.

For several years the International, Olmos, and Lamar mines were all in production; maximum production was on the order of 20 cars per day. The coal was used in locomotives, at the Central Power and Light Company power plant, and for other industrial uses. The industry flourished from about 1900 to 1925, employing up to 300 miners, but about 1925 competition from oil became too strong and most mining operations ceased. Some local residents continued to mine coal from the outcrop along Elm Creek until about 1930.

Coal has been penetrated in wells north and northeast of Eagle Pass. Vaughan (1900, pp. 25, 55–60) reported 6 feet of coal at a depth of 525 feet in an artesian well drilled on a hilltop near the present northeastern city limits of Eagle Pass. Northward from the artesian well the rocks rise in the synclinal fold and the depth to coal decreases. In the International (first the Dolch and later the Rio Bravo) mine 7 feet of coal was encountered at a depth of 230 feet. The Olmos (formerly the Maverick County Coal Company) mine encountered 6 feet of coal at 210 feet. A prospect shaft approximately half a mile northwest of the International mine found 7 feet of coal at a depth of 134 feet; another prospect shaft half a mile farther northwest encountered 6¾ feet of coal at 96 feet. The Hartz (old mine tunnel) mine worked 4 to 5 feet of coal down dip from the outcrop. In the Lamar mine, the main coal body occurred at about 150 feet. Other prospect shafts up to 8 or 10 miles north of Eagle Pass encountered coal at variable depths up to 100 feet. Northward, the coal zone maintains a thickness of 6 to 8 feet, but the commercial beds thin and decrease in quality, and intercalated bone and shale beds are more numerous. The northern limit of minable coal is probably not more than 8 miles north of Eagle Pass.

The best grade of available coal in the Eagle Pass area is in the vicinity of the old mines; the coal zone probably extends down toward the east-northeast for several miles before it splits into benched bony coal and disappears or becomes too deep for profitable mining. Vaughan (1900, p. 59) reported no coal outcrops along Salado, Chacon, Palo Blanco, and Mula Creeks northeast of Eagle Pass. According to Vaughan (1900, p. 59) there is 6 or 7 feet of coal at a depth of 65 feet in a well 2½ miles southeast of Eagle Pass. Udden (1907, pp. 77–78, 102) reported minable coal in sections 166, 198, and 199, block 7, and in sections 4, 5, 6, and 7, block 16 (fig. 2). Udden also suggested prospecting in sections 193 and 145, block 7, in order to determine depth and thickness of the coal.

More recent well-log records have been of little help in determining the eastern extent, thickness, and depth of the coal. The log of a well drilled in section 166, block 7 (fig. 2), about 3 miles east of the Lamar mine (Pl. IV), showed 12 feet of coal and shale topped at a depth of 57 feet; a log of a well drilled in section 169, block 7, showed only 3 feet of coal at a depth of 553 feet. These values and the thickness and depth to coal at other localities are shown on figure 2 and Plate IV as a fraction—for example 3/553 indicates that 3 feet of coal was encountered at a depth of 553 feet. These data indicate that the coal thins toward the east. It appears likely that the coal is absent or too thin and deep to be profitably mined east of the western boundary of section 169, block 7 (fig. 2). Farther east and especially in the area near section 145, block 7 (one of the sections suggested for exploratory drilling by Udden, 1907, pp. 77–78), the lithology of the rocks suggests that the presence of coal is unlikely.

There is not much published information available regarding the extent, thickness, and quality of the Maverick County coal except in the immediate vicinity of the old mines, and much of the detailed data once available to former mine superintendents were not published and are now lost. Recent studies indicate that the area with the largest reserves is along Elm Creek on the Edgar Kincaid ranch about 8 or 9 miles northeast of Eagle Pass (Pl. IV, Loc. 1). Here 32 inches of coal and 13 inches of bone and shale are exposed along the east bank of Elm Creek. The base of the coal is below water level and total thickness of the coal zone was not measured. The overburden ranges from 20 to 40 feet in thickness at the outcrop. The general terrain suggests that strip mining may be the most practical method of exploitation. The probable tonnage at this locality is not known and can be determined only by systematic exploration. In all probability, the quality of the coal can be up-graded by washing. Elm Creek is a permanent stream with sufficient water to operate a washing plant.

Coal crops out on the Hart farm about 6 miles northwest of Eagle Pass (Pl. IV, Loc. 2). The principal outcrop can be traced from about 150 feet north of Mr. Hart's home northward for at least three-quarters of a mile in the bottom and along the banks of a dry stream. The coal ranges in thickness from about 4.5 to 7 feet, but the zone contains several shale partings. The overburden is about 30 to 65 feet at the outcrop. There is not enough information available to make a realistic estimate of the reserve, but it appears to be a smaller deposit than was seen at the Elm Creek locality.

Coal blossom, weathered coal, and dark carbonaceous shale crop out at several localities along the breaks of the Rio Grande south of the old mines (Pl. IV). These areas are also worthy of further investigation because coal is known to extend across the Rio Grande into Mexico. There is no detailed information regarding the thickness, depth, or quality of the coal in these southern outcrop areas, and it is not possible to estimate their potential value at this time. Vaughan (1900, p. 24) reported 4 to 5 feet of minable coal at the Fuente mine in Mexico, 5 to 6 miles west of Eagle Pass, which would suggest a similar thickness for the coal beds along the Rio Grande northwest of Eagle Pass.

The early reports indicate that the coal seam in Maverick County is as much as 7 feet in the principal mines and in many of the prospects, but at most localities there are numerous partings of bone, shale, and dirt. Baker (1935, p. 318) reported that the usable coal has an average thickness of about 4 feet. The better coal layers are reasonably hard, have subconchoidal cleavage, do not air slack, and are either lustrous or brownish black. The coal is of bituminous rank but is high in ash, fairly high in sulfur, and ranges from 9,000 to 12,000 (dry basis) B.T.U. Some of the coal is suitable for making coke. Analyses of coal from five mines in Maverick County are given in table 18 (in pocket) (Baker, 1935, pp. 319–321; Schoch, 1918, pp. 91–93, 197–198; Phillips and Worrell, 1913, p. 26).

Analyses of samples collected along Elm Creek on the Kincaid and Hart properties are given in table 19.

Lignite

Production and Utilization

In the past, lignite in Texas has been used principally as a solid fuel for industrial and domestic requirements and as a raw material for the manufacture of activated carbon. Dietrich and Lonsdale (1958, p. 58) reported that lignite was mined along a belt stretching from Medina County northeastward to Louisiana, but the lignite markets were gradually captured by oil and gas and the mining of lignite for solid fuel in Texas ceased in 1946. Since 1946 limited quantities of lignite have been used for the manufacture of activated carbon and production for that purpose has continued. Since 1955 a large power plant at Sandow, near Rockdale in Milam County, has used lignite as a fuel. The electric power produced is used by the Aluminum Company of America in the refining of aluminum. Past utilization of lignite has been restricted geographically to areas close to mining operations, and it is believed that this limitation will probably continue in future industrial development.

It is probable that lignite will continue to be used as a source of activated carbon and possibly as a solid fuel in large power plants. It seems likely that any major future use of lignite as a solid fuel will employ a process that will also yield one or more by-products. The Parry char process now used in the plant of the Aluminum Company of America at Rockdale, Texas, produces char, a solid fuel used in producing electric power, and tar, a basic raw material for the chemical industry. Some lignites from east Texas yield as much as 40 gallons of tar per ton, and Texas lignites in general are rich in recoverable tar. Texas lignite is also a potential basic raw material for synthetic liquid fuel and other chemical by-products.

Parry (1955) reported that the major industrial uses for char produced by low-temperature carbonization of coal or lignite are: (1) as fuel for generating electric power, (2) for blending with metallurgical coking coal as a substitute for low-volatile coal, and (3) for gassification to produce synthetic gas for chemical utilization. The char process involves heating the coal or

TABLE 19. *Analyses of samples collected along Elm Creek on Kincaid and Hart properties, Maverick County, Texas* (Mineral Technology Laboratory, Bureau of Economic Geology).

Min. Tech. Lab. No.	60105		60106		60107		60108	
	Kincaid ranch Channel sample		Kincaid ranch Channel sample 100 yards below 1-A		Hart ranch Channel sample, coal beds only		Hart ranch Channel sample, all partings and coal	
Field Sample No.	1-A		1-B		2		2-A	
Approximate analysis in percent								
	As received	Dry basis	As received	Dry basis	As received	Dry basis	As received	Dry basis
Moisture	12.76	.....	13.40	.....	20.30	.....	17.70	.....
Volatile matter	24.82	28.45	33.66	38.87	39.76	49.89	37.82	45.95
Fixed carbon	12.18	13.96	18.21	21.03	17.14	21.51	6.22	7.56
Ash	50.24	57.59	34.73	40.10	22.80	28.60	38.26	46.49
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ultimate analysis in percent								
Sulfur	0.17	0.20	0.29	0.33	0.38	0.48	0.31	0.38
Heating value— B.T.U. per pound	3,060	3,506	4,940	5,704	5,265	6,606	3,635	4,417

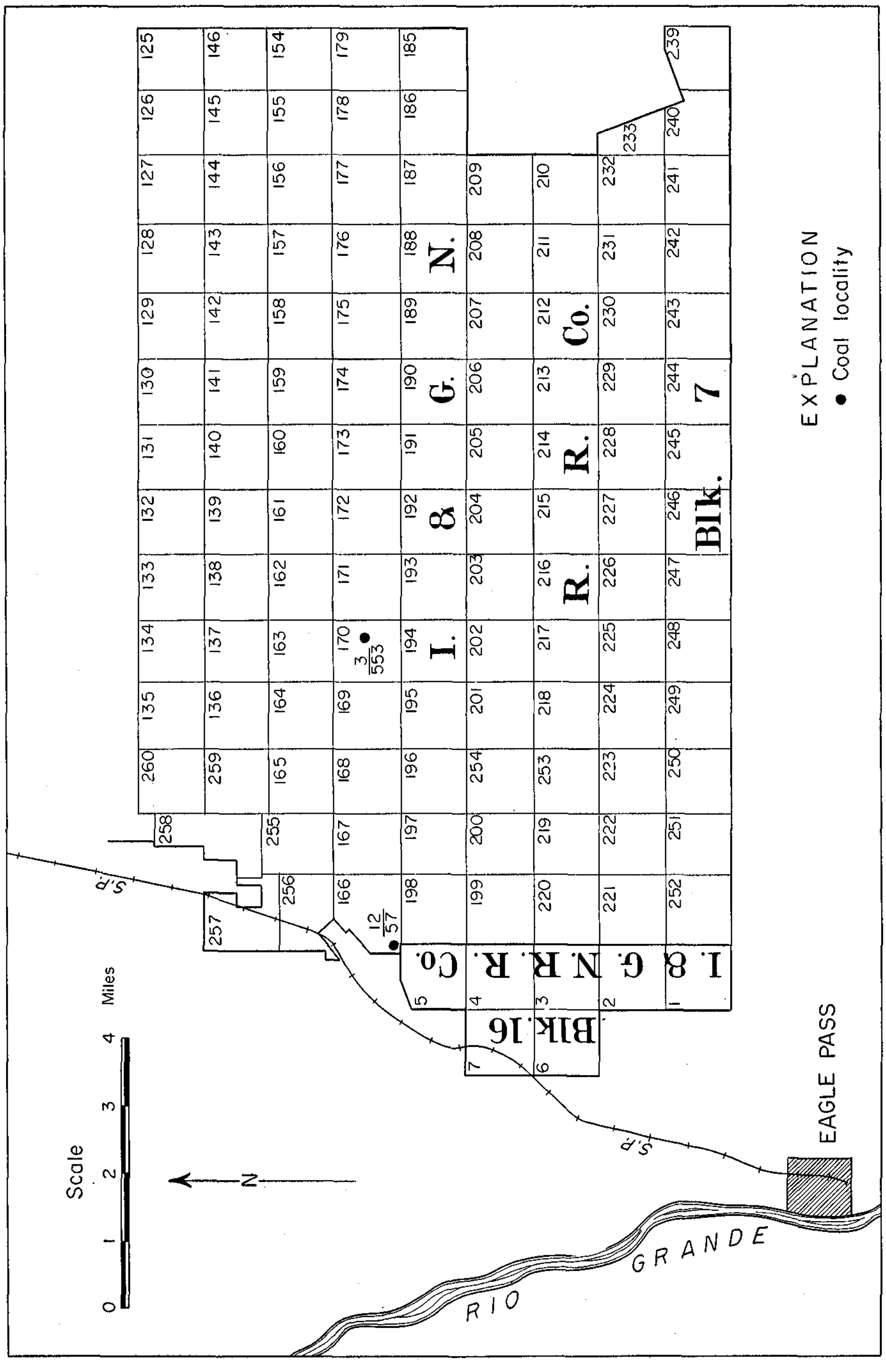

FIG. 2. Coal localities, Eagle Pass area, Maverick County, Texas.

lignite to about 900 to 1,200 degrees Fahrenheit during which the lignite is decomposed into four main products: (1) char or semicoke, (2) tar as complex, partly oxygenated, liquid hydrocarbons, (3) mixed gases, and (4) water. If the coal or lignite is heated rapidly under controlled conditions that prevent decomposition of the primary product, 68 to 87 percent of the net heat in the raw coal or lignite is retained in the char and 10 to 23 percent of the potential heat remains in the tar. The yield of tar from the different ranked coals in the United States ranges from 9 to 44 gallons per ton, and it is important, therefore, to study carefully and test any deposit if carbonization of lignite for industrial uses is being considered. Char can be burned more efficiently at higher temperatures with a higher heat release per cubic foot of furnace value than raw lignite, but unless the volume of tar compensates for a substantial percentage of the costs of char production, it may be more economical to burn raw lignite. In recent years, there has been increasing interest in the char process because of the possible value of the tar as a raw chemical material and in the smokeless quality and high heating values of char for an industrial solid fuel.

The renewed interest in Texas lignite as a source of solid fuel is due to (1) the increased price of natural gas, (2) the possibility that natural gas may become more valuable as a chemical raw material than as fuel, (3) the possibility of treating lignite to produce char for fuel and tar as a by-product, and (4) the potential value of lignite for synthetic liquid fuel and chemicals. The most likely use of lignite in the near future is for large power plant operations, and lignite is potentially important in the State's future industrial development.

Most of the lignite mining in Texas prior to 1947 was by conventional underground methods. Nearly everywhere the lignite and associated strata dip toward the Gulf or away from major structures, so that depth to the lignite body increases down dip from the outcrop. The cost of underground mining increases with depth and recovery is poor. It appears likely that any future large-scale lignite mining in Texas will be by the strip or open-pit method. Perkins and Lonsdale (1955, p. 43) have expressed the ratio of overburden to minable lignite as a fraction. For example, 6/1 refers to a thickness of overburden six times as thick as the minable lignite. They considered the economic limit to be a 10/1 ratio with a minimum thickness of 5 feet of lignite. Strip or open-pit mining is now in progress at Sandow in Milam County and at Darco in Harrison County. At Sandow as much as 150 feet of overburden has been stripped; Lonsdale and Perkins (1955, p. 43) considered 90 feet as a general limit.

South Texas Coastal Plain Occurrences

Lignite in the Texas Coastal Plain occurs in the sedimentary rocks of Tertiary age. It is widely distributed in several formations, but at most localities the beds are either too thin or of insufficient extent to be of commercial importance. The more important deposits are in the Wilcox group and the Yegua formation. The outcrop belts of both units extend across the area of this investigation and are shown on the accompanying map (Pl. IV). Lignite also occurs in the Jackson group and in the Mount Selman and Cook Mountain formations, but the deposits probably are not commercially important in the south Texas area. The better lignite deposits in northern Atascosa, Dimmit, Guadalupe, and Zavala counties are in Wilcox strata, and the lignite in southern Atascosa, Gonzales, Karnes, and McMullen counties is in the Yegua formation.

The strata dip toward the Gulf of Mexico and most lignite beds lie at relatively shallow depths down dip from the outcrop. Locally, the formations have been uplifted and lignites in Wilcox and Yegua formations have been recorded in wells drilled in structurally high areas at considerable distances from the outcrop. Well logs, on file at the Bureau of Economic Geology, in which lignite is recorded are plotted on Plate IV; enlargements of some areas are shown on Plate V. The thickness of the lignite bed and its depth are shown by a fraction. For example, 10/360 indicates that 10 feet of lignite was encountered at a depth of 360 feet. When more than one lignite zone is recorded in the well log all values are shown. Thicknesses of 35 to about 50 feet shown at some localities as the thickness of lignite appear to be abnormally high and perhaps include dark carbonaceous shale.

McMULLEN COUNTY.—The lignite deposits at several localities along San Miguel Creek about 8½ miles north of Tilden were described by Deussen (1924, pp. 82–84) who reported 10 feet of lignite with interstratified layers of bituminous shale or bone in the Yegua formation. Deussen (1924, p. 83, fig. 24) also published a columnar section of the lignite exposed in a shaft 8 miles east-northeast of Tilden. These areas were restudied during the current investigation; the old shaft is no longer accessible but some of the outcrops were located.

The most accessible lignite outcrops are in the south bank of San Miguel Creek upstream about 300 yards west of State Highway 173 and along the north bank of San Miguel Creek east of Highway 173 (Pl. IV; Pl. V, C, Loc. 2, 7).

In the outcrop west of Highway 173 (Pl. V, C, Loc. 2) the principal lignite layers are 19, 10, 20, and 24 inches thick. These are interbedded with thinner bands of lignite, lignitic shale, clay, and dark carbonaceous shale (Section I, below). The lignite section is exposed beneath 15 to 18 feet of gypsiferous and carbonaceous shale that dip about 1½ degrees toward the east. The surface is relatively flat so that excessive overburden would not be expected for considerable distance east-southeast of the outcrop. Analyses of several samples are given in table 20.

SECTION I. *Measured in the south bank of San Miguel Creek, about 300 yards west of State Highway 173, 8½ to 9 miles north of Tilden, McMullen County, Texas.*

Field Sample No.	Min. Tech. Lab. No.		Thickness Feet	Thickness Inches
		Gypsiferous shale	12–15	....
		Lignitic shale	....	8
		Carbonaceous shale	....	10
		Lignitic shale	....	10
		Carbonaceous shale	....	8
2-C	60097	Lignite	2	..
		Carbonaceous shale	....	8
2-B	60096	Lignite	1	8
		Clay	....	4
2-D	60189	Lignite	....	10
		Carbonaceous shale	....	6
2-A	60095	Lignite	1	7
		Carbonaceous shale, exposed in bed of stream	1	6

Summary: Top of lignite, 18′; bottom of lignite, 25′7″; thickest lignite bed, 24″ at depth of 18′; total thickness of lignite beds, 7′1″.

TABLE 20. *Analyses of lignite samples from south bank of San Miguel Creek, about 300 yards west of State Highway 173, 8½ to 9 miles north of Tilden, McMullen County, Texas.*

Min. Tech. Lab. No.	60189		60097		60096		60095	
Field Sample No.	2-D		2-C		2-B		2-A	
APPROXIMATE ANALYSIS IN PERCENT								
	As received	Dry basis	As received	Dry basis	As received	Dry basis	As received	Dry basis
Moisture	12.05	......	16.13	......	16.55	....	15.07	....
Volatile matter	43.62	49.60	41.09	48.99	40.89	49.00	41.59	48.99
Fixed carbon	14.73	16.75	29.88	35.63	27.20	32.59	27.33	32.17
Ash	29.60	33.65	12.90	15.38	15.36	18.41	16.01	18.84
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
ULTIMATE ANALYSIS IN PERCENT								
Sulfur	1.71	1.95	1.89	2.25	1.85	2.22	1.28	1.56
Heating value— B.T.U. per pound	6,652	7,563	8,403	10,019	8,350	10,006	8,665	10,203

East of State Highway 173, the principal lignite zones are 21, 25, 10, and 10 inches thick (Pl. V, C, Loc. 7; Section II, below). The most notable change between the east and west exposures is a decrease in thickness of the two upper lignite beds and a slight increase in thickness of the overburden; analyses are given in table 21.

Recent field studies failed to find any significant lignite deposits along San Miguel Creek except those near the State Highway 173 crossing. Some of the older reports indicate lignite at a locality about 3 miles below the Highway 173 crossing. Louis M. Gubbels, who owns the land, reported (oral communication, June 7, 1961) that San Miguel Creek changed its channel during flood stage a few years past and covered the lignite outcrop, but that 10 to 12 feet of lignite was encountered in a well near that locality. This is believed to be near the shaft where Deussen (1924, p. 83, fig. 24) measured about 14 feet of lignite and bone partings.

Deussen (1924, p. 82) also reported brown lignitic shale on San Miguel Creek about 700 feet above the old Crowther-Tilden road crossing which is now abandoned. This locality was recently visited but no commercially important lignite was seen. Mr. Thetford, who lives 200 yards southeast of the old crossing, reported (oral communication, June 1960) that to a depth of 42 feet no lignite was encountered in his water well. Deussen's (1924, p. 82) measured a section in the Yegua formation near this locality (summarized on page 82).

SECTION II. *Measured in the north bank of San Miguel Creek, east of State Highway 173, about 8½ to 9 miles north of Tilden, McMullen County, Texas.*

Field Sample No.	Min. Tech. Lab. No.		Thickness Feet	Inches
		Soil and clay	8	....
		Clay	5	....
		Band of calcareous concretions	1	6
		Clay	5	....
7-G	60188	Lignite	....	10
7-F		Shale	....	6
7-E	60187	Lignite	....	10
7-D		Shale	....	4
7-C	60186	Lignite	2	1
7-B		Shale	....	10
7-A	60109	Lignite, exposed to water level in San Miguel Creek	1	9

Summary: Top of lignite, 19′6″; bottom of lignite, 26′8″; thickest lignite bed, 25″ at depth of 22′; total thickness of lignite beds, 5′6″.

TABLE 21. *Analyses of lignite samples collected in the north bank of San Miguel Creek, east of State Highway 173, about 8½ to 9 miles north of Tilden, McMullen County, Texas.*

Min. Tech. Lab. No.	60109		60186		60187		60188		60110	
Field Sample No.	7-A		7-C		7-E		7-G		7	
APPROXIMATE ANALYSIS IN PERCENT										
	As received	Dry basis	As received	Dry basis	As received	Dry basis	As received	Dry basis	As received	Dry basis
Moisture	20.87	....	14.14	....	10.60	....	10.84	....	10.06	....
Volatile matter	41.55	52.61	43.06	50.15	43.72	49.03	41.79	46.87	37.97	42.22
Fixed carbon	21.48	27.15	28.93	33.69	18.29	20.50	27.63	30.99	7.11	7.91
Ash	16.10	20.34	13.87	16.16	27.19	30.47	19.74	22.14	44.86	49.87
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
ULTIMATE ANAYLSIS IN PERCENT										
Sulfur	1.84	2.32	2.67	3.10	1.23	1.38	1.77	1.99	.80	.89
Heating value— B.T.U. per pound	7,700	9,731	8,836	10,291	6,610	7,410	7,860	8,816	5,010	5,570

	Thickness Feet	Inches
Brown lignitic shale	8	8
Brown shale	2	0
Brown lignitic shale	1	0
Gray-brown sandy shale	5	0
Brown slightly sandy shale	3	6

Core drilling exploration.—An exploratory drilling project to establish the depth, thickness, and quality of lignite at the locality on San Miguel Creek east of State Highway 173 was completed during 1927. Mr. W. C. Price, Industrial Engineer for the Central Power and Light Company, Corpus Christi, Texas, furnished the writer data from seven holes drilled during that project (letter of transmittal, May 31, 1960). Locations of the test holes are shown on Plate V, C (nos. 8–14). Thickness and depth of lignite encountered during the drilling project are shown in the following logs.

Hole No. 8

	Thickness Feet	Inches	Total depth Feet	Inches
Top soil	1	8	1	8
Clay	40	9	42	5
Gray sandstone	21	6	63	11
Dark sandy shale	8	11	72	10
Gray shale	....	3	73	1
Black shale	2	10	75	11
Lignite	4	10	80	9
Parting	....	10	81	7
Lignite	2	6	83	9
Parting	....	4	84	1
Lignite	....	10	84	11
Parting	....	3	85	2
Lignite	2	3	87	5

Summary: Top of lignite, 75′11″; bottom of lignite, 87′5″; thickest bed of lignite, 4′10″ at 75′11″; total thickness of lignite beds, 10′5″.

Hole No. 9

	Thickness Feet	Inches	Total depth Feet	Inches
Top soil	1	8	1	8
Clay	39	4	41	..
Sandstone	42	5	81	9
Lignite	1	2	82	11
Sandy shale parting	....	8	83	7
Lignite	4	2	87	9
Shale	....	11	88	8
Lignite	6	1	94	9
Shale	....	8	95	5
Lignite	1	4	96	9
Blue clay	6	4	103	1
Lignite	1	11	105	....
Parting	....	1	105	1
Lignite	....	5	105	6
Gray and dark shale	1	4	106	10
Sandstone	22	8	129	6

Summary: Top of lignite, 81′9″; bottom of lignite, 105′6″; thickest bed of lignite, 6′1″ at 88′8″; total thickness of lignite beds, 15′1″.

Hole No. 10

	Thickness Feet	Inches	Total depth Feet	Inches
Surface formations	23	4	23	4
Brown sandstone	8	....	31	4
Gray sandstone	40	7	71	11
Black shale	....	1	72	....
Black shale	1	2	73	2
Lignite	1	1	74	3
Parting	....	6	74	9
Lignite	3	2	77	11
Parting	....	11	78	10
Lignite	2	3	81	1
Parting	....	6	81	7
Lignite	....	10	82	5
Parting	....	3	82	8
Lignite	3	....	85	8
Parting	....	0.5	85	8.5
Lignite	....	7	86	3.5
Parting	....	7	86	10.5
Lignite	....	6	87	4.5
Clay	....	2	87	6.5
Gray shale	1	2	88	8.5
Gray shale	1	3.5	90	....
Lignite	....	8	90	8
Black shale	....	2	90	10
Gray shale	....	4	91	2
Lignite	2	2	93	4
Brown shale	1	9	95	1
Gray shale	14	..	109	1
Gray sandstone	12	10	121	11
Green shale	9	....	130	11
Green sand	21	8	152	7
Lime	1	2	153	9
Gray shale	8	....	161	9
Green sand	9	3	171	....

Summary: Top of lignite, 73′2″; bottom of lignite, 93′4″; thickest bed of lignite, 3′2″ at 74′9″; total thickness of lignite beds, 14′3″.

Hole No. 11

	Thickness Feet	Inches	Total depth Feet	Inches
Surface formation	22	5	22	5
Lignite	....	11	23	4
Shale	....	7	23	11
Lignite	1	2	25	1
Shale	....	6	25	7
Lignite	2	4	27	11
Shale	....	9	28	8
Lignite	2	1	30	9
Shale	....	8	31	5
Lignite	1	4	32	9
Shale	....	3	33	....
Lignite	3	9	36	9
Shale	....	4	37	1
Lignite	....	9	37	10
Green shale	13	7	51	5
Black shale	....	2	51	7
Lignite	....	11	52	6
Shale	....	3	52	9
Lignite	....	7	53	4
Shale	....	9	54	1
Lignite	1	2	55	3
Blue shale	1	10	57	1

Summary: Top of lignite, 22′5″; bottom of lignite, 55′3″; thickest bed of lignite, 3′9″ at 33′0″; total thickness of lignite beds, 15′0″.

Hole No. 12

	Thickness Feet	Thickness Inches	Total depth Feet	Total depth Inches
Surface soil and clay	22	6	22	6
Sandstone	3	4	25	10
Gray shale	3	6	29	4
Black shale	1	2	30	6
Lignite	1	1	31	7
Shale	....	8	32	3
Lignite	1	....	33	3
Shale	....	4	33	7
Lignite	2	3	35	10
Shale	....	8	36	6
Lignite	2	....	38	6
Shale	....	4	38	10
Lignite	1	5	40	3
Shale	....	6	40	9
Lignite	3	7	44	4
Shale	....	7	44	11
Lignite	....	9	45	8
Gray shale	11	2	56	10
Lignite	....	11	57	9
Shale	....	2	57	11
Lignite	....	9	58	8
Shale	....	4	59	....
Lignite	....	8	59	8

Summary: Top of lignite, 30′6″; bottom of lignite, 59′8″; thickest bed of lignite, 3′7″ at 40′9″; total thickness of lignite beds, 14′5″.

Hole No. 13

	Thickness Feet	Thickness Inches	Total depth Feet	Total depth Inches
Soil and clay	8	....	8	....
Sand and flints	5	....	13	....
Brown clay	8	8	21	8
Brown shale	4	8	26	4
Gray shale	6	10	33	2
Green shale	17	1	50	3

No lignite encountered in Hole No. 13.

Hole No. 14

	Thickness Feet	Thickness Inches	Total depth Feet	Total depth Inches
Clay	12	....	12	....
Sand and flints	6	....	18	....
Shale	2	....	20	....
Gray shale	10	7	30	7
Brown shale	1	7	32	2
Slate	1	6	33	8
Shale	....	8	34	4
Lignite	1	2	35	6
Shale	....	4	35	10
Lignite	2	3	38	1
Shale	....	9	38	10
Lignite	2	1	40	11
Shale	....	3	41	2
Lignite	1	6	42	8
Shale	....	7	43	3
Lignite	3	5	46	8
Shale	....	10	47	6
Lignite	....	6	48	....
Green shale	2	....	50	....

Summary: Top of lignite, 34′4″; bottom of lignite, 48′0″; thickest bed of lignite, 3′5″ at 43′3″; total thickness of lignite beds, 13′8″.

Analyses of lignite samples taken during this drilling project were also made available to the writer by Mr. Price (personal communication, May 31, 1960); these are given in table 22.

TABLE 22. *Analyses of lignite samples from locality on San Miguel Creek east of State Highway 173, McMullen County, Texas.*

SAMPLE No. 1 (Hole No. 10). Complete core from 73′2″ to 87′4.5″, including partings.

As Received

	Percent	
Moisture	15.5	
Ash	36.02	
Fe	1.10	
FeO	1.58	
Sulfur	2.44	
Sulfur	2.53	
B.T.U. wet		6,035.94
B.T.U. wet		6,040.04

Dry Basis

	Percent	
Ash	42.70	
Fe	1.31	
FeO	1.87	
Sulfur	2.88	
Sulfur	2.99	
B.T.U. value		7,143.24
B.T.U. value		7,147.97

SAMPLE No. 2 (Hole Nos. 11, 12, 13). Core, all partings eliminated.

Moisture	18.5	
Ash	39.503	
Sulfur	2.39	
Sulfur	2.295	
B.T.U. pellet		5,049.88
B.T.U. pellet		5,025.38
B.T.U. fired loose		4,867.97
B.T.U. fired loose		4,856.37

Ash	48.47	
Sulfur	2.932	
Sulfur	2.915	
B.T.U. pellet		6,196.17
B.T.U. pellet		6,166.11
B.T.U. fired loose		5,972.97
B.T.U. fired loose		5,958.74

W. C. Price (personal communication, May 31, 1960) provided a map showing the location of 44 drill holes in the San Miguel Creek area of north-central McMullen County and also made available a copy of an unpublished report on the 1955 exploration project. The drill hole locations, indicated by numbers (15 to 58), are plotted on the accompanying map (Pl. V, C); thickness and depth to the lignite beds encountered in each well are shown in table 23.

Samples from some of the test holes shown in table 23 were analyzed by the U. S. Bureau of Mines (W. C. Price, personal communication, May 30, 1960) but unfortunately, as indicated in table 24, the analyses cannot be related with certainty to the borings. The samples analyzed were

TABLE 23. *Record of lignite in drill holes, McMullen County, Texas.*

Drill Hole No.	Thickness of lignite bed *Feet*	Depth to lignite bed *Feet*	Drill Hole No.	Thickness of lignite bed *Feet*	Depth of lignite bed *Feet*
15	12	20–32	49	2	114–116
16	8	22–30		3.4	117.6–121
17	8	22–30		5.6	122–127.6
18	None	....	50	3	83–86
19	None	....		2	87–89
20	12	32–44		2	89.6–91.6
21	13	71–84		1	92–93
22	14	98–112	51	4.6	117–121.6
23	None	.....		2	123–125
24	18	41–59		4.4	125.6–130
24-A	15	42–57	52	0.6	54–54.6
25	13	70–83		0.6	63–63.6
26	15	89–104		2.6	163–165.6
27	13.6	85–98.6		1.4	166.6–168
28	12.6	90–102.6		2	170–173
29	15	98–113	53	None	...
30	10	16–26	54	Trace	129–130
31	12	26–38	55	1	188–189
32	13.6	47–60.6		2.6	190–192.6
33	7	21–28		3	195–198
34	13	53–66	56	1	75.6–76.6
35	14	62–76		2	77–79
36	14	136–150		1.6	80–81.6
37	9	115–124		1	82–83
	3.4	124.6–128		2.4	83.6–86
38	15	169–184		1.7	86.3–88
39	14	144–158	57	0.4	52.6–53
40	None	...		2.6	54–56.6
41	4.4	33.6–38		2.6	58–60.6
41-A	3	26–29		3	61–64
	7	30–37	58	4	59–63
42	3.6	43–46.6		2	63.6–65.6
	2	48.6–50.6		3	66–69
	3	51.6–54.6	74	1.4	84.6–86
	0.4	55.6–56		2	86.6–88.6
43	12.6	86–98.6		1	90–91
44	3	139.6–142.6		3	92.6–95.6
	1	146–147	75	1	53.6–54.6
	2.6	149–151.6		2.4	55.6–58
45	5.6	84–89.6		1.4	59.6–61
	2	91.6–93.6	76	3.6	21–24.6
	4	94–98		2	25.6–27.6
46	16?	27–43?		2	29–31
47	None	...		0.4	31.6–32
48	1	66–67			
	2	68.6–70.6			
	1	72–73			
	1.6	74–75.6			
	3.6	76–79.6			

apparently all air-dried; analyses indicate a high ash content (table 24).

The logs of numerous wells drilled in northeastern McMullen and adjacent parts of Live Oak and Atascosa counties indicate lignite or lignitic shale beds at relatively shallow depth in the area southeast, east, and northeast of the lignite outcrops on San Miguel Creek. The well locations with the thickness and depth of the lignite are plotted on accompanying maps (Pl. IV and Pl. V, C). The lignite beds range from about 4 to 10 feet thick and are at depths up to 325 feet. No information is available as to the quality of the lignite.

A shaft 4 by 4 feet in diameter was sunk to a depth of 42.5 feet at a locality near the western boundary of section 3, south bank of the Frio River, about midway between Tilden and Fowlerton (Pl. IV). Lignite was encountered at a depth of 28.5 feet; log of the shaft follows (personal communication, W. C. Price, May 31, 1960), and analyses of the shaft samples are given in table 25.

Prospect shaft, section 3, south bank of Frio River.

	Thickness		Total depth	
	Feet	*Inches*	*Feet*	*Inches*
Clay	24	4	28	4
Lignite	....	2	28	6
Clay	1	5	29	11
Lignite	1	5	31	4
Sandstone	....	2	31	6
Lignite	....	2	31	8
Black shale	....	8	32	4
Lignite	1	6	33	10
Shale	....	2.5	34	0.5
Lignite	1	2.5	35	3
Shale	....	5	35	8
Lignite	1	4	37	....
Shale	....	3	37	3
Lignite	1	3	38	6
Sandstone	2	10	42	4

Summary: Top of lignite, 28′4″; bottom of lignite, 39′8″; thickest bed of lignite, 1′6″ at 32′4″; total thickness of lignite beds, 11′4″.

ATASCOSA COUNTY

Metate and La Parita Creeks.—Deussen (1924, p. 82) reported a lignite bed 8 feet thick in a well at a depth of 60 feet at the Emmanuel Tom ranch on Metate Creek, about 3 miles west of Campbellton in Atascosa County, and 8 to 13 feet of lignite in a number of prospect holes in that vicinity. The location of the old Emmanuel Tom ranchhouse, which is now included in the Arrow S ranch, is shown on the accompanying maps (Pl. IV; Pl. V, C). Lytle Tom, nephew of Emmanuel Tom, reported (oral communication, June 1960) that lignite was encountered in a well about 1 mile west of the old ranchhouse. Graves Peeler of Christine reported (oral communication, June 1960) that Emmanuel Tom dug

TABLE 24. *Analyses of samples from drill holes, McMullen County, Texas* (U.S. Bureau of Mines).

Core Sample No.	20	26	27	29	30	31	32	42
U.S. Bur. Mines Test No.	845	839	840	841	842	843	844	846
				LIGNITE AS RECEIVED (Air-Dried)				
Moisture	8.0	7.5	9.0	10.0	6.4	10.5	8.2	8.5
Volatiles	28.5	21.1	27.6	31.6	27.6	33.0	30.1	31.1
Fixed carbon	18.1	17.0	19.7	23.7	18.5	25.5	22.7	22.9
Ash	45.4	48.4	43.2	34.7	47.5	31.0	39.0	37.5
B.T.U.	5,610	5,250	5,590	6,720	5,510	7,300	6,430	6,630
Sulfur	2.2	2.5	2.0	0.8	2.4	1.1	2.3	0.9
				MOISTURE FREE				
Volatiles	31.0	29.2	30.5	35.1	29.4	36.9	32.7	34.0
Fixed carbon	19.7	18.5	21.7	26.4	19.9	28.5	24.8	25.1
Ash	49.3	52.3	47.8	8.5	50.7	34.6	42.5	40.9
B.T.U.	6,100	6,570	6,170	7,470	5,890	8,160	7,010	7,240
Sulfur	2.4	2.7	2.2	0.8	2.6	1.2	2.5	1.0
				MOISTURE AND ASH FREE				
Volatiles	....	....	....	57.2	....	56.4	56.9	5.5
Fixed carbon	....	....	....	42.8	....	43.6	43.1	42.5
B.T.U.	....	....	....	12,160	....	12,470	12,180	12,260
Sulfur	....	....	....	1.4	....	1.9	4.4	1.7

TABLE 25. *Analyses of shaft samples from western boundary of section 3, south bank of Frio River, McMullen County, Texas.*

	As Received		Dry Basis	
	Sample No. 1	Sample No. 2	Sample No. 1	Sample No. 2
Moisture	18.5	24.5		
Ash	51.36	31.39	63.01	41.57
Ash	49.82	32.38	1.80	42.88
Fe	1.47	1.18	1.80	1.56
Fe O	2.11	1.68	2.58	2.23
Sulfur	4.75	1.49	5.82	1.97
Sulfur	4.85	1.52	5.82	2.01
B.T.U.	3,191.79	5,882.56	3,916.31	7,261.66
B.T.U.	3,216.29	5,486.94	3,946.36	7,267.47

SAMPLE No. 1. Channel sample from top of lignite at 29′11″ to base of lignite at 38′6″.
SAMPLE No. 2. Similar to Sample No. 1; partings omitted.

TABLE 26. *Record of lignite in drill holes southeast of La Parita Creek, Atascosa County, Texas.*

Drill Hole No.	Thickness of lignite bed *Feet*	Depth to lignite bed *Feet*
59	None	......
60	3	72–75
	1	75–76
	1	78–79
	2.4	79.6–82
	1	82.6–83.6
61	1	37–38
	8.4	40.6–49
62	1	19–20
	7	21–28
63	Trace	7–12
64	2.4	43.6–46
	4.6	47–51.6
65	4	27–31
	0.4	32.6–33
66	1	45.6–46.6
	3.4	47.6–51
	4	52–56
	2	58–60
67	1	47–48
	2	49–51
	2.6	52–54.6
	4.6	55–59.6
	1	60–61
68	3	7–10
69	1	20–21
	5	23–28
	3.6	29–32.6
	0.4	33.6–34
70	1.6	46–47.6
	2.4	48.6–51
	5.6	52–57.6
	0.4	58.6–59
71	1	74–75
	1	76–77
	2	77.6–79.6
	1	80–81
	1.6	82–83.6
	1	84.6–85.6
72	Trace	42–45
73	1	21–22
	1	23–24
	3	25.6–28.6
	3	30–33
	0.4	33.6–34

20 or more wells in the area between the Tom ranchhouse and Campbellton and that lignite was encountered in each well at a depth of about 30 feet. During the exploratory drilling prior to construction of the Farm Road 140 bridge at Metate Creek, 12 feet of lignite was penetrated at a depth of 20 to 32 feet.

W. C. Price (personal communication, May 31, 1960) supplied a map showing the location of 15 drill holes in the La Parita Creek area, southern Atascosa County. These are shown on Plate V, C (Nos. 59–73), and depth to and thickness of lignite beds encountered are given in table 26.

Kirkwood mine.—Dumble (1889, p. 67) published a description of the Kirkwood mine, which is in Bexar County about three-fourths of a mile north of the Atascosa County line (Pl. IV). The mine, now long abandoned, had been in operation for several years prior to Dumble's inspection in 1888. The lignite bed, in the Wilcox group, was 5 feet 3 to 6 inches thick. Although the lignite disintegrated during handling and necessitated special grates, it was sold as a fuel in San Antonio. The following analysis is given by Dumble (1889, p. 185):

Moisture	13.285
Volatile matter	59.865
Fixed carbon	18.525
Ash	8.325

Kinney mine.—The Kinney mine on an adjacent property (now abandoned) was also in operation at the same time (Pl. IV).

The lignite was of similar thickness and quality and was also sold as a solid fuel in San Antonio. Dug wells at several nearby localities encountered the lignite, and Dumble estimated that dozens of small mines could be opened in the area. Dumble did not record the depth to the lignite in any of the wells, but it was probably not more than 50 feet.

Cassin Station.—Baker (1935, pp. 334, 342) published analyses of lignite samples collected from near Cassin Station on the Medina River in Bexar County and these are repeated in table 27.

TABLE 27. *Analyses of lignite samples from near Cassin Station, Bexar County, Texas.*

	Sample No. 1249	Sample No. 1250
AS RECEIVED		
Moisture	23.64	14.60
Volatile matter	43.15	18.00
Fixed carbon	23.15	8.60
Ash	9.70	58.60
Sulfur	2.03	....
B.T.U. value	8,104	....
DRY BASIS		
Volatile matter	56.98	21.08
Fixed carbon	30.32	10.07
Ash	12.70	68.85
Sulfur	2.66	....
B.T.U. value	10,613	....

SAMPLE No. 1249. From outcrop in river bank 40 to 45 feet below surface.
SAMPLE No. 1250. From a well at 164 feet.

Carr-Bertelli mines.—The old Carr mine (now abandoned) is in Medina County about 0.7 mile west of Lytle close to the Atascosa County line (Pl. IV). A lignite bed 5 feet 3 inches thick was mined at a depth of 40 feet in the Carr mine. In the Bertelli mine 1 mile farther southwest, 4 feet 6 inches of lignite was mined at a depth of 90 feet; the operators were probably mining the same lignite bed. The difference in depth is due to faulting. The lignite from both mines was sold in San Antonio for fuel. Analyses published by Baker (1935, p. 337) are repeated in table 28.

Poteet mine.—Lignite was mined at Poteet about the beginning of this century but all activity ceased many years ago. One of the old shafts can still be seen along the road to Shady Oak Dam about 1 mile southeast of Poteet. The lignite with partings is reported to be about 5 feet thick; reports as to depth range from 30 to 40 up to 125 feet. Analyses of this Poteet lignite were published by Baker (1935, p. 334) and are repeated in table 29.

Well logs on file at the Bureau of Economic Geology support Dumble's conclusion that a belt of lignite is present at relatively shallow depths in northern Atascosa County. The well locations have been plotted on the accompanying map (Pl. IV), and thickness of and depth to the lignite beds are shown as a fraction. Most of the lignite is in the Wilcox group; the logs indicate the presence of at least two or more lignite zones which range in thickness from 2 or 3 feet up to 10 or 12 feet. Unfortu-

TABLE 28. *Analyses of lignite from Carr and Bertelli mines, Medina County, Texas.*

Mine Sample No.	Carr 1322	Carr 1324	Carr 1325	Carr 1326	Bertilli 1323	Bertelli 1327
AS RECEIVED						
Moisture	35.30	31.67	32.92	27.39	34.39	28.34
Volatile matter	36.33	24.81	27.42	35.07	40.31	41.49
Fixed carbon	28.85	26.49	27.08	28.16	18.50	21.63
Ash	7.52	17.03	12.58	9.38	6.90	8.54
Sulfur	....	3.55	1.46	0.88	....	0.87
B.T.U. value	....	....	6,840	7,485	....	7,846
DRY BASIS						
Volatile matter	....	....	....	....	....	....
Fixed carbon	....	....	....	....	....	....
Ash	....	....	....	....	....	....
Sulfur	0.93	....	....	....	1.20	....
B.T.U. value	12,215	....	....	....	11,470	....

TABLE 29. *Analyses of lignite from Poteet area, Atascosa County, Texas.*

	No. 1241	No. 1242	No. 1243
As Received			
Moisture	25.00	34.82	24.00
Volatile matter	18.20	19.73	36.07
Fixed carbon	43.80	34.62	32.79
Ash	13.00	10.80	6.96
Sulfur	1.23	1.26	0.62
B.T.U. value	8,105	7,860	9,002
Dry Basis			
Volatile matter	24.27	26.50	47.46
Fixed carbon	58.40	58.90	43.38
Ash	17.33	14.60	9.14
Sulfur	1.64	1.73	0.82
B.T.U. value	10,131	10,598	11,845

SAMPLES No. 1241 and 1242. Lignite taken from the Poteet mine.

SAMPLE No. 1243. From outcrop on a ranch near the town of Poteet.

nately, most logs of oil wells do not include the detailed information necessary to make an accurate appraisal of the lignite resources. It is possible that some black carbonaceous shales were logged as lignite; probably the log that indicates 30 feet of lignite is not accurate.

East-central Atascosa County.—Thin beds of lignite crop out in central and east-central Atascosa County. For the most part the lignite beds are in the Mount Selman and Cook Mountain formations which underlie outcrop bands between the Wilcox and Yegua units shown on Plate IV; these formations extend across several counties within the area of this investigation. Little is known regarding the quality of the lignite. None of the localities visited during the current investigation appear to be of commercial interest.

Logs of scattered wells in central and east-central Atascosa County indicate that lignite is present in the subsurface. In a well about 3 miles northeast of Pleasanton, three lignite beds (16, 9, and 35 feet thick) are shown in the log at depths of less than 400 feet. The log of a well about 10 miles east-southeast of Jourdanton indicates lignite zones 5, 3, 6, and 29 feet thick at depths up to 389 feet (Pl. IV). Nothing is known regarding the quality of the lignite and no samples are available for testing.

ZAVALA COUNTY.—Both the Indio formation of the Wilcox group and the Bigford member of the Mount Selman formation are lignitic and where their outcrop crosses the Nueces River valley in northern Zavala County there are several exposures of lignite (Pl. IV; Pl. V, A) that have been described by Owen (1889, p. 69), Dumble (1892, p. 188), Vaughan (1900, pp. 61–62; 1900a, p. 5). Ashley (1919, p. 268), Getzendaner (1931, pp. 117–118), and Baker (1935, pp. 131–333). Lignite in well borings on the I. T. Pryor ranch were noted by Getzendaner (1931, p. 117) and Baker (1935, p. 333).

During recent field studies, lignite outcrops were found along the Nueces River on the George Horner ranch, formerly the old Pulliam and McDaniel ranches, about 12 miles southwest of Uvalde. The most promising exposure is in the east bank of the Nueces River about 1 mile southeast of the bridge on U.S. Highway 83; the locality is opposite the old McDaniel ranch (Pl. V, A, Loc. 1). The following section was measured at this locality, and analyses of collected samples are given in table 30.

SECTION III. *Measured in the east bank of the Nueces River about 1 mile below the bridge on U.S. Highway 83, Zavala County, Texas.*

Field Sample No.	Min. Tech. Lab. No.		Thickness Feet	Thickness Inches
		Overburden is gravel and sandy or silty shale	20–25	....
1-A	60085	Lignite	1	8
		Black shale	8	....
1-B	60086	Lignite	2	8
		Black shale	6–7	....
		Lignite, not sampled	....	10
		Black shale and sandstone to water level	10	....

TABLE 30. *Analyses of channel samples collected from the two thickest lignite beds in east bank of the Nueces River about 1 mile below the bridge on U.S. Highway 83, Zavala County, Texas.*

	Sample No. 1-A (Min.Tech.Lab. No. 60085)		Sample No. 1-B (Min.Tech.Lab. No. 60086)	
	APPROXIMATE ANALYSIS (*percent*)			
	As Received	Dry Basis	As Received	Dry Basis
Moisture	7.48		7.99	
Volatile matter	28.89	31.20	35.56	38.65
Fixed carbon	11.64	12.60	24.39	26.51
Ash	51.99	56.20	32.06	34.84
Totals	100.00	100.00	100.00	100.00
	ULTIMATE ANALYSIS (*percent*)			
Sulfur	0.30	0.32	0.68	0.74
Heating value—B.T.U. per pound	3,299	3,566	6,855	7,550

Vaughan (1900, p. 62; 1900a, p. 5) measured a section opposite the old McDaniel ranch which was probably near the above-described locality but he did not sample the lignite; this section is repeated below.

SECTION IV. *Measured on McDaniel ranch, near the Nueces River, Zavala County, Texas.*

	Thickness Feet	Thickness Inches
Flaggy clay and sandstone	25–30	....
Chocolate-covered clay	6	....
Coal not clearly exposed	1 or 2	....
Chocolate-covered clay	3	....
Coal	1	10 or 11
Chocolate-covered clay	6 or 7	....
Coarse sand	....	11
Chocolate-covered clay and sand	3	4
Coal	0	8
Bone	..	3
Chocolate-covered clay	6	....

Unexplored to water's edge, about 20 feet.

Ashley (1919, p. 268) also visited this locality and reported three beds of lignite—"the middle one 22 to 23 inches thick, a 'rider' 1 to 2 feet thick 3 feet above, and an 8-inch bed 4 feet 3 inches below." His sections differ slightly from the values shown in Sections III and IV (pp. 88, 89).

Lignite occurs in the Nueces River bed about 200 yards above the measured section (Pl. V, A, Loc. 1), but at the time of this investigation the lignite was under water. A recent drill hole on the river bank is reported to have penetrated about 5 feet of lignite, most of which was below the level of the river bed. Owen (1889, p. 69) probably visited this locality; he reported a lignite stratum 4 feet 10 inches thick with a 3-inch division of slate in the center. Dumble (1892, p. 188) reported that the lignite (probably from this locality) was used by blacksmiths at Fort Inge and was found to be of good quality.

There are two old mine shafts on the Nueces River bank (Pl. V, A, Loc. 2) about 1 mile above the bridge on U. S. Highway 83. George Horner (oral communication, June 1960) reported that the Missouri Pacific Railway Company mined some lignite at this locality years ago. The lignite was about 10 feet thick at a depth of 25 to 30 feet. One of these shafts may be the old shaft reported by Dumble (1892, p. 188). He stated that "Mr. Gillespie sunk a shaft into the coal and found it to be of excellent quality, and to be 4 feet 10 inches thick with a 2-inch division in the center. The thickness and center parting is more like the lignite seam in the river bed 1 mile below the bridge on U. S. Highway 83."

Lignite has been reported at a locality about midway between the old Missouri Pacific mine shaft and the Nueces River highway bridge. This locality was under water at the time of the field investigation. Vaughan (1900, p. 47) measured the following section (V, p. 90) through exposed lignite at a locality which he described as half a mile below the old Pulliam ranch (approximately midway between the mine shafts and the highway bridge).

Thin beds of lignite crop out at several localities along the Nueces River above the old mine shafts as far north as the State Highway 481 crossing in Uvalde County, SECTION V. *Measured about half a mile below the old Pulliam ranch, Zavala County, Texas.*

	Thickness Feet	Inches
Silt, gravel, fluvial	35	....
Laminated brownish sandstone, containing many carbonaceous specks and a few fossil leaves	2	3
Laminated blue carbonaceous clay	5	..
Laminated black clay	1	6
Coal, bony at top	2	4
(Water level in Nueces River)		

but all are too thin to be commercially important.

Getzendaner (1931, p. 117) reported that "a bed of coal 5 or 6 feet thick, with an 8-inch shale parting, crops out in the east bank of the Nueces River near the south line of the Pulliam ranch, and there is a similar outcrop on the same side of the river two or three miles farther north on the same ranch." It is difficult to correlate his observations with the localities previously described but the general outcrop area is the same. Getzendaner (1931, p. 117) also reported a thin coal in the Bigford where it crosses the Nueces River southeast of La Pryor. Several thin lignite and lignitic shale seams occur in this area but none of them are thick enough to be commercially important.

Coal, probably all of it lignite, has been reported from many water wells, either drilled or dug in the Wilcox in the northern part of Zavala and the southern part of Uvalde counties. Coal has also been reported in Cretaceous formations farther north in Uvalde County. Dumble (1892, p. 188) reported a seam of bituminous coal several feet thick on the Nueces River about 10 miles west of Fort Inge. Johnny Roberts of Sabinal (oral communication, June 1960) reported 8 feet of coal at a depth of 65 feet in a well near the Blanco River on the McWoodley ranch east of Uvalde. About two tons of Wilcox lignite were mined from a depth of 30 feet on the Kincaid ranch (Pl. IV, Loc. 1) near State Highway 140 about 10 miles southeast of Uvalde. Lignite was encountered at a depth of 65 feet in a well about half a mile farther south. George Horner (oral communication, June 1960) reported that a well drilled on the eastern part of his ranch encountered 10 feet of lignite at a depth of about 100 feet (Pl. V, A, Loc. 3).

The Ike T. Pryor ranch joins the Horner ranch on the south. Getzendaner (1931, pp. 117–118) reported that 26 wells drilled on the Pryor ranch logged 194 feet of coal (lignite) for an average of 7.4 feet per well. In 1920, Jeffreys (1920) directed the drilling of five wells in the northern part of that ranch (exact location unknown), which encountered 16, 15, 4, 3, and 4 feet of lignite. Air-dried samples from the five wells were analyzed by David Hancock of Birmingham, Alabama. Getzendaner (1931, p. 118) calculated the average of 13 analyses from the five wells; these calculations, reprinted by Baker (1935, p. 333), are repeated in table 31.

TABLE 31. *Calculated average of thirteen lignite analyses from five wells on Pryor ranch, Zavala County, Texas.*

	Percent	
Impurities	16.5	
Clean coal	83.5	
Moisture	6.11	
Volatile matter	37.30	
Fixed carbon	40.99	
Ash	15.50	
Sulfur	1.97	
B.T.U. value (dry-coal basis)		11,231

Getzendaner (1931, p. 118) and Baker (1935, p. 333) published an analysis of a sample from one of these five wells on the Pryor ranch; this analysis is repeated in table 32.

TABLE 32. *Analysis of lignite sample from Pryor ranch, Zavala County, Texas.*

	Percent	
Ash	11.05	
Sulfur	3.02	
Moisture	15.32	
Fixed carbon	53.00	
Average specific gravity	1.32	
Calorific value, B.T.U.'s		11,530

Analysis of a lignite bed encountered at 118 feet in an artesian well drilled 12 miles west of La Pryor in Zavala County was published by Baker (1935, pp. 340, 351) and is repeated in table 33.

TABLE 33. *Analysis of lignite from artesian well, 12 miles west of La Pryor, Zavala County, Texas.*

SAMPLE NO. 1436

AS RECEIVED

Moisture	8.37
Volatile matter	25.93
Fixed carbon	36.40
Ash	29.30
Sulfur	1.68
B.T.U. value	8,104

DRY BASIS

Volatile matter	28.30
Fixed carbon	30.72
Ash	31.98
Sulfur	1.83
B.T.U. value	8,844

Lignite in the Wilcox is widespread but commonly the beds are only about 1 or 2 feet thick and thin both down the dip and along the strike. Getzendaner (1931, p. 117) reported that logs of some wells on the Ike T. Pryor ranch show no important lignite beds. He concluded that this is due in part to hurried drilling and lack of attention to the drill cuttings. However, some wells were carefully sampled, proving that there are locations where the lignite is too thin to be economically important. Getzendaner believed that such "blind spots" are local because thicker lignite seams occur on all sides.

From the Nueces River outcrops in northern Zavala and southern Uvalde counties, the Wilcox lignite belt extends east and northeast across southern Medina, northern Atascosa, southern Bexar, northern Wilson, and central Guadalupe counties. The old Carr and Bertelli mines in southwestern Medina County and the old Kirkwood and Kinney mines in southwestern Bexar County, as well as most of the wells in northwestern Atascosa County in which lignite occurs, are in the Wilcox lignite belt. The locations of wells encountering lignite in Guadalupe County have been plotted (Pl. IV; Pl. V, D) and most of these are also in the Wilcox. These data show the widespread distribution of the Wilcox lignite, but unfortunately there is but little detailed information available regarding depth, thickness, and quality of the deposits. Detailed information can be obtained only by further exploration and careful study of the information obtained.

FRIO COUNTY.—Thin impure lignite beds in the Mount Selman and Cook Mountain formations crop out at several localities in Frio County. Some of these were recognized as early as 1888 when Tait (1889, p. 68) reported lignite exposures 6 miles northeast of Pearsall, on San Miguel Creek 9 miles south of the International Railroad crossing, and along the Frio River southwest of Pearsall. Dumble (1892, p. 187) reported that coal from a locality on San Miguel Creek in Frio County was hauled 50 miles to San Antonio where it was being used by blacksmiths, who pronounced it moderately fair quality. Dumble (1892, p. 188) published the following section from the San Miguel Creek locality.

Soft bluish-black bituminous shale.
Brown coal, 2 feet thick.
Shale of the same character as above.
Shale.
Brown coal, 20 inches thick.

During the field investigations for this study, all of the lignite exposures visited in this area were found to be less than 2 feet thick, highly irregular in lateral extent, and impure. Several well logs indicate that lignite is present in the subsurface of Frio County (Pl. IV). A group of three closely spaced wells about 5 miles southwest of Pearsall encountered three lignite beds of the same thickness. This uniformity in thickness of lignite and intervals separating the lignite seams suggests that they may have considerable lateral extent. Further search may find these beds at a much shallower depth up dip toward the north-northwest at some point along the Frio River or Hondo Creek.

A log of the Derby well, south of Pearsall, indicates two lignite zones 35 and 105 feet thick (Pl. IV). Although lignite was probably penetrated during the drilling, the thicknesses quoted are probably excessive. The wells at Dilley, 4 miles northwest of Divot, and near Frio Town all indicate lignite of abnormal thickness. Northeastward, along the Mount Selman and Cook Mountain outcrop in Atascosa County, some well logs indicate lignite beds 27 and 35 feet thick. The lignite at Poteet is described on page 87.

KARNES COUNTY.—Baker (1935, pp. 336, 345) published an analysis of lignite from 1,011 to 1,013 feet in the Manhattan Oil Company well, Karnes City; this is repeated in table 34.

TABLE 34. *Analysis of lignite from Manhattan Oil Company well, Karnes City, Karnes County, Texas.*

SAMPLE No. 1296
AS RECEIVED

Moisture	34.70
Volatile matter	33.23
Fixed carbon	21.87
Ash	11.20
Sulfur	0.76
B.T.U. value	7,056

The wells plotted on Plates IV and V were chiefly drilled for oil during a period when lignite was not considered of economic significance, and there was not much reason to record accurately the thickness and depth of shallow lignite zones. Also in some instances there was hurried drilling, superficial inspection of the drill cutting, and because it is not always easy from casual observations to distinguish between black carbonaceous shale and lignite in the old churn-drill cuttings, it is probable that some carbonaceous lignitic shales were logged as lignite. It is probable, therefore, that some of the greater thickness values recorded for lignite deposits are not realistic, and all well log records should be carefully scrutinized as to thickness and depth of the lignite. None of the logs give information as to the quality. Areas in which well logs suggest the presence of commercially important lignite should be investigated carefully.

Several oil companies are currently in the midst of extensive drilling related to geophysical prospecting in the lignite areas of the Gulf Coastal Plain. The "shot holes" are generally 75 to 100 feet deep, and much information regarding shallow lignite deposits can be obtained from these surveys.

Peat

Definition, Utilization, and Occurrence

Peat is a brown or black, spongy, organic substance formed by the accumulation of organic matter of plant origin in poorly drained marshes and bogs. It consists of a mass of partially disintegrated moss, ferns, rootlets, leaves, sedges, algae, grass, and partially decayed wood all pressed together to form a soft, spongy layer beneath the living moss, fern, and sedge cover of the marsh.

Because of its humus content, water-absorbing qualities, acid properties, and cleanliness, peat has been extensively used by Texas florists, gardeners, and horticulturists to condition alkali soils, to lighten and enrich heavy clay loams, to propagate seedlings, and for potting plants. Plummer (1941) reported that before the beginning of World War II most of the peat moss used in the Southwest came from Europe, but when that supply became unavailable Texas peat bogs were worked to supply the local market. The first production of peat in Texas was from two bogs north of Giddings in Lee County.

GONZALES COUNTY. — Chelf (1941) described the Soefje and Hershop (Alex) peat deposits in Gonzales County and the Denman and Berger peat deposits in Guadalupe County. Present utilization of the Gonzales County peat is limited to intermittent local use.

Soefje peat bog.—The Soefje deposit is in a swamp along a small tributary to the San Marcos River, near the village of Ottine. There are two peat deposits over an area of about 10 acres. The largest one is on the south margin of the swamp and is primarily a slope deposit, the upper portion of which is above flood level and consequently free from silt. The smallest bog is along the northwest margin of the swamp; much of it lies below the flood plain of the San Marcos River and is subject to periodic flooding and silting. Occasional lenses of sand occur in both deposits as a result of sheet wash from adjacent slopes.

The south peat deposit is a narrow strip about 2,000 feet long and from 100 to 250 feet in width. The average thickness is 5 to 6 feet, with a maximum thickness of 22 feet on the west end and an average thickness of 10 feet in the western portion of the deposit. Chelf collected samples and published a map of the deposit and the analyses given in table 35 (Chelf, 1941, fig. 1; p. 3).

Alex peat bog.—The Alex peat deposit (formerly the Hershop deposit) is in a basin about half a mile south of the Soefje bog and 1 mile west of Ottine. It is farther from the San Marcos River than the Soefje bog, and peat development has not been as inhibited by silting from floods on the river. The visible peat area is somewhat smaller than the original bog because sand and soil have washed over the edges of the deposit. The total area of recoverable peat without overburden is about 450 by 450 feet, and the thickness ranges up to about 50 feet. The following analyses (table 36) are from Chelf (1941, p. 9).

Rutledge peat bog.—The Rutledge peat deposit, until late 1959, was within the exterior boundaries of Palmetto State Park and during that period was not available for exploitation. The swamp in which the peat is accumulating is adjacent to the Soefje bog and is similarly related to the drainage of the San Marcos River. The peat has not been tested, it appears to consist chiefly of altered sedge and cat-tails, and it is probably similar in quality to the peat in the Soefje bog (table 35). The available tonnage is not known.

GUADALUPE COUNTY

Denman and Berger deposits.—The Denman peat deposit, about 6 miles southwest of Belmont in Guadalupe County, covers about half an acre in a relatively flat valley that joins the Guadalupe River. The deposit is about 1 foot thick and contains a high percentage of silt.

The Berger peat deposit, also in Guadalupe County, is about 7½ miles southwest of Belmont and covers an area of about 1 acre; it is up to 3 feet thick. The following analyses (table 37) of samples collected at the Berger peat deposits are given by Chelf (1941, p. 10).

TABLE 35. *Analyses of samples from Soefje peat bog, Gonzales County, Texas.*

Traverse	Hole	Position	Moisture (Percent)	Ash (Percent)	pH 2 days	pH 6 days	pH 14 days	Color of ash
A-B	1	Spring water from swamp			3.7	6.6	3.7	....
A-B	4	Surface to 4″	9.0	2.8	5.8	5.2	4.6	White and yellow
A-B	4	Upper	20.0	12.2	4.9	4.5	3.9	White
A-B	4	Middle	23.2	12.7	4.4	4.4	4.1	White
A-B	4	Lower	28.2	19.4	3.9	4.1	3.8	White
C-D	3	Upper	24.0	13.7	5.2	5.0	4.7	White with brown and purple
C-D	3	Lower	58.2	54.2	6.0	5.0	4.2	Gray-lavender
E-F	1	Upper	20.5	13.5	3.1	3.2	3.4	Light brown
E-F	1	Lower	15.6	10.1	6.1	5.5	4.7	White
G-H	1	Upper	17.3	7.8	3.6	3.7	3.5	Brown
G-H	1	Middle	36.3	24.1	4.6	4.7	4.4	Brown and white; SO_2 upon ignition
G-H	1	Lower	23.0	10.5	6.1	6.3	6.0	White and brown

TABLB 36. *Analyses of samples from George Hershop (Alex) bog, Gonzales County, Texas.*

Sample and position	Moisture (Percent)	Ash (Percent)	pH	Color of ash
No. 1, 3 feet, center of main dome	23.1	11.3	3.6	Gray and brown
No. 2, 6 feet, center of main dome	29.8	16.2	4.6	Dark brown; SO_2 on ignition
No. 3, 12 feet, center of main dome	21.7	11.8	4.7	Dark brown
No. 4, 12, AB-6	32.6	17.6	4.1	Dark brown

Table 37. *Analyses of samples from the Berger peat bog, Guadalupe County, Texas.*

Sample and position	No. 1, upper	No. 2, middle
Moisture	23.8	28.6
Ash, percent	9.7	15.9
pH	6.5	6.3
Color of ash	Gray	Gray; SO_2 on ignition

Filler for Fertilizer

The Orga-Min Products Company, Inc., of Laredo, Webb County, Texas, produces carbonaceous shale that is used by the citrus fruit growers as a soil conditioner. Some of the shale is shipped to San Antonio where it is used as a base for fertilizers. The shale is associated with the coal series beds, and the site of the present operation is near the old cannel coal mine northwest of Laredo (Pl. IV). The carbonaceous shale layer ranges from 2 to 6 feet thick and crops out over an area of several hundred acres. Annual production is about 2,000 tons from open pits.

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GRINDING PEBBLES

UTILIZATION AND PRODUCTION

Grinding pebbles and rock mill liners are used in grinding operations where it is essential that the product be free of contamination by metal such as iron or steel. Most of the grinding pebbles used in the United States have been imported, but domestic pebbles were used in limited quantities during World War II and domestic production was increased at that time. The grinding-pebble industry is small and the market limited. In 1958, according to the United States Bureau of Mines, only 1,985 short tons of grinding pebbles, valued at $97,000, were produced in the United States, and only a few carloads came from Texas.

During 1925, hand-picked flint gravel from Cretaceous limestone north of Austin was used in laboratories at The University of Texas; so far as known, this is the first use of Texas grinding pebbles. Thereafter, Parkinson, of the Bureau of Engineering Research of the University, conducted a series of tests on the flint pebbles from several localities (Parkinson and Barnes, 1944, p. 47).

Most Texas flint pebbles have a soft coating or rind which is readily removed by milling. Parkinson found that after processing, the Texas flint pebbles compared favorably with imported beach-rolled pebbles. Parkinson interested F. Clay McGaughy of San Antonio in processing grinding pebbles, and in 1940 McGaughy and Carter formed a partnership for that purpose; McGaughy and Carter's processing plant on the south edge of San Antonio was later purchased by the H. B. Zachry Company. The Zachry Company processed pebbles shipped by rail from a deposit about 3.3 miles north of Pearsall in Frio County. The pebbles were tumbled in a wet conical flint-lined pebble mill until clean and rounded and then passed over a sorting belt where broken pebbles and foreign material were removed by hand picking.

Later, Southern Products & Silica Company established a processing plant about 2 miles west of Columbus in Colorado County. At the Columbus plant the flint pebbles were processed dry in a granite-lined mill which held a 5-ton charge. A collector was used to draw off the dust and fine silica particles. After about 3½ hours of milling, the pebbles were passed over a screen to remove the flat pebbles and hand sorted on a moving belt.

Parkinson and Barnes (1944, p. 47) reported that grinding pebbles were also produced in the early 1940's by Philip S. Hoyt, and in recent years flint pebbles gathered with hand rakes in fields and from pits in Travis and Bastrop counties were shipped by the Dezendorf Marble Company of Austin.

OCCURRENCE AND DISTRIBUTION

The gravel deposits containing the highest percentage of rounded flint pebbles are generally found on high divides along rivers that head in or flow across the Edwards Plateau. The flint was derived from erosion of the massive cherty Cretaceous limestones that crop out in the Edwards Plateau. The flint nodules were rolled about, shifted, reworked, and sorted numerous times until they came to rest at lower elevations along the Plateau margins. During this process the soft and weak materials were reduced to sand or clay and removed, leaving the more resistant flint pebbles rounded by abrasion.

The flint gravels generally occur in isolated layered deposits ranging from a few yards to 5 miles or more in length, and they dip gently southeast. In some areas there are only scattered flint pebbles; in others there is a thin veneer of gravel; more rarely deposits of flint and limestone pebbles approach 100 feet in thickness. The better grades of flint pebbles are commonly in deposits less than 10 feet thick.

The roundest pebbles are less than 3 inches in diameter, but some cobbles up to 5 or 6 inches can be used when properly processed.

Terraces along most of the major rivers that cross the interior margin of the Coastal Plain range from 20 to 100 or more feet above the normal water level in the drainage channel, and many of these high river terraces also contain flint pebbles. The intermediate terraces contain mixtures of flint and limestone, and the lower terraces consist chiefly of mixed rocks from the upper drainage basin. Commonly, however, the flint pebbles from the lower terraces are rounder because they have been transported and rolled the greatest number of times. The materials in terraces immediately adjacent to the Edwards Plateau are predominantly flint and limestone, but farther downstream where the rivers cross the Tertiary formations the terrace gravels also contain sandstone, silicified fossil wood, and other materials. The gravels along the Colorado River, which crosses the Llano uplift area, and the Pecos and Rio Grande, which head outside the State, are a mixture of the many rock types found in their respective drainage basins.

Deussen (1924) mapped and described certain of the gravel deposits of the Texas Coastal Plain between the Brazos and Nueces rivers (fig. 3). Parkinson and Barnes (1944) reported on the grinding pebbles of Texas. Counties which contain extensive gravel deposits that are most likely to contain flint pebbles that can be processed to form a commercial product are Atascosa, Dimmit, Frio, Gonzales, Guadalupe, Karnes, Kinney, La Salle, Live Oak, Maverick, McMullen, Uvalde, Val Verde, Webb, and Zavala.

ATASCOSA COUNTY.—Flint gravel up to 10 feet thick covers much of the divide between La Parita and Atascosa Creeks about 4 miles east of Christine in southern Atascosa County. Most of the flint pebbles are well rounded, but all have a brownish rind of soft material.

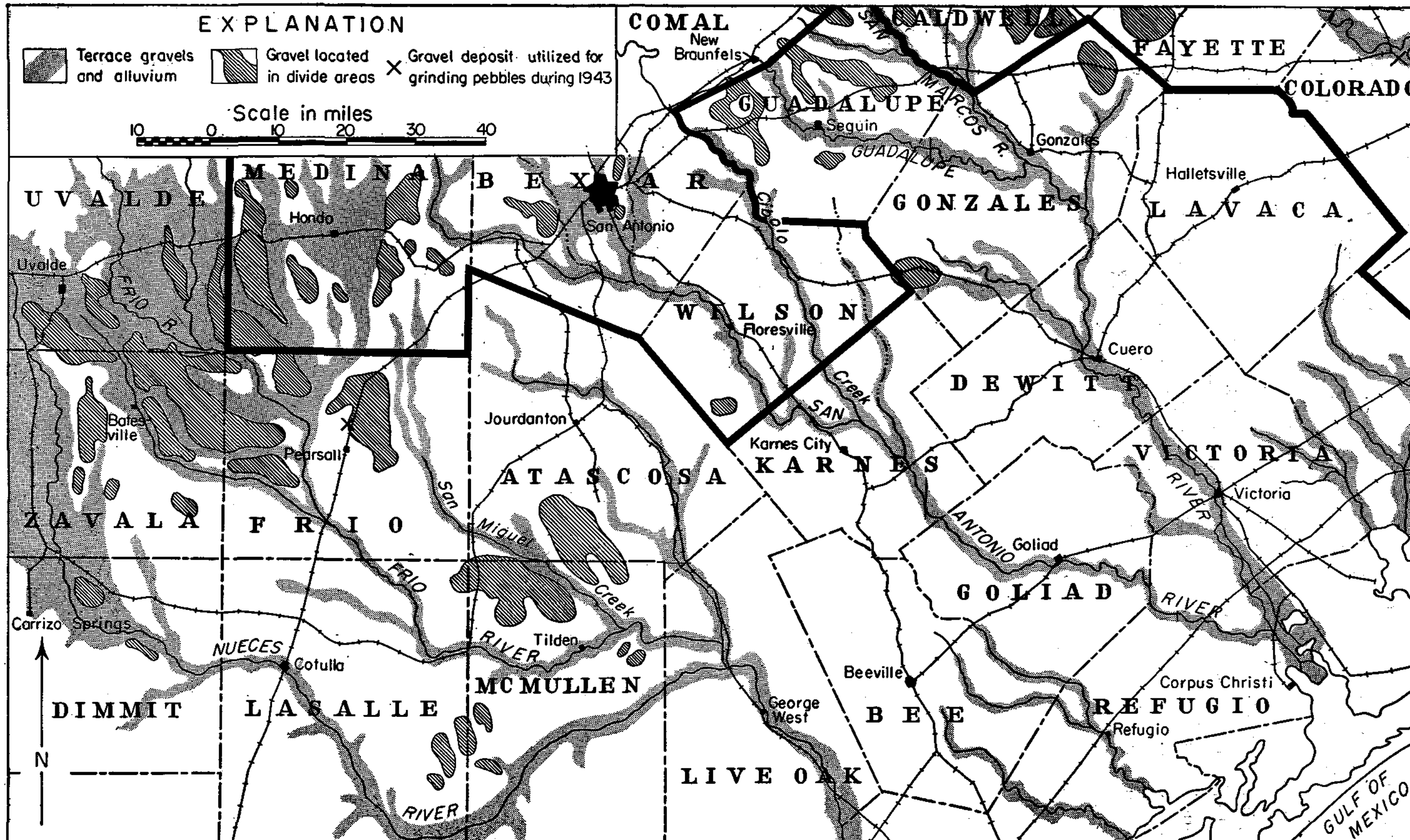
DIMMIT COUNTY.—A limy conglomerate with some flint pebbles caps the plateau about half a mile northeast of the courthouse in Carrizo Springs.

FRIO COUNTY.—A rather extensive gravel deposit crops out on the divide between Hondo Creek and the upper headwaters area of San Miguel Creek north of Pearsall in Frio County. The flint cobbles are loose on the surface but grade downward into a conglomerate consisting of flint cobbles cemented with lime. It was from a pit in this deposit that H. B. Zachry Company obtained the raw material for producing milled grinding pebbles.

GUADALUPE COUNTY. — Flint gravel is exposed in the road cuts on top of the divide along State Highway 1104 for about 6 miles southeast of Kingsbury in Guadalupe County. Most of the flint pebbles range from 1 to 4 inches in diameter. The smaller pebbles are the more rounded; those 3 inches in diameter or larger are generally angular or flat. Although the pebbles are coated with soft material, the interiors are fresh and clean; these pebbles would probably make satisfactory grinding pebbles if properly processed. A veneer of flint pebbles forms the surface in the vicinity of Marion, also in Guadalupe County.

McMULLEN COUNTY. — Flint gravel, most of which has a brown rind, occurs on the higher elevations in northwestern McMullen County. Similar deposits cap the top of Opossum Hill 1½ miles southwest of Crowther, McMullen County, and subangular to rounded flint cobbles are strewn over the prairie east of Tilden, McMullen County.

UVALDE-ZAVALA COUNTIES.—Deposits composed almost entirely of flint occur on top of some divides along the Frio River in Uvalde County, and extensive gravel deposits containing abundant flint pebbles crop out on the divides between the Leona and Nueces Rivers in southern Uvalde County. Isolated outcrops of the same deposit continue southward and occur 6½ miles west of Batesville, Zavala County, and similar gravels crop out 3½ miles west of Loma Vista, Zavala County.



Adapted from Plate VIII of U.S. Geological Survey Prof. Paper 126, 1923

FIG. 3. Gravel deposits of south Texas area.

VAL VERDE COUNTY.—Gravel deposits consisting of both flint and limestone pebbles are common on divides along the Pecos and Devils Rivers in Val Verde County.

WEBB COUNTY.—Gravel 2 to 8 feet thick consisting of flint, chert, chalcedony, quartz, and feldspar, mixed with limestone and sandstone, caps the divide between the Nueces River and the Rio Grande about 13 to 18 miles north of Laredo in Webb County.

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BAT GUANO

USE AND VALUE FOR FERTILIZER

Bat guano is used primarily as a fertilizer, and its market value depends upon the nitrogen, phosphoric acid, and potash content. Fresh bat guano is light, fluffy, dry, and may contain 8 or more percent nitrogen, a little phosphoric acid, and generally nonappreciable amounts of potash. Guano of this quality may be sold to fertilizer manufacturers or locally to farmers. Bat guano production and sales are regulated by the State's fertilizer law; producers must register with the State chemist and have the product tagged if the guano is sold in Texas to anyone except fertilizer manufacturers.

Best quality guano is generally found at the top of a deposit. Below the top layer, bat cave deposits frequently contain material of such low grade that it is almost worthless to fertilizer manufacturers. The low-grade material is usually heavy brown guano that is low in nitrogen content but may contain more phosphoric acid than the light top layer.

The commercial value of bat guano can be determined by chemical analysis. Care is necessary in order to secure a sample which is representative of the deposit. Samples should be taken from several parts of a single layer, thoroughly mixed, quartered, and an appropriate portion sent for analysis. A partial list of commercial laboratories that perform analytical services is on file at the Bureau of Economic Geology.

Several layers of different quality guano will probably be present in the same deposit, and separate samples should be taken from each layer without mixing material from the different layers. It is difficult to sell bat guano containing less than 6 percent nitrogen, and it is important to practice selective mining by layers that have been properly sampled and whose analyses show a satisfactory nitrogen content. If inferior guano layers are mixed with material from nitrogen-rich layers, a shipment may run below the grade of the sample, which will cause a disappointing sale price or even rejection of the shipment.

OCCURRENCE

The better known caves in the Edwards Plateau have been described by Mohr et al. (1948). A number of central Texas caves are inhabited by bats and contain deposits of guano. Two guano caves in Uvalde County were examined during this investigation. The Frio cave on the Fitzgerald ranch (owned by Mr. Marback of San Antonio) is located about 14 miles northwest of Sabinal; the Parker cave on the Lewis Parker ranch is about 12 miles north of Sabinal. Guano also occurs in the Devil's Sinkhole in Edwards County south of State Highway 41 about 8½ miles northeast of Rocksprings; in the Celestite Cave in Real County; in Webb Cave in Kinney County; in the Sargent Ranch Cave near the Kinney-Edwards County line north of Brackettville; in the Murrah Cave; and in an abandoned railroad tunnel in Val Verde County. No doubt there are other guano deposits, but since most caves are small, the deposits are probably small and not of commercial importance.

EDWARDS COUNTY

Devil's Sinkhole.—The Devil's Sinkhole in Edwards County was visited by the writer during the mid-1950's, and the results of an expedition into this cavern were published by White (1948, pp. 3–14). The opening to Devil's Sinkhole is about 75 feet wide and flush with the surface of a flattish plain. The surface rim overhangs the main part of the cavern, and from the surface piles of rock debris some 150 feet below are clearly visible. These rocks, which from the surface appear to be resting on the cave floor, are actually a small mound of debris about 200 feet high and 300 feet across the base, formed when the cavern roof collapsed.

The guano deposits in the Devil's Sinkhole have not been thoroughly explored. Guano, several feet thick, occurs over a considerable portion of the floor as well as on the sides and slopes of the debris piled on the floor. There are several small tunnels and grottos leading from the entrance chasm and there are reported to be two or more large rooms containing guano; these have not been seen by the writer. Remnants of old rotten ladders dangling along the sides of the chasm and remains of some old hoisting equipment at the surface are reportedly relicts of an attempt to mine guano some 35 years ago.

KINNEY COUNTY

Webb Cave.—Webb Cave in Kinney County is about 5 miles from the Webb ranch headquarters on the Brackettville-Rocksprings road 7 miles north of Brackettville. The cave is reported to contain small quantities of guano. Old hoisting equipment at the cave entrance suggests that guano may have been mined at an earlier date.

REAL COUNTY

Celestite Cave.—The Celestite Cave in Real County is discussed on page 37. Guano, which covers the floor of the cave, is locally 3 to 4 feet deep. The cave is about 25 feet long and 14 feet wide; therefore, the guano deposit is small.

UVALDE COUNTY

Frio Cave.—The Frio Cave guano deposit, about 14 miles northwest of Sabinal in Uvalde County, is easily accessible by a truck road which leads into the largest room of the cave. This room is about 600 by 1,000 feet in size with ceiling up to 80 feet high. Another large room is about 300 by 500 feet in size, and in addition there is a long tunnel with several small rooms and corridors along its sides. There is guano in all the rooms, corridors, and along the tunnel.

It has been reported that guano was mined from this cave by the Confederate Army for nitrate to manufacture gun powder. An old wooden track extending the length of the cave is evidence of an early mining operation, but it is not certain if the track was used during the 1860's or during the 1920's, when guano was again mined. Production figures are not available for the early operations. Within recent years it was discovered that high-grade phosphate occurs beneath the guano blanket. Twin Star Industries of Austin, Texas, explored this deposit. Locally, the phosphate is as much as 32 feet thick but the thickness is irregular and no significant tonnage was developed. The phosphate rock was reported to be unusually high in potash and alumina.

Parker Cave.—The Parker Cave is on a ranch east of the Utopia road, about 12 miles north of Sabinal in Uvalde County. Some mining was attempted years ago but there has not been any recent production.

VAL VERDE COUNTY

Murrah Cave.—The Murrah Cave is in the east wall of the Pecos River canyon (Val Verde County), about 15 airline miles from the Rio Grande. Jackson (1948, p. 74) described the cave as 60 feet below the canyon rim and about 200 feet above water level in the river. The cave extends back into the canyon wall about 125 feet and is 25 feet wide and 10 feet high at the entrance. At a point about 100 feet inside the entrance, the cave is about 45 feet wide but toward the back, the cave narrows to a passageway only a few feet wide. Human occupation is evident but was confined to the front 50 feet of the cave floor. The rear parts of the floor are covered with 2 to 3 feet of guano.

Old railroad tunnel.—A railroad tunnel was constructed in the 1880's when the Southern Pacific road bed extended along the precipitous north wall of the Rio Grande and crossed the Pecos River canyon near its mouth instead of spanning the canyon by a high bridge as it now does. About 4 miles south of Shumla (Val Verde County) a tunnel about 1,500 feet long, 15 feet wide, and 30 feet high was excavated. The tunnel is now inhabited by bats and the floor, except for the area near the two portals, is covered with 1 to 3 inches of guano.

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MANGANESE

USE AND DISTRIBUTION

The principal use of manganese is in the steel industry. Manganese-steel alloys are especially important because of their tensile strength, ductility, hardness, and resistance to abrasion. Manganese is also used in the chemical industry. When free from iron it is used to decolorize glass, as a depolarizer in dry-cell batteries, and as a drier in paints and varnishes. High-grade manganese ore containing iron is used to color glass, pottery, brick, and as a pigment. Other uses are in disinfectants, the manufacture of oxygen, manganese bronze and similar alloys. Low-grade manganese ore is used for flux in lead, copper, and silver smelting; some manganese is used in the manufacture of chlorine and bromine, as a gas purifier, and in the printing and dyeing industry.

Manganese compounds are widely distributed in the rocks of the earth's crust, but deposits of sufficient concentration and tonnage to be of commercial value are relatively scarce in the United States. Most of the manganese used in the United States is imported, and the workable domestic deposits are residual concentrations of manganese oxides formed at or near the surface.

VAL VERDE COUNTY.—Manganese deposits in Val Verde County have been known for half a century or more and several geologic reports have been published on individual areas. Small shipments have been made from some of the Val Verde County areas, but the results were not sufficiently successful to encourage systematic prospecting or exploration; detailed information on reserves is not available.

Feely deposit.—Manganese minerals occur in sections 44 and 52, block N, G.H. & S.A. Railroad Company survey, on property owned by W. H. Allen of Del Rio, Texas. The deposit is about 1 mile west of Feely, a siding on the Southern Pacific tracks, about midway between Comstock and the Devils River (Pl. II, Loc. 4; and fig. 4). The mineralization occurs along a northeast-trending minor fault in the Buda and Boquillas (Eagle Ford) formations.

Roberts and Nash (1918, pp. 28, 34–37) described these deposits in considerable detail. At the time of their investigation there were four small exploration pits in the Boquillas and two pits in the Buda. The most promising pit in the Boquillas was about 20 feet deep. The material exposed in walls of the pit consists of alternating layers, 2 inches or less in thickness, of thinly laminated calcareous sandy shale and 3- to 4-inch beds of impure, marly, porous limestone stained with manganese oxide (wad?). The character of the material suggests a secondary deposit in a solution cavity. The sides and bottom of the pit are now mostly covered by slumped material and no additional information is available.

Mineralized rock in a 9-foot deep pit on the opposite side of the fracture dips at a steep angle into a cavity in the Buda limestone. The highest grade material occurs in a lenticular mass 2½ to 3 feet thick that is underlain and overlain by clay. The clay disappears with depth and the "ore body" appears to fill the entire opening in the southern side of the pit. This zone of mineralization may continue for some distance into limestone.

Roberts and Nash (1918, pp. 28, 34–37) concluded that prospecting was inadequate to estimate reserves. In the early part of 1942, workers on a unit of the Works Projects Administration State-wide Mineralogic Survey, a project sponsored by the Bureau of Economic Geology of The University of Texas, dug several test pits in the Feely district. The results of their work were not encouraging, and there has been no recent exploration in the area. To date, manganese-bearing materials have been found along only one fracture.

Observations in the Feely district indicate that several truck loads of manganese nodules can be gathered from the surface

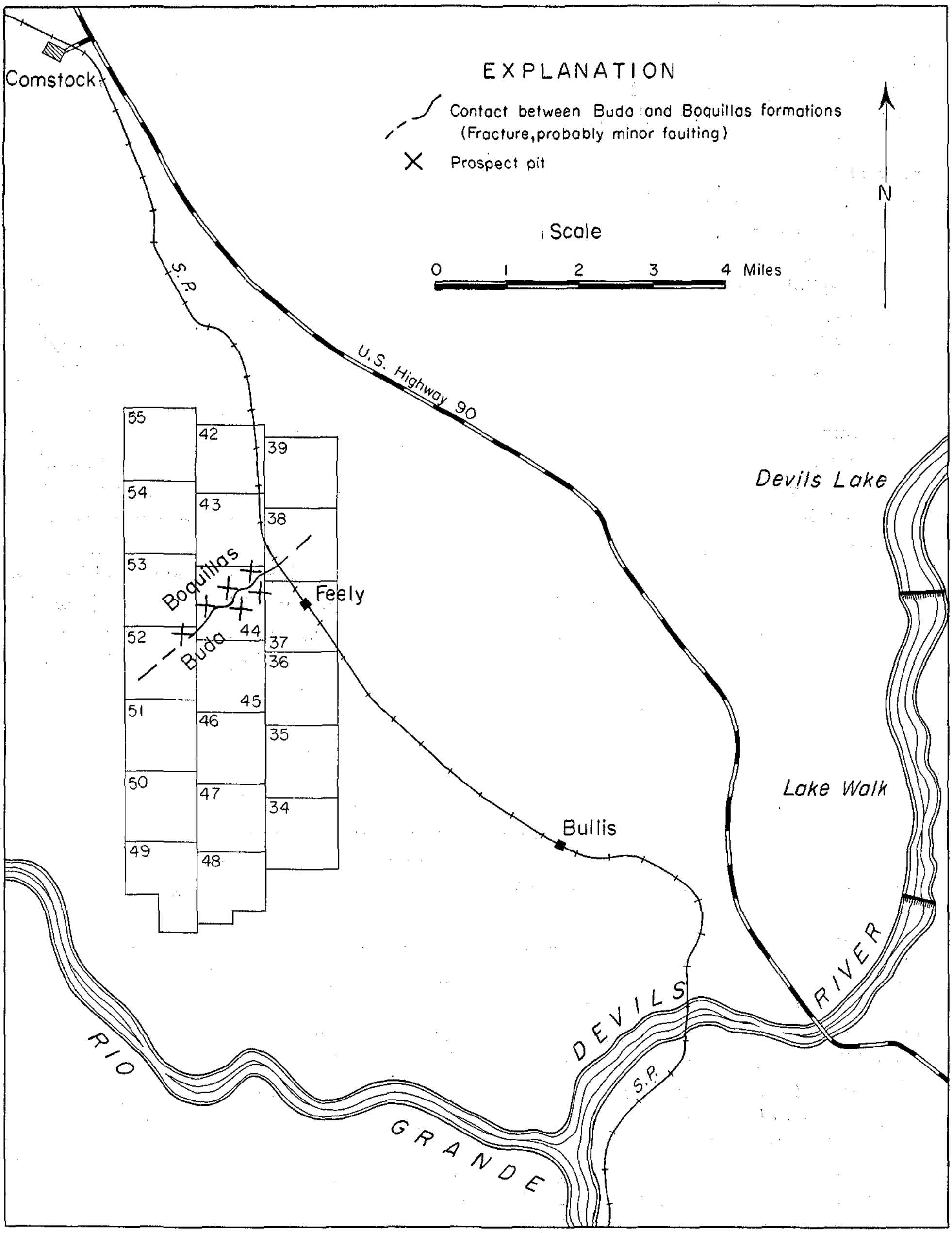

FIG. 4. Manganese localities, Feely area, Val Verde County, Texas.

and from small excavations at selected localities along the mineralized fracture. The ore is low grade (table 38; Roberts and Nash, 1918, p. 38). Irregularity of mineralization and mixture of manganese minerals with clay and limestone cobbles make it difficult to estimate tonnage.

Shumla deposit.—Manganese minerals

TABLE 38. *Analyses of samples from the Feely manganese district, Val Verde County, Texas.*

Location	Boquillas pit	Buda pit
Silica	10.66	59.7
Iron oxide	8.86	7.39
Alumina	8.92	4.08
Phosphorous pentoxide	0.32	0.25
Manganese oxide	4.74	4.93
Lime	31.07	11.37
Magnesia	0.95	0.72
Water	1.42	0.44

crop out in sections 59, 60, 62, 63, and 64, southwest, west, and northwest of Shumla; in section 615, southeast of Shumla; and in section 42, north of Shumla, all in block S2 of the E.L. and R.R. Railroad Company survey (Pl. II and fig. 5). The mineralization occurs chiefly in small caverns or sinks along northeast-trending joints and fractures. The largest fractures are approximately parallel and are from 1 to 2 miles apart; they range up to about 2 miles in length and have been widened by solution from a few inches up to shallow depressions 200 to 300 feet across at the surface. Most of the fissures have been filled with surface debris and depth of mineralization is not known; locally, joints in canyon walls 200 to 300 feet below the surface are stained with manganese oxides.

Lateral, secondary joints trending north and/or east intersect the primary joints. The area of intersection of the two joint systems appears to have been the most favorable for the development of sink holes and caverns and the accumulation of manganese minerals. The joints are marked on the surface by small nodules of manganese, by the greenish color of the residual soil in shallow depressions between the massive limestone walls that outline the fissure, and by a heavier growth of scrubby vegetation that reflects deeper soil and more available moisture along the trace of the fracture.

Prospecting and limited exploration of the manganese deposits near Shumla began during World War I. Roberts and Nash (1918, pp. 23–42) studied the area and described some of the prospects. The most accessible locality is in section 64, block S2, immediately south of U.S. Highway 90 and 0.3 mile east of the highway sign reading "10 miles to Langtry." The mineralization occurs along a major northeast-trending fracture in massive Comanche limestone (Buda?); the largest concentration appears to be where the fissure is 3 or more feet wide. The fracture dips at a high angle. Solution has formed many irregular cavities which are now filled almost to the level of the surface. Manganese minerals occur in nodules and lenses in a fissure filling of clay and blocks of weathered limestone. Most of the manganese is hard, but some is soft and sooty. Shipments made from this locality in 1917 were of low grade. Mr. R. R. Williams, who has the Shumla area under grazing lease, advised (oral communication, June 11, 1960) that he shipped a few truckloads of ore in 1951 or 1952, but that there has not been any manganese shipped from the Shumla area since that date. The results of an analysis of a selected sample taken from this locality are shown in table 42 (No. 60082).

Along the same fracture arid about one-fourth mile southwest of the above locality, trenches across a small sink expose lenticular masses of manganese minerals and cobbles and blocks of weathered limestone in clay. Irregular horizontal bedding in clay suggests deposition in a shallow depression. Shipments were made from this locality in 1917 and again in 1951 or 1952, but there has not been any activity since that date.

Another excavation along the same fracture a few hundred yards north of the highway was opened during the 1917 program. Here also manganese minerals occur as nodules and lenticular masses mixed with clay and blocks of weathered limestone in solution cavities along a fracture.

Farther southwest in section 62, block S2, about 1½ miles southwest of U.S. Highway 90, excavations along the same fracture expose manganese mineralization. A short adit 6 by 6 feet at the portal was driven in massive Comanche limestone (Georgetown) about 10 feet above the bottom of a dry arroyo, and a small pit was dug just above the arroyo bottom a few feet below the adit. The manganese minerals appear to be a mixture of pyrolusite and wad associated with clay and blocks of weathered limestone that probably filled a small subsurface solution cavity. The clay ranges from coarse-textured bluish-black lumps to compact, fine, waxy dark-yellow to white masses. There are thin stringers of manganese oxides in the clay, but the larger concentrations are nodules and lenticular masses associated with the

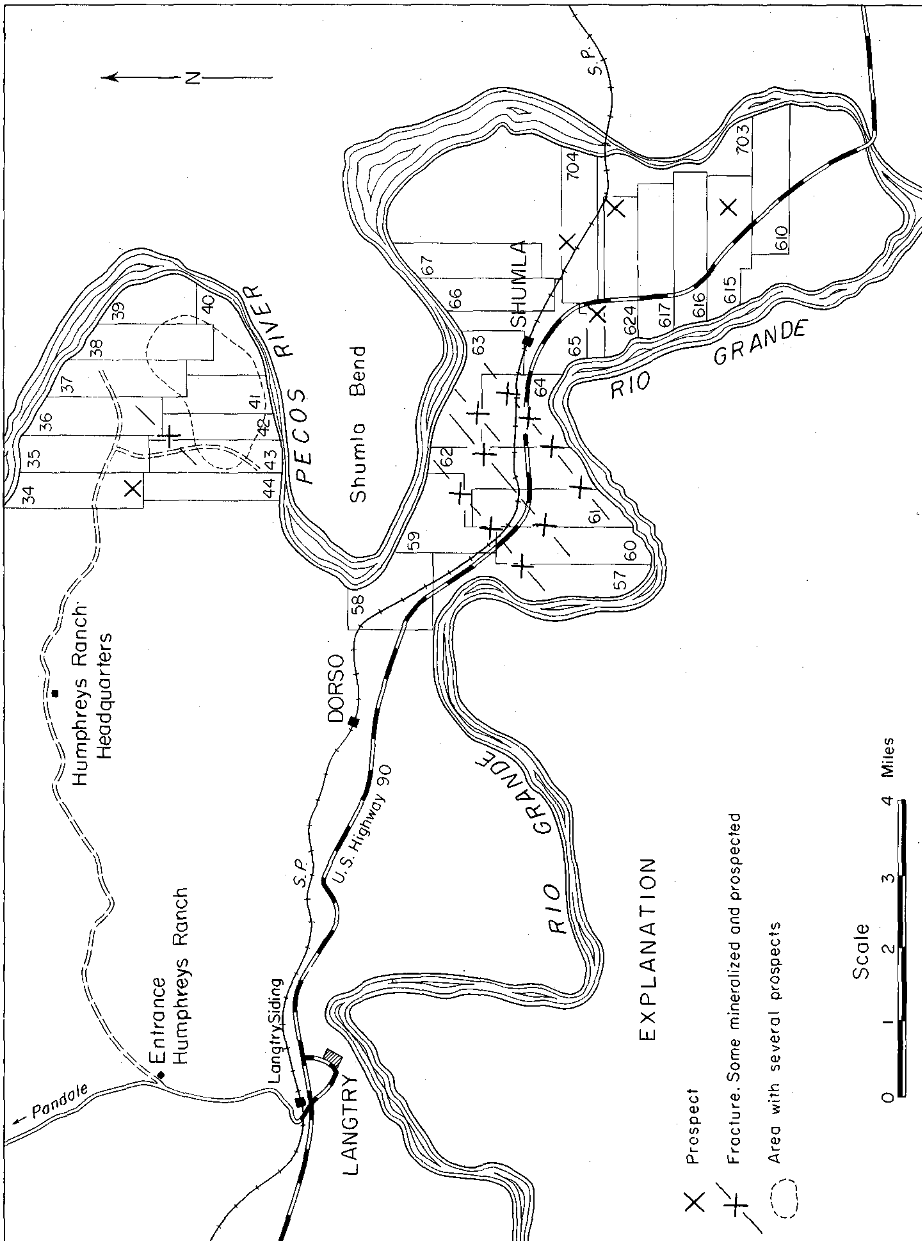

Fig. 5. Manganese localities, Shumla area, Val Verde County, Texas.

larger limestone blocks in the fill. The highest grade material is at the surface and manganese content decreases downward. The excavation is old and there does not appear to have been any recent activity at this locality.

At a prospect pit in the northern part of section 63, block S2, northwest of Shumla, northwest of the localities discussed above, manganese minerals associated with clay form the cement in a nodular limestone conglomerate. The deposit is a steeply dipping fracture filling. The principal mineralization is in a lenticular mass about 18 inches thick that extends downward into an enlarged fracture; some of the clay contains thin stringers of manganese minerals.

Farther west, in section 62, block S2, about 200 yards north of the Southern Pacific tracks and about 1½ miles northwest of Shumla, manganese oxides mixed with clay occur in a solution cavity along a fracture in the Buda limestone. The mineralization appears to be low grade and most of the manganese is soft and sooty.

Near the line common to sections 57 and 60, block S2, about 3 miles west of Shumla, is a low hill capped by Boquillas formation. A solution-enlarged fracture about 2 feet wide extends across the hill, and pits along it expose thin bands of Boquillas flags impregnated with manganese oxide.

In section 42, block S2, about 5½ miles north of Shumla, a test pit sunk in massive Comanche limestone exposes an 18-inch layer of manganese oxides accumulated in a solution cavity.

Small nodules of manganese occur in the Del Rio clay in section 615, block S2, about 3½ miles southeast of Shumla. The deposit has no commercial value but shows that the manganese mineralization is stratigraphically widespread.

The irregularity in size and distribution of the manganese deposits and the erratic mixtures of manganese minerals with clay and limestone in the cavernous accumulations make it difficult to estimate the tonnage of available ore materials in the Shumla district. All of the workings are old and there is little to be seen in most of the pits because of surface material washed into the pits. Roberts and Nash (1918, p. 40), studied the area during active prospecting and estimated about 10,000 tons of available ore. No new deposits have been reported and none have been found during the current investigation. Systematic prospecting in some of the old prospects is likely to develop additional tonnage. Probably there is not enough ore to justify large-scale operations.

Transportation facilities are excellent, as the area is served by the Southern Pacific Railway and U.S. Highway 90. Several of the most promising prospects are within half a mile of the railroad, and a truck haul of 4 to 5 miles to Shumla would be the maximum distance to any of the known prospects.

Analyses of samples collected by Roberts and Nash (1918, pp. 37–39) are given in table 39.

Ingram-Howe deposit.—The Ingram-Howe property, now owned by George A. Humphreys of Del Rio, Texas, is on the west side of the Pecos River north of Shumla Bend. It is reached via the Langtry-Pandale road to the Humphreys ranch entrance, thence over a well-graded ranch road northwestward for about 5½ miles to

TABLE 39. *Analyses of samples from the Shumla manganese district, Val Verde County, Texas.*

Location	Manganese oxide	Iron oxide	Alumina	Silica	Phosphorous pentoxide	Lime	Magnesia	Moisture	Loss on ignition
Section 64, immediately south of U.S. Highway 90	5.86	10.34	15.23	15.16	0.23	25.59	0.91	0.94	24.26
Section 62, 1½ miles southwest of U.S. Highway 90	3.26	20.68	13.41	31.60	0.61	10.59	1.16	4.20	11.90
Section 62, 1½ miles southwest of U.S. Highway 90	8.09	11.81	7.49	11.78	none	31.02	3.62	1.48	16.56
Section 62, 12 miles southwest of U.S. Highway 90	3.52	3.70	16.48	14.90	0.48	17.16	1.20	4.90	21.90
Section 62, 1½ miles northwest of Shumla	2.57	4.42	4.23	17.30	0.25	34.43	1.23	2.60	23.60
Section 63, ¾ mile northwest of Shumla	4.59	10.34	1.81	18.46	0.25	37.07	0.91	2.24	28.20
Section 42, 5½ miles north of Shumla	5.54	9.60	10.73	1.90	0.27	35.42	0.80	0.90	23.70
Shipping platform at Shumla[1]	6.20	3.47	6.70	13.87	none	33.97	none	0.76	27.10

[1] Probably representative of the ore that was shipped in 1917 and probably representative of the best ore that remains in the Shumla district.

the Humphreys ranch headquarters, thence east and southeast on ranch roads for another 5 miles. Mineralization occurs at a number of small scattered localities (fig. 5) in parts of sections 37, 38, 39, 40, 41, 42, and 43, block S2, E. L. and R. R. Railroad Company survey. The locality in the northern part of section 42 was described by Roberts and Nash (1918, p. 34). Small nodules of manganese float were observed in section 34, but this locality has not been prospected.

The manganese deposits in this district were studied and described by Warren (1946, pp. 250–252), who supervised the excavation of several test pits as a part of the Work Projects Administration Statewide Mineralogic Survey (a project sponsored by the Bureau of Economic Geology of The University of Texas). Manganese oxides occur in shallow depressions mixed with gravel, brecciated limestone, vegetable matter, and soil (fig. 5). The mineralized areas are recognized by manganese float and by the reddish-yellow or brown soil. The mostly surficial deposits are not restricted to any single formation and occur at various stratigraphic positions in the Edwards, Georgetown, Buda, and Boquillas formations. Manganese oxides also occur as cement in some of the high-terrace gravels. At some localities on divides between canyons, manganese and iron oxides cement the gravel and form a crust on the surface. This crust is not more than 2 to 3 inches thick and the underlying gravel is generally loose and unconsolidated. The amount of manganese exposed at the surface does not indicate the depth of mineralization. At one locality, manganese oxides occur over an area of approximately 2,000 square feet, but test pits revealed that the manganese mineralization does not extend below a depth of 2 feet. Manganese minerals occur in irregular lenses that appear to be related to the present surface.

The massive Comanche limestones are well jointed and some of the joints have been enlarged by solution, but there is no regular joint pattern such as in the Shumla area. Where the joints have been widened by solution, the cavities are filled with surficial debris and some contain small manganese deposits. The walls of some joints are manganese stained but in general manganese concentrations are small and relatively sparse along the joints.

Sink holes that range up to 100 feet in diameter are common. Most of them have circular outlines, but oval or irregular shapes are not uncommon. They are probably collapsed caverns in the Buda or older formations. At a few localities small bodies of manganese overlap the margins of the sink. Although much of the bouldery debris in the sinks is stained with manganese or iron oxide, there is no indication that the limestone has been replaced by manganese; the relations of the small bodies that overlap the margins of the sinks suggest that the manganese was deposited after the sink formed.

Manganese oxides occur (1) as cement in the surficial deposits capping divides, (2) as crusts on the surface in shallow depressions, (3) in sink holes, and (4) near the head of small arroyos. The relations suggest that the manganese is secondary and was deposited on an ancient surface that is now being dissected. This differs from the Shumla-Feely area where the manganese oxides occur chiefly in solution-enlarged joints.

Warren (1946, p. 254) reported that the amount of available ore probably does not exceed 2,000 tons, but irregularities in size and shape of the manganese bodies and the variable amounts of associated clay, limestone boulders, and gravel make it difficult to estimate tonnage.

The ore is low grade but analyses are higher than the several analyses for samples from the Shumla-Feely area (tables 38, 39). Analyses of samples from the Ingram-Howe deposit collected by Warren (1946, p. 252) are given in table 40.

TABLE 40. *Analyses of samples from Ingram-Howe deposit, Val Verde County, Texas.* (R. W. Wheeler, analyst).

	Percent
Manganese oxide	42.92
Iron oxide	0.05
Silica	3.92
Calcium carbonate	43.33
Alumina	0.78

Samples taken by the writer at several prospects were mixed, quartered, and analyzed; this analysis is included in table 42 (No. 60083).

Walter Babb deposit.—A small manganese deposit on the old Walter Babb ranch was studied and described by Warren (1946, p. 252). This property is now owned by Elmo (H. E.) Arledge and is reached via the Pandale road north from Langtry for a distance of approximately 25 miles. At the ranchhouse, which is on the west side of the Langtry-Pandale road, a ranch road turns east and follows the south bank of the Pecos River for about 2 miles to the deposit (fig. 6).

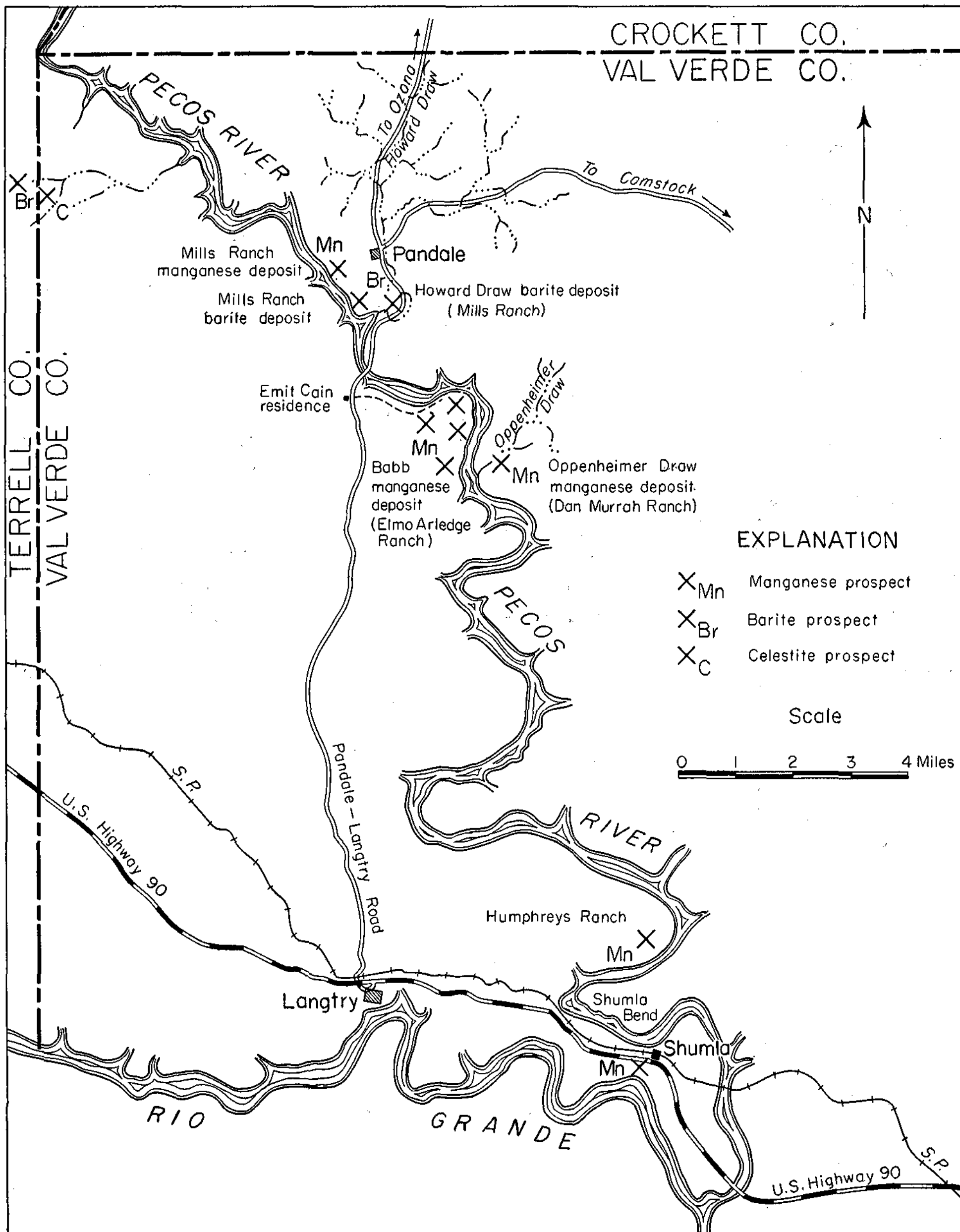

FIG. 6. Manganese, barite, and celestite localities, Pandale area, Val Verde County, Texas.

The writer was not permitted (June 11, 1960) to inspect the manganese deposit. The following description is from Warren (1946, p. 252).

> The manganese on the Walter Babb ranch, 7 miles airline south of Pandale, is mixed with sand and gravel between limestone ledges at the edge of Pecos River. The deposits are thin and occupy space between the beds scooped out by the river. They extend along the bluff for about one-fourth of a mile. The distance the manganese extends back under the ledges is unknown but the exposed portion of the manganese suggests only a short distance. The manganese is of poor grade. The manganese is also mixed with gravel of the flood plain which in its greatest width is about one-half of a mile. These gravels are as much as 50 feet in thickness. The manganese is disseminated through the flood-plain deposits as a cementing agent. One hill of gravel 50 by 200 feet in size has a greater concentration of manganese than any other in this area seen by the writer. The manganese is disseminated throughout the gravels, and in one shallow test pit manganese seems to be in a greater concentration than is required to fill the pore space of a gravel deposit.
>
> In this locality manganese also occurs on high hills three-fourths of a mile to the south and approximately 300 feet above water level of Pecos River [fig. 6]. The manganese is in shallow depressions on the Devils River limestone and resembles very closely the occurrence on the Ingram-Howe ranch. The "high" gravels have been almost removed by erosion, only occasional pebbles of rounded, black chert and igneous rock remain.

Mr. Cain advised the writer (oral communication, June 11, 1960) that he had lived on the property for about seven years, and that to the best of his knowledge there has not been any prospecting or exploration during that period. Warren (1946, p. 252) reported that the manganese is low grade. The deposit is probably not commercial.

Mills-Pandale deposit.—Manganese mixed with rock debris occurs on the Mills ranch about 3 miles west of Pandale (fig. 6).

Mineralization occurs approximately 75 feet above the level of the Pecos River, in a terrace gravel, where the ore body is up to 2 feet thick at the exposures visited. Exposures in old excavations and in arroyos suggest that manganese mineralization underlies several acres.

Two carloads of manganese ore had been shipped from the Mills deposit prior to the time of Warren's (1946, p. 252) investigation in 1943. Mr. Mills reported (oral communication, June 13, 1960) that several shipments were made after 1943, but that the major activity was in 1959 when 450 tons of manganese ore was trucked to Eagle Pass. The ore did not meet the required minimum specifications and was not sold. Mr. Mills further advised that analysis of the shipment showed a manganese content of about 18 percent, which was later passed through a shaker that upgraded the ore to 32 percent manganese oxide. Analysis of a sample from this deposit, given by Warren (1946, p. 252), is repeated in table 41.

TABLE 41. *Analysis of sample from Mills ranch manganese deposit, Val Verde County, Texas* (R. M. Wheeler, analyst).

	Percent
Manganese oxide	38.30
Iron oxide	Trace
Silica	4.46
Calcium carbonate	47.11
Alumina	2.06

Analyses of two samples from the Mills ranch are given in table 42. Sample No. 60084 is from the low-grade part of the deposit, and No. 60151 is a selected sample from what appeared to be the richest part of the manganese concentration.

Oppenheimer Canyon deposit.—Manganese mineralization occurs on the Dan Murrah ranch in Oppenheimer Canyon about 1½ miles above its junction with the Pecos River (fig. 6). This area has not been previously reported in the literature but is similar to other mineralized areas along the Pecos River. The mineralization consists of manganese stains along joints and bedding planes that have been widened by solution, coatings of manganese oxides on cobbles, and manganese oxide cement in gravel. The deposit is probably small and not of commercial interest.

Summary, Pandale area.—The tonnage of available manganese ore of different grades at the Mills-Pandale, Oppenheimer Canyon, and Babb deposits is not known. High-grade ore that requires no beneficiation and can be cheaply mined may be

TABLE 42. *Analyses of Val Verde County manganese samples* (Mineral Technology Laboratory, 1961).

Geographic location Min. Tech. Lab. No. Locality No., Pl. II	Shumla Sec. 64, Blk. S2, E.L.&R.R. Railroad Company Survey 60082 1	Humphreys ranch 60083 2	Mills ranch 60084 3	Mills ranch 60151 3
Total iron as Fe_2O_3	2.85	0.94	20.70	9.74
Total manganese as MnO	18.60	39.70	6.44	28.70
Calcium oxide (CaO)	35.20	23.20	14.30	13.80
Water	0.87	0.48	0.78	0.68
Ignition loss, 105°–1050° C.	30.40	25.02	21.21	23.42
Total iron as Fe	....	....	14.50	......
Total manganese as MnO_2	22.60	48.60	....	35.10

profitably extracted from small deposits such as occur in this area. However, a large quantity of low-grade ore must be available to justify the installation of milling equipment. Transportation costs likewise have an important bearing on the success of a potential operation. It is approximately 30 miles from the Mills deposit and 25 miles from the Babb deposit over a graded gravel road to the Southern Pacific tracks at Langtry and an equal distance to U. S. Highway 90.

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INDUSTRIAL SAND

Murphy (1960) discussed industrial sand and its uses. The portions of his report that bear on sand deposits in south Texas are summarized below.

Sand, in the general sense, is a granular siliceous raw material that has been segregated and refined by natural processes until it approaches a monomineralic deposit. By virtue of a high degree of purity and/or grain size and shape, it has special and somewhat restricted commercial uses. At some localities these raw sand materials occur naturally as unconsolidated quartzose sands and can be exploited and used with very little preparation and expense. More commonly, they occur as sandstone, conglomerate, quartzite, or similar rock that must be crushed, washed, screened, and sometimes chemically treated before commodities of suitable composition and texture can be successfully prepared.

Murphy (1960) classified sands according to use, including (1) abrasives, (2) glass and chemical sands, (3) metallurgical sands, (4) refractory sands, and (5) miscellaneous sands. The abrasives include (1) blasting sand, (2) glass-grinding sand, and (3) stone-sawing and rubbing sand.

ABRASIVE USES

Blasting Sand

Blasting sand is a sound closely-sized quartz sand which, when propelled at high velocity by air, water, or controlled centrifugal force, is effective for cleaning metal castings, removing paint and rust, or removing stone veneer.

Specifications are chiefly based on size-frequency distribution but the grains must be free of adhering clay or iron coatings. Material that dusts upon handling is not acceptable. There is no uniform trade designation for the many blasting sand grades. Grade is commonly designated by the limiting sieve sizes. Thus, in a No. 1220 grade sand, 98 percent of the material must pass a 12-mesh sieve and be retained on a 20-mesh sieve. Specifications generally call for narrow limits of gradation requiring precise sizing methods.

Glass-grinding Sand

Glass-grinding sand is clean, sound, fine- to medium-grained silica sand, free from foreign material, and properly sized for either rough grinding or semifinal grinding of plate glass.

Clean, washed silica sand with uniform particle-size distribution is required so that each grain does its share of work. Soft rock particles are not tolerated. Shape is not significant, although highly angular grains tend to break down more readily owing to the vulnerability of the sharp edges and corners. Size-frequency distribution is chiefly minus 30-mesh and plus 100-mesh.

Stone-sawing and Rubbing Sand

Stone-sawing and rubbing sand is relatively pure, sound, well-sorted, coarse-grained silica sand free from flat and fine grains. It is used for sawing and rough-grinding dimension stone.

Neither texture nor quality specifications are rigorous on this type of material as long as it is high in free silica and contains no clay, mica or soft rock fragments. Chert tailings and river terrace deposits have been successfully used in some areas. Sand ranging from 12-mesh to 100-mesh with some tolerance at either end meets particle size requirements. Closer grading is demanded for material used on rubbing tables than is required for use in gang saws or cable saws.

GLASS AND CHEMICAL USES

Glass and chemical sands are high-purity sands. Grain shape is not a critical factor, but specifications call for size-frequency distribution with narrow limits. Available source materials are more limited than for any other sand. Glass and chemical sands command relatively high prices and are shipped greater distances than other sands.

As sold, the sand must be a chemically pure silica sand free of inclusions, coatings, or stains. Limits on iron, magnesia, and alumina are strict. If the Fe_2O_3 content exceeds 0.02 to 0.025 percent, expensive decolorizers must be employed. Most specifications place a ceiling of 0.02 percent on the alumina content, the maximum allowable for lime and magnesia is about 0.05 percent, and for alkalies 0.01 percent or less. In all instances these impurities must be held to uniform amounts. It is difficult to generalize on specifications, but the quartz sand for glass-melting purposes must not depart from specified particle-size distribution. Mid-west and eastern glass producers demand a minus 30-mesh quartz sand with not more than 2 percent passing the 140-mesh sieve. West coast and mid-continent glassmakers have adapted to generally finer-grained sands and permit up to 2 percent minus 200-mesh sand.

Uniform grain size is an important consideration as it promotes even melting in the glass tank. Excessive fines are undesirable as they may be carried over into the checker-work of the regenerators or into the flues; fines may also cause a small but persistent seed in the glass. On the other hand, excessively coarse sand grains often survive in the melt and form harmful batch scum, stones, and cords.

METALLURGICAL USES

Metallurgical sand is clean graded silica sand low in iron and alumina used chiefly in preparation of silicon alloys or as a flux in preparation of elemental phosphorus.

A quartzite or quartz gravel must meet rigorous specifications to qualify as a raw material for metallurgical silica. Alumina is undesirable because it is not easily reduced in the electric furnace and produces a sticky slag. Alumina content must be less than 0.4 percent. Total iron can be as high as 0.2 percent, combined basic iron oxides should not exceed 0.3 percent, and titanium should be held to a minimum. Phosphorus and arsenic are dangerous because of their toxic qualities and should not be present even in trace amounts. Opaline silica is detrimental because of its molecular water, which causes spalling in the furnace and seals the charge against free circulation. The clue to the presence of opaline silica is high ignition loss in the analysis. Ignition loss should be kept below 0.3 percent.

Impurities collect on grain and pebble surfaces, and the contamination is roughly inversely proportional to the square of the diameter of the pebble. Hence, a limit is placed on finer-grained materials with greater total surface area. According to standard practice the lower limit is about three-eighths inch. A maximum size limit of 6 to 8 inches is common.

Specifications for siliceous pebbles used as a flux in production of elemental phosphorus by the electric-furnace method are not as rigid as for pebbles used in alloy manufacture. Specifications call for a clean washed material with not more than 2.5 percent moisture up to 1.5 percent each for Fe_2O_3, Al_2O_3, and CO_2, and not more than about 0.2 percent CaO. A silica content of above 90 percent is generally satisfactory. Size specified is 1 to 4 inches, with not more than 5 percent of minus one-fourth-inch material, screened dry.

REFRACTORY USES

Foundry sand used in contact with molten metal must be refractory and resist sintering. To be used successfully to construct molds or cores into which or around which molten metal is cast, it must also be highly permeable. This allows escape of steam and gases generated by action of the hot metal. Such a sand must have sufficient strength under compression, shear, and tension to retain its molded form not only in the green state at room temperature but also at the elevated temperatures induced by pouring and after drying and baking. Finally, it must be durable and resistant to deterioration and breakdown with repeated use.

Murphy (1960, pp. 766–770) discussed refractory sands as (1) core sand, (2) furnace-bottom sand, (3) ganister mix, (4) naturally bonded molding sand, (5) processed molding sand, (6) refractory pebbles, and (7) runner sand.

Core Sand

Core sand is washed and graded silica sand low in clay and with high permeability. The silica sand, whether natural or synthetically bonded, must have a high sintering point, adequate permeability, and the proper collapsibility characteristics to give good performance as a core sand. A satisfactory particle-size distribution ranges from minus 30- to plus 140-mesh with 90 percent or more between the 40- and 100-mesh sieves.

Furnace Bottom Sand

Furnace bottom sand is unwashed partially aggregated silica sand suitable for lining and patching open-hearth and electric-steel furnaces which utilize an acid process. A satisfactory sand for making bottom in an acid-type furnace is one that contains enough clay bond to give the material cohesiveness and enough silt-size fines and iron oxide impurities to promote rapid fusion as the bottom is run in. In addition, some compound particles in the coarse mesh size are desirable as they are violently disrupted when their mechanical moisture flashes to steam and this popcorn-like effect tends to promote an even distribution and consequently a level floor. A good size distribution ranges from 3-mesh down through gravel, sand, silt, and clay sizes.

Ganister Mix Sand

Ganister mix is a self-bonding, ramming mixture composed of varying proportions of crushed quartzose rock or quartz pebbles and plastic fire clay suitable for lining, patching, or daubing hot metal vessels and certain types of furnaces. There are two broad classes of materials used for this purpose. One is a naturally occurring mixture of quartz sand and refractory clay; the other is a prepared mixture of quartz pebble, granule, or sand sizes bonded by clay to a given plasticity.

Naturally Bonded Molding Sand

Naturally bonded molding sand is crude silica sand containing sufficient indigenous clay to make it suitable for molding ferrous or nonferrous castings. The high amount of clay which naturally occurs in this material generally limits its use to light iron, brass, or bronze castings, although many of the largest steel castings are poured in naturally bonded molding sand that is very coarse grained. Specifications generally define a minimum limit for silica and a desired range for the alumina and iron oxide. Foundries usually adapt to a particular molding sand of selected grain fineness, bond strength, base permeability, and sintering point. Uniformity of product, both chemically and physically, is of utmost importance.

Refractory Pebble

Refractory pebble is clean graded silica gravel low in iron and alumina used as a raw material to make superduty acid refractories. Practice in the manufacture of superduty acid refractories demands careful control of alumina, the maximum tolerance being about 0.4 percent. Total iron should be less than 0.4 percent. Lime should be less than 1 percent and total alkalies should not exceed 0.5 percent. Terrace gravels and bedded conglomerates furnish the bulk of this raw material. The specifications closely parallel those for the metallurgical silica but are slightly less rigid.

Runner Sand

Runner sand is a crude coarse-grained silica sand, moderately high in natural clay bond, used to line runners and dams on the casting floor of blast furnaces. Runner sand is also used in the casting of pig iron. Generally any coarse-grained silica sand with sufficient natural bond to give plasticity will serve for this purpose. No particular grain size is specified and permeability is not an important consideration. The sintering point should be sufficiently high so that no sand burn results and so that the pigs will break away from the molds with relatively clean surfaces.

MISCELLANEOUS USES

Several valuable and useful industrial

silica sands currently in demand by industry include (1) coal-washing sand, (2) filter media, (3) hydraulic-fracturing sand, (4) standard testing sand, and (5) traction sand.

Coal-washing Sand

Coal-washing sand is a washed and graded quartz sand of constant specific gravity used in a flotation process for cleaning anthracite and bituminous coal. Specifications call for a material with a specific gravity of not less than 2.64, which implies a clean quartz sand free of low-density rock fragments. The grains must be subangular to rounded and free of sharp edges and corners. Iron oxide coatings are not objectionable if they adhere firmly enough so that they do not wear off in the washing process. The clay content is limited to 0.5 percent and no organic matter is tolerated. Ideal particle size distribution ranges between 30-mesh and 100-mesh with 5 percent tolerance at each end and a median size of about 50-mesh.

Filter Media

Filter media consist of washed and graded quartzose gravel and sand, produced under close textural control, for removal of silt and bacteria from municipal and industrial water-supply systems.

Underdrain gravel for mechanical or rapid sand filters is placed in beds made up of layers carefully graduated according to size. Close conformity to a specific diameter in each grade size is of critical importance. Specifications of underdrain control soundness, shape, and composition. Hard rounded quartzose gravel with an average specific gravity of not less than 2.6 is required. Not more than 2 percent by weight of flat or elongate fragments is tolerated, and no clay, silt, sand, rock, or organic impurities of any kind may be present. Porosity of the gravel after emplacement should range from 35 to 45 percent. Typical size range is from 3½ to ¼ inches for the lower courses and from ¼ to 3/32 inch for the upper courses. No iron or manganese in form or quantity adversely affecting the water to be filtered is tolerated. The acid solubility of the gravel is of minor importance where filters follow lime softening.

Hydraulic-fracturing Sand

Hydraulic-fracturing sand is a sound, rounded quartz sand free of aggregated particles and possessing high uniformity in specified size ranges which, when immersed in a suitable carrier and pumped under great pressure into a formation, increases fluid production by generating greater effective permeability. It is commonly referred to by such trade names as Sandfrac or Hydrofrac sand.

This commodity has been in demand since hydraulic-fracturing methods were made commercially practicable early in 1949. Hydraulic fracturing is accomplished by forcing sand suspended in a carrier fluid into the bedding and joint planes of the sedimentary rocks comprising the pay zone and prying them apart sufficiently to increase the original fracture flow capacity. When the pump pressure is withdrawn, the carrier fluid drains back into the well but leaves the emplaced sand as a propping agent to keep the fractures open. Thus, effective permeability is increased and production stimulated.

Size-frequency distribution of the sand and texture and structural characteristics of the grains are of paramount importance. In the popular 20-40 grade, specifications call for 100 percent between 16- and 60-mesh with a minimum of 80 percent between 20- and 40-mesh. A preferred distribution is 100 percent between 20- and 30-mesh. A minimum Krumbein roundness factor of 0.7, and a maximum density of particle of 2.7 is desired. Minimum compression strength requirements are 2,500 pounds per square inch in concentrations of 0.394 grains per square inch with a maximum subsequent closure of 50 percent in the fracture width. Compositionally, the propping agent must be clean, sound, and inert and contain no clay, silt, or organic matter that would affect the viscosity of the carrier or cause dusting in handling.

Standard Testing Sand

Standard testing sand is washed and dried quartz sand of selected shape characteristics, prepared to exact size specifications for use in research or any testing work involving a comparison of methods or materials.

Grades of sand for reference and testing are produced under very carefully controlled conditions. Sands for use in standard test procedures involving cement mortars have been approved by the American Society for Testing Materials. One specification calls for natural silica sand from the St. Peter sandstone, Ottawa, Illinois, graded to pass a No. 20 (840-micron) sieve and to be retained on a No. 30 (590-micron) sieve. Specifications for other test sands are equally as strict.

Traction Sand

Traction sand is sound, well-sorted, free-flowing, medium-grained silica sand with a minimum of soft rock fragments, used to increase the tractive effort of locomotives on slippery rails.

Traction sand does not require the special properties demanded of some of the other industrial sands. A clean washed sand which is composed esentially of quartz, is uniformly graded so that excessive segregation will not take place in the sand box, will not cake when dry, is not dusty, and will flow freely, is suitable for this purpose. The desired size-frequency distribution range is between 20- and 70-mesh. Most railroads and coal mines utilize the closest and cheapest supply source that will give a satisfactory performance.

SOUTH TEXAS SANDS

The above discussion, in part from Murphy (1960, pp. 763–772), is included in order that the south Texas sand producers may have a summary of the requirements and specifications for the various types of silica sand now being utilized in industry. Not all sand deposits in the area of this investigation were sampled during the study, but the writer collected representative samples from several localities. Not any of the raw material as collected will meet the rigid specifications for the sand types listed above, but some of them with proper processing may be up-graded to meet the requirements of some types.

Analyses of these collected samples are given in table 43 (in pocket). All samples were dispersed in water containing Calgon (sodium hexamethophosphate), scrubbed by rolling in a polyethylene-lined jar containing a bottle filled with lead shot, washed and separated from the minus 20-micron fraction in a cone hydroclassifier. The washed material was then dried, weighed, and sieve-analyzed. The sieve analysis of the plus 200-mesh sand was calculated from the general sieve analysis using the yield of the plus 200-mesh sieve as 100 percent. All fractions are available at the Mineral Technology Laboratory for inspection.

There has been considerable interest in locating glass sand deposits in south Texas, and the samples collected during this study were tested especially for that purpose. Murphy (1960) reported that if the Fe_2O_3 content of a flint-quality glass sand exceeds 0.02 to 0.025 percent, expensive decolorizers must be employed in the manufacture of glass. Specifications are less strict for manufacture of common glass for containers. The analyses in table 43 show that none of the samples tested meet the specifications for high-grade glass sand; some shipments of glass sand are being made from quarries near Leming and Poteet in Atascosa County. Sand from this area was used at the Three Rivers glass plant at the time that plant was in operation.

Prospective glass sands can be beneficiated by acid washing and/or magnetic separation to lower the iron content. Heating the sand in a reducing atmosphere converts paramagnetic iron impurities to the ferromagnetic state and makes them susceptible to magnetic separation. Of course, any beneficiation adds to the cost of production so that sand so treated may not be competitive.

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SALT DOMES

Salt domes are salt masses that have been pushed upward and have raised the overlying strata to form a dome. The domes range in size and complexity of deformation from relatively simple arches a few miles in diameter to comparatively slender salt plugs that both pierced and complexly deformed the overlying beds and caused folding and faulting in adjacent formations. Salt has been encountered in wells in many of the salt domes, but there are other domes believed to overlie deeply buried salt masses in which the salt plug has not been penetrated.

A feature common to most salt domes is the cap rock, a mass of anhydrite, gypsum, and limestone; at some localities sulfur blankets the top of the salt plug. Generally, the anhydrite and gypsum layer adjacent to the salt is overlain by the limestone, but this arrangement is not uniform in all salt domes. When present, sulfur is most commonly in the limestone, but at some localities it is also found in the anhydrite.

Proven salt domes within the area of this investigation include Gyp Hill in Brooks County, Palangana and Piedras Pintas domes in east-central Duval County, Dilworth Ranch dome in northwest-central McMullen County, Moca dome in northeastern Webb County, and Pescadito dome in southwestern Webb County (Pl. II). Buried salt plugs are indicated by geophysical surveys at Palo Blanco and Alto Verde in northwestern Brooks County and San Miguel Creek and Henry domes in northern McMullen County.

DESCRIPTION OF SOME SALT DOMES

Gyp Hill.—Gyp Hill, about 6 miles southeast of Falfurrias in Brooks County, is a prominent topographic feature with central core of massive crystalline gypsum (selenite). The plug-like gypsum mass, surrounded by a salt marsh and unusual structural phenomena, indicated a salt dome to early geologists. In 1911 the Producers Oil Company drilled three holes into the top of the hill and logged at least 400 feet of gypsum. Deep wells drilled in 1945 and 1946 encountered salt at 1,010 feet; the deepest well in salt is at 4,926 feet. Perkins and Lonsdale (1955) estimated that the salt mass includes an area of 1.56 square miles and has a volume of 2.76 cubic miles.

Palangana dome.—The surface expression of the Palangana dome in east-central Duval County is a saucer-like central depression surrounded by a rim of hills, except on the southwestern side where the rim has been breached by erosion. The central depression is probably a solution-collapse feature due to partial solution of the underlying salt by percolating ground water. Palangana dome has been drilled for oil, gas, sulfur, and uranium. Sulfur was produced from 1927 to 1929 from a depth of about 450 feet in the cap rock; the sulfur was depleted in 1929. From about 470 to 850 feet the cap rock is anhydrite; the upper surface of the salt plug occurs at 850 feet and is more or less a planar surface. Wells drilled into the salt plug produce brine for the Chemical Division of the Pittsburgh Plate Glass Company in Corpus Christi. Perkins and Lonsdale (1955) estimated that the salt mass has an area of 2.04 square miles and a volume of 3.61 cubic miles. Uranium deposits on the Palangana dome are discussed on page 127.

Piedras Pintas dome.—The Piedras Pintas dome, also in east-central Duval County, has a dome structure at the surface. In 1905 a well encountered salt at 1,350 feet. Subsequent wells found salt as high as 1,150 feet. Perkins and Lonsdale (1955) estimated that the salt mass includes an area of 1.58 square miles and has a volume of 2.62 cubic miles.

Moca dome.—The Moca dome, in east-central Webb County, is a prominent topographic dome. Steeply tilted beds of various hardness form concentric bands around the structure. Salt was encountered at a depth of 6,366 feet. Perkins and Lonsdale (1955) estimated the area of the salt plug to be 1.56 square miles with a volume of 1.23 cubic miles.

Dilworth Ranch dome.—Salt was encountered at a depth of 7,736 feet at the Dilworth Ranch dome in McMullen County. Perkins and Lonsdale (1955) estimated that the salt mass has an area of 0.78 square miles and a volume of 0.41 cubic miles.

SALT

Salt is an important industrial mineral. Perkins and Lonsdale (1955) reported that there are 1,400 uses, the largest of which is probably in the preparation of soda ash. Vast quantities of salt are also used in other chemical processes, food industries, refrigeration, agriculture and livestock industry, metallurgy, and water treatment.

In the area of this report the principal salt deposits are in the salt domes, but there has been sporadic production from some inland water bodies. Much salt is blown inland from the lagoons of Baffins Bay and Laguna Madre by the southeast trade winds. The wind-transported salt along with sand and clay accumulates on the land surface. Rain leaches the salt from the higher areas and carries it in solution. In areas with impervious clay soils the salt water collects in local depressions and upon evaporation the salt remains. Examples of such salt basins are Sal del Rey and La Sal Vieja in Willacy County and Laguna Salada in Brooks County.

Salt bodies at shallow depths are mined by conventional methods, but deep salt bodies are generally exploited through wells. Unheated water is circulated through wells drilled into the salt and brine is recovered. Development requires large quantities of water and may require pumping for periods of several months. After the brine has reached the desired salinity, only replacement water is required to maintain the operation. The principal constituents of the brine are sodium chloride, calcium sulfate, calcium chloride, and magnesium chloride, but several trace element salts, such as barium sulfate, lead and zinc sulfate, potassium chloride and other potassium salts, are also recovered.

Salt reserves in the Texas Coastal Plain as estimated by Perkins and Lonsdale (1955, pp. 30–32) are shown in table 44.

SULFUR

Sulfur is a basic 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 the approximate order of importance, are in fertilizers, chemicals, petroleum refining, paint, metallurgy, rayon and film, pulp and paper, insecticides, rubber, and explosives.

The native sulfur produced in Texas occurs in the cap rock of salt domes and is recovered by the Frasch process. This process involves melting the sulfur in the cap rock by superheated water (325°F.) which is forced into the sulfur-bearing formation. The liquid sulfur is forced to the surface by compressed air and carried by heated and insulated pipelines to storage bins or to insulated transport barges for delivery in the liquid state. After the sulfur solidifies in the bin, it is marketed without additional purification. According

TABLE 44. *Salt reserves in south Texas salt domes.*

Dome	County	Depth to top of salt (feet)	Area of salt (sq. miles)	Volume of salt (cubic miles)
Dilworth Ranch	McMullen	7,736	0.78	0.41
Gyp Hill	Brooks	1,175	1.56	2.76
Moca	Webb	6,366	1.56	1.23
Palangana	Duval	1,200	2.04	3.61
Piedras Pintas	Duval	1,350	1.58	2.62

to Lundy (1949, pp. 998–999), sulfur produced by the Frasch process commonly averages 99.8 percent and is guaranteed to contain not less than 99.5 percent sulfur.

The sulfur is associated with the cap-rock limestone and to a lesser extent with anhydrite or gypsum. It occurs in a more or less continuous bed or, more commonly, disseminated through the porous cap rock. Normally, sulfur is not recoverable from anhydrite because of lack of porosity.

Sulfur does not occur in all salt domes. Of the 231 salt domes reported in Texas, Louisiana, Mississippi, and Alabama, only 16 contain sulfur deposits of commercial significance. Most of the commercial deposits are at depths of 1,500 to 2,000 feet, but Hoskins Mound in Brazoria County has been commercially productive at a depth of 2,400 feet. Palangana dome in Duval County is the only salt dome in the area of this study that has been commercially productive. Perkins and Lonsdale (1955, p. 19) reported that the Duval Texas Sulphur and Potash Company produced a total of 237,607 tons of sulfur from the Palangana dome, but the deposit is now depleted. Gyp Hill in Brooks County also contains sulfur but the deposit probably is not of commercial interest.

GYPSUM AND ANHYDRITE

Anhydrite and gypsum are found in the cap rock of many salt domes in the Gulf Coastal Plain. Anhydrite is anhydrous calcium sulfate ($CaSO_4$), and gypsum is hydrated calcium sulfate ($CaSO_4 2H_2O$). Gypsum occurs in several forms, but the common types are (1) rock or bedded gypsum composed of small interlocking crystals, (2) selenite, a crystalline form found as crystals in veins and openings, or as sheets disseminated through shale, and (3) gypsite, a loose powdery material.

Rock gypsum is the most important type of deposit commercially because it occurs in large tonnages and can be ground, processed, and utilized in many types of industry. Selenite, the crystalline variety, tends to split into tiny flakes on grinding instead of powdering and is undesirable for some commercial purposes. Normally, selenite is not found in sufficient quantities to be commercially important, but Gyp Hill, about 6 miles southeast of Falfurrias in Brooks County, is a mound of selenite that covers 50 acres and stands 75 to 100 feet above the surface of Laguna Salada. It is at least 1,000 feet thick. Gypsite, a secondary mineral, has a loose, powdery earthy character. Gypsite deposits of sufficient size and purity are desirable because the gypsite can be excavated cheaply and requires relatively little grinding. An extraordinary deposit occurs at White Sands, New Mexico.

Gypsum is an important industrial mineral in the construction industry. About 25 percent of the gypsum used in the United States is sold in the 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 largest gypsum deposits are interbedded with salt and dolomite and were probably derived from anhydrite. Thick gypsum deposits have been recorded in many of the deep oil tests in the northeastern Coastal Plain counties and also in Uvalde, Val Verde, Maverick, and Kinney counties within the area of this report. Most of this gypsum is too deeply buried to be of commercial importance. Gypsum is also present in the Edwards limestone of central Texas, especially in Gillespie County, and limited quantities have been reported from near Pleasanton and Campbellton in Atascosa County.

A number of salt domes in the Coastal Plain contain gypsum in their cap rock. Ground water is abundant in the rocks above and around most salt domes, and hydrogen sulfide gas is generally present in the cap rock. This makes underground mining difficult and hazardous; probably only cap-rock gypsum which is at or near the surface can be profitably mined.

At Gyp Hill the gypsum cap rock of the dome is at the surface. The deposit was mined from a surface pit approximately 350 feet wide, 800 feet long, and 35 feet deep. The mining operation was intermittent during the period 1929 to 1942 when approximately 350,000 tons of gypsum were produced. An estimated 13,000,000 tons of gypsum is available in an area of about 200 acres at the surface. Deeper mining is probably practicable and the reserves are large. Limited amounts of the crushed gypsum left at the site when the 1942 operation was abandoned are being used for agricultural purposes by the Valley Gypsum Company, Harlingen, Texas.

In the other salt domes in the area, the gypsum is several hundred feet beneath the surface. It appears that the Gyp Hill deposit is the most promising source of gypsum within the area of this report.

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TITANIUM

Active prospecting for commercial deposits of titanium in Starr County began in the late mid-1950's when it was learned that some of the local sandstones in the Jackson group contain ilmenite. Ilmenite, associated with some magnetite, very little rutile, and a few other heavy minerals, is disseminated throughout some sandstone beds and occurs sporadically in small lenses or pockets in the sandstone. Commonly, the dark minerals are not easily seen because of iron-oxide stain on the surface or obscuring soil and vegetation. Streaks of "black sand" in washes and streams indicate the presence of ilmenite and/or magnetite in the source rocks.

STARR COUNTY.—In early 1959 a drilling program was conducted by the U.S. Bureau of Mines to test the ilmenite content of the sandstone at some of the most promising localities. Holes were drilled on the Guerra ranch northwest of Roma, along the Rio Grande flood plain west and northwest of Roma, on the Sandoval and Ramirez farms west of Roma, and on the Gonzales ranch about 7½ miles northwest of Roma.

The heavy mineral content of 73 samples taken from the Guerra ranch ranged from 0.10 to 5.25 percent. An analysis of the samples containing over 0.74 percent heavy minerals showed a titanium oxide content range from 0.31 to 2.72 percent with an average of 0.81 percent. Analyses of 37 samples taken on the Sandoval and Ramirez farms showed a heavy mineral content ranging from 0.26 to 26.30 percent. The titanium oxide content of the samples that tested more than 0.74 heavy minerals ranged from 0.42 to 5.03 and averaged 1.43 percent. The heavy mineral content from eight samples taken on the Gonzales ranch ranged from 0.10 to 1.40 percent and the titanium oxide content from 0.44 to 0.97 percent.

WILLACY COUNTY.—In Willacy County two holes were drilled about 5 miles northeast of Raymondville, but the heavy mineral content of the eight samples collected was low, ranging from 0.50 to 1.0 percent.

The drilling and analytical data from Starr and Willacy counties indicate that the heavy mineral concentrations are spotty, quite small in extent, have a low average titanium oxide content, and probably do not have commercial value.

PADRE ISLAND.—Titanium minerals are also known throughout much of the sand on Padre Island, and lean concentrations have been studied at several localities. These minerals were first recognized in the beach sand, later in the sand dunes of the island, and at shallow depths below the strand line. Some shallow exploratory drilling has been done in this area. The results are not available to the writer, but there appears little evidence of commercial concentrations of heavy minerals.

LEE, BURLESON, AND FAYETTE COUNTIES.—A number of lenticular deposits of heavy minerals occur along a linear belt within the Wellborn formation of the Jackson group in Lee and Burleson counties. These deposits were described briefly by Flawn (1956). The heavy mineral concentrations are in a soft, friable, light to medium gray sandstone and overlying sandy soil. Ilmenite and zircon are the principal heavy minerals present. Because of the high zircon content, the deposits are characterized by weak radiation anomalies.

The individual concentration contains a high percentage of heavy minerals but available tonnage of heavy mineral-bearing sandstone is small. As currently known, these deposits are not of commercial interest.

Drilling tests in the Lee-Burleson County area were conducted in 1958 by the U.S. Bureau of Mines. A total of 34 holes was drilled in Lee County, 33 about 18 airline miles northeast of Giddings, and one about 5 miles south of that town. The titanium oxide content of 27 of the highest grade samples averaged 1.71 percent and ranged from 0.70 to 18.75 percent. In Burleson County, about 20 airline miles northeast of Giddings, 59 of the highest grade samples taken from 57 holes showed a titanium oxide range from 0.25 to 3.89 percent and averaged 1.59 percent. In Fayette County, about 7 miles southeast of Giddings, eight samples from three holes contained less than 0.50 percent heavy minerals.

OTHER AREAS.—The formations of the Jackson group extend southwest from the Lee-Burleson County area across Fayette, Gonzales, Karnes, Atascosa, and McMullen counties and thence southwest and south to the Roma area in western Starr County. Airborne and vehicle-mounted scintillation equipment passed over this rock belt numerous times during the period of active prospecting for uranium and a number of radiation anomalies were located. Ground investigations revealed that most of the anomalies were associated with uranium mineralization, but some weak radiation anomalies were located that are not associated with any detectable uranium mineralization. A number of samples from weakly radioactive sandstones were submitted to the Bureau of Economic Geology for mineralogical determinations. Some of the rocks were found to carry abnormal concentrations of heavy minerals, chiefly ilmenite-magnetite and zircon. The radioactivity is apparently due to the high zircon content.

Currently available data on titanium minerals in the Texas Coastal Plain indicate that there is widespread distribution of ilmenite associated with magnetite, zircon, rutile, and other heavy minerals in some sandstone layers of the Jackson group. The heavy minerals are either in local small-tonnage lenticular deposits or very sparsely distributed.

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URANIUM

HISTORY OF DISCOVERY AND PROSPECTING

Uranium mineralization was discovered in sandstone of the Jackson group, near Tordilla Hill, northwestern Karnes County, during the fall of 1954. According to common report (Eargle and Snider, 1957, p. 6), G. H. Strodtman, pilot for Jaffe-Martin and Associates, San Antonio, discovered a radioactive anomaly northeast of Tordilla Hill while making radiometric surveys with an airborne scintillation counter in exploring for oil. This led to further airborne scintillation-counter surveys, carborne scintillation-counter surveys, and surface studies which located uranium minerals in sandstone and soils at the foot of Tordilla Hill and in other areas to the northeast near Deweesville. Uranium had not been previously reported from the Texas Gulf Coastal Plain, and confirmation of commercial grade and tonnage of uranium ore came as a big surprise to many. Subsequent exploratory work led to the establishment of a new uranium district.

Eargle and Snider (1957, p. 6) reported that by August 1955, at least twelve properties had been prospected and that uranium mineralization and/or high radioactivity had been reported from several more. The campaign of intensive prospecting and exploration continued into the summer of 1956 and resulted in discovery of uranium mineralization and/or abnormally high radioactivity in separated areas extending along a belt that stretched northeast from the original discovery at Tordilla Hill across Gonzales and Fayette counties, and southwestward and south from Tordilla Hill into eastern Atascosa, Live Oak, southern McMullen, extreme east-central Webb, and west-central Starr counties (Pl. IV). Areas with anomalous radioactivity were reported from Edwards and Val Verde counties, and occasional fragments of fossil wood containing uranium minerals were found on ridgetops in Edwards County.

Prospecting and exploration declined during the summer of 1956. This was in part due to the lack of available milling and marketing facilities in Texas and, also, by that date most of the surface prospects were located and the more promising areas were under lease. About a quarter of a million tons of uranium ore, as estimated by the Atomic Energy Commission (Eargle, 1959b, p. 2), were proved in the Karnes County district. About eight tons were shipped to Grants, New Mexico, in December 1958. This shipment, from the Boso prospect at the foot of Tordilla Hill (Pl. V, B), was handpicked high-grade ore containing about 2½ percent U_3O_8. Mining and stockpiling operations by the San Antonio Mining Company began in July 1959 at the Gembler-Lyssy-Korzekwa property (Pl. V, B) while awaiting completion of a mill. The mill, Susquehanna-Western, Inc., at Deweesville, near Falls City, was started in late 1960 and began operations in April 1961 (fig. 7); it is utilizing an acid leach-solvent extraction process to produce "yellow cake" (p. 129).

GEOLOGIC OCCURRENCE OF URANIUM

Concentrations of uranium minerals occur in the Texas Gulf Coastal Plain in fine- to medium-grained tuffaceous sandstone and tuff beds and are frequently associated with carbonaceous plant remains or lignite and occasionally with silicified fossil wood. For the most part, the host rocks were deposited by streams as delta-like accumulations, in shallow-water swamps containing variable amounts of vegetation, on flattish land surfaces where running water and wind spread the debris over broad areas, by deposition along stream valleys, and at some localities in ancient stream channels. As the land and sea bottoms rose and fell, these fluctuations brought about advances and retreats of the shore-

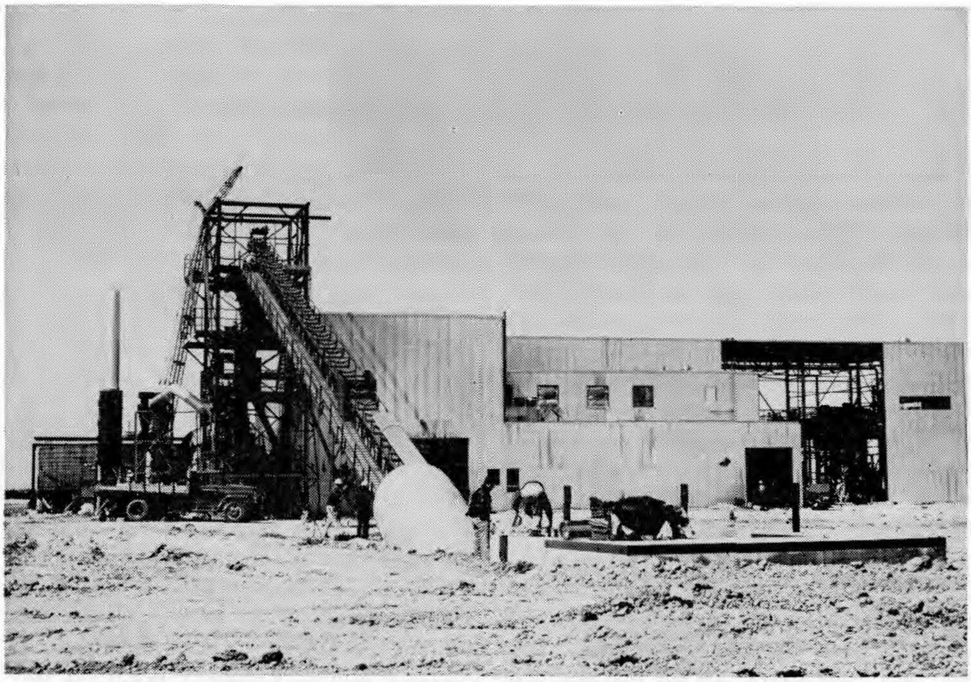

FIG. 7. Susquehanna-Western, Inc., uranium mill near Falls City, Karnes County, Texas.

line with corresponding change in the carrying power of the streams and also changes in the type of materials that the streams carried and deposited. If the adjacent land area was relatively high, the streams were swift and carried coarse material (sand) ; if the land was low, the streams were sluggish and carried fine material (mud). These environments account for the alternating zones of relatively coarse clean sand, which is generally permeable to the movement of ground water, and the fine-grained, impure tuffaceous sands and clays that are impervious. These changing conditions in the depositional environment also caused a variety of sedimentary structures such as the thickening or thinning of beds, pinch-out of certain lithologic units, overlap of formations, and stream channel fills. The sedimentary structures, together with the alternating permeable and impermeable layers, account for the lithologic and sedimentary traps in which many of the uranium mineral concentrations have been found.

The Jackson group in the area of uranium mineralization was described in detail by Eargle (1959, pp. 2623–2635). The Caddell, Wellborn, and McElroy formations of the lower part of the Jackson group are chiefly marine and to date have not been of primary importance as a host rock for concentration of uranium minerals. The Whitsett, uppermost formation in the Jackson group, includes both marine and nonmarine members. The most important uranium deposits in the Karnes County area are in the Stones Switch and Dubose members of that formation. The Stones Switch, basal member of the Whitsett, occurs between the marine Conquista clay member of the McElroy formation and the overlying nonmarine ashy beds of the Dubose (Whitsett) sandstone and is a transitional unit. The uranium minerals are found chiefly in tuffaceous sandstones, commonly associated with lignitic material, bentonitic clay, tuff or tuffaceous clay, and siltstone. Uranium mineralization and/or areas of high radioactivity also occur in the overlying Catahoula and basal Oakville formations in Karnes, Atascosa, and Gonzales counties; one prospect has been reported in the basal Jackson or possibly the Yegua formation (upper Claiborne group) in Gonzales County. The Frio clay, a slightly calcareous bentonitic clay, contains sporadic concentration of uranium minerals in Starr County, but the Frio is not exposed in Karnes County. The Catahoula (Gueydan of Bailey, 1926) extends southwestward from Karnes County and overlies the Frio clay. In the belt that extends across parts of Live Oak, McMullen, Duval, Webb, and Starr counties, the formation consists chiefly of tuff and fluviatile deposits derived mainly from tuffs and contains sporadic concentrations of uranium minerals and local areas of high radioactivity. In Duval County, the basal Oakville contains areas of high radioactivity. Also in Duval County, the Goliad contains important uranium reserves and several promising prospects (Pl. IV). Further prospecting and exploration along the belt of anomalies may reveal new localities not previously reported.

KARNES COUNTY.—Eargle and Snider (1957) described uranium-bearing rocks and uranium deposits in Karnes County. Their report includes a geologic map of the mineralized area that shows the location of fourteen uranium prospects and a generalized stratigraphic section on which uranium occurrences are indicated. On the accompanying map (Pl. IV), these fourteen localities are shown by red crosses or by mine symbols, and other localities where uranium minerals or abnormally high radioactivity have been recorded are shown by red dots. Detailed data with respect to roads, drainage, property ownership, and location of the uranium mill in Karnes County are shown on Plate V, B. Most of the uranium mineralization is in the Stones Switch sandstone north and east of Tordilla Hill, a northward-facing cuesta in western Karnes County near the Atascosa County line, but mineralized areas extend south and southwest from Tordilla Hill into the adjacent part of eastern Atascosa and northern Live Oak counties.

Most of the known uranium ore in Karnes County occurs at depths not exceeding 40 feet. Many of the deposits are either on, or just below, the surface and lend themselves to inexpensive open-pit mining. A few abnormally radioactive zones have been encountered in drill holes at depths up to 150 feet down dip from the outcrop, but no uranium minerals have been identified.

The Tordilla Hill uranium area lies in a deformed and warped block of gently dipping beds between the Falls City and Fashing en échelon faults. The rocks are strongly jointed and locally highly silicified. The highest grade ore occurs filling interstices between sand grains and/or selectively replacing fine tuffaceous sandstone or siltstone. Commonly the uranium minerals are concentrated in the sandstone at or near the contact with an impervious layer, such as a bentonitic clay, or around local clay zones which are rich in carbonaceous material. Some of the clays are also mineralized along joints and bedding planes. It appears that the mineralization is controlled by local faulting and jointing, ground-water circulation, lithology and composition of the host rock, and primary sedimentary structures.

Theories for ore concentration.—Weeks et al. (1958, p. 1659) suggested a possible genetic relationship between zeolitic alteration of tuffaceous sediments and uranium concentration. According to this hypothesis, the tuffaceous sediments of the Jackson group were altered by alkaline ground water. The alteration produced heulandite, which is a common mineral in the rocks of the Tordilla Hill uranium area but is not common outside the mineralized zone; the alteration also released silica and trace elements from the tuffs. The trace elements while in solution were redistributed by percolating ground water and concentrated in a reducing environment caused by the presence of carbonaceous matter, or by petroleum or H_2S-bearing solutions that ascended from the Edwards limestone along the faults and fractures.

De Vergie (1958, pp. 23–29, figs. 1, 3, and 4) discussed some of the Karnes County deposits and showed a relationship between the uranium concentrations and the lithology and/or sedimentary structures in the host rock. De Vergie (1958,

p. 27) stated that the highly tuffaceous rocks of the Whitsett and Catahoula formations have a relatively high average uranium content and suggested that ground water may have leached the uranium minerals from this source. The uranium in solution moved through the permeable parts of the Stones Switch and Dubose sands and was precipitated where hydrogen sulfide was held in stratigraphic traps. The hydrogen sulfide could have been derived from decomposition of lignite and other organic material, present in the host rock, or from a deep-seated natural gas source, such as the Fashing gas field. Hydrogen sulfide gas formed in permeable sands would either disperse or be carried away by ground water, but the bentonitic silty sands or tuffaceous lignitic clay in the Whitsett could trap the gas. The trapped hydrogen sulfide gas would precipitate the uranium from solution.

Eargle (1960, p. 148) reported the discovery of uranium in tuffaceous rocks from other localities in the Coastal Plain. Uranium minerals are associated with beds containing lignite, fossil wood, or other carbonaceous materials and locally are associated with oil or gas fields. The new Person field in northern Karnes County is in the same area as a uranium prospect which was found several years before the oil field was brought in (Eargle, 1960, p. 148). This adds weight to the suggestion that uranium minerals were precipitated and concentrated by hydrogen sulfide gas.

Uranium minerals.—The principal uranium minerals in the Karnes County area include autunite, carnotite, schoepite, tyuyamunite, and uranophane; uraninite, as sooty pitchblende, was found in a limited area on the Gembler tract mined by the San Antonio Mining Company. De Vergie (1958, pp. 26–27) reported that autunite, with lesser amounts of carnotite, is commonly disseminated in the bentonitic fine- to very fine-grained sands and silts; the carnotite concentrations are generally found immediately underlying the more impervious lignitic clays and around local concentration of carbonaceous material. The mineralogic relationships suggest that the uranium was originally deposited in a thin zone, probably immediately underlying impermeable zones, and possibly in the oxide form. Oxidation and leaching by surface waters redistributed the uranium as secondary minerals (vanadates and phosphates). This redistribution has caused the ores to be highly out of equilibrium. The relatively insoluble vanadates (carnotite and tyuyamunite) tend to remain fixed while the more soluble minerals are mobile. Abundant limonite, jarosite, and gypsum in the mineralized zones indicate the former presence of pyrite and availability of sulfate ions to promote oxidation.

Mining and milling.—As of early April 1961, mining and stockpiling activities have been limited to the Gembler-Lyssy-Korzekwa properties (Nuhn mine), leased to the San Antonio Mining Company, and the Lyssy-Niestroy property (Luckett mine), leased to Susquehanna-Western, Inc. (Pl. V, B). Both companies mined and stockpiled material averaging approximately 0.2 percent U_3O_8. The San Antonio Mining Company contract was for 100,000 tons, all of which had been delivered by April 1961. Susquehanna-Western, Inc., mined an ore body estimated at approximately 80,000 tons; this mining was completed by July 1961. The two companies probably will deplete the supply of approximately 0.20 percent ore in the deposits, but there is a substantial tonnage of lower grade ore which is marginal at this time. With the completion of a mill and the establishment of marketing facilities, there should be increased activity in the Karnes County uranium district.

Much of the information contained in the following discussion of county occurrences (pp. 126–129) is based on work done by Atomic Energy Commission personnel and given the writer in oral communications (P. C. de Vergie) over the period of this present investigation.

ATASCOSA COUNTY.—Uranium minerals and radiation anomalies have been reported from at least four localities in eastern Atascosa County. The mineralization is at the contact of the Dubose–

Stones Switch and in the basal Stones Switch members of the Whitsett formation; the geology is comparable to that described in Karnes County. Eargle and Snider (1957, p. 23) described and showed the location of two localities (Pl. V, B, Nos. 11 and 14). They reported carnotite and other unidentified uranium minerals. Most mineralized bodies are small pods and lenses.

DUVAL COUNTY.—Near the Duval-McMullen County line, north of Seven Sisters, north-central Duval County, uranium mineralization occurs in localized pods in medium-grained sandstone and ash beds in the lower conglomeratic sandstone of the Oakville formation.

A core hole about 300 feet deep, 0.3 mile southeast of the Seven Sisters Post Office, is reported to have penetrated a radioactive zone at a depth of 280 feet. At time of inspection the hole had caved and the probe penetrated to only 244 feet. The zone is presumably in the Chusa member of the Gueydan (Catahoula) formation.

Immediately west of Seven Sisters scattered spotty uranium mineralization occurs in thin flat-lying tuff layers (Chusa?) exposed in a caliche pit.

Radioactivity was recorded in a caliche pit on the west side of State Highway 173 about 8.3 miles north of Freer. The anomalous readings came from a gray to brown tuffaceous sandstone exposed in a bulldozed trench 4 feet deep. No uranium mineralization was visible.

Beginning about 2 miles north of Freer and extending northwestward for 6½ airline miles is a belt which includes six or more radioactive localities. The radiation comes from light to dark green kaolinitic fracture fillings in tuffaceous sandstone beds of the Soledad member of the Gueydan. The fillings (possibly fault gouge or dikes) range from inches up to several feet in thickness and at one locality contain visible pods of uranium minerals. The pods are small in size and not of commercial value, but assays of several selected samples showed significant amounts of U_3O_8.

High-grade sporadic mineralization on the Wiederkehr tract occurs in surface rock and in wells up to depths of 40 feet in the Soledad member of the Gueydan formation at the North Government Wells oil field near Freer. The visible mineralization consists predominantly of uranophane as small pods in a medium-grained sandstone and an underlying volcanic ash bed. The mineralized pockets are variable both in depth and amount of uranium mineralization.

At Cedro Hill, about 14 miles southwest of Freer, a highly fractured, light gray, limonitic, flinty rock is radioactive. No visible mineralization was reported but a sample supposedly from this hill contains 0.37 percent U_3O_8 by chemical assay. The amount of flinty fractured rock is limited.

On the Piedras Pintas salt dome, about 5 miles northeast of Benavides, uranium minerals occur as faint yellowish coatings along minute fractures in white clay. The clay is exposed in the north wall of a quarry and is overlain by a highly silicified sandstone bed in the Goliad formation. The mineralization appears to be associated with a northeast-southwest fault. The outcrop overlies a salt dome that has marginal oil production from its top and flanks. The future potential is unknown and the area warrants exploration.

Uranium ore occurs in a highly calcareous clay-ball conglomerate interbedded with fine- to medium-grained sandstone locally impregnated with oil in the base of the Goliad (Pliocene) formation at a depth of about 325 feet and more than 100 feet above the cap-rock of the Palangana salt dome. The uranium minerals, chiefly finely divided sooty pitchblende with small amounts of microcrystalline uraninite with disseminated pyrite, occur in a greenish-gray sandstone. Hydrogen sulfide emanating from the cap-rock of the dome caused a reducing environment above the salt dome. Weeks and Eargle (1959, pp. 1695–1696; 1960, p. B-50) described the deposit in detail and theorized that the uranium was leached by alkaline carbonate water from the tuffaceous formations northwest of Palangana dome, and that the uranium minerals were precipitated from uranyl carbonate solution in a reducing environment above the salt dome. Prospecting and exploration for uranium mineralization at Palangana include one shaft, limited tunneling, and gamma-ray logging in drill holes. The thickness, distribution, and intensity of the radioactivity in the mineralized zone are erratic, but there appears to be substantial uranium mineral reserves in the deposit.

EDWARDS COUNTY.—On Little Hackberry Creek, about 14 miles by road northwest of Barksdale, two small radioactive areas have been reported. One area is in highly fractured Fredericksburg limestone that may be in part float, and the other is in recently accumulated carbonaceous soil in the canyon bottom. Neither is of commercial interest. Locally, fossil wood with visible uranium minerals has been found along the ridgetops.

GONZALES COUNTY.—The formations that are mineralized in Karnes County extend northeastward across Gonzales County. Although commercial deposits of uranium have not been found, there are localities in which the rocks contain visible uranium minerals, and there are several localities where anomalous radioactivity has been recorded.

The southwesternmost prospect, closest to the Karnes County uranium district, is about 18 miles southeast of Nixon. The uranium minerals (carnotite and tyuyamunite) occur as scattered pods in coarse-grained, cross-bedded sandstone (rice sands) of the basal Catahoula formation, containing fossil wood, and overlain by a Catahoula tuff unit. The individual pods are small but high grade; perhaps 100 tons of uranium ore is available on the surface.

Areas with anomalous radioactivity have been reported farther northwest in Vanham Creek and the Valley Branch drainage of Peach Creek, north of Dilworth. The anomalies are in fine-grained tuffaceous sandstone which is locally cross-bedded and is probably a part of the Whitsett formation. No uranium minerals are visible, but abundant limonite is associated in the radioactive zone.

In the extreme northeastern corner of Gonzales County, 4 to 5 miles southwest of Flatonia, anomalous radioactivity was detected in drill holes, trenches, and surface exposures of fine-grained silty or tuffaceous sandstone, probably the upper part of the Whitsett formation. Anomalies were also recorded in a poorly cemented sandstone (Catahoula?) that caps a small hill. No uranium minerals were recognized.

GUADALUPE COUNTY.—A uranium prospect, about 9 miles southeast of Seguin, was visited in 1955. At the time of the inspection three trenches and a few shallow holes were probed. No uranium minerals were seen, but anomalous radioactivity was recorded.

LIVE OAK COUNTY.—In the northern corner of Live Oak County, near the Atascosa-Karnes County line, very finely disseminated uranium minerals occur in tuff and tuffaceous shale (Catahoula?). At the time of the inspection, the property had been prospected with a number of trenches.

The Mabel New property is in the northwest corner of Live Oak County, approximately 6 airline miles from Whitsett, (Pl. V, C). This property was described by Eargle and Snider (1957, p. 25) and shown on their map as locality No. 13. Some visible uranium minerals have been reported, and abnormally high radioactivity was recorded from a 2- to 10-foot layer of very friable, limonitic tuffaceous sandstone that is underlain by a white ash bed. This locality has recently been investigated by drilling and may prove to be a small commercial ore body.

Prospects from beds in the Oakville sandstone and the basal part of the Goliad formation have been reported from north of Oakville and east of George West in east-central Live Oak County. At one locality east of George West, anomalous radioactivity is confined to silicified wood embedded in a fine-grained, white, friable sandstone. The silicified wood is in fragments up to 1 foot long, and about one-third of the fragments are radioactive. The visible uranium minerals consist of small blebs along the grain of the wood, within the outer one-fourth inch of the fragment. The sandstone surrounding the wood is not abnormally radioactive. The deposit has no commercial value other than for specimens, but it is of scientific interest because of the mineralized fossil wood and the relatively young age of the host rock (Pliocene).

McMULLEN COUNTY.—Radiation anomalies have been recorded in a bed of light gray, fine- to medium-grained sandstone (Gueydan?) in an area approximately 200 by 200 feet at about 2½ miles southwest of Loma Alta. No uranium minerals were seen.

MAVERICK COUNTY.—Radioactivity has been recorded in the vicinity of some coal outcrops north of Eagle Pass, but no visible uranium mineralization has been reported.

STARR COUNTY.—Uranium prospects have been reported along the Los Olmos Creek drainage north of Rio Grande City, in west-central Starr County. The visible uranium minerals occur as traces in faint yellow coatings on quartz grains, in pore spaces between the grains, and in small scattered pods in a medium-grained, friable sandstone locally impregnated with silica (chalcedony). Locally, the sandstone overlies green and brown gypsiferous clay, probably the upper part of the Frio formation. Selected samples contain from 0.04 to 0.25 percent U_3O_8.

VAL VERDE COUNTY.—Anomalous radioactivity was recorded in at least two localities northwest of Langtry. The rock is flat-lying Cretaceous limestone, honeycombed with small caves, with abundant calcite coating the cave walls. No uranium minerals were seen at the localities visited, and it appears unlikely that commercial amounts of uranium will be found at either of the localities.

WEBB COUNTY.—A prospect was inspected in east-central Webb County, a few miles northwest of Moglia. No uranium minerals were visible and the radiation anomaly was weak.

ECONOMIC SIGNIFICANCE

The impact of the discovery of commercial-grade uranium ore, the results of prospecting and exploration, and the future influence on the economy of south Texas of mining, milling, and sale of the refined product are difficult to evaluate. The initial benefits came largely from the sale of mineral leases and damage payments to property owners for the right to trench, core drill, and strip overburden during the exploratory activities in the development program. These benefits of a substantial, but unknown, amount have chiefly influenced the local economy. In late July 1960, the Atomic Energy Commission and Susquehanna-Western, Inc., signed a uranium purchase contract involving the construction and operation of a uranium ore processing mill in Karnes County. The mill, which cost about $2,000,000 and has a rated capacity of approximately 200 tons of ore a day, began operations in April 1961. The plant is chemically treating the uranium-bearing ores to produce "yellow cake," a refined product which is sold to the U. S. Atomic Energy Commission. The plant is located near the abandoned village of Deweesville, about 9 miles by road southwest of Falls City; it is the twenty-sixth such plant in the United States and the only such in Texas.

The mill, built primarily for processing the known uranium ore deposits in Karnes County, will also provide a market for production from independent ore producers in the area. The mill employs approximately 100 persons, most of whom are hired locally, and this activity through wages and the purchase of both raw and prefabricated materials should benefit both the local and regional economy; with the uranium mines and mill in operation and the establishment of a market for the south Texas area, there should be further prospecting and exploration.

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VOLCANIC ASH

Deposits of volcanic ash or pumicite result from violently explosive volcanic activity. The explosion shatters the rock in the upper part of the volcanic vent and quantities of lava, gases, steam, and volcanic ash are ejected. Some of the ash is rock that was broken into tiny fragments by the forces of eruption, but most ash is composed of fragments of volcanic glass formed when viscous, gas-charged lava was blown from the vent and chilled in the air. The large particles fall close to the eruption area, but the ash may be caught in wind currents and carried hundreds, or thousands, of miles. Most of the volcanic ash in the Texas Coastal Plain area probably settled out of the atmosphere at a distance from the eruption area. Some of it was subsequently reworked by streams and other agents of erosion and redeposited.

Volcanic ash is generally light colored and has a gritty feel when rubbed between the fingers. Most deposits contain abundant small angular particles of glass (shards) that range from colorless to brown. Altered glass shards show a variety of colors including pink and purple hues. Fibrous, tube-like or teardrop-shaped bodies are common in ash. The larger tubes and teardrops are hollow and originally contained bubbles of gas or steam. In some areas volcanic ash is loose and incoherent, elsewhere it has been altered to bentonitic clay, and in other areas it is compact, hard, and stony. Indurated volcanic ash is called tuff. Ash, tuff, and bentonite are found in the rocks of the Texas Coastal Plain.

USES

Volcanic ash is used in a wide variety of industries. A relatively large amount of ash is mixed with small amounts of soap powder, soda ash, and other ingredients to make cleaning compounds. Volcanic ash is also used in abrasive hand soaps, mechanic's paste soaps, silver and other metal polishes, cleaning and scouring compounds, toothpastes and powders, dustless sweeping compounds, fillers for paint, abrasives in rubber erasers, and for both hot and cold insulation preparations. Some partly altered volcanic ash has been used for bleaching in the petroleum industry; deposits that are low in iron oxide, lime, and magnesia but high in silica, potassium, and soda can be used in some phases of the ceramic industry. One of the important uses in Texas is for the production of pozzolan cement.

Pozzolan Cement

Knowledge that volcanic ash can be mixed with lime to form cement goes back to the time of the Romans, who developed their famous hydraulic cement called Pozzuolana. The Romans used the cement in walls, aqueducts, and buildings, some of which are still standing.

Pozzolans are artificial or natural siliceous and aluminous compounds which themselves are not cementitious but which contain substances capable of forming cementing compounds when mixed with lime and water at atmospheric temperatures. The siliceous and aluminous pozzolans also react with the calcium hydroxide formed during the hydration of Portland cement and increase the strength of the mortar or concrete mix. Calcination of natural pozzolans at controlled temperatures improves their reactivity with lime and the products from hydration of Portland cement; calcination at high temperatures may destroy the pozzolanic activity.

There is need for further field and laboratory studies of the Texas volcanic ash deposits in order to evaluate their properties, reserves, and economics. Utilization of pozzolanic materials is particularly desirable in construction of massive concrete structures, high-standard highway structures, and marine installations. Locally, there may be economic advantages in the substitution of pozzolans for Portland cement, because pozzolans improve workability, reduce permeability, and reduce heat of hydration.

Klemgard (1958) reported that the usual chemical analyses give no real measure of the pozzolanic activity of pumice (volcanic ash). Petrographic or mineralogical composition is a much better index of probable pozzolanic activity. Even these data do not explain anomalies such as the difference in reactions of materials similar in both chemical and mineralogical composition. Klemgard (1958, p. 4) concluded that the following factors control pozzolanic activity:

1. Each pumice or clay has an optimum calcining temperature for the generation of maximum pozzolanic activity.
2. The optimum temperatures of calcination are believed to fall within a range wherein drastic disintegration of at least some of the crystalline structures occurs.
3. In minerals heated to the optimum temperature the crystal structure is either completely disintegrated or may be in a highly disordered slate because of partial disintegration.
4. If calcination is above the optimum temperature there is a reduction in pozzolanic activity.
5. Imperfections in crystal structure and the related factor of surface area also affect pozzolanic activity.
6. Nonsilicates having crystal imperfections and high surface area have been shown to possess inadequate pozzolanic activity.
7. Uncalcined pumice material containing silica of high surface area is known to have appreciable pozzolanic activity. To some extent, such pozzolanic activity depends to a considerable extent on the nature of the ions present in the structure, their ionic radius, and whether the structure is such that they can accommodate calcium ions.
8. Water is essential to promote pozzolanic activity. In aqueous phase the calcium ions can diffuse through the crystal structure of the pozzolan and arrive at a suitable fixed position.

Klemgard (1958, pp. 4–18) also discussed such topics as X-ray diffraction research, relation kinetics, strength, elastic creep, volume changes, heat of hydration, permeability, workability, sample preparation, grinding, grindability work index, specific gravity, specific surfaces, unit weight, available alkalies, mixing and curing procedures, density, water requirements, drying shrinkage, compression strength, and economics of the Washington State pumice deposits. Some of the discussion which applies specifically to the Washington State pumice deposits may not be applicable to the volcanic ash deposits in Texas, but some of the general subject data are quoted:

Strength.—The tensile strength of mortars and concretes containing pumicites as a replacement of part of the Portland cement normally continues to increase with moist curing time, attaining a maximum value in about one year. The tensile strength of pumicite mortars under continuous drying ordinarily is greater than corresponding mortars made with Portland cement. This drying effect is greater for tensile strength than compressive strength.

Elasticity and creep.—Usually creep or plastic flow of pozzolanic concrete under both tension and compression is only slightly greater than corresponding normal Portland cement mixes.

Volume changes.—In most cases pozzolanic concretes and mortars expand slightly more under wet curing and shrink more under dry curing conditions than corresponding non-pozzolanic mixtures. The magnitude of drying shrinkage is not always an indication of the anticipated extent of surface cracking.

Heat of hydration.—For equivalent weights the heat of hydration is in general greater for a given Portland cement mixture than for a mixture of such cement and a pozzolanic material. It is believed that the pozzolan does contribute to the total heat liberated during hydration, but the quantity is relatively small. Also it has been reported that some pozzolans have a greater initial rate of hydration than Portland cement. In massive concrete structure construction this may be desirable because more heat may be dissipated from a dump of concrete before covering with another. The heat of hydration of cement-pumice-pozzolan mixes is usually greater than for mixes containing diatomite or opaline-shale pozzolans. From a general consideration it is concluded that for the more active pozzolans the percentage of reduction in the 28 days of hydration is about one-half the percentage of the pozzolan replacement for the Portland cement.

Permeability.—In lean concrete mixes pozzolanic material has a definite value in the improvement of impermeability and increasing the resistance to aggressive waters. Pozzolans of opaline character are more effective in reducing permeability during the early curing stages than the glassy pozzolans such as pumicite and fly ash.

Workability.—The workability of pozzolan mixes is superior to non-pozzolanic concretes. With the pozzolan formulations there is frequently less tendency for segregations and water gain. In massive structures where the concrete pouring rate is great and the time for obtaining the desired maximum density is limited, the improved workability of the pozzolan mixes has been found to be an important advantage.

Other Uses

Otis and Foley (1960) have reported on new technology in the utilization of pumice. In their report, pumice includes not only volcanic ash but also cinders and all other pumiceous materials ejected during volcanic eruptions. They summarize a method by which pumice building blocks were placed in drying kilns and fired with natural gas to a temperature of 400 degrees Fahrenheit. This reduced the contained moisture from the usual 30 percent to an average of 6 percent and reduced the drying time by 67 percent.

Other products, methods, and procedures summarized by Otis and Foley (1960) include pumice as one of the suggested ingredients in a patented tile mixture.

A potential wall plaster to replace gypsum consists of (1) a scratch coat made from a mixture of pumicite, sand, cement, cellulose glycolate, an alkyl sulfate, and exfoliated vermiculite and (2) a finish coat of vermiculite, sand, cement, cellulose sulfite, and a fungicide.

A patented composition for coating pipes before encasing them in concrete comprises a mixture of grease and a porous aggregate such as pumice or vermiculite. A coating of this type permits moderate expansion of the pipes without damage to the concrete.

Pumice is one of the suggested aggregates mentioned in a patent for making masonry water repellent with a decorative surface finish. The pumice was sprayed with a wax emulsion, or solution of stearate, potassium silicate, sodium silicate, or latex.

The ingredients of a patented soil stabilizer are 5 to 25 percent pumice, diatomite, or fly ash, 35 to 75 percent plastic soil, 20 to 50 percent aggregate, and 2 to 9 percent brine.

A stabilizer for soils to improve roads is composed of lime, soil, water, and crude or calcined pumicite.

A composition filler material patented for asphalt bitumens is made by mixing lime or ground limestone with pulverized pumicite.

DEPOSITS IN SOUTH TEXAS

Gueydan Formation

Bailey named and described the Gueydan formation from exposures on the Gueydan ranch and survey in southwestern McMullen County and mapped it along a belt in parts of Gonzales, Karnes, Live Oak, McMullen, Duval, Webb, and Starr counties (Bailey, 1926, Pl. I). The thickest and most extensive volcanic ash deposits in the south Texas Coastal Plain are within the Gueydan formation, but the deposits are by no means all volcanic ash, and the ash is not without impurities. The Gueydan consists of a mixture of air-deposited tuff and mud-flow tuff (indurated volcanic ash) interbedded with volcanic conglomerate, tuffaceous sandstone and clay, impure bentonite, and stream-deposited sandstone and clay.

The Gueydan outcrop belt ranges in width from about 3 miles in Gonzales County to 15 miles in southwestern Duval County. Bailey (1926) published lithologic description of the beds measured at localities in Live Oak, McMullen, Duval, Webb, and Gonzales counties as well as petrographic description of many samples. The data are especially valuable to any person hoping to locate and utilize the volcanic ash deposits in south Texas, but further sampling and testing will be necessary in order to determine the quality and extent of the volcanic ash deposits.

LIVE OAK COUNTY.—Three volcanic ash samples collected during this study are from localities 2 and 3 in Live Oak County (Pl. II). Petrographic examination of samples from these two localities shows the following mineral content.

Locality 2 (Min. Tech. Lab. No. 60135): Soft, buff, montmorillonitic clay about 50 percent and fine-grained partially devitrified rhyolitic glass with traces of glass shards, quartz, and biotite grains. Dark heavy minerals are conspicuously absent.

Locality 3 (Min. Tech. Lab. No. 60136, 60137): Soft, pale bluish-gray, slightly devitrified rhyolitic glass. No significant quartz and no clay, biotite, or dark heavy minerals.

STARR COUNTY.—A soft, powdery, slightly limy, pinkish-white, very fine volcanic ash crops out locally in the vicinity of Rio Grande City in Starr County. Good exposures are rare, but one outcrop is clearly visible along the north side of Loma de la Cruz, a few miles east of Rio Grande City. It is from this general volcanic ash outcrop area about 5 miles east of Rio Grande City that the Valley Brick and Tile Company obtains materials for pozzolan cement and insecticide diluent (Pl. II, Loc. 8). Baker (1935) reported that estimates of thickness range from 60 to 300 feet. The rock is a partially indurated ash (tuff) composed of montmorillonite clay minerals and numerous glass shards of partly devitrified rhyolitic glass (index, n = 1.498), silt-size quartz grains (approximately 20 percent), and a trace of plagioclase. The major accessory mineral is magnetite; minor accessory minerals include ilmenite, leucoxene, biotite (hexagonal flakes), and zircon.

In counties farther north and northeast along the Gueydan belt, volcanic ash is better exposed and there should be less difficulty in obtaining samples for testing. Beds of volcanic ash also occur at certain levels in the Jackson group and Frio formation, but most of them are thin and impure.

GONZALES COUNTY.—Chelf (1942, p. 8) in his discussion of bleaching clay deposits noted ash beds at several localities. One of these is at the Terrysville community in Gonzales County, where volcanic ash in the Jackson is as much as 21 feet thick. This deposit has also been described by Evans (1941, pp. 36–37), who outlined the ash body by systematic hand-auger holes. The ash deposit extends from a small wash just west of the Terrysville Church eastward for about 10 miles and does not exceed 500 to 600 feet in width. The ash is underlain by 1 to 2 feet of bentonite and rests in an asymmetrical depression. The thickest part of the deposit is near a sandstone ridge on the southern edge of the depression. Another volcanic ash deposit occurs on the Baker ranch, about 10 miles south of Gonzales and approximately 2 miles south of the Terrysville community.

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