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THE BROWN IRON ORES OF EASTERN TEXAS

BY

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THE BROWN IRON ORES OF EASTERN TEXAS

By Edwin B. Eckel

ABSTRACT

The brown iron ore deposits of eastern Texas occupy part of the Coastal Plain province in the eastern and northeastern parts of the State. Though some ferruginous material exists in at least 22 counties, deposits that could be profitably worked under reasonably predictable economic conditions are restricted to a comparatively small area in Cass, Cherokee, Marion, and Morris Counties. In addition, Anderson, Henderson, Upshur, Nacogdoches, and Smith Counties might produce some ore if sufficient demand should arise. None of the deposits are more than a few miles from existing railroads, and a network of good highways and secondary roads traverses the area.

The field work on which this report is based was made possible by an allotment from Public Works Administration funds and continued from April through November 1934.

The existence of rich deposits of iron ore has been known almost from the time of the first settlement of eastern Texas, and several small furnaces were erected to utilize the ores during the fifties of the last century. Since 1855 somewhat less than 700,000 long tons of iron ore has been produced, largely for use in local furnaces, and much capital has been expended in the acquisition of ore lands and the production of iron. All the local furnaces have been abandoned for some years, and most of the ore reserves are now in the hands of a few large companies.

The iron ores occur near the tops of the flat-topped, sand-covered hills that form a prominent feature of the landscape in a large part of eastern Texas. Nearly all the rocks exposed at the surface in this part of the State were laid down during the Eocene epoch of Tertiary time. Iron ore of commercial grade is confined almost entirely to the Weches greensand member of the Mount Selman formation, which is the lowest formation of the Claiborne group. The Weches greensand is a mixture of a granular iron silicate mineral of the glauconite group with varying proportions of quartz sand and clay. Two facies are recognized here. Plant remains are the only fossils contained in the facies of the North Basin. It is typically composed of intermixed oolitic glauconitic sand, quartz sand, and clay, cross-bedded in part. Its thickness ranges from a few inches to more than 100 feet but averages only about 25 feet. The facies of the South Basin contains abundant marine fossils and much glauconitic clay, but little or no quartz sand. It averages 40 to 50 feet in thickness, contains no plant remains, and is not cross-bedded. It was apparently deposited in deeper waters than the facies of the North Basin.

All the iron ores occur within the eastern Texas geosyncline, a troughlike structural feature that lies on the northern and western border of the Sabine uplift. On structural and stratigraphic grounds this geosyncline is divided into the North Basin and South Basin. The dividing zone extends from the extreme northern part of Gregg County northwestward through Upshur County.

The most abundant type of ore is limonite, or brown ore. In the North Basin the ore occurs chiefly in nodular forms or as thin lenticular bodies that are distributed irregularly through the weathered zone in the upper part of the Weches greensand. The ore-bearing material ranges from 5 to 30 feet in thickness, and the ratio of waste to ore is rarely more than 5 to 1. The best ores occur near the outcrop of the Weches greensand, and few of them extend beneath heavy cover.

In the South Basin the ore occurs as one solid bed of brown laminated and "buff crumbly" ore, which is almost continuous along the outcrop and ranges from a few inches to 3 or 4 feet in thickness. The ore bed lies on a layer of white clay that grades downward into partly weathered greensand. The parting between the ore and the white clay is notably irregular. As little or no ore has been formed where the Weches is covered by more than 10 feet of sand, the ore bed does not generally extend more than 500 feet from the outcrop.

Iron carbonate, or siderite, is somewhat plentiful in the ore beds, especially in the North Basin. It occurs as white or gray dense nodules or thin beds, at or near the ground-water level.

Chemical considerations, based on analyses of the greensand, siderite, brown ore, and spring waters, and the observed relation of the ore deposits to the present water table and the topography indicate that the ores of the North Basin have been derived from the greensand by ordinary weathering processes. It is believed that ground waters leach iron from the greensand and deposit it as iron carbonate. This is later altered to limonite or brown ore.

The ores of the South Basin are formed by the same processes, but it is believed that the more impervious nature of the greensand and the higher water table in this area have caused the iron-bearing solutions to rise by capillary force to the top of the Weches greensand, where they deposit iron ore.

Study of curves based on a great number of analyses of the North Basin brown ores shows that, although there is a wide range in composition, a large proportion of the samples fall within the limits indicated below:

	Percent
Iron	48–57
Silica	5–13
Alumina	2–7
Phosphorus	0. 04–0. 12
Sulphur	0. 02–0. 10
Manganese	0. 15–0. 30
Water	10–13

It is possible that the shipping ore will contain only about 45 percent of iron, however, with correspondingly higher percentages of impurities. The carbonate ores as mined contain less iron than the brown ores, but roasting to drive off carbon dioxide will yield a product as high in quality as the best brown ores.

Analyses of the laminated and buff crumbly ores of the South Basin indicate the following probable range in composition:

	Percent
Iron	42–48
Silica	10–12
Alumina	8–12
Phosphorus	0. 10–0. 25
Water	12–14

Detailed mapping of all important deposits, measurement of all available natural and artificial exposures, and data supplied by several private companies have made possible a rather definite limitation of the areas from which commercial production of ore can be reasonably expected. With certain limits as to grade of ore, ratio of ore to waste, and ratio of ore-bearing material to overburden, it is estimated that the total reserves of ore in the North Basin are about 109,800,000 long tons and cover an area of 35,300 acres and that the total reserves in the South Basin are about 66,808,000 tons and cover an area of 21,655 acres. Between 150,000,000 and 200,000,000 tons of comparatively high-grade iron ore is, therefore, apparently available in eastern Texas. These figures do not take into account an enormous tonnage of low-grade ferruginous material that might possibly be used in the distant future.

The future of the district appears to depend on the solution of transportation problems. Whether the ores are shipped to other States or used in local furnaces, the freight rates on ore or on coal and limestone have been so high in the past that reasonable profits could hardly be obtained by the operators. If present plans for the development of water transportation should be realized, the Texas ores could probably be utilized in the near future. It seems more probable that they will be shipped to existing iron centers rather than that they will be reduced in local furnaces.

The report contains detailed descriptions of individual iron-ore deposits in the North and South Basins, arranged by counties and districts. Representative sections of the ore-bearing formations are presented, and the area, thickness of ore and overburden, and ratio of ore to waste are described. Maps of parts of Cass, Marion, Morris, Cherokee, and Henderson Counties are included. In addition to the geology, they show the distribution and classification of the iron ores.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The iron-ore deposits of eastern Texas occupy parts of the Coastal Plain province, in the eastern and northeastern parts of the State. Ore deposits have been reported by various authors to occur in the following 22 counties, which have an aggregate area of more than 20,000 square miles; Anderson, Camp, Cass, Cherokee, Franklin, Gregg, Harrison, Henderson, Hopkins, Houston, Marion, Morris, Nacogdoches, Panola, Rusk, Sabine, Shelby, Smith, Titus, Upshur, Van Zandt, and Wood. (See pl. 1.)

Unquestionably some ferruginous material exists in all these counties, but deposits that could be profitably worked under any reasonably predictable economic conditions are restricted to an area of less than 1,000 square miles in a few of the counties. In fact, a very large proportion of the production should be obtained from an area of less than 100 square miles in Cass, Cherokee, Marion, and Morris Counties (pl. 1). In addition, Anderson, Henderson, Upshur, Nacogdoches, and Smith Counties might conceivably produce some ore if sufficient demand should arise.

FIELD WORK AND ACKNOWLEDGMENTS

Field work on the project whose results are here set forth, which was made possible by an allotment from Public Works Administration funds, began early in April 1934 and continued through November of the same year. The work was sufficiently detailed to enable a sharp limitation of the areas from which commercial production can be reasonably expected, to permit a careful estimate of the available ore reserves, and to yield many data showing the relation of the ore deposits to depth of overburden and position of the water table. Geologic maps were prepared of a large part of eastern Texas which has received but scant attention in the past.

J. R. Stone assisted during the early part of the season and is responsible for the descriptions of the John Davis and Hagerty districts and for the field work in much of the Prewitt district and parts of several districts in the northeastern part of Cass County. E. C. Williams served as rodman through the greater part of the season. Paul E. M. Purcell joined the party June 28 and remained in the field until early in December. His wide professional experience in the geology of eastern Texas made him an especially valuable addition to the party. He is responsible for many of the ideas on stratigraphy and structure as here presented and for detailed studies of many of the iron-ore deposits. The writer was in the field from April 6 to November 1. Ernest F. Burchard, geologist in charge of the section of iron and steel metals, Geological Survey, made three visits to the field and gave much helpful advice both in the field and during the preparation of this report.

Everyone with whom the writer has come into contact has willingly given assistance in the work. Mr. Charles Denby, Jr., and Mr. Brandon Barringer, of the East Texas Iron Co., placed all the records of that company at the Survey's disposal. Officials of other companies interested in the region were equally generous. F. W. Galbraith contributed materially with his studies of thin and polished sections of the iron ores and greensand. A. C. Spencer and E. C. Eckel gave much advice, particularly on the questions of origin and available reserves of ore. LaCharles G. Eckel assisted throughout the field and office work, not only with timely encouragement but also in preparation of maps and tabular data, and in proofreading. Grateful acknowledgment is due to all members of the Geological Survey's administrative, editorial, and clerical force who have in any way had a part in the work.

It is a pleasure to acknowledge the writer's indebtedness to Dr. E. H. Sellards, Director, and Mr. C. L. Baker, of the Texas Bureau of Economic Geology; to Judge L. L. Harper and Mr. Will Surratt, of Linden; to Mr. R. C. Hardy, of Atlanta; to Mr. E. A. Wendlandt, of the Humble Oil & Refining Co., Tyler; to Mr. Albert J. Jones, of Jamestown, Calif., and to many others for advice, criticism, and much information that could not otherwise have been obtained.

METHODS OF FIELD WORK

The field work consisted in large part of preparing maps to show the areal distribution of the iron-ore deposits and of the geologic formations. The character and quantity of the iron ore were examined in detail in all available natural and artificial exposures, such as wells, road cuts, and prospect pits. Maps of local areas were furnished by several iron companies and were of great assistance, as were the company records of test pits and other prospecting data. The data obtained have since been used in drawing up an estimate of the reserves of commercial ore within the area, which was considered to be one of the most important phases of the work.

The best available base maps were used. Except for maps of three quadrangles (Atlanta, Linden, and Daingerfield) that cover parts of Cass and Morris Counties, no topographic maps were available. The Bureau of Soils, United States Department of Agriculture, kindly furnished an excellent newly prepared but unpublished soil map of Cass County, by M. W. Beck, which was used for mapping the geology in the southern part of the county. Soil maps of Henderson, Morris, and Smith Counties, published by the Department of Agriculture, were very useful, not only as base maps but because some of the soil units portrayed correspond in a general way with the geologic units. In other counties rural post-route maps kindly furnished by the Division of Topography, United States Post Office Department, were used. In some areas, particularly in Cherokee and Marion Counties and southeastern Morris County, where no accurate maps were available, the geology was plotted on base maps prepared by the present party.

Because of the large area to be covered and the heavily wooded nature of most of the iron-ore bearing hills, plane-table work was not feasible. Most of the mapping was therefore done by a combination of automobile and pacing traverses. Altitudes were determined by means of a Tycos 5-inch surveying aneroid. This instrument proved to be accurate within 5 feet for long traverses and even more accurate for short traverses where benchmarks were relatively close together.

PREVIOUS WORK IN THE DISTRICT

From 1859 to the present time, the iron-ore deposits of eastern Texas have been examined by many geologists, both for the State and Federal Surveys and for private companies. The following bibliography includes all the more important published reports that deal primarily with these deposits. In addition, a great number of papers have been published on the general geology, stratigraphy, structure, paleontology, and water supplies. A few of these papers are referred to in the text, but no attempt to present a complete bibliography has been made. In recent years petroleum companies have accumulated quantities of information on the structure and stratigraphy of this part of Texas, but unfortunately only a small fraction of this information has been made available to the general public.

Shumard, B. F., Texas Geol. and Agr. Survey 1st Rept. Progress, pp. 13–14, 1859. Briefly describes occurrence of iron ore in seven counties. Contains first published references to presence of carbonate ores and to existence of Nash furnace.

Buckley, S. B., Texas Geol. and Agr. Survey 1st Ann. Rept., 142 pp., Houston, 1874. Brief descriptions of several furnaces and ore deposits in a number of counties on pp. 17–21.

Birkinbine, John, The iron industry of Texas: U. S. Assoc. Charcoal Iron Workers Jour., vol. 6, pp. 168–172, June 1883. Not seen by the writer.

Johnson, L. C., The iron regions of northern Louisiana and eastern Texas: 50th Cong., 1st sess., H. Ex. Doc. 195, vol. 26, 54 pp., map, 1888. Outlines ore-bearing area in Louisiana and Texas and gives data regarding the geologic formations. The South Basin ores are ascribed to lacustrine or bog deposition, the North Basin ores to alteration of original iron carbonate. The few notes on thickness of ore are more conservative and truer to fact than those of some later writers.

Penrose, R. A. F., Jr., A preliminary report on the geology of the Gulf Tertiary of Texas: Texas Geol. Survey 1st Ann. Rept., for 1889, pp. 5–101, 1890. (Iron deposits described on pp. 65–86.) The subject is approached primarily from a scientific rather than a practical angle. Describes the deposits under three headings—Brown laminated ores, Nodular or geode ores, and Conglomerate ores. Discussion of the origin of the ores is clear and convincing.

Dumble, E. T., Kennedy, William, and others, Reports on the iron-ore district of east Texas: Texas Geol. Survey 2d Ann. Rept., for 1890, pp. 7–326, map, 1891. Descriptions of iron-ore deposits throughout eastern Texas, with many incidental notes on geography, timber, clay, glass sand, etc. Map shows approximate boundaries of ore deposits. Estimate 1,500,000,000 tons of ore as very conservative. Give many analyses of ores and greensands. Data on actual thickness of ores are extremely optimistic in general. Most complete report extant on iron-ore deposits.

Penrose, R. A. F., Jr., The Tertiary iron ores of Arkansas and Texas: Geol. Soc. America Bull., vol. 3, pp. 44–50, 1892. Contains a well-organized discussion of the origin of the ores.

Kennedy, William, Houston County, Tex.: Texas Geol. Survey 3d Ann. Rept., pp. 3–40, 1892. Describes deposits of siliceous conglomerate and of laminated and buff crumbly iron ores in Houston County. Points out that the former are too low in grade and the latter too thin to be of value.

Kennedy, William, The age of the iron ores of east Texas: Science, new ser., vol. 23, pp. 22–25, 1894. General summary of geologic relations of iron ores. All ores thought to be of Claiborne (Eocene) age, the nodular ores being derived from the laminated type, which were in part bog deposits and in part derived from oxidation of greensand.

Kennedy, William, Iron ores of east Texas: Am. Inst. Min. Eng. Trans., vol. 24, pp. 258–288, 862–863, 1895. Abstract, Eng. and Min. Jour., vol. 57, pp. 222–223, 1894. Contains but few data that are not in 2d Ann. Rept. of Texas Geol. Survey, but material is better organized and somewhat more complete. Many analyses of ores and of iron made in local furnaces.

Phillips, W. B., The iron resources of Texas: Eng. Soc. Western Pennsylvania Proc., vol. 19, pp. 62–79, 1902. Reviewed in Eng. and Min. Jour., vol. 73, p. 656,

1902. Largely a description of existing furnaces and discussion of economic factors.

Eckel, E. C., Iron ores of northeastern Texas: U. S. Geol. Survey Bull. 260, pp. 348–354, 1905. Reports results of a rapid reconnaissance examination of deposits in Cass, Marion, and Morris Counties. Recognizes great areal extent and richness of deposits but points out difficulties in the way of large-scale mining operations.

Cloyd, W. C., Iron-ore development in east Texas: Manufacturers' Record, Feb. 14, 1907, p. 123. Good summary of the history of the district.

American Iron and Steel Association, Directory of the iron and steel works of the United States, 3d ed., 1876, to 17th ed., Philadelphia, 1908. Data on history, equipment, and production capacity of the later furnaces in east Texas.

Phillips, W. B., The iron-ore situation in east Texas: Min. World, vol. 33, p. 994, November 26, 1910. Largely a discussion of transportation and other economic factors that bear on development of Texas iron ores.

Phillips, W. B., Iron and steel making in Texas: Iron Age, vol. 89, pp. 14–16, 141–143, 1912. Discussion of possibility of establishing local iron and steel industry. Contains a valuable classification of chemical analyses of ores.

Phillips, W. B., The new iron-ore dock at Port Bolivar, Galveston Bay, Tex.: Iron Age, April 18, 1912, pp. 974–978. Largely a description of facilities at Port Bolivar but contains some data on transportation costs, production, and history of blast furnaces.

Linton, Robert, Texas iron-ore deposits: Eng. and Min. Jour., vol. 96, pp. 1153–1156, map, 1913. Summary of geologic relations, with data on results of recent prospecting and concentration experiments. Contains several analyses of raw, concentrated, and calcined ores and several photographs.

Phillips, W. B., Concentration by the Goltra process: Iron Age, November 12, 1914, pp. 1148–1150. Describes concentration tests made on Texas brown ores at Waukon, Iowa.

Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee Counties, Tex.: U. S. Geol. Survey Bull. 620–E, pp. 69–109, map, 1915. Clear description of deposits in counties named, with many sections of ore-bearing strata. Several new analyses of ores and illustrations of mode of ore occurrence. Closing chapters on development and utilization of ores very useful.

Baker, C. L., Oxide, silicate, and carbonate iron ores of northeastern Texas, in The geology of Texas, vol. 2: Texas Univ. Bull. 3401, pp. 427–482, 1935. Compilation of data on iron-ore deposits, with extensive original discussions of character of greensand, origin of the ores, and general economic factors involved in their utilization.

Eckel, E. B., and Purcell, P. E. M., The iron ores of east Texas, in The geology of Texas, vol. 2: Texas Univ. Bull. 3401, pp. 482–503, 1935. Prelimary report, superseded by this paper.

HISTORY OF THE DISTRICT

Most of the matter that follows has been taken from the reports of Dumble [1] and Kennedy [2] and from the publications of the American Iron and Steel Association.[3] For further details the reader is referred to the original reports by these and other early writers. The first

[1] Dumble, E. T., Kennedy, William, and others, Reports on the iron-ore district of east Texas: Texas Geol. Survey 2d Ann. Rept., for 1890, pp. 7–325, map, 1891.

[2] Kennedy, William, Iron ores of east Texas: Am. Inst. Min. Eng. Trans., vol. 24, pp. 258–288, 862–863, 1895.

[3] American Iron and Steel Association, Directory of the iron and steel works of the United States, Philadelphia, 1876–1908.

published reference to the deposits of iron ore in eastern Texas seems to be that made by Newell,[4] who said in 1839, "Iron is found in abundance in the eastern, northern, and middle portions of Texas."

The first furnace of which there is any record was erected about 1855. This was the Nash furnace, of which Shumard,[5] writing in 1859, said:

> The only iron furnace our State can boast of is situated in this [Cass] county. It was erected several years since by Mr. [J. S.] Nash and has been in nearly constant and, I believe, profitable operation up to the present time. The ore is mined near the furnace, and the kinds preferred are a porous variety of hematite, termed by the proprietors "honeycomb ore", and compact brown hematite. The pig metal and castings produced from these ores are of excellent quality and command a high price in the market.

The location of this furnace is in doubt. Shumard places it in Cass County. Penrose [6] describes it as located in Cass County, just north of Barnes Hill, 3 miles from Avinger. The context strongly suggests that Barnes Hill was northwest of Avinger. Dumble locates the furnace in the Gilbert tract, in northwestern Marion County. Judge L. L. Harper, of Linden, kindly investigated the matter for the writer and states in a letter to him that there is little doubt that the Nash furnace was situated on the Walter H. Gilbert tract in Marion County.

Apparently the Nash furnace was operated throughout the Civil War, as Buckley states [7] that it was seized by the United States Government at the end of the war and never resumed operations.

Several small furnaces and bloomeries were in operation about 1860. At an extra session of the State legislature in 1861 a joint resolution was passed which pointed out that inexhaustible supplies of iron ore, together with several successful foundries, existed in Cass and Marion Counties, and invited the Government of the Confederate States "to consider the propriety and importance of establishing a foundry and manufactory for the manufacture of ordnance and arms for the Confederate States."

This invitation was accepted, and the Confederate Government took charge of and operated several of the existing furnaces and erected others. In addition to the works constructed by the Government, a few others were erected by private capital. After the war all of them finally fell into disuse.

The erection of the Hughes furnace was begun in 1859, but no iron was produced until 1861. It was about 1½ miles southeast of Hughes Springs and had a capacity of 20 tons of iron a day. Mr. Hughes, who built the furnace, never operated it, as the Confederate Govern-

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[4] Newell, C., History of the revolution in Texas, p. 172, 1839.

[5] Shumard, B. F., Texas Geol. and Agr. Survey 1st Rept. Progress, pp. 13-14, 1859.

[6] Penrose, R. A. F., Jr., A preliminary report on the geology of the Gulf Tertiary of Texas. Texas Geol. Survey, 1st Ann. Rept., for 1889, p. 78, 1890.

[7] Buckley, S. B., Texas Geol. and Agr. Survey, 1st Ann. Rept., p. 19, Houston, 1874.

ment took charge soon after its completion. Under Government operation large amounts of pig iron and castings were made. After the war production was continued for a short time by the Federal authorities.

Young's Iron Works were about 8 miles southwest of Jacksonville and 3 miles from the Neches River, on an isolated hill known as Iron Furnace Mountain. This hill is probably part of the chain of ridges now known as Tillman Mountain. The furnace was substantially constructed of brown ferruginous sandstone and cost between $6,000 and $7,000. It was 34 feet square at the base and 34 feet high. Local ore was used. Limestone came from a source only 18 miles distant, possibly from the salt dome west of Palestine. This smelter operated successfully for a time and produced pig iron and castings, but it closed down soon after the Civil War. Plans were later made to resume operations. Construction of new railroad facilities were under way when the owner, Dr. Young, was killed in an accident. Nothing further was ever done.

About 8 miles northwest of Alto, in Cherokee County, and the same distance southwest of Rusk, was the Philleo (Filleo) furnace, where ore was smelted on a large scale during the Civil War. The ore and the charcoal used came from the isolated hills in the immediate vicinity of the furnace. Limestone is said by Buckley [8] to have been "abundant, only 3 miles distant." The location or geologic occurrence of this limestone deposit is unknown. James J. Perkins, of Rusk, informed the writer that the furnace, which was built against a steep hill slope so that ore, fuel, and flux could be dumped in at the top of the stack, cost about $55,000 and produced 3 to 4 tons of iron a day for some years. Three hundred men are said to have been employed at these works, but smelting was discontinued at the end of the war, and only the foundry business continued.

The Nechesville bloomery, which was in northeastern Anderson County, near Nechesville (now Neches), was erected in 1863 by Col. Charles Bussey and Joseph D. Griggs. A single 25-horsepower engine, using an ordinary fan blast, was tried first, but it was found inadequate and later a second engine and two tub bellows, or blowing cylinders, were added. The expected yield of iron was 3,000 to 4,000 pounds a day, but when production had reached 1,500 pounds a day and success seemed assured the works were burned. The total production was 50,000 pounds of iron, said to be of superior quality. Ore for the furnace came from a mountain a mile north of Nechesville, and the fuel used was local pine charcoal.

The Montalba bloomery was on the south side of Mound Prairie Creek, near Montalba, in Anderson County, about 8 or 9 miles north

[8] Buckley, S. B., op. cit., p. 18.

of Palestine. This was one of the plants operated by the Confederate Government. Gun barrels and other munitions were the chief products. Nothing more is known of its history.

The Confederate Government began construction of a bloomery near Kickapoo, a small settlement not far south of Frankston, in northeastern Anderson County, but the work was never completed.

The R. W. McClain or Linn Flat bloomery was in northwestern Nacogdoches County, about 12 miles from Nacogdoches. It was constructed and operated during the latter part of the Civil War, ceased operations with the coming of peace, and was later burned. Buckley [9] says: "No lime was used. The blowing process, which consists of roasting and breaking up the ore, was here adopted." About 150,000 pounds of hammered iron bars were made by this bloomery in about 8 months.

In 1863 the legislature passed a law which offered a section of land for each $1,000 invested in the erection of certain manufactories. The Sulphur Fork Iron Co., incorporated in the same year, was the first to take advantage of this offer. The company was organized on June 15, with 19 stockholders. There is no record of the number of shares, which were valued at $1,000, although it is known that among the stockholders was the State of Louisiana, with 52 shares. The furnace was just west of Springdale, in northeastern Cass County, and ore was obtained from nearby Bowie Hill. The furnace was built of brick and was 34 feet square and 36 feet high. In addition to the furnace, the plant equipment consisted of a large coal shed, engine room, molding room, steam sawmill and gristmill, machine shop, and the necessary dwellings. The capacity was 8 tons of iron a day, and both pig iron and hollow ware were produced. Work stopped April 1, 1865, and was never resumed. The value of the plant, as determined by a commission appointed to determine how many sections of land were due to the owners, was $97,500.

Erection of the Kelly furnace was begun in 1869 by G. A. Kelly about 6 miles northwest of Jefferson, Marion County. It went into blast in 1870 and ran almost continuously until 1886. Originally square, the stack was changed to the round form in 1874. The bosh diameter was 9 feet, and the height, which had been 34 feet, was raised to 45 feet. Hot-blast charcoal soft foundry iron was produced. According to Buckley [10] the furnace in 1874 was producing 1,000 pounds of pig iron a day. The proportions of material in the charge were 18 bushels of charcoal, 750 pounds of ore, and 60 pounds of lime. The lime was in the form of oyster shells, brought in from New Orleans and elsewhere. At this time 70 men were employed at the furnace and 50 in the foundry.

[9] Buckley, S. B., op. cit., p. 19.
[10] Buckley, S. B., op. cit., pp. 19-20.

In 1882, owing to financial difficulties, the furnace was sold to the Marshall Car Wheel & Foundry Co., which remodeled it slightly, changed the name to Loo Ellen, and began producing hard iron suitable for chilled castings such as car wheels. The capacity was 10 tons of iron a day. Charcoal was used for fuel, and limestone was brought from the vicinity of Dallas. The furnace operated continuously until 1886, when the owners found that they could not dispose of all the iron produced. As the plant was in a dilapidated condition as well, it was shut down, and finally dismantled in 1888. This was the last of the old furnaces.

Early in the eighties a penitentiary was established by the State at Rusk, in Cherokee County. The site was chosen on account of the presence of abundant iron ore in the vicinity and for the purpose of employment for convict labor in making pig iron and related products. The original plans called for a 25-ton furnace, which was expected to cost about $25,000. Construction of the furnace, which was first named the Old Alcalde but was later known both as the Sam Lanham and as the State furnace, began in 1883. It was blown in, with charcoal fuel, on February 27, 1884. The yield of iron was at first only 8 to 10 tons a day, and the quality of the product was not as good as had been expected. By November 1885, after a number of shut-downs during which the bosh was altered several times and other changes made, the capacity was raised to 25 or 30 tons a day and the grade of the product greatly improved. The furnace operated successfully from 1886 to 1888 except for two or three brief shut-downs due to necessity for repairs or to lack of fuel. During this 2-year period 9,000 tons of iron was made, in the production of which 18,903 tons of ore, 4,525 tons of limestone, 1,276 cords of wood, and 1,207,761 bushels of charcoal were used. Little is known of the interval from 1888 to 1896, but production is believed to have been nearly continuous.

The furnace was rebuilt in 1896 and the capacity increased from 7,000 to 10,000 tons of iron a year. The single stack was at that time 55 feet high and 9½ feet in diameter. It ran almost continuously until 1903, when it was again torn down and completely rebuilt. The new stack was 65½ feet high and 12 feet in diameter. Three hot-blast stoves, each 60 by 16 feet, were part of the plant. The furnace was blown in, using charcoal fuel, on April 6, 1904, with a capacity of 23,000 tons a year. The next year charcoal was replaced by coke, and the first coke pig iron was produced in September 1905. The capacity was then 36,000 tons a year. Production continued with but few interruptions until December 1909, when the furnace went out of blast permanently. It was leased and relined by the Texas Iron Association in 1913, but no production was made. The penitentiary has since been replaced by one of the State insane

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asylums, and there is but little evidence of the site of the Old Alcalde. The furnace was removed to Collinwood, Tenn., in 1920, as an adjunct to a charcoal byproduct plant constructed by the United States Government.[11]

A gray-iron foundry and a plant for the manufacture of cast-iron gas and water pipe were operated in conjunction with the furnace for many years. At various times car-wheel, foundry, basic pig, and forge pig iron, and some 8 to 10 percent ferrosilicon were produced. The whole undertaking is said to have cost the State of Texas about $500,000. Opinions differ as to whether or not the operations were economically profitable. The furnace unquestionably answered the primary purpose of providing labor for convicts, and furthermore it showed that iron could be produced in commercial quantity and quality from the east Texas ores.

With the apparent eventual success of the State furnace about 1885 and 1886, considerable speculation in iron-ore lands took place, and furnace companies were organized and began operations in several localities. Only three of these companies erected plants. These were the Tassie Belle and the Star and Crescent furnaces, near Rusk, and the Lone Star, at Jefferson.

The Tassie Belle furnace was built in 1889–90 at New Birmingham, a new town that sprang up 1½ miles southeast of Rusk. It had one stack 60 feet high and 11 feet in diameter and two Weimer pipe stoves. Blown in, with charcoal fuel, during November 1890, it produced from 13,500 to 15,000 tons of car-wheel pig iron a year until some time in 1896, when it was shut down and never reopened. Today the only evidence of the furnace or of New Birmingham is the presence of a little slag and charcoal and a few bricks, all nearly hidden by second-growth pine.

The Star and Crescent furnace, which was about a mile southeast of Rusk, was built in 1890–91, and blown in with charcoal fuel on November 26, 1891. The stack was 65 feet high and 11 feet in diameter, and there were four iron stoves. Hot-blast foundry pig iron was the chief product, though some car-wheel iron is said to have been made. The annual capacity was between 18,000 and 25,000 tons of iron. Available records indicate that the furnace operated less than a year and that it was idle until 1907, when it was relined and remodeled to allow the use of coke fuel. The first coke pig iron was made in the spring of 1907, but the furnace went out of blast before the end of the year and never resumed operations.

The Lone Star furnace, at Jefferson, known also as the Jefferson furnace, was built in 1889–91 and blown in, using charcoal, on March 15, 1891. It had one stack, 60 feet high and 12 feet in diameter, and two Durham iron stoves. The product was hot-blast foundry pig

[11] Burchard, E. F., personal communication.

iron, and the capacity about 13,500 tons a year. Erection of a rolling mill was begun in 1891. This was partly completed and all necessary machinery was on the ground when work was suspended in 1893. The whole plant remained idle until 1898, when the furnace was again blown in, and apparently operated successfully until 1904, when another shut-down occurred. According to reports of the American Iron and Steel Association, plans were made to remodel the furnace and change from charcoal to coke in 1908, but little is known of its subsequent history. A comparatively large production of brown ore from mines at Lassater and Atlanta was reported to the United States Geological Survey during the years 1907–10. (See table, p. 14.) This ore was said to have been shipped to the Lone Star furnace. Exact figures are not available, but it is also known that pig iron was produced in Texas as late as 1911 (table, p. 14), presumably by the Lone Star furnace.

All these furnaces were abandoned long ago, and with the exception of the Lone Star, where some of the machinery still remains, there is nothing to mark the sites but a few remnants of the old foundations and the slag dumps.

Since about the year 1900 there have been several strong revivals of interest in the district. Intensive prospecting campaigns have been carried on, and some ore-bearing tracts have changed hands several times. Intense rivalry developed temporarily between some of the companies in regard to the acquisition of particularly desirable properties. Experimental washing and concentrating plants were erected, and test shipments of ore were made. Plans for the erection of blast furnaces and steel plants have been drawn up repeatedly. The Port Bolivar & Iron Ore Railway, designed to tap the ores in part of the northern area, was constructed from Longview to Ero, a point in northwestern Marion County, and loading facilities were built on Galveston Bay. Estimates of ore reserves have been almost as numerous as the engineers who have examined the deposits and in general as optimistic as the stock market in early 1929.

Some very promising deposits of ore have apparently been overlooked or ignored in the acquirement of ore lands, but by far the greater part of the reserves are now in the hands of a few large companies. Some of these plan to produce eventually iron ore or iron and steel themselves, but others are holding the properties as investments. One result of the activity in the district has been the accumulation of quantities of data on the character and extent of the ore deposits. Many of these data were made available to the Survey through the courtesy of several of the more interested companies and have been of the greatest possible value in the preparation of this report.

PRODUCTION OF IRON ORE AND PIG IRON

Records of the production of iron ore and pig iron in eastern Texas are necessarily incomplete. The total production during the Civil War period and even the daily capacity of most of the small furnaces and bloomeries are not known. It seems probable, however, that not more than 10,000 short tons of iron was produced during the period 1855–65. On the assumption that the ore contained 50 percent of metallic iron, this corresponds to about 17,860 long tons of iron ore.

Iron ore and pig iron produced in eastern Texas, 1855–1935

Year	Pig iron (short tons)	Iron ore (long tons)	Production periods of local furnaces. (× = in blast)					Remarks
			Kelly (Jefferson)	State (Rusk)	Tassie-Belle (Rusk)	Star and Crescent (Rusk)	Lone Star (Jefferson)	
1855–65	[1] 10,000	[2] 17,860						Production from a number of small furnaces and bloomeries.
1870	[1] 300	[2] 534	×					
1871	[1] 300	[2] 534	×					
1872	[3] 619	[2] 1,104	×					
1873	280	[2] 500	×					
1874	1,012	[2] 1,804	×					
1875	None		(?)					
1876	426	[2] 760	×					
1877	525	[2] 936	×					
1878	None		(?)					
1879	400	[2] 712	×					
1880	2,500	[2] 4,456	×					
1881	3,000	[2] 5,350	×					
1882	1,321	[2] 2,360	×					
1883	2,381	[2] 4,244	×					
1884	5,140	[4] 10,200	×	×				
1885	1,843	[4] 3,650	×	×				
1886	3,250	[4] 7,220	×	×				
1887	4,383	[5] 9,320		×				
1888	6,587	[5] 14,000		×				
1889	4,544	[6] 13,000		×				
1890	10,865	22,000		×	×			
1891	20,902	51,000		×	×	×	×	
1892	9,647	22,903		×	×	×	×	
1893	7,008	25,620		×	×		×	
1894	5,232	15,361		×	×			
1895	5,244	8,371		×	×			
1896	1,368	4,777		×				
1897	6,916	13,588		×				
1898	5,799	9,705		×			×	
1899	6,499	14,729		×			×	
1900	11,368	16,881		×			×	
1901	2,546	None		(?)				
1902	3,466	6,516		×			×	
1903	13,051	34,050		×			×	
1904	6,194	None		(?)				
1905	[7] 11,453	24,347		×				
1906	17,245	36,600		×				

[1] Estimated by E. B. Eckel.
[2] Estimated from production figure for pig iron, assuming ore to contain 50 percent of iron.
[3] Production figures for pig iron, 1872–1904, from annual statistical reports of American Iron and Steel Association. Production figures for 1905–11 grouped with those for other States.
[4] Estimated from production figure for pig iron, assuming ore to contain 45 percent of iron (both North and South Basin ores).
[5] Estimated from production figure for pig iron, assuming ore to contain 42 percent of iron (all South Basin ores).
[6] Production figures for iron ore, 1889–1935, supplied by H. W. Davis, Bureau of Mines.
[7] Production figures for pig iron, 1905–10, estimated from figures for iron ore, assuming ore to contain 42 percent of iron.

Iron ore and pig iron produced in eastern Texas, 1855–1935—Continued

Year	Pig iron (short tons)	Iron ore (long tons)	Production periods of local furnaces. (X=in blast)					Remarks
			Kelly (Jefferson)	State (Rusk)	Tassie-Belle (Rusk)	Star and Crescent (Rusk)	Lone Star (Jefferson)	
1907	55,715	118,442	-----	X	X	-----	X?	Production of ore from mines at Lassater and Atlanta, reported as shipped to Lone Star furnace.
1908	26,326	55,966	-----	X	-----	-----	X?	
1909	3,045	6,474	-----	X	-----	-----	X?	
1910	13,893	29,535	-----	-----	-----	-----	X?	
1911	-----	None	-----	-----	-----	-----	X?	
1912	None	3,000	-----	-----	-----	-----	-----	In part from Harris district, Cass County.
1913	None	7,232	-----	-----	-----	-----	-----	5,232 tons from Gilbert district, Marion County; 2,000 tons from Harris district, Cass County.
1914–17	None	None	-----	-----	-----	-----	-----	Source and disposal of ore unknown; probably all test shipments.
1918	None	100	-----	-----	-----	-----	-----	
1919	None	12,300	-----	-----	-----	-----	-----	
1920	None	None	-----	-----	-----	-----	-----	
1921	None	131	-----	-----	-----	-----	-----	
1922–35	None	None	-----	-----	-----	-----	-----	
Total	282,693	638,222	-----	-----	-----	-----	-----	

The figures in the preceding table for pig-iron production for the years 1872 to 1904 have been compiled from the annual reports of the American Iron and Steel Association. Figures from 1889 to the present were supplied by Mr. H. W. Davis, of the Bureau of Mines.

Comparison of the figures for iron ore and pig iron for the years 1889 to 1904 is of interest. During this 16-year period 258,501 long tons of ore and 107,722 long tons of pig iron are reported to have been produced. If all of the ore was used in local furnaces, an average metallic-iron content of about 42 percent is indicated. This is somewhat lower than the average grade of the ore indicated by analyses (pp. 61, 64).

As shown in the table above, the total production of iron ore from 1855 to 1935 has been 638,222 long tons. Even if the production during the Civil War period was considerably greater than has been estimated, and if the average ore contained as little as 35 percent of iron, eastern Texas can hardly have produced more than 700,000 long tons of ore. This is but a fraction of the apparent reserves. (See table on p. 67.)

GEOGRAPHY

Topography and physiography.—The index map, plate 1, shows the area that is covered by this report. The Gulf Coastal Plain of eastern Texas, of which all of this area is a part, consists of a dissected plain that slopes gently toward the south and southeast. The dissection is general but varies from place to place in depth and completeness.

The relief ranges from nearly level to hilly, and steep-sided, flat-topped ridges and isolated hills, which are locally called mountains, characterize the topography in a large part of the area. These hills are largely due to differential erosion of the geologic formations. In the iron-ore districts the presence of beds of oxidized greensand, brown iron ore, and ferruginous conglomerate, which are resistant to weathering, has produced the characteristic topography. The beds of the major streams range from about 200 to 250 feet above sea level, and the highest hills attain altitudes of about 700 feet. The maximum relief is thus about 500 feet.

The main streams in the region are Cypress Creek and the Sulphur, Sabine, Angelina, Neches, and Trinity Rivers, all of which flow toward the east or southeast, in the direction of the Gulf of Mexico. A feature of the drainage pattern is the greater development of the southeastward-flowing tributaries, those flowing to the northeast being relatively few and small. This inequality of drainage development is due in part to the general Gulfward slope of the original plain surface and to the efforts of the streams to adjust themselves to the regional structure of the underlying formations. The bottom lands of the major streams, as well as those of the larger tributaries, are nearly level. Abandoned stream channels remain as partly filled bayous, shallow depressions, and small lakes in the wider valleys. During floods the flood plains of most of the larger streams are covered with backwater over large areas.

Vegetation.—The greater part of the region lies within the eastern Texas timber belt. On bottom lands or alluvial plains hardwood forests flourish and are made up of various oaks, pecan, hickory, ash, cottonwood, sycamore, elm, and other trees. On the uplands and divides pine forests predominate, consisting of short-leaf, loblolly, and long-leaf pines, interspersed in places with upland oaks and other hardwood trees. Much timber has been removed over a long period of years, and today nearly all the timber that is cut is second- or even third-growth material.

Industry and transportation.—Farming, lumbering, and the production of petroleum and natural gas are the chief industries of the region. Cotton is the chief crop, but grain, sugar cane, vegetables, melons, and fruit are also produced. The famous eastern Texas oil field is the largest producer of petroleum. Since its discovery the whole complexion of the oil industry and of the economic life of eastern Texas has been changed. A number of smaller oil fields are scattered throughout the southern part of the area. Natural gas is produced in Marion and Cass Counties from the western part of the Caddo Lake field. Among other mineral industries of some importance are the production of lignitic coal, pottery and brick clays, and ferruginous gravel for highway and railroad construction. Salt is produced from brine wells on the Palestine salt dome, in west-central Anderson County.

Eastern Texas is traversed by several railroads, which are shown on plate 1, and the main towns are connected by an excellent system of paved or graded highways. Secondary roads are numerous but are frequently difficult to travel on account of floods and muddy conditions in winter and spring or of deep, loose sands during the dry summers.

Climate.—The climate of the region is characterized by relatively mild winters and long, warm summers, with gradual transitions from one season to the other.

During the winter pleasant, sunshiny days, with crisp, cool nights, alternate with periods of cloudy weather or slow, gentle rains of 2 or 3 days' duration. Sudden cold waves, locally known as "northers," occur between November 1 and April 1, varying in duration from a few hours to 2 or 3 days. They are marked by an abrupt fall in temperature to freezing or below, by a brisk north or northwest wind, and occasionally by a fall of sleet or snow, but more often by clear, cold weather.

The spring is pleasant, though this season is usually the period of heaviest precipitation. The rains of the early spring are generally warm and gentle, but in the late spring thunderstorms characterized by short downpours occur with great frequency.

During the summer the long periods of hot weather combine with high humidity to lower the efficiency of field or other work. A southerly breeze from the Gulf of Mexico tempers the excessive heat during the greater part of the nights, but hot, dry northerly winds sometimes occur. The precipitation during this part of the year is mainly of a torrential nature, and cyclones, or "clouds", as they are locally known, sometimes do considerable damage.

The fall is marked by warm, pleasant weather. With the approach of winter the heavy local rains characteristic of the summer become less frequent, and the slow, general rains of the winter season begin, making many secondary roads almost impassable.

The annual precipitation ranges in different parts of the region from less than 20 to more than 60 inches, with an average over a number of years of about 40 inches. The mean annual temperature is about 65° F., but the average temperature during 3 months or more of summer is usually 80° F. or higher. Extremes of more than 110° are not uncommon in June, July, and August. Once or twice in every winter the mercury may drop to several degrees below zero for short periods.

GENERAL GEOLOGY

STRATIGRAPHY

GENERAL FEATURES

With the exception of a few small areas, where older rocks have been brought to the surface in the vicinity of the interior salt domes, all the formations in eastern and northeastern Texas are of early Tertiary (Eocene) age. Unconsolidated sand and clay predominate, but greensand, lignitic coal, and ferruginous sandstone are all present in considerable amounts. The land surface was depressed and elevated several times throughout the Tertiary period, and marine deposits alternate with those formed under land conditions. Not only does one type of sedimentary rock overlie the other, but some of the stratigraphic units also exhibit complete lateral gradations from land to marine facies. The major transgressions and regressions of the sea divide Tertiary time into natural divisions that form a basis for the classification of the strata. The complicated gradations of the sediments, the similarity of many of the formations, and the lack of good exposures have made stratigraphic studies difficult and correlation of beds in places uncertain. Knowledge of the stratigraphy has steadily advanced, however, particularly since the discovery of oil in eastern Texas, when there arose among petroleum geologists a real necessity for subdivision and classification of mappable units in order to work out the surface and subsurface structural conditions successfully. The Eocene stratigraphy of eastern Texas, as it is now known, is fully discussed by Sellards and others,[12] and most of the material that follows has been condensed from their report. The work of Wendlandt and Knebel,[13] who subdivided the lower Claiborne into the units now accepted by most geologists, has also been drawn upon freely. The chief contribution to the knowledge of the stratigraphy of eastern Texas made in the present report is the recognition of two facies in the Weches greensand. The following table shows the Eocene formations as they are used in this report.

[12] Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, 1007 pp., 1932 [1933].

[13] Wendlandt, E. A., and Knebel, G. M., Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1347–1375, map, 1929.

Outline of Eocene stratigraphy in northeastern Texas

System	Series	Subdivision			Thickness (feet)	Lithology
Tertiary	Eocene	Jackson formation.			(?)	Medium- and fine-grained, thin-bedded sand, argillaceous and tuffaceous clay and tuff, and lentils of coarse rounded sand grains. Shallow-water, marine, and beach deposits.
Tertiary	Eocene	Claiborne group	Yegua formation.		600–1,000	Cross-bedded sand, sandy clay, and dark to chocolate-brown clay, with lentils of lignite and bentonite. Continental deposits.
Tertiary	Eocene	Claiborne group	Cook Mountain formation.		125–450	Dark clay with some sandy shale, siliceous sand, and greensand; ferruginous and calcareous concretions. Largely of marine origin.
Tertiary	Eocene	Claiborne group	Sparta sand.		230–300	Fine- to medium-grained gray to buff unconsolidated quartz sand, cross-bedded in places, with sandy clay and a little lignite in upper parts. One or more lentils of siliceous greensand. Continental deposits in large part.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Weches greensand member.	2–150	Greensand, with varying proportions of glauconitic oolites, clay, and siliceous sand. Cross-bedded in places. Characterized by abundance of iron ore in weathered parts. Marine deposits.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Queen City sand member.	65–400	Light-gray medium-grained cross-bedded unconsolidated quartz sand and sandy clay, with lentils of lignite, bentonite, and greensand. Abundant pebbles of brown iron ore at one or more horizons. Largely of continental origin.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Reklaw member.	80–180	Glauconitic clay and sand. Low-grade limonitic iron ore in weathered parts. Marine deposits.
Tertiary	Eocene	Claiborne group	Carrizo sand.		10–60	Medium-grained quartz sand with some sandy clay. Continental in large part.
		—Unconformity—				
Tertiary	Eocene	Wilcox formation.			500–1,000+	Sandy clay, sand, and lignite, with some ferruginous and calcareous concretions of continental, littoral, and marine origin.
Tertiary	Eocene	Midway group.			300–900	Silty clay and greensand, with calcareous lentils and concretions. Largely of marine origin.
		—Unconformity—				

EARLIEST EOCENE ROCKS

The Midway group, which rests unconformably on the Upper Cretaceous beds, the Wilcox group, and the Carrizo sand all contain ferruginous concretions in places, but nowhere in large enough quantity to constitute iron ore. These formations crop out along the flanks of the east Texas geosyncline, and within it they appear only in a few small areas where salt domes or other structural uplifts have exposed the lower rocks.

MOUNT SELMAN FORMATION

REKLAW MEMBER

The Reklaw member of the Mount Selman formation is named for the town of Reklaw, in northeastern Cherokee County, where the beds are well exposed. The surface exposure typically exhibits a gently rolling, mature type of topography, characterized by soils of a deep-red or brownish-red color. There are two belts of outcrop. One extends around the flank of the Sabine uplift from the northeast corner of Marion County southwestward to northeastern Cherokee County, thence southeastward toward the Louisiana line. Near the eastern edge of Nacogdoches County the Queen City sand member loses its identity and merges into the Reklaw and Weches members to form the Cane River formation of Louisiana. The other belt of outcrop extends from the Sulphur River on the Arkansas line southwestward to Van Zandt County, where it swings southward, crosses the Trinity River in west-central Anderson County, and continues as far as Atascosa County, where it again turns to the southwest.

The Reklaw is 80 feet thick in eastern Texas but much thicker to the west. It lies conformably upon the Carrizo sand and is overlain conformably by the Queen City sand. The lower contact is marked in places by a thin bed of dark green fossiliferous greensand but more generally by an abrupt downward change from the glauconitic Reklaw sand and clay to laminated yellowish sand typical of the Carrizo. The upper contact is marked by an abrupt change from ferruginous clay to medium-grained quartz sand of the Queen City. In eastern Texas the Reklaw is made up of thin beds of glauconitic black sandy clay, green glauconitic clay, and gray or yellow gypsiferous clay. Marine fossils are widely distributed but are nowhere numerous.

Small concretions, crusts, and thin lenticular beds of limonite occur in the weathered portions and are locally rather abundant. The limonite is high in iron as a rule, but at no place does there seem to be a sufficient concentration of limonitic material to justify classification of the deposits as iron ore. Its rich soils are valuable, but the chief interest of the Reklaw to geologists is as a marker or key horizon, which is of great importance in mapping the geology of a region where distinctive stratigraphic units are rare.

QUEEN CITY SAND MEMBER

The Queen City sand member of the Mount Selman formation was named for Queen City, in Cass County, but it is more typically developed in the central part of the geosynclinal area. The outcrop produces a gently rolling, mature topography of somewhat more relief than that of the Reklaw, and is covered largely by pine and oak forests. The surface exposure occupies a large part of the trough of the eastern Texas geosyncline except where it is overlain by the Weches greensand and the Sparta sand. Southwest of the geosyncline the member changes in facies and loses its identity, finally merging into the sands of the lower part of the Claiborne. It also loses its identity in eastern Nacogdoches County and thins markedly toward the northeast in Cass County. The thickness ranges from less than 100 feet to about 400 feet and in places varies considerably within short distances.

The Queen City sand overlies the Reklaw member conformably and is overlain disconformably, at least in places, by the Weches greensand. The lower contact is taken as the plane where the Reklaw beds of glauconitic clay underlie the sand and sandy clay strata. The contact with the Weches is taken where the cross-bedded siliceous sands change abruptly upward to thick beds of greensand.

The Queen City is believed by Plummer [14] to have been laid down in large part by meandering rivers on a flat coastal plain, but the presence of some glauconitic and bentonitic material throughout the member suggests that it may have been formed in shallow marine waters. Lentils of greensand at least indicate that the sea encroached upon the land several times during the Queen City epoch. The glauconitic material may have possibly been washed in from eroded Midway and Reklaw strata, but this seems unlikely, because the greensand alters very readily on weathering and hence would not be available for transportation and deposition in its original form.

The Queen City is made up predominantly of light-gray cross-bedded medium- to fine-grained quartz sand. The cross bedding is commonly strong and is very irregular. Thin partings of light-colored clay are common and, especially near the top of the section, where the beds are somewhat iron-stained, give a characteristic mottled appearance to the outcrop. Lenticular bodies of clay and sandy clay are widely distributed but generally not more than 1 or 2 feet thick. Several thin beds of brown, impure lignite ordinarily occur between 50 and 125 feet below the top of the member. Thin layers of bentonite are present in many places in the section but are best developed in the zone immediately under and within 100 feet of the base of the Weches. Some glauconitic material occurs throughout the Queen City, and there are one or more greensand lentils of considerable thickness. One of these is the Omen lentil of Wendlandt and Knebel,[15] who say of it:

> Approximately 140 feet above the main glauconite of the Reklaw and varying between 240 and 280 feet below the top of the Weches occurs a local greensand member. This member is well exposed near Omen and Arp, in eastern Smith County, and is here termed Omen, from the community where it was first recognized. This greensand extends from Harrison through Gregg, northwestern

[14] Plummer, F. B., in The geology of Texas, vol. 1, p. 633.
[15] Wendlandt, E. A., and Knebel, G. M., op. cit., p. 1355.

Rusk, and eastern Smith Counties into Cherokee County. Its thickness ranges from 10 to 15 feet of partly cross-bedded mealy, sandy glauconite. It weathers rapidly and is difficult to recognize.

Other geologists have observed greensand beds in the Queen City member. Although little study was devoted to the Queen City by the present party, observations of the beds at many places throughout the area gave the distinct impression that most if not all of these greensands are purely local developments and that correlations based on widely separated outcrops are probably impracticable.

At several localities beds of conglomerate, ferruginous in part, were observed. Whether such beds occur at a definite horizon is unknown. One of these beds is well exposed in a highway cut 0.7 mile west of Reese, in Cherokee County. Here is a zone 6 to 8 feet thick in which much iron-ore gravel occurs. Strong cross bedding of the torrential type is a noticeable feature. The gravel consists of subangular water-worn pebbles of limonite, some of which exhibit ghost structures of what were probably originally glauconitic oolites, a few rounded to subangular chert pebbles, and much coarse quartz sand. Most of the pebbles range from a quarter of an inch to about 1 inch in diameter, but a few are larger. In places the gravel is cemented with ferruginous material to form large irregular masses of hard conglomerate. These gravel deposits are significant in that they indicate that either just before or during Queen City time iron ores were being formed from older greensand, much as they are forming today along outcrops of the Weches greensand. Whether the pebbles were derived from oxidized greensand in the Midway or Reklaw units or came from the lower greensand lentils in the Queen City is unknown.

Crusts and concretions of limonite occur sparingly throughout the beds but are most abundant near the top, where their presence is doubtless due to infiltration of iron-bearing solutions from the overlying Weches.

WECHES GREENSAND MEMBER

OCCURRENCE AND CHARACTER

Nearly all the commercial iron ore of eastern Texas is associated with the Weches greensand member of the Mount Selman formation. This member is named for the town of Weches, in northeastern Houston County, near which one of the facies is well developed. The greensand is essentially made up of beds of glauconitic sand and clay and is characterized in its weathered portions by deposits of brown iron ore. The resistant ferruginous beds cap hills and escarpments throughout most of the area of outcrop in eastern Texas and produce a picturesque, rugged topography of steep, flat-topped hills, dissected by deep V-shaped valleys. In central and southern Texas, where little or no iron ore has been deposited, the beds weather to form rolling open prairies characterized by a rich red soil.

The Weches crops out on isolated hills of varying size, or along slopes and ridges that are covered by the Sparta sand throughout the central part of the eastern Texas geosyncline. Southeast of the basin proper, in Nacogdoches and San Augustine Counties, the greensand merges with the Reklaw member to form the Cane River formation of Louisiana. It has also been traced southwestward as far as the Frio River, Frio County. The thickness of the greensand varies considerably from place to place, between limits of almost nothing to as much as 150 feet in the area south of the eastern Texas geosyncline. Some of the variations in thickness are due to local structural conditions; others are of a more regional character. Variations due to both causes are further described below.

The base of the Weches greensand is taken as the contact of the glauconitic sands with the underlying gray siliceous sands and clays of the Queen City. This contact is in many places marked by a pronounced bench and not uncommonly is a spring horizon, but as both springs and benches also occur higher in the section their presence is by no means a sure guide to the contact. The only certain method of distinguishing the contact is in fresh exposures, where there is seldom any doubt, but on poor exposures it can often be located correctly by noting the feel of the soil underfoot. The Weches soil, even where there is little or no iron ore, tends to be firmer and more harsh than the light, spongy, sandy loam that characterizes the Queen City.

The basal contact of the Weches is more or less conformable in eastern and northeastern Texas, but slight unconformities have been noted in several localities. One such unconformity is illustrated in plate 6, *A*, which shows horizontal beds of Queen City sand and clay slightly truncated and overlain by beds of Weches greensand that are somewhat inclined to the horizontal. In most places where the contact is well exposed it is sharply distinct, but in a few localities there is some evidence of interfingering between these members. In several trenches in the Prewitt district southeast of Linden, for instance, the lowest beds of the greensand contain a very high proportion of buff or gray quartz sand and but little glauconitic material. In the description of the ore deposits of the Knight-Field (Lanier) district, in Cass County, a section is given which strongly suggests interfingering of the beds. (See p. 109.) There iron carbonate, derived from greensand, occurs below a bed of clay and sand of typical Queen City aspect.

The upper contact of the Weches is marked by a change from greensand, which is usually weathered and contains abundant limonitic material, to the buff or gray quartz sand of the Sparta. A thin bed of ferruginous sandstone is characteristically developed at the base of the Sparta sand and serves as an excellent and unmistakable marker bed. As both the actual contact and the upper beds of the Weches are in many places obscured by sandy soil that has washed down from the overlying Sparta, the general practice among field geologists in eastern Texas is to map the contact between the Weches and Sparta at the highest point where ferruginous sandstone or iron-ore gravel is found. This procedure must necessarily be altered in the vicinity of ferruginous lentils within the Sparta. The contact appears to be conformable in most places.

No detailed study of the mineralogic character of the greensand has been made by the present author. In particular, the identity of the oolitic iron silicate mineral that characterizes the greensand is in doubt. Throughout this report the word "glauconitic" has been applied to this material, implying that it is related to glauconite, a well-known mineral species that is essentially a hydrous silicate of ferric iron and potash. Baker [16] has recently presented reasons for believing that "most of the iron formation is a mixture of varying proportions of chamosite, thuringite, and perhaps of greenalite, with perhaps some content of glauconite present locally." Chamosite and thuringite are hydrous silicates of ferrous iron and alumina; greenalite is a hydrous silicate of ferrous iron. Most of Baker's discussion is based on a study of chemical analyses, and while these are important and illuminating, it should be remembered that few if any available analyses are based on samples of the iron silicate mineral itself, but rather on samples of the Weches greensand, which contains an abundance of impurities in the form of quartz sand and clay. The table below shows the results of analyses of several samples of the Weches greensand from the North Basin. All samples represented the freshest greensand obtainable, and sample 6 represents material made up almost wholly of oolitic silicate. Schoch [17] records several analyses of greensand from both the North and South Basins. Nearly all available analyses agree in that they show too much silica and alumina and too little potash to fit the generally accepted composition of glauconite. Much of the excess silica and alumina may be due to the presence of sand and clay. Nearly all analyses show a considerable proportion of ferrous carbonate, which indicates that the formation of siderite was already in progress at the time the samples were taken. If potash is extracted early in the weathering process, it would naturally not be present in samples that contain any considerable proportion of ferrous carbonate. Clarence S. Ross, in conversation with the writer, stated that the iron silicate mineral does not have the optical characteristics of glauconite. He further stated, however, that P. F. Kerr, of Columbia University, examined samples

16 Baker, C. L., Oxide, silicate, and carbonate iron ores of northeastern Texas in The Geology of Texas, vol. 2: Texas Univ. Bull. 3401, pp. 427-482, 1935.

17 Schoch, E. P., Chemical analyses of Texas rocks and minerals: Texas Univ. Bull. 1814, p. 170, 1918.

of glauconitic material from the Weches greensand by X-ray methods and found them to give figures nearly identical with those of glauconite. Whatever the true character of the iron silicate mineral may be, its chief interest in connection with this report is that it yields iron on weathering and hence is the source of the iron-ore deposits.

Analyses of representative samples of the facies of Weches greensand from the North Basin

	1	2	3	4	5	6	7
SiO_2	28.67	39.10	27.21	39.39	24.48	13.47	----------
Al_2O_3	16.80	23.69	18.87	16.83	5.59	8.20	----------
Fe_2O_3	8.41	20.06	9.32	8.09	7.74	13.20	6.30
FeO	20.74	.58	18.55	15.38	35.70	37.26	2.70
MgO	1.55	.02	1.49	1.51	----------	Present	----------
CaO	.45	None	.38	----------	----------	----------	----------
Na_2O	.03	.10	.11	.02	.02	None	----------
K_2O	.70	.79	.43	.45	.34	None	----------
H_2O	11.76	14.65	13.12	11.41	5.00	9.42	----------
TiO_2	.30	.41	.42	.27	.40	.04	.66
CO_2	10.03	.02	9.85	5.66	20.12	15.16	None
P_2O_5	.25	.26	.31	.23	.25	.64	----------
MnO	.11	.11	.12	----------	----------	----------	----------
C	Present	Present	Present	----------	----------	----------	----------
	99.80	99.79	100.18	99.24	99.64	97.39	----------

1. Fresh greensand, Surratt tract, 4½ miles north of Linden, east bank of Bowman Creek.
2. Oxidized greensand, same location.
3. Fresh greensand, west bank of Bowman Creek.
4. Outcrop in stream three-fourths mile S. 60° W. of Lanier, Cass County. Greensand.
5. Outcrop in stream three-fourths mile S. 60° W. of Lanier, Cass County. Greensand indurated with carbonate.
6. Well on Daingerfield Hill, 0.6 mile N. 45° W. of Daingerfield, Morris County. Fresh oolitic glauconite(?).
7. Water well 2 miles N. 45° W. of Hughes Springs, Cass County. Greensand with much sand and clay.

Analyses 1, 2, and 3 by J. J. Fahey, Geological Survey; analyses 4, 5, 6, and 7 by J. G. Fairchild, Geological Survey.

Lateral variations in character and composition of the greensand are common, but in general there are two distinct facies of Weches sediments. These facies are typically developed in the two parts of the eastern Texas geosyncline for which the names "North Basin" and "South Basin" have been proposed.[18] A zone that passes through the central parts of Harrison, Upshur, and Wood Counties (pl. 1) appears to mark the division between these basins.

The chief differences between the Weches greensand of the North and South Basins are summarized in the following table. The list of primary features is followed by one noting the secondary features, such as type of ore or behavior on weathering, which are directly related to the original characters.

As shown on plate 1, the boundary between the North and South Basins extends northwestward from the northernmost point of Gregg County in a direction parallel to the course of the Sabine River. There is apparently an intermediate zone in which some gradation takes place, the boundary not being as sharp as the single line on the map indicates. However, the two facies are so distinct that it is nearly

[18] Eckel, E. B., and Purcell, P. E. M., The iron ores of east Texas: Texas Univ. Bull. 3401, p. 486, 1935.

always possible to state with some certainty whether a given outcrop of ore or greensand is of the North Basin or South Basin type. The distinction between the facies has much practical interest, as the physical and mineralogic characters of the original greensands have had profound effects on the quantity and character of the resulting iron ores. Furthermore, the recognition of these facies should be of some use to petroleum geologists, who generally consider the top of the Weches greensand member one of the best marker horizons in eastern Texas. In the monoclinal area south of the eastern Texas geosyncline the Weches greensand is not unlike the facies in the South Basin except that it appears to contain an even higher proportion of clay and a greater abundance of fossils.

Comparison of facies of Weches greensand

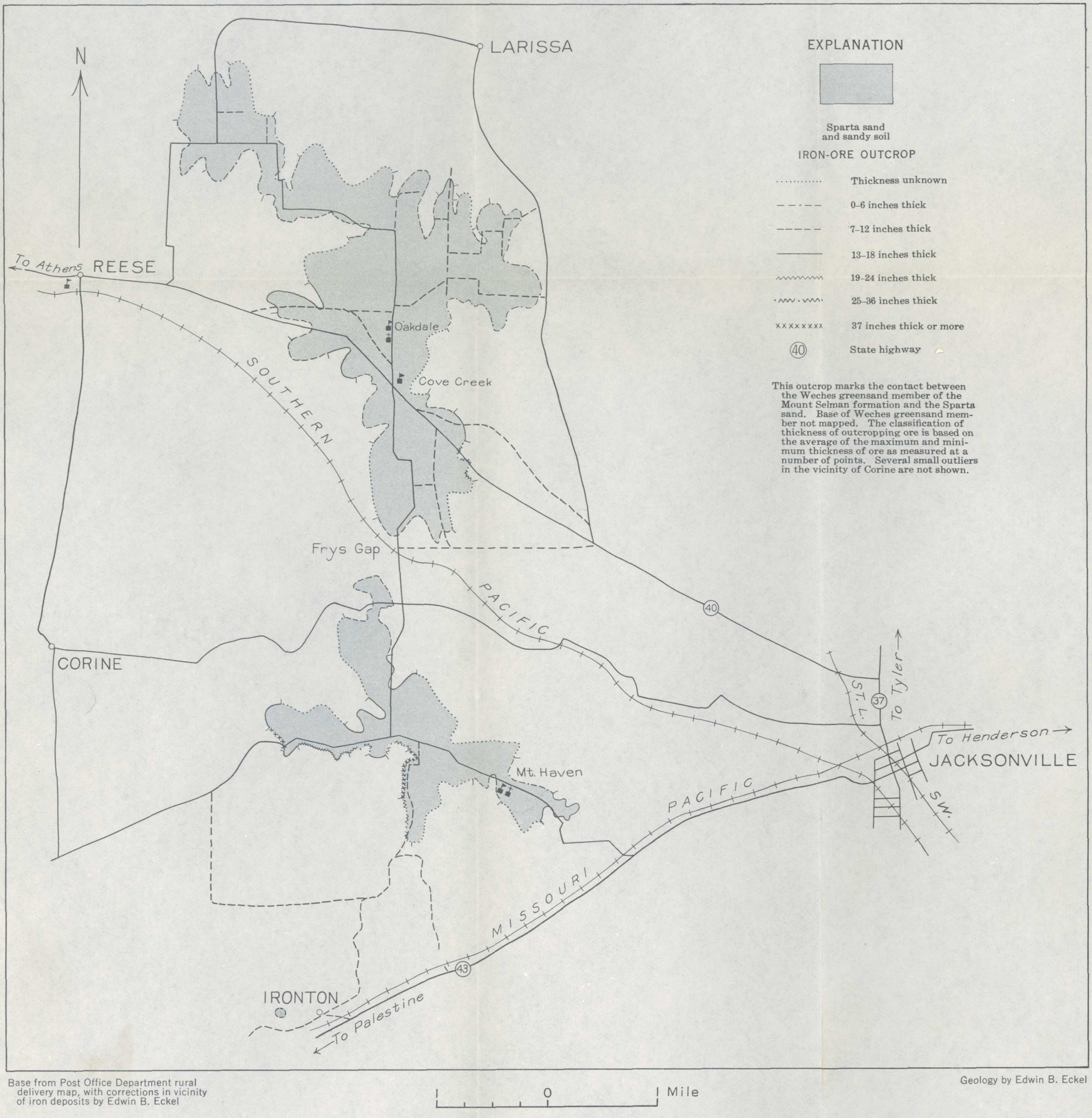
Primary features

North Basin	South Basin
1. No marine fossils visible.	1. Marine fossils abundant.
2. Plants remains widespread.	2. No plant remains visible.
3. Abrupt variations in thickness common.	3. Variations in thickness very gradual.
4. Average thickness 25 feet or less.	4. Average thickness 40 to 50 feet.
5. Typically composed of intermixed oolitic glauconitic sand, quartz sand, and clay.	5. Typically composed of glauconitic clays of uniform composition. Very little quartz sand.
6. Glauconitic grains commonly coarse.	6. Glauconitic grains commonly fine.
7. Strong cross-bedding not uncommon.	7. Cross-bedding lacking.
8. Several areas of nondeposition.	8. No areas of nondeposition.

Secondary features

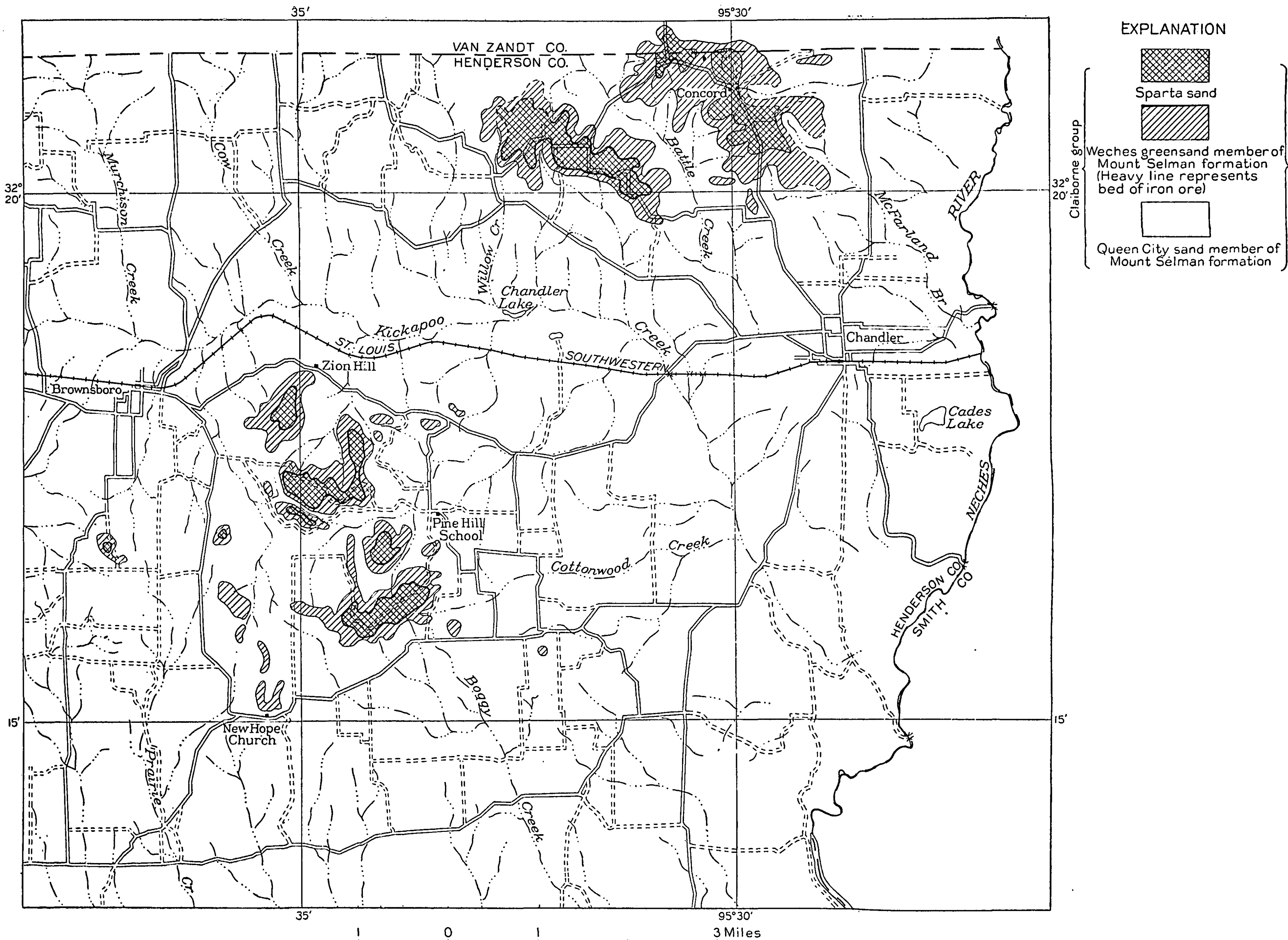
9. Ferruginous sandstone cap seldom cemented to ore.	9. Ferruginous sandstone cap always cemented to ore.
10. Iron ore distributed throughout the section.	10. Iron ore confined almost exclusively to top of member.
11. Ore concretionary and nodular.	11. Ore laminated or massive.
12. Ore discontinuous along outcrop.	12. Ore continuous along outcrop.
13. No white clay beneath ore layers.	13. Ore bed underlain by white clay.
14. Siderite nearly always present in depth.	14. Little siderite present except locally.
15. Soils rough and gravelly.	15. Soils commonly soft except for debris from top ore bed.
16. Weathered surface light brownish red to yellowish brown.	16. Weathered surface greenish brown to dark red.
17. Topography rugged, with steep slopes.	17. Topography less rugged, with more gentle slopes.

The greensand of the facies found in the North Basin is olive green to nearly black in fresh exposures, but near the surface it is commonly altered to a light brownish-red or yellowish-brown color. It is typically composed of intermixed oolitic glauconitic sand, quartz sand, and clay. Flakes and fragments of lignitic material are very widespread but nowhere abundant. Small masses of pyrite are sporadically distributed throughout the unweathered portions. Individual beds are commonly from 6 inches to several feet thick, and except for sparse lenticular bodies of light-colored clay in the weathered portions, there is little difference between the beds. This clay is believed to be in large part of secondary origin. Horizontally bedded members alternate with cross-bedded members in many places. The cross-

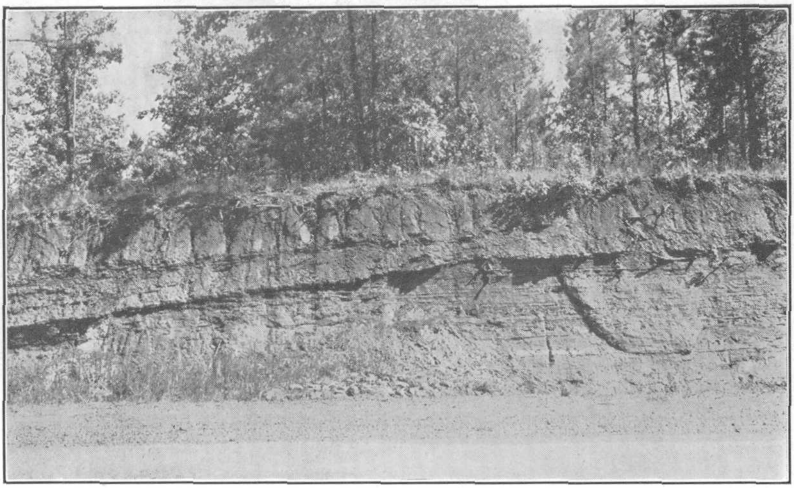


SKETCH MAP OF IRON-ORE OUTCROPS WEST OF JACKSONVILLE, CHEROKEE COUNTY, TEXAS

1938

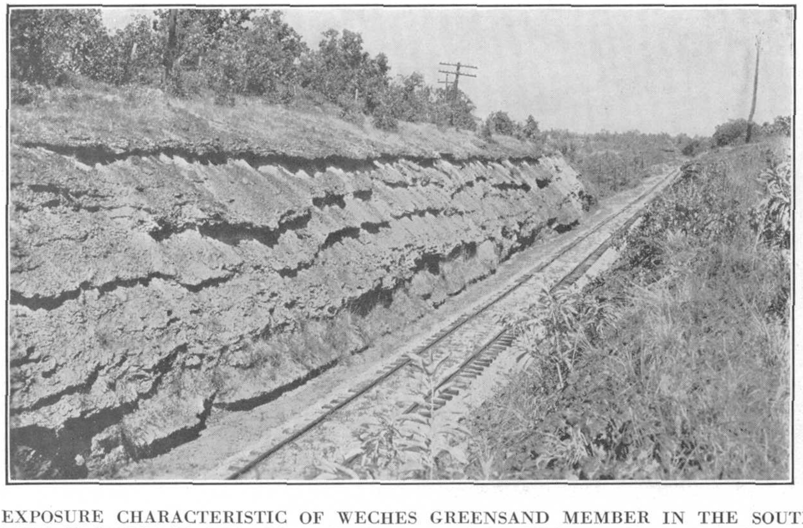


GEOLOGIC MAP OF NORTHEASTERN HENDERSON COUNTY.



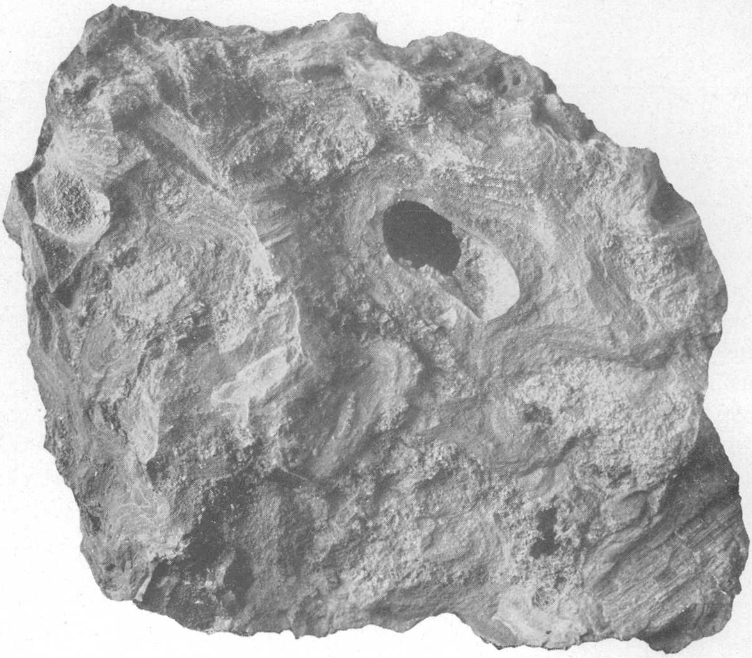
A. UNCONFORMITY AT BASE OF WECHES GREENSAND MEMBER OF THE MOUNT SELMAN FORMATION.

Road cut on highway between Linden and Atlanta half a mile north of Frazier Creek. Horizontal beds of white and light-colored Queen City sand are truncated and overlain by greensand and limonite of the Weches greensand. *Thin ledge of limonite marks the contact.*



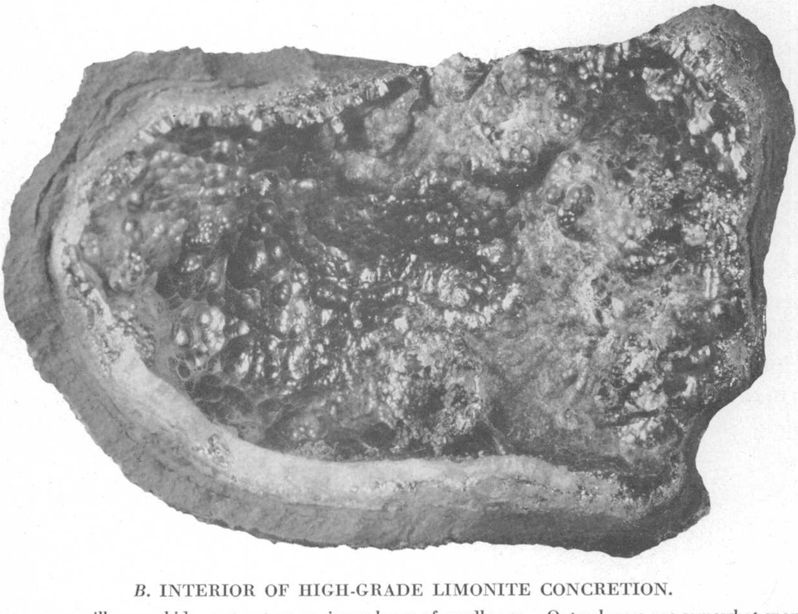
B. EXPOSURE CHARACTERISTIC OF WECHES GREENSAND MEMBER IN THE SOUTH BASIN, IN RAILROAD CUT 4 MILES NORTH OF JACKSONVILLE, CHEROKEE COUNTY.

Uppermost bed of brown ore, which is only 6 inches thick and is underlain by white clay, marks contact of Weches greensand with overlying Sparta sand and surface soil. The two irregular ledges beneath top ore bed are low-grade sandy limonite. All the greensand is thoroughly oxidized except the grass-covered bed near the base, which is comparatively fresh. The thin ledge at the base of the section is impure iron carbonate.



A. LOW-GRADE BROWN ORE CONTAINING MUCH PARTLY REPLACED GLAUCONITIC MATERIAL, TO WHICH THE GRANULAR CHARACTER IS DUE.

Note the concentric structures that form about nuclei. A fragment of limonitized wood appears in lowe right corner. From surface exposure in Waters district, northern Cass County. Natural size.



B. INTERIOR OF HIGH-GRADE LIMONITE CONCRETION.

Shows mammillary or kidney structure on inner layer of needle ore. Outer layers are somewhat spongy, ocherous, and of lower grade. White film on inner surface is mostly opal. Near Lanier, Cass County. Two-thirds natural size.

bedded members range from 4 or 5 inches to 4 feet in thickness; the horizontal members are rarely more than 1 foot thick. As a rule the material in both cross-bedded and horizontal members is identical, but locally there appears to be more clay in the horizontal beds. All the false-bedding planes of the cross-bedded members are inclined in the same general direction in any one locality, but observations are too scattered to indicate regional trends. The type of bedding is that which might be expected to form under marine conditions with the influence of currents.

The proportion of glauconitic material in the greensand varies between wide limits, in general directly with the thickness of the Weches. Thus, in the vicinity of Daingerfield, where the member is abnormally thick, the greensand is composed almost exclusively of glauconitic material, with little or no quartz sand or clay. Where it is thin the Weches commonly contains much quartz sand and comparatively little glauconitic or clayey material. The thickness varies widely and is dependent in large part on the structure that existed during the deposition of the sediments. The average thickness in the North Basin is somewhat less than 25 feet, and in but one locality is the greensand more than 35 or 40 feet thick. This is on Daingerfield Hill and on the ridges southwest of Daingerfield, where the greensand ranges from 50 to 112 feet in thickness (pl. 2). The most logical explanation of the great thickness and uniformity of the greensand there seems to be that it was laid down in a deep, narrow trough, which probably subsided as deposition progressed. The trough extended at least 6 miles in a north-south direction but was probably not much more than 2 miles wide, as is shown by the thinness and more sandy character of the deposits 2 to 3 miles east and southeast of Daingerfield.

On structurally high areas the greensand is thinner than elsewhere and contains more quartz sand. Likewise, along some faults the Weches is thicker on the downthrown side, indicating that some of the movement along the faults took place during the deposition of the greensand. The opposite condition, where the Weches is thicker on the upthrown side of the fault, exists on the Orrs Switch fault, in Marion County (pl. 2), and perhaps elsewhere. The true explanation of this condition is unknown, but it seems probable that the variations in thickness are not directly related to the faulting but are merely coincidental. In other words, the Weches may have been laid down in a deep, narrow trough, similar to that at Daingerfield and of erosional or structural origin. Later faulting along the trend of the trough might easily leave a thick section of greensand along the upthrown side.

A large area from 2 to 5 miles southwest of Linden, Cass County, is shown on plate 2 as Sparta sand and Queen City sand member undivided. There is definite evidence that the Weches was never deposited here. The greensand thins rapidly on approach to this area and finally disappears. Separation of the two sands was not possible in the time allotted for the work. The presence of other areas of non-deposition of the Weches is suspected on the hills 2 miles east and 3 miles west of Linden, but the evidence is not sufficient to justify mapping them as such.

Most of the variations in thickness and composition are local, and many of them are described in the section on individual ore deposits in the final part of this report. The chief regional variation within the North Basin is a thinning along the northwest flank of the Sabine uplift. This is particularly well shown in northeastern Cass County, in the area east of the Texas & Pacific Railway (pl. 2). Here the Weches is somewhat less than 20 feet thick and, on account of a general lack of iron ore, shows considerably less relief than that west of the railway. The eastern type is made up of thin-bedded sand and clay which contain small amounts of oolitic glauconitic material. Cross bedding is of the same type as that of the facies characteristically developed in the North Basin. The member is light-colored and is similar in many respects to the underlying Queen City sand. The difference in cross bedding and the presence of ferruginous sandstone and a little limonite gravel in the Weches are the chief criteria that were used in mapping the two formations in this area.

The facies of the Weches developed in the South Basin (pl. 6, *B*) is bluish green to olive green in fresh exposures, but the weathered parts are greenish brown to red. The greensand is typically composed of beds, 6 inches to 2 feet thick, of intermixed oolitic glauconitic sand and greenish glauconitic clay, with very little quartz sand and no lignitic material. The glauconitic sand and clay are characteristically more or less segregated into small irregular masses, which give a mottled appearance to the unaltered beds, but neither constituent is anywhere entirely free of the other. The oolites are small and even sized and usually possess a concentric structure. Fossils are abundant in places. Most of the shells are small and exceedingly delicate and are filled with glauconitic material. The calcareous shells weather rapidly, and near the outcrop the fossils have been destroyed or are represented only by molds. Cross bedding has not been observed. Beds or lenticular bodies of white clay occur beneath beds of iron ore in the weathered portions, but are believed to be of residual origin and to be closely related to the iron ores. Pyrite is sporadically distributed throughout the fresh greensand but nowhere in large amounts. The thickness of the Weches is fairly uniform over large areas and ranges in general from 40 to 60 feet, about twice the average thickness of the facies of the North Basin. Some thinning occurs on most of the structurally high areas. The greensand is remarkably uniform in character and composition over an enormous area, but in a few places, notably in northeastern Henderson County and southeastern Van Zandt County, it becomes coarser, contains a rather high proportion of quartz sand, and approaches the facies of the North Basin in appearance.

CONDITIONS OF SEDIMENTATION

The Weches greensand member was laid down in a long, narrow trough, which corresponded closely to the present eastern Texas geosyncline and probably never extended much farther than the present outcrop indicates. The fact that the greensand thins rapidly and becomes much more sandy near the Sabine uplift, in eastern Cass and Marion Counties, indicates an approach to shore-line conditions there. Evidence as to the position of the western shore line is more obscure, but the coarser and more siliceous character of the greensand along the western flank of the geosyncline in Henderson, Van Zandt, and Smith Counties indicates that the shore line was probably not very far west of the present western limit of the Weches greensand. In the North Basin shallower waters and more oscillatory conditions must have prevailed than in a large part of the South Basin. This would account for all the differences in primary features of the two facies. The depth of the water is unknown. In the South Basin and in the monoclinal area south of it the thick beds of greensand, rich in fragile gastropod shells, indicate offshore conditions where animal life was very abundant and where little detrital sediment was available. In the North Basin the rapid variations in character of the beds, the presence of detrital quartz sand and lignitic material, the cross bedding, and the lack of marine fossils all indicate that the greensand was laid down in shallow waters, probably not far below the zone of wave action.

ECONOMIC RESOURCES

The chief economic resource of the Weches greensand member is its iron ore. Though no iron ore is produced as such at the present time, thousands of cubic yards of low-grade ferruginous material is used annually in highway construction, for railroad ballast, and for riprap on fills and bridge piers.

Oil occurs in the Weches in the shallow Chireno field, southeast of Nacogdoches, in eastern Nacogdoches County, where it has been produced on a small scale since 1877.[19] The greensand is well over 100 feet thick and is commonly indurated to a hard rock with comparatively low porosity. The oil comes from the lower part of the section, at depths of 70 to 400 feet, depending on topography and dip of the beds. In the early days of the field 6- and 8-inch holes were drilled to the producing horizon. A few wells flowed for a day or two when

[19] Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, vol. 1, p. 650.

first opened, but nearly all had to be pumped or bailed, as the oil was viscous and seeped slowly into the holes. But few of the wells produced more than half a barrel of oil a day.

Throughout eastern Texas there are persistent rumors of the occurrence of gold deposits in the Weches greensand. On theoretical grounds there seems to be no reason for expecting gold to occur in more than minute quantity in a formation that was in large part laid down by chemical precipitation under marine conditions. No evidence of the presence of gold was seen anywhere in the area, and the conclusion is reached that the pyrite, or "fools' gold," that is sporadically distributed through the greensand has been mistaken for gold. Several samples of the greensand, both weathered and fresh, were taken from a supposed gold deposit several miles southwest of Lanier, in Cass County, and assayed in the chemical laboratory of the United States Geological Survey. Not a trace of either gold or silver was found. The same was true of a sample of pyritiferous greensand taken from a "gold mine" that was recently opened in the vicinity of Appleby, about 10 miles northeast of Nacogdoches. This "mine" apparently never produced anything but pyrite and greensand.

In places the weathered portions of the greensand are indurated to form a firm rock which finds some local use as a building stone, particularly in chimney construction. The rock is comparatively strong but soft enough to be easily worked, and it has a rather pleasing yellow-brown color.

Whether the greensand is of value as a fertilizer material is open to question. The potash and phosphorus content are very low according to most analyses. Nevertheless, the soils produced by the Weches, particularly in those areas where no iron ore is present, are notably more fertile than the soils from such units as the Queen City member and the Sparta sand. The greensand is so widespread and abundant that experiments with its use in land enrichment would seem to be in order.

SPARTA SAND

The Sparta sand occurs on the high ridges above the Weches greensand and caps most of the ferruginous hills along stream divides in the eastern Texas geosynclinal area. The outcrop continues southward and southwestward for many miles. The total thickness of the Sparta ranges from 230 to 300 feet, but within the geosyncline much of the sand has been eroded, and the remaining beds range from a few inches to a maximum of about 100 feet.

The Sparta sand apparently lies conformably upon the Weches greensand. In a few places a basal conglomerate occurs, which contains rounded subangular pebbles of chert, quartzite, and silicified wood. The individual pebbles are commonly less than 1 inch in diameter.

The base is placed at the contact of gray quartz sand with the weathered Weches greensand. A thin bed of ferruginous sandstone, composed of grains of quartz, cemented with iron hydroxide, is almost universally present at the contact and is an easily recognized and almost unmistakable key bed. The sandstone, which is usually only an inch or two and rarely more than 6 inches thick, is believed to have been formed by the cementation of sand grains by iron-bearing solutions, which rose by the force of capillarity from the underlying ferruginous greensand beds. Little or no sandstone has been developed at the contact where the Sparta is thick and the Weches has not been weathered to form iron ore.

The Sparta consists largely of thinly laminated fine- to medium-grained gray or buff quartz sand with some sandy clay. The clay is more abundant in the upper part of the section. Cross bedding is locally prominent but is not as characteristic of this formation as it is of the Queen City sand. In most places the sand is unconsolidated and erodes easily to rounded, uneven slopes. Small irregular masses of pyrite were noted near the base at one or two places, and, as is pointed out in the discussion of the origin of the ores, pyrite is probably widely but sparingly distributed throughout the sand. In the southern part of Smith County and in the vicinity of Tyler a bed of siliceous greensand occurs about 120 feet above the base of the Sparta and can be traced for some distance. Most geologists consider it to be a lentil in the Sparta, but some think it belongs to the Cook Mountain formation. It has been named "Tyler greensand" by Wendlandt and Knebel [20] but is also known locally as "Noonday greensand." In places its outcrop is marked by a heavy bed of ferruginous sandstone as much as 2 feet thick, but the greensand contains so much quartz sand that any limonitic material derived from it would not be of ore grade.

It is difficult to differentiate between the Sparta sand and the Queen City sand member except by noting their relations to the Weches. Where the Weches is missing differentiation of the sands is almost impossible. The Sparta is typically somewhat grayer, contains less clay, and exhibits less of the mottled appearance and cross-bedded structure that characterizes most of the Queen City exposures. In addition it is commonly less compact and so forms flatter slopes than the Queen City.

The chief resources found in the Sparta sand are water near its outcrop and oil in deep wells located on or near salt domes, as on the Clay Creek dome in Washington County, several miles southwest of the eastern Texas geosyncline. On the hills in eastern Texas the contact

[20] Wendlandt, E. A., and Knebel, G. M., op. cit., p. 1359.

between the Sparta and Weches is a very important water horizon, and as a rule only the wells that are dug too close to the outcrop, where most of the Sparta sand has been eroded, fail to obtain an abundant supply of good water (fig. 1).

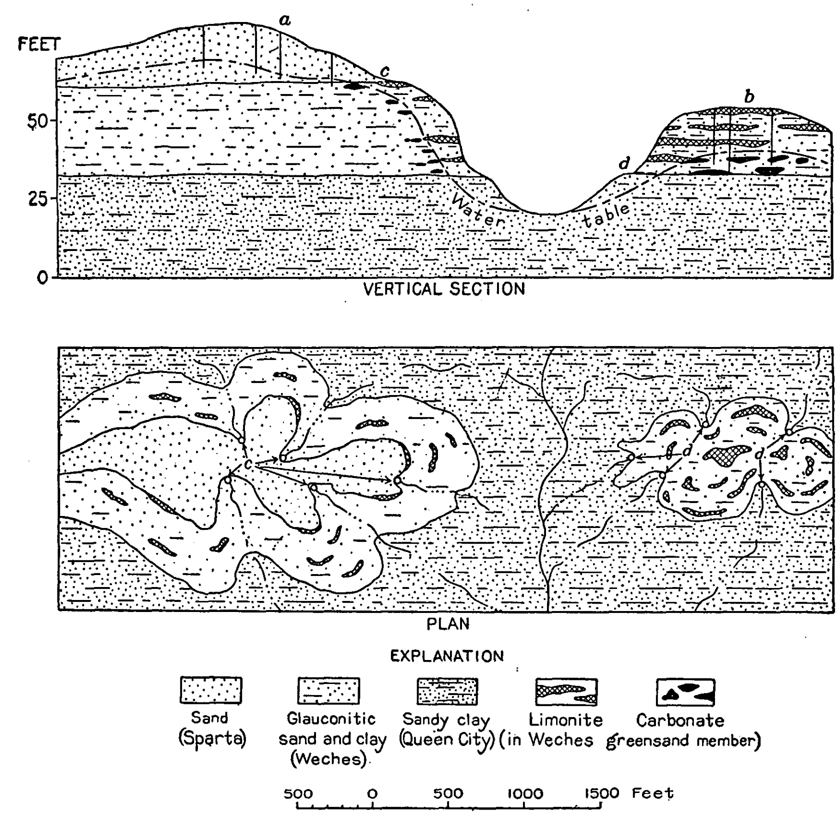


FIGURE 1.—Ideal plan and vertical section showing relation of iron-ore deposits of eastern Texas to the local water table. At *a* a thick overburden of Sparta sand and a relatively large amount of clay in Weches greensand combine to cause a high water table near the top of the Weches and to prevent the formation of ore except at outcrop. At *b* the lack of overburden and the sandy, permeable facies of the Weches member combine to cause a low water table at the base of the Weches and to allow the formation of rich ore throughout the hill. At *c* and *d* the relative impermeability of the beds causes springs to emerge from perched water tables during seasons of heavy precipitation. Heavy vertical lines denote water wells. Vertical scale exaggerated.

COOK MOUNTAIN FORMATION

As the Cook Mountain formation and other deposits younger than the Sparta sand do not appear in the eastern Texas geosynclinal area and commonly contain little or no iron ore, they do not need further description here.

STRUCTURAL GEOLOGY

GENERAL RELATIONS

Plummer's general statement of the relations that exist between regional structure and the distribution of Cenozoic sediments is applicable to the Weches greensand member of the Mount Selman formation. He says: [21]

Regional structure has had two marked effects on the extent and character of the Cenozoic formations. First, the uplifts and basins determined the facies of the sediments and lithology of the formations. The waters were deepest and the sea remained longest in the synclinal areas. Most formations in the middle of the troughs are made up of fine-grained muds and silts. Traced laterally toward an uplift, the same strata change to coarser sediments of littoral origin and merge with continental sediments having so different an aspect that geologists have assigned in some cases two names to the same formation. Second, the shape of the trough in which the sediments were deposited and the shape of the local abnormal structure in the basins controlled the shape of the shore line and extent of the deposits. The outcrops of nearly all the formations broaden and extend landward in the basin areas, narrow and bend Gulfward around the arches and uplifts, are repeated or widened by the faults having upthrow sides on the southeast, and are displaced, punctured, and broken by the salt plugs.

There is little direct relationship between the structure and the deposits of iron ore, but the quantity, quality, and character of the iron ores depend largely on the character of the original Weches sediments. As these sedimentary characteristics are in large part related to the structural conditions that existed during Weches time, it may be said that there is an indirect relation between the iron ores and the regional structure.

The structural features that are of most importance from the present viewpoint are the Sabine uplift, the eastern Texas geosyncline, and the monoclinal area south of the geosyncline. The upward movement of the Sabine uplift, which probably began during Wilcox time, was in progress during the deposition of the Claiborne sediments and was undoubtedly the most important factor in molding the eastern Texas geosyncline, a downwarped troughlike basin that lies on the northern and western borders of the Sabine uplift. The trough is 30 to 50 miles in width, and its influence extends downward at least through the Upper Cretaceous rocks. In central Anderson County and southern Cherokee and Nacogdoches Counties the geosyncline is shallower than it is farther north and it broadens into a Gulfward-dipping monocline that continues far out into the present Gulf of Mexico.

Within the geosyncline the formations have been warped into numerous gentle folds, cut in places by faults of varying degrees of magnitude. The more regional surface structures extend downward through the Upper Cretaceous rocks, but the minor folds are often not true reflections of subsurface structures.

AGE OF FAULTING AND FOLDING

The geologic age of the folding and faulting in eastern Texas cannot be stated definitely, but most of the structural features were certainly

[21] Plummer, F. B., Cenozoic systems in Texas, The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, pp. 525–526, 1932. See also, The geology of Texas, vol. 2, Structural and economic geology: Texas Univ. Bull. 3401, pp. 32–72, 1935.

in process of formation throughout most of the Eocene epoch. In general, the Eocene sediments are much thicker in the trough of the geosyncline than along its flanks, indicating progressive downwarping during their deposition. Nearly all the Eocene formations are thinner and sandier on structural highs than in intervening synclinal areas, indicating that the structural highs were also topographic highs at the time of deposition. This thinning is particularly noticeable in the Weches greensand, but applies to other divisions as well. Thus the Reklaw is very thin in the vicinity of the LaRue anticline, in Henderson County, and about the east edge of the Van anticline in Van Zandt County. The Wilcox formation is several hundred feet thinner on the Cayuga anticline, in Anderson County, than it is elsewhere in the region. Along several faults the Weches greensand is much thicker on the downthrown side, indicating considerable movement along the faults while the greensands were being deposited.

NORTH BASIN AND SOUTH BASIN

Though the eastern Texas geosyncline is commonly regarded as a unit, it is roughly divisible into two synclinal troughs or basins. Through Cass, Marion, Morris, and northern Upshur Counties the trend of the geosyncline is southwestward, but this trend shifts abruptly at the zone that separates the two facies of the Weches greensand developed in the North and South Basins. The dividing zone extends from the north end of the East Texas oil field, in the extreme northern part of Gregg County, northwestward through the Kelsey anticline, 6 miles west of Gilmer, in Upshur County (pl. 1).

Studies of surface structure and drill records show that the structural axis of the Cretaceous rocks in the South Basin is parallel to and almost exactly under the synclinal axis of the Eocene beds. In the North Basin, however, the axis of the Eocene syncline is some miles southeast of that shown by the Cretaceous formations. In both Eocene and Cretaceous series a marked difference in lithologic characteristics in the two basins is apparent, but the structural difference is much greater in the Eocene formations.

Drill holes north of the East Texas field have penetrated the Woodbine sand at considerably greater depths than it occurs in the producing area and have demonstrated a marked northerly dip in the subsurface structure. Several wells near Jamestown, in Upshur County, produce oil from the Woodbine sand at depths of 50 to 180 feet lower than the salt-water level in the East Texas field.[22]

In general the structure of the North Basin is synclinal, the beds rising gently to the northwest north of the axis of the trough and to the southeast toward the Sabine uplift. This regional structure is

[22] Oil Weekly, vol. 73, No. 10, p. 54, and No. 13, p. 48, 1934; vol. 76, No. 2, p. 52, 1934.

interrupted, however, by a series of anticlines and synclines, which show no systematic orientation.

Many relatively minor folds occur within the South Basin. The subsurface folds to which the accumulation of oil and gas in all oil fields except the East Texas field is due are reflected in the surface formations.

There are several faults in both basins. Their effect on the character of the Weches greensand is discussed on page 27. The major system in the North Basin is known as the Rodessa fault system and comprises a series of northeastward-trending faults that can be traced individually for distances ranging from 200 feet to several miles and as a group through Marion and Cass Counties, Tex., into Caddo Parish, La., and Miller County, Ark. The vertical displacements along the faults range from a few inches to nearly 100 feet. Only a few faults were mapped during the present investigation, but there is strong reason to believe that many more could be discovered with detailed studies.

The major faults in the South Basin are in the Jarvis fault system of Anderson and Cherokee Counties and in the Mount Enterprise fault system of Cherokee and Rusk Counties. Some of the faults in these two systems, which also trend east or northeast, show displacements of 100 feet or more on the surface and considerably greater displacements in subsurface determinations.

Many of the faults, which are ordinarily very difficult to trace except in areas where good marker beds have been displaced, are marked by lines of rounded to subangular pebbles of chert, quartzite, or petrified wood, usually cemented into large conglomerate boulders. Some of the chert and certainly all of the petrified wood must have been dragged along the faults from gravel-bearing formations, but it seems possible that some of the chert and quartzitic material may have been formed by the induration of siliceous sands subjected to pressure along the faults.

THE IRON ORES

In correspondence with the two facies of the Weches greensand there are marked differences in the physical characteristics of the brown iron or limonitic ore of the North and South Basins. Nodules or concretions of brown ore, which in many places have coalesced to form layers or irregular beds, are characteristic of the North Basin ores; light-brown laminated and massive and "buff crumbly" ores are typically developed south of the Sabine River. In a few places, notably near Cusseta, in northwestern Cass County, ore of the South Basin type occurs in the northern area, and here and there concretions of brown ore occur in the lower parts of Weches exposures in the South Basin. In general, however, the zone between the two basins separates the two types of ore just as sharply as it does the differences in primary character of the Weches greensand. The distribution of the ores in Cass, Marion, and Morris Counties, all in the North Basin, is shown on plate 2. Those in the South Basin that bear most promise occur in the vicinities of Rusk and Jacksonville, Cherokee County, and Brownsboro, Henderson County. These areas are shown on plates 3, 4, and 5. Other deposits in Anderson, Henderson, Nacogdoches, Smith, Upshur, and other counties (pl. 1) are briefly described below.

In addition to the two types of ore that characterize the deposits of the North and South Basins, there are two other varieties that merit consideration. These are the carbonate ores and the conglomerate ores. All four types are further described below.

MINERALOGY

The brown ores are essentially hydrous iron oxide of the general type known as brown iron ore, brown hematite, or limonite. The terms "limonite" and "limonitic" are used throughout this report in referring to the principal mineral in the brown ore and to the ore itself. Several species of hydrous ferric oxides have been recognized in the past, but Posnjak and Merwin [23] have stated that there are probably only two true species, both of which are ferric oxide monohydrates, with a composition indicated by the formula $Fe_2O_3.H_2O$. One of these species, goethite, is crystalline; the other, limonite, is apparently amorphous. Limonite has the same composition as goethite but also contains variable amounts of adsorbed and capillary water. Lepidocrocite is a polymorphic form of goethite. Other so-called mineral species, such as turgite, are thought by Posnjak and Merwin to be solid solutions of goethite and hematite (Fe_2O_3) with varying proportions of enclosed or adsorbed water. F. W. Galbraith, who made optical and X-ray examinations of the Texas brown ores, found them to consist of about 80 to 85 percent of goethite and 15 to 20 percent of hematite.[24]

The iron carbonate ore is made up of densely crystalline ferrous carbonate, or siderite, having a composition expressed by the formula $FeCO_3$. At one locality near Montalba, in Anderson County, some of the brown ore contains small bladed crystals of siderite, and in a few places in both the North and South Basins small bladelike cavities in the brown ore are probably negative pseudomorphs of relatively coarsely crystalline siderite.

The chief impurities in both brown and carbonate ores are silica and alumina, which occur in large part as quartz sand and clay or as resid-

[23] Posnjak, Eugen, and Merwin, H. E., The hydrated ferric oxides: Am. Jour. Sci., 4th ser., vol. 47, pp. 311-348, 5 figs., May 1919.

[24] Galbraith, F. W., A microscopic study of goethite and hematite in the brown iron ores of east Texas: Am. Mineralogist, vol. 22, pp. 1007-1015, 1937.

ual glauconitic grains. There are but few other minerals associated with the iron deposits. Thin films of white or clear opal, an amorphous form of silica with varying amounts of water, occur in places as linings to concretions or as thin septa that fill cracks in concretionary masses of brown ore.

Films and crusts of a light-green fibrous mineral, determined by W. T. Schaller to be a hydrous iron phosphate near dufrenite in composition, were reported by Burchard [25] to occur in cavities of limonite near Veal's Switch, in Morris County. A very small quantity of what appears to be the same mineral was collected by the writer at the same locality, but no further identification has been made.

Pyrite, or iron disulphide, occurs as small nodular masses sporadically distributed throughout the unaltered greensands and rarely forms the central nucleus in concretions of carbonate. The total amount of pyrite at any one locality is commonly small.

NODULAR OR CONCRETIONARY ORES OF THE NORTH BASIN

The nodular or concretionary type of brown ore, typically developed in the North Basin, is more abundant and in general richer in iron than any of the other varieties. It occurs in forms of almost endless variety, as nodular concretions or as honeycombed, botryoidal, stalactitic, and mammillary masses. Individual concretions range from a fraction of an inch to 1 or 2 feet in length and from ocher yellow through various shades of brown to black in color. Most of the concretions are irregular-shaped, but some are nearly spherical, others are flattened ellipsoidal or biscuit-shaped, and still others are nearly square in outline, like the one shown in plate 8, *A*. Though generally hollow or partly or wholly filled with gray and brown clayey material, some of the masses are solid limonite, and others have a residual core of iron carbonate. A few of the hollow ones are partly filled with liquid, and carbon dioxide gas, which is under some pressure (pp. 49–51).

The walls of the concretions are commonly made up of concentric shells of limonite that differ in appearance and in degree of purity. As a rule the inner layers are richer in iron than the outer ones and are made up of radiating dark-brown "needle ore," which in the hollow concretions has a glossy black botryoidal surface. Plate 7, *B*, shows a typical concretion with an outer layer of dull earthy and somewhat spongy limonite that encloses the inner layer of kidney or needle ore. The outer surfaces show all gradations from soft ocherous material to hard, smooth limonite.

In places the individual concretions are distributed throughout a matrix of weathered greensand and clay; more commonly several

[25] Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee Counties, Tex.: U. S. Geol. Survey Bull. 620, p. 90, 1915.

concretions have coalesced to form botryoidal masses of varying size, which retain more or less evidence of the original concretions. Plate 12, *B*, shows a concretion with a peculiar rough surface that is somewhat suggestive of a turtle shell. Each of the protuberances clearly possesses a concentric structure of its own. In botryoidal masses of limonite such as that shown in plate 11, *A*, the coalesced concretionary structure is seldom distinguishable except on the outer surfaces. Plate 7, *A*, shows a lump of low-grade ore that contains much oxidized glauconitic material. The concentric rings or sworls about hollows and other nuclei show a coalesced concretionary structure, even though no actual concretions have been developed.

Great quantities of the brown ore occur as horizontal ledges or lenses from a fraction of an inch to several feet in thickness. Individual ledges rarely extend for more than a few feet, and pinch and swell structure is common. The ledges are surrounded by weathered greensand. Plate 9 illustrates the mode of occurrence of the ledge ores. Close inspection of such masses commonly serves to show that they too are made up of concretions which have either coalesced during growth or have been cemented to a solid mass by ferruginous material. Most of the limonite is cellular or porous and ranges according to size of openings from a fine-grained spongy ore, similar to that on the outer parts of the concretions shown in plates 7, *B*, and 12, *B*, through a honeycombed or cellular type to coarsely cellular boxwork, such as that shown in plate 8, *B*. The interstices between the limonite walls may be hollow or filled with clay or oxidized greensand. The most noteworthy characteristics of the nodular ores as a class are their porous, cellular nature and their extreme variability in character and composition.

The deposits occur within the greensand in the upper parts of the flat-topped, sand-covered hills that characterize the topography of northeastern Texas. They are best developed near the outcrop, or where the greensand is overlain by less than 10 to 15 feet of Sparta sand. In some areas the central parts of the hills, where the overburden is thick, are barren of ore; in others only carbonate ore is present. These relations are brought out repeatedly in the descriptions of the individual districts below. The position of the water table marks the lower limit of the brown nodular ores (fig. 1).

LAMINATED BUFF CRUMBLY ORES OF THE SOUTH BASIN

The laminated and buff crumbly ores of the South Basin, in contrast to the concretionary or ledge ore of the North Basin, characteristically consist of one solid and fairly continuous bed of brown ore at the top of the Weches greensand, with comparatively little ore in seams and nodules below. The ore has a resinous luster and is light brown or buff, several shades lighter than most of the ore in the North Basin.

At the top of the ore bed the thin ferruginous basal sandstone of the Sparta sand is almost universally present in natural exposures. It ranges from half an inch to 6 or 8 inches in thickness and adheres closely to the ore bed, though it is rather easily split from the bed in mining. The upper 2 to 6 inches of the ore bed generally has fine open laminae parallel to the bed. Each lamina, however, is made up of short segments an inch or two long, which are all convex downward. The laminae range from a sixteenth to less than half an inch in thickness and characteristically exhibit glossy black coatings. Plate 10 shows a typical specimen of laminated ore. According to Burchard [26] the laminated ore "is said by furnace men who have had experience in its use to contain a higher percentage of phosphorus than the rest of the ore in the bed." Only one bit of information can be added to this statement. Analyses 36 and 37, (p. 58), of laminated and buff crumbly ore, show 0.20 and 0.23 percent of phosphorus respectively. Whether this relation would be found to hold true in a greater number of analyses is not known.

The lower part of the ore bed, which grades upward into the laminated ore to some extent, is made up of compact massive brown ore. This is the "buff crumbly" ore. It presents a curly structure when freshly broken and cracks and crumbles to a fine angular gravel on weathering. Although little structure or variation in composition is visible in the fresh ore, weathering tends to bring out a structure resembling the coalesced concretionary structure of some of the North Basin ores. Furthermore, the weathered crumbly ore contains minute films of reddish clay between the particles and between concentric shells of the concretionlike bodies, which probably explain the crumbly nature of the ore. Plate 11, *B*, shows a typical block of South Basin ore. The sandstone cap and the laminated brown ore are present, though poorly developed, but the curly or concretionary structure of the buff crumbly ore is clearly shown.

The top of the ore bed is nearly horizontal, but at the base botryoidal and rootlike protuberances of limonite extend downward into the underlying clay so that the basal surface is extremely irregular. Plate 13, *A*, shows a well-exposed section of the South Basin ore and, besides showing the character of the ore bed and of its irregular lower surface, illustrates one of the difficulties that stand in the way of making accurate measurements of thickness and hence in making reliable estimates of tonnage.

In a very few places both the laminated and the buff crumbly ore contain small spherical "ghosts" with concentric structure that almost certainly represent original glauconitic oolites. This feature

[26] Burchard, E. F., op. cit. (Bull. 620), p. 92.

is particularly well developed in an exposure about 2½ miles northwest of Palestine, Anderson County (pl. 1), but has been recognized in other places. Relatively coarse crystals of brown siderite were seen in the buff crumbly ore in a few places, and in others small bladelike hollows that are probably negative pseudomorphs after siderite are known to occur.

A bed of nearly pure white clay lies directly beneath the ore bed. It is composed almost entirely of the mineral kaolinite,[27] but in places it retains ghosts of original glauconitic oolites (pl. 14, *A*). The clay bed is usually somewhat thinner than the ore bed, but in general its thickness varies with that of the ore. The lower boundary of completely leached clay is roughly parallel to the base of the ore bed, but a downward gradation to less altered greensand is evident in most places. The clay bed shows only fairly well in plates 6, *B*, and 13, *A*, but is a prominent feature of these exposures in the field. Similar zones of light-colored clay underlie the thin beds of limonite that appear below the top ledge, but such clay has not been observed where ore is absent.

The ledge of ore that marks the top of the Weches member shows variations in thickness within short distances, but ore occurs at the outcrop at this horizon over an area of several hundred square miles. Few of the outcrops seen in Smith, Henderson, Van Zandt, and northern Anderson and Cherokee Counties failed to show some ore at this horizon. The persistence of ore at the outcrop is therefore well demonstrated; however, although intensive prospecting to prove the existence of ore beneath the whole surface of the plateaus of Cherokee County has never been attempted, the weight of all evidence available at present leads to the conclusion that, except under unusual conditions, ore deposits of commercial size are confined to a relatively narrow fringe about the edges of the hills. According to well diggers and other local residents many of the wells on the plateaus of Cherokee and other counties in the South Basin encountered no ore or ferruginous sandstone, though they penetrated the upper parts of the Weches strata. Other wells encountered the top ore bed, but nearly all such wells are within 300 or 400 feet of the outcrop, and the overburden is relatively thin. Cuttings were examined from numerous holes drilled by private seismograph parties for the purpose of setting off explosives. Some of these holes were 50 feet or more deep, and most of them penetrated fresh greensand, but it was found that iron ore was present only in the holes that were close to the outcrop of the ore bed. Many new road cuts show the ore to be continuous through the hills, but in all such cuts that were seen the hills were very small and overburden was thin or lacking. Mr. E. A. Wendlandt, of the Humble Oil & Refining Co., writes that his own experience and that of other

[27] Galbraith, F. W., personal communication.

geologists and geophysicists who have worked in the South Basin confirm the writer's belief that little or no ore is present at the top of the Weches in places where 10 to 15 feet or more of cover exists. The relation between iron ore and thickness of cover was recognized by Penrose many years ago but seems to have been lost sight of in recent years, as some purchases of land and most estimates of tonnage have been based on the assumption that the ore underlies the whole surface of the hills. Penrose[28] said, "As a rule the thickness of the ore depends, in a general way, on the thickness of the overlying sand bed, it being thicker where the sand is less than 15 or 20 feet than where it is greater. * * * When the overlying sands and clays reach a great thickness, the ore grows thin and very often runs out altogether."

There is little apparent relationship between the thickness of the South Basin ores and the regional or local structure. The fact, however, that some of the best deposits in Cherokee County occur in the immediate vicinity of Rusk, on a local structural high, and that the ore thins southward, or down the dip, and finally gives out, is suggestive of a relationship such as that which exists in the North Basin.

Vertical veins of limonite are common in the vicinity of some faults and extend downward from the main ore bed at least 10 to 15 feet. The veins range from less than an inch to about 5 feet in thickness. They are difficult to trace and their horizontal and vertical extent is not known. Such veins are particularly well exposed along the highway between Rusk and Jacksonville, Cherokee County, but they are probably present throughout the South Basin. They commonly have a central band of laminated ore, similar to the uppermost horizontal ore bed but more compact, which is flanked on one or both walls by botryoidal masses of buff crumbly ore, similar in all respects to the main ore bed. In one vein the laminated band was flanked on one side by buff crumbly ore and on the other by ferruginous sandstone, which gave it the appearance that would be obtained by turning a block of South Basin ore on edge.

CARBONATE ORES

Carbonate ore is by no means as abundant as brown ore, but it is sufficiently abundant to add materially to the ore reserves in many districts. It is also of importance genetically in that most if not all of the brown ore has been derived from the oxidation of carbonate.

The carbonate ore is made up of densely crystalline siderite, with more or less silica, alumina, and other impurities. When fresh it ranges from very light cream-colored or gray to medium gray. It occurs as rounded, irregular nodules or as thin layers and lenses. Individual nodules range from less than an inch to about 1 foot in diameter. The greatest thickness of the lenses measured by the

[28] Penrose, R. A. F., Jr., Texas Geol. Survey 1st Ann. Rept., for 1889, p. 67, 1890.

writer was 9 inches, and most of them are not over 2 or 3 inches thick.

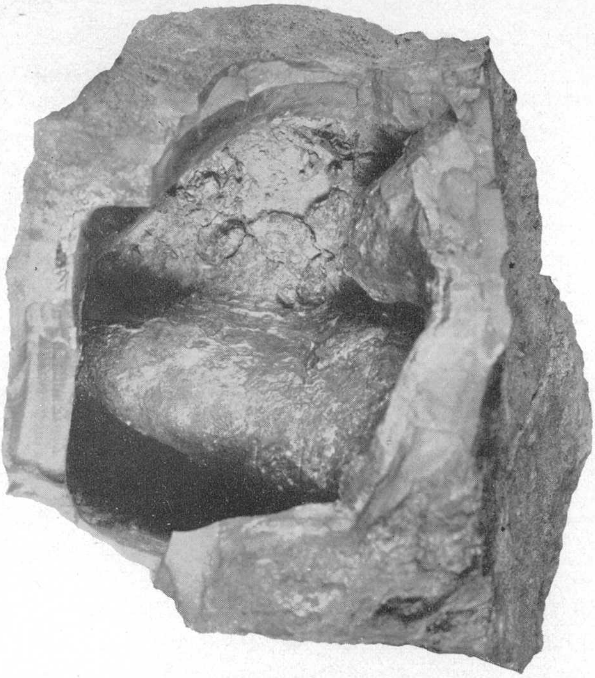
Some carbonate nodules contain a few flakes or specks of lignitic material near the center, and very rarely the carbonate encloses a nucleus of pyrite. Oolitic grains of glauconitic material are rather commonly present within both concretions and lenses. They vary greatly in abundance between the extremes represented by massive carbonate with few or no glauconitic grains and beds or lenses of fresh-appearing greensand, the grains of which are merely cemented by siderite. Some nodules exhibit traces of bedding planes which conform to those of the enclosing sand and clay (pl. 12, *A*).

Like the brown ore, the carbonate ore is closely associated with beds of greensand. It is present in both the North and South Basins but is less common in the South Basin. The upper limit of the zone of carbonate ore, which ranges from a few inches to 10 or 12 feet in thickness, is marked by the local water table, above which the brown ores occur. Thus carbonate is exposed at the surface only under exceptional conditions, as in the beds of streams where there is an almost constant flow of water. Some of the most noteworthy of such occurrences are in the Duncan and Knight-Field districts, near Lanier, Cass County (pp. 106–111), and in the Morris County line district (pp. 128–130). They are rare elsewhere.

When essentially fresh the carbonate ore is dense and contains a minimum of pore space. When exposed to weathering, however, it darkens in color and alters rapidly to limonite, with a great increase in porosity. In the early stages of alteration radial shrinkage cracks commonly form in the centers of partly altered nodules, or cracks with a pattern similar to those in dried mud develop on the surface. Oxidation proceeds most rapidly along the walls of the cracks or on the outer surfaces of the concretions. The cracks develop in concretions and ledges alike and apparently produce the "turtle back" structures found on some concretions, such as that pictured in plate 12, *B*, and the boxwork structures that characterize many of the brown ledge ores. Plate 12, *A*, shows a concretion of carbonate that is partly altered to limonite. The increase in porosity due to alteration is here obvious.

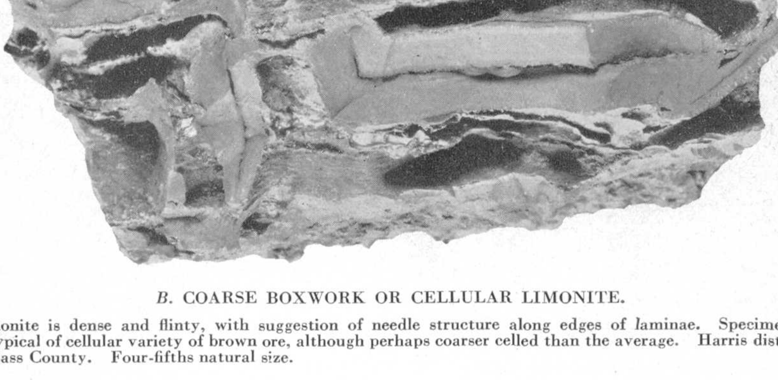
The rate of oxidation is usually rather rapid. For instance, much of the dark color on the carbonate core of the concretion shown in plate 12, *A*, was assumed in less than 6 months that elapsed between sawing and photographing the specimen. Only when the material is kept wet is oxidation retarded.

Aside from the basic difference in chemical and mineral composition, the chief difference between carbonate ore and nodular or concretionary brown ore is the general compactness and lack of porosity in the carbonate as compared with the cellular, highly porous limonite.



A. ANGULAR HOLLOW CONCRETION OF GOOD-GRADE LIMONITE.

Earthy material in interior is light-colored clay that is probably residual from the breaking down of the original greensand. Waters district, Cass County. Natural size.



B. COARSE BOXWORK OR CELLULAR LIMONITE.

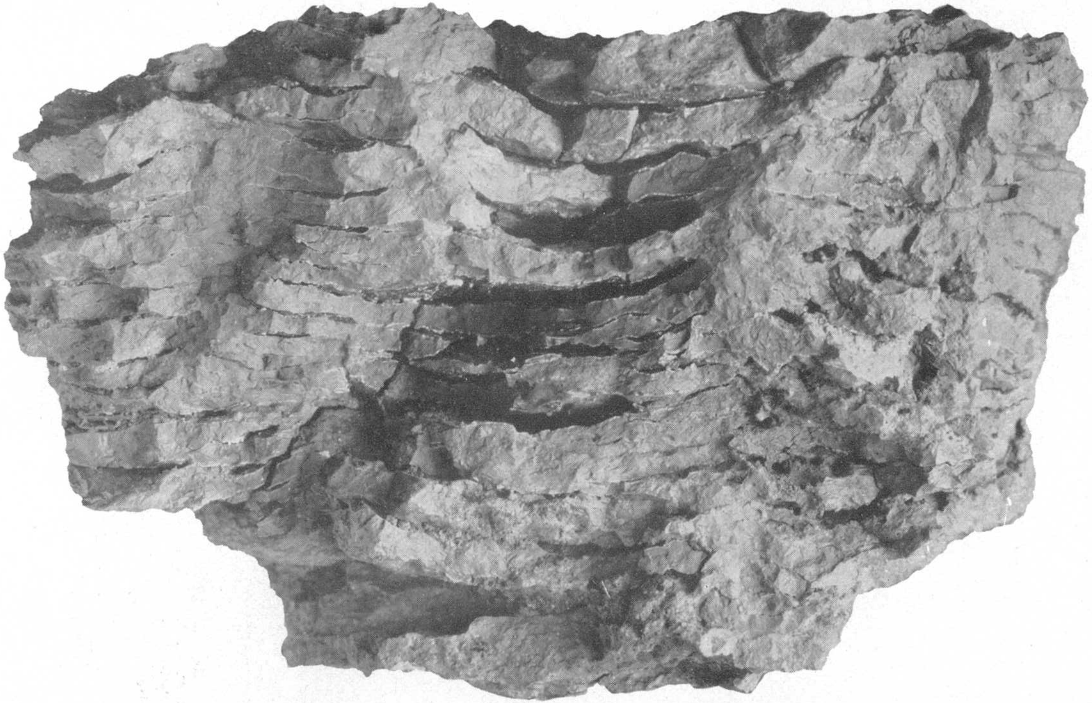
Limonite is dense and flinty, with suggestion of needle structure along edges of laminae. Specimen is typical of cellular variety of brown ore, although perhaps coarser celled than the average. Harris district, Cass County. Four-fifths natural size.

A. VIEW ALONG PROSPECT TRENCH ON BOWIE HILL, CASS COUNTY.

Shows irregular beds of brown ore in matrix of oxidized greensand.

B. VIEW IN LARGE PROSPECT TRENCH IN HARRIS DISTRICT, SOUTHEAST OF LINDEN, CASS COUNTY.

Shows an unusually thick concentration of brown ore, in irregular ledges and lenses, in a matrix of oxidized greensand.

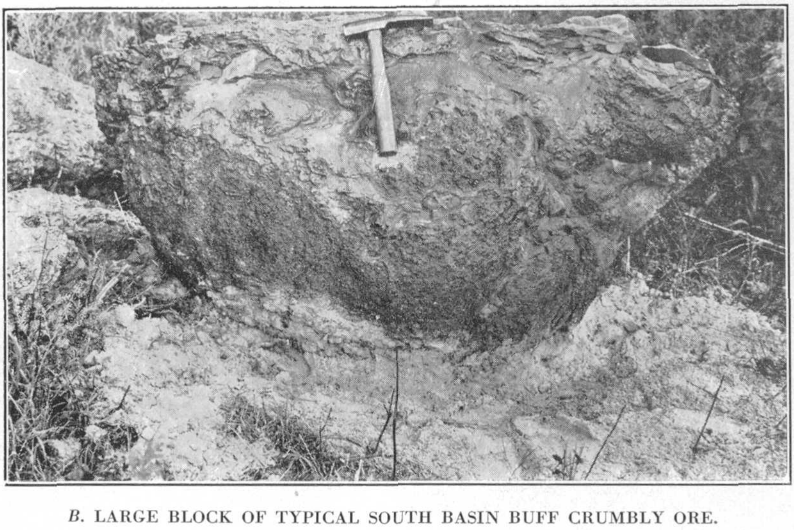


SPECIMEN OF TYPICAL LAMINATED BROWN ORE OF SOUTH BASIN.

This type of ore commonly overlies the buff crumbly ore. From Mount Haven, Cherokee County. Natural size.

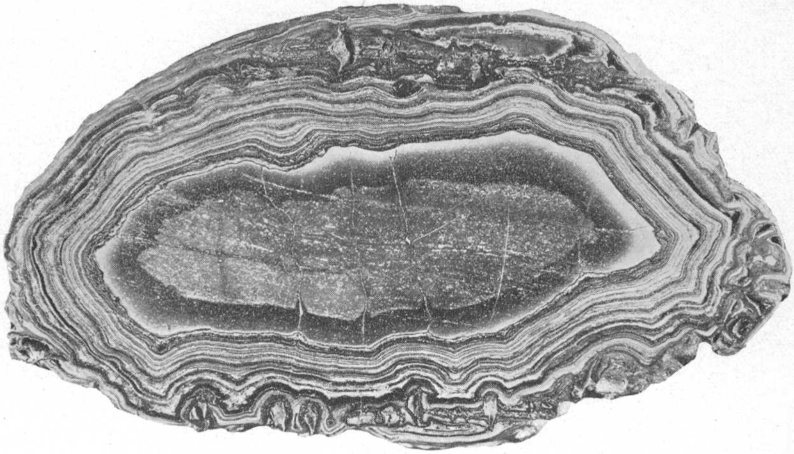
A. BOTRYOIDAL STRUCTURE ON LIGHT-BROWN LIMONITE ON DAINGERFIELD HILL, MORRIS COUNTY.

This ore is very similar to the buff crumbly ore of the South Basin.



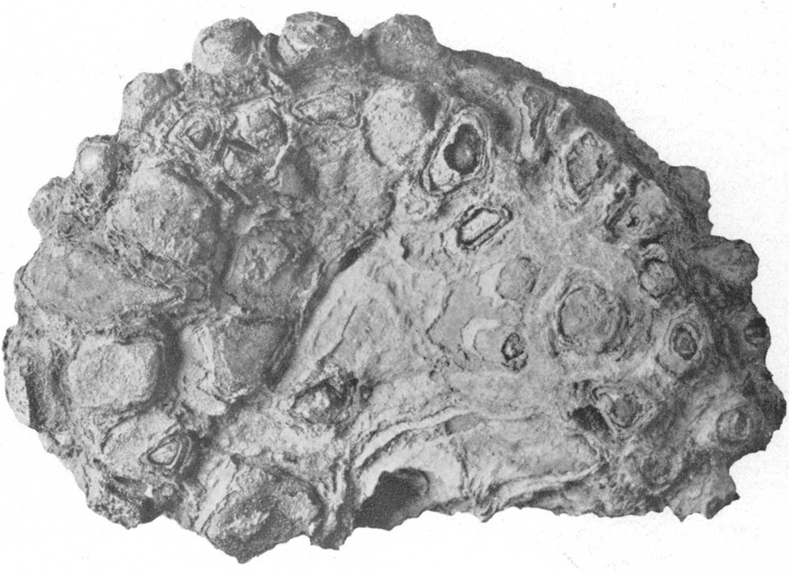
B. LARGE BLOCK OF TYPICAL SOUTH BASIN BUFF CRUMBLY ORE.

Note botryoidal surface and suggestion of coalesced concretionary structure. A few fragments of the ferruginous sandstone cap adhere to the upper surface, but the layer of laminated ore is not well developed. Near Rusk, Cherokee County. Hammer handle is 11 inches long.



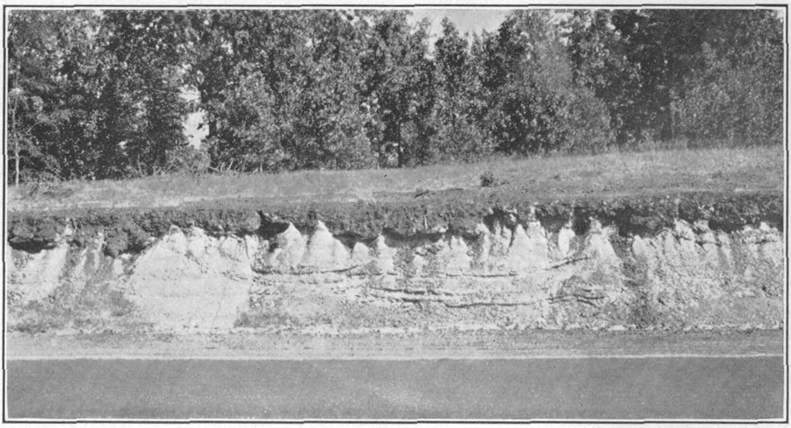
A. POLISHED SECTION OF LIMONITE CONCRETION WITH SOLID CORE OF IRON CARBONATE (BOUNDED BY RELATIVELY BROAD WHITE ZONE).

A suggestion of original horizontal bedding planes is visible in the carbonate core. Note shrinkage cracks in carbonate and great increase in porosity on change from carbonate to limonite. Most of the darkening of the carbonate took place during the 6-month period between cutting and photographing of the specimen. Stream bed southeast of Lanier, Cass County. Two-thirds natural size.



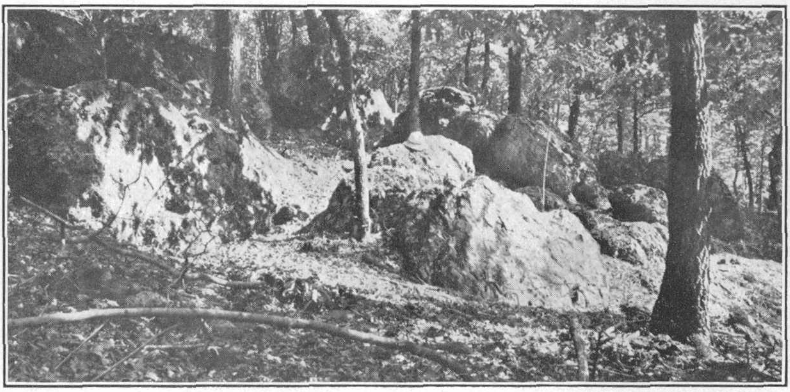
B. CONCRETION OF SPONGY LIMONITE SHOWING PECULIAR ROUGH SURFACE.

Development of the surface pattern is apparently controlled by shrinkage cracks in the parent carbonate. Each protuberance evidently possesses a concentric structure of its own. Harris district, Cass County. Four-fifths natural size.



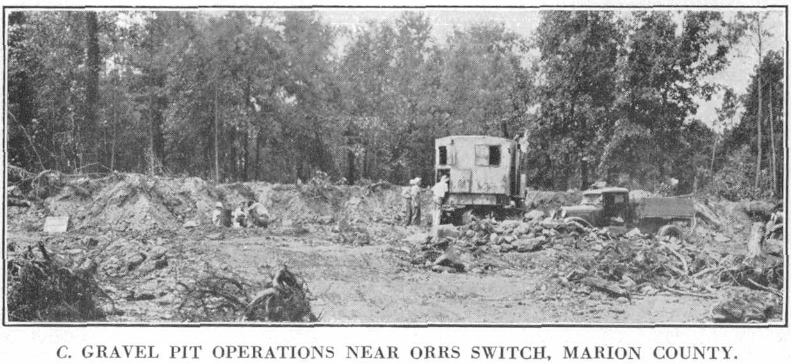
A. TYPICAL OCCURRENCE OF BROWN IRON ORE IN SOUTH BASIN.

Ferruginous sandstone cap and layer of laminated ore poorly developed. Note mammillary lower surface of buff crumbly ore bed, which is underlain by white clay, grading downward to oxidized greensand. A few thin seams of sandy limonite occur in lower beds. Along road cut 4 miles east of Reese, Cherokee County.



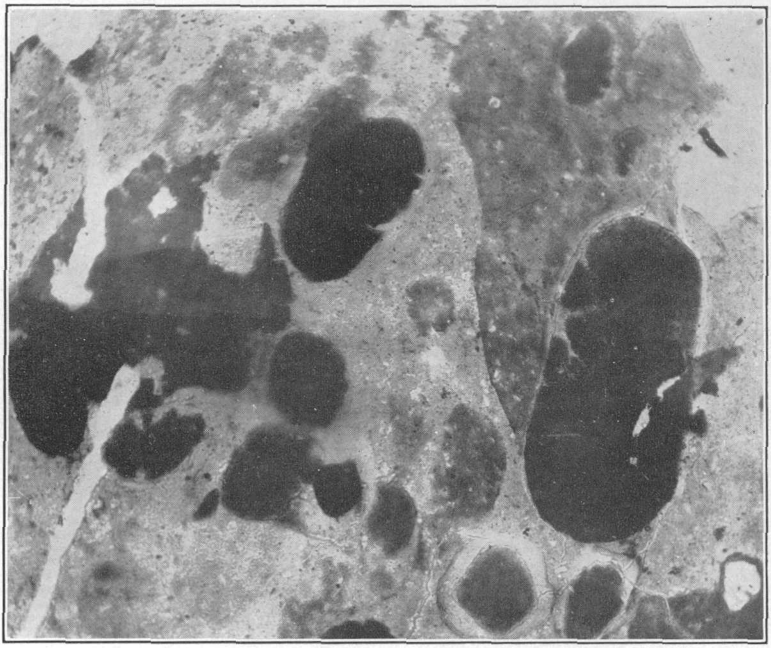
B. UNUSUALLY LARGE BLOCKS OF BROWN IRON ORE OF SOUTH BASIN TYPE.

Ledge in extreme upper left corner is in place; other blocks have weathered out and moved a few feet down the slope. Block in center background is 4 feet thick. Near Fry's Gap road on Mount Haven, Cherokee County.



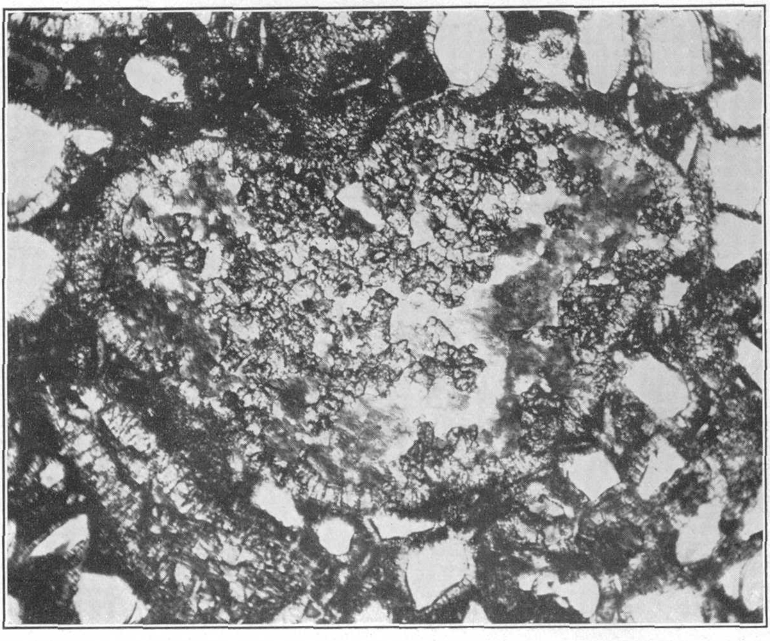
C. GRAVEL PIT OPERATIONS NEAR ORRS SWITCH, MARION COUNTY.

The "gravel" is oxidized greensand containing much low-grade iron ore. Large blocks piled back of the shovel are mostly indurated greensand and are sold for riprap.



A. RELICS OF OOLITIC GREENSAND STRUCTURE IN CLAY.

The greensand is apparently altering to clay. The matrix of the unaltered greensand appears to be largely kaolin stained with iron, which is leached to form white clay, while the glauconitic material itself alters to kaolin. Plain light. Enlarged 62 diameters.



B. EXTENSIVE REPLACEMENT OF GREENSAND BY SIDERITE.

The clay matrix is almost entirely replaced and the large-grained or glauconitic material is about half replaced by carbonate. Plain light. Enlarged 62 diameters.

CONGLOMERATE ORES

Deposits of ferruginous conglomerate occur on hill slopes, and along the sides of many stream valleys and are even forming today in some stream beds. This conglomerate is composed of pebbles of ferruginous sandstone, limonite, quartz sand, and a few quartz or chert pebbles and fragments of silicified wood, the whole cemented by limonitic material. Some of the recently formed conglomerate in a stream bed near Lanier, in Cass County, contains much fragmental carbonate ore. This is a rare occurrence, and in view of the strong tendency of carbonate ore to oxidize to limonite it indicates a very rapid rate of accumulation and cementation of the conglomerate.

In places the deposits of conglomerate ore are several feet thick, but the material is always siliceous and few if any deposits contain more than 30 percent of metallic iron. The conglomerate is much more abundant in the vicinity of deposits of iron ore in the Weches greensand but is present to some extent almost everywhere and even occurs interbedded with the Queen City sand in places. Though of some interest in dating the formation of the iron ores in the region (p. 55), the conglomerate has little or no potential value as an iron ore itself, and it is not considered further in this report.

ORIGIN OF THE ORES

An understanding of the origin of the ores is essential to the estimation of available reserves of iron ore. There is reason to believe that both the concretionary ores of the North Basin and the laminated ores of the South Basin were derived from the iron silicates of the Weches greensand by weathering processes and that most of the ore went through an intermediate carbonate stage. There were differences in the details of the iron-enrichment process, and they are specially marked between the two chief types of ore, but it can hardly be doubted that the greensand was the principal original source of iron for all the deposits.

ORIGIN OF THE NORTH BASIN ORES

In summation of the statements that were made on the preceding pages, a generalized section through the ore deposits of the North Basin is given below:

Generalized section through ore deposits of the North Basin

	Ft.	In.
1. Unconsolidated quartz sand (Sparta)	1–20	
2. Thin, hard, ferruginous sandstone (basal Sparta)		1–6
3. Greensand, thoroughly oxidized, with nodules and ledges of brown ore. Much reddish and yellowish clay in places. Horizon of brown iron ore	5–20	

Generalized section through ore deposits of the North Basin—Continued

	Ft.	in.
4. Greensand, partly oxidized, with nodules of siderite (iron carbonate) somewhat altered to brown ore. Transition zone		6–12
5. Greensand, nearly fresh, partly cemented by siderite and containing nodules or thin ledges of fresh siderite. Horizon of carbonate ore	3–10	
6. Greensand, fresh, unaltered	1–10	
7. Light-colored quartz sand and clay (Queen City).		

This section shows a progressive change downward from thoroughly oxidized greensand and brown iron ore near the surface, through an intermediate zone where iron carbonate appears, to fresh greensand near the base of the Weches member. The degree of alteration varies in actual sections between the extremes represented by completely oxidized material and essentially unaltered greensand. This variation is apparently due in part to variations in composition of the original greensand but in greater part to variations in the relation of the overburden of Sparta sand to local water-table conditions.

The thickest and richest ores commonly occur in relatively small outliers where the Weches member has been bared by erosion or retains only a very thin cover of Sparta sand. Next in importance are the narrow, thinly covered spurs or ridges that project from larger hills. In the large areas where the Weches is covered by 15 feet or more of sand good brown ore is not abundant along the outcrop, and little or no brown ore is encountered in wells or drill holes, although carbonate ore extends back beneath the overburden for several hundred feet. The central parts of the larger hills are nearly or quite barren of ore.

As a general rule two of the chief horizons for shallow water wells on the uplands of eastern Texas occur near the top and base of the Weches greensand. Where the Sparta sand is more than about 12 to 15 feet thick the wells encounter water at the top of the Weches member, but where the Weches occurs at the surface, water is ordinarily found at or near the base of the greensand. The greensands are thus above the water table and subject to weathering only where the cover of Sparta sand is thin. Figure 1 illustrates the general relations between water-table conditions, extent of overburden, and character of ore deposits. The perched water tables indicated at *c* and *d* appear to be due to relative impermeability of the underlying beds and thus vary in position with the seasons and with precipitation. In other words, the springs which mark these perched water tables and most of which are intermittent may be likened to overflow pipes through which water flows only when the beds are thoroughly saturated with water.

The top of the ground-water level is commonly at the transition zone between units 3 and 5 shown in the generalized section above.

Siderite occurs at the surface in a few places, but only in stream beds or in other positions where there is sufficient water to prevent oxidation. It forms most abundantly near the top of the water table and is commonly rare or absent in the saturated, unaltered greensand.

In addition to the areal relationships outlined above, the following facts have a bearing on the origin of the ores. Most of the spring waters that issue from the greensand beds in the North Basin contain small but appreciable amounts of iron and also contain both sulphate (SO_4) and bicarbonate (HCO_3) ions. Samples of water were taken from two springs in the Surratt district, north of Linden, and from a spring about a mile west of Lanier. The springs all issue from beds within the Weches section. The waters are clear to very slightly cloudy, tasteless, and very soft. Partial analyses were made in the Geological Survey laboratory by E. W. Lohr, who found them to contain 0.54, 0.11, and 0.30 part per million of iron, respectively.

The springs that give the name to the town of Hughes Springs issue from a point at or very near the base of the Weches greensand. The water has a moderately strong chalybeate taste and deposits a little iron hydroxide at the surface. The water is carried through iron pipes for a short distance, and some of the iron may be derived from the pipe. Mr. Lohr found a sample from one of these springs to contain 8.6 parts per million of iron. A more complete analysis of the water from another of the springs in the town of Hughes Springs follows:

Chemical analysis of water from spring at Hughes Springs, Cass County [29]

[Analysts, J. R. Bailey and A. M. McAfee]

	Parts per million
Silica (SiO_2)	21
Iron (Fe)	12
Aluminum (Al)	4. 9
Calcium (Ca)	4. 9
Magnesium (Mg)	4. 4
Sodium (Na)	3. 4
Potassium (K)	2. 7
Carbonate radicle (CO_3)	. 0
Bicarbonate radicle (HCO_3)	18
Sulphate radicle (SO_4)	25
Nitrate radicle (NO_3)	. 0
Chlorine (Cl)	5. 2
Total solids	86

This analysis shows not only that iron is carried in solution by the ground waters and hence is available for the formation of iron ore, but also that considerable quantities of silica and other constituents are removed by ground water during the weathering of the greensand.

The sulphate contained in the spring waters is undoubtedly derived

[29] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, pp. 74-75, 1911.

from the pyrite that occurs in the Weches greensand and Sparta sand. Small amounts of pyrite are rather widespread, even in partly oxidized exposures of the Weches, and it seems reasonable to suppose that even more pyrite would be found in unaltered beds. Pyrite in the Sparta was observed in only one locality (p. 107) but has been reported elsewhere by Penrose. (See p. 54.) It may well be that careful study of unweathered Sparta sand would serve to show the widespread presence of small quantities of the mineral.

An adequate supply of carbon dioxide is supplied to the ground waters in part from the air and in part from decaying vegetable matter in the soil. Though most of the ore-bearing lands of eastern Texas support a fairly heavy cover of vegetation, the soil and humus layers are in general thin or absent. This is apparently due to rapid decomposition and leaching of the organic matter in consequence of the permeable and essentially lime-free character of the Weches and Sparta sands. Oxidation of the humus in the soil and of the minor amounts of organic matter in the greensand by bacteria or other agents would supply additional carbon dioxide to the ground waters.

Students of soils have shown that the carbon dioxide content of soil air is usually seven to eight times as great as that of atmospheric air and that it varies directly with biochemical activity and with seasons.[30] Russell [31] cites evidence to show that from 20 to 50 grams of carbon dioxide is evolved from different soils per square meter per day.

The mode of origin as deduced from the above facts is as follows: Surface waters charged with oxygen and carbon dioxide from the air seep downward through the Sparta and Weches beds. The roots of plants at the surface contribute more carbon dioxide, and still more is formed by the decay of organic matter, which uses up part of the oxygen. Any remaining oxygen will be available to react with pyrite, forming ferrous sulphate and sulphuric acid. The waters thus became weak solutions of carbonic and sulphuric acid which are able to dissolve much of the ferrous and ferric iron in the greensand. Some silica and alumina are dissolved and transported at the same time, but large quantities of these constituents are left behind as clay or sand.

Ferrous carbonate, if not oxidized, can be carried in solution as long as there is an excess of carbon dioxide. Wherever conditions are such that the solutions can lose carbon dioxide, solid ferrous carbonate, or siderite, can be deposited. Such conditions occur at the top of the water table, where the overburden is thin enough to allow circulation of air, and near the outcrop of the beds. The same

[30] Comber, N. M., An introduction to the scientific study of the soil, pp. 81-84, New York, Longmans, Green & Co., 1927.

[31] Russell, E. J., Soil conditions and plant growth, pp. 311-312, New York, Longmans, Green & Co., 1932.

result would occur when the excess carbon dioxide is used up by reaction with more greensand. After the deposition of siderite any iron remaining in solution would become oxidized on reaching the air and be deposited as brown or red oxide.

Microscopic examination of thin sections of relatively fresh and altered greensand shows that the iron carbonate is formed in large part by replacement of the greensand. All the samples studied were necessarily taken at or near the surface and are, therefore, partly altered, but they give the best approximation to the true character of the greensand and its alteration products that is possible without deep drilling. The first step in the alteration of the greensand is leaching of iron from the clay matrix that surrounds the glauconitic grains.[32] Further alteration is indicated by partial or complete replacement of the matrix and of the glauconitic material by siderite. In most of the thin sections examined by Galbraith replacement of the clay appears to have progressed further than that of the glauconitic grains, although in some sections (pl. 14, *B*) these grains are extensively replaced by iron carbonate. In nearly all sections the siderite is partly altered to limonite, and in some the glauconitic grains appear to have altered directly to limonite without going through an intermediate carbonate stage.

The suggested mechanism would lead to deposition of siderite in open spaces, but it does not explain the evidence of replacement of the minerals of the greensand as seen in thin sections and in the field.

Deposition of siderite can probably take place only through a small vertical range at any one time, but seasonal and annual fluctuations in the water table would allow its formation over a much greater range during a long period of time. Siderite may be deposited about some already formed nucleus of iron carbonate or other material, thus building up concretions, or the carbonate may replace the interstitial clay between the glauconitic grains, cementing them to a greater or less extent. The process of carbonatization is completed by replacement of the remaining glauconitic grains with siderite.

Field and microscopic evidence shows rather conclusively that most if not all of the brown ore has been formed by the oxidation and hydration of siderite, but there has been some rearrangement of material and possibly some addition of iron. Many masses of siderite contain grains of unreplaced glauconitic material (pl. 14, *B*), and some of the brown ore, particularly that of lower grade, such as that shown in plate 7, *A*, retains unmistakable ghosts and pseudomorphs of these original oolitic grains. In general form and distribution the bodies of carbonate and brown ore are closely similar, except that the siderite

[32] Galbraith, F. W., personal communication.

is everywhere compact and the brown ore contains many vugs and other openings and has a high aggregate porosity. All stages in the alteration process are visible in the field. A shrinkage in volume of about 27.5 percent during the change from carbonate to brown ore is to be expected on chemical grounds [33] and is clearly proved by the field evidence (pl. 12, *A*).

That most of the brown ores contain about twice as much silica and alumina as the parent carbonate ores is in large part due to the fact that the removal of 30 to 40 percent of carbon dioxide causes a relative increase in all other constituents. It is probable also that most of the few published analyses of carbonate ore have been made on samples more carefully cleaned than those of the brown ore. Samples of limonitic ore as ordinarily taken for analysis contain much oxidized glauconitic and silica sand, which adheres to the surface of the ore fragments.

The beds or ledges of ore are formed either during the carbonate stage by gradual accumulation of ferrous carbonate until the concretions coalesce or during the change to brown ore when water carrying more iron in solution cements the original concretions into more or less solid masses. The additional iron may possibly be derived from the partly altered greensand that encloses the carbonate nodules and ledges.

Nearly half a century ago Penrose [34] clearly described the change of carbonate to brown ore and showed that most if not all of the brown ore was derived from that source. He also recognized the importance of the position of the water table in controlling the formation of limonite. He thought, however, that the iron carbonate was formed at about the same time that the greensands were laid down and did not attribute its formation to the alteration of the greensand by ground waters. The relation between the carbonate ore and the present water table and the field and microscopic evidence of origin by replacement make it seem hardly possible that the bulk of the iron carbonate can be of primary origin.

The physical character of the original greensand determines in part the character and amount of iron ore that results from weathering. If much clay or sand are included the ore will tend to be of lower grade on account of these impurities. But more important is the effect which these constituents have on the physical character of the beds and their permeability to ground water. If the beds contain so much clay as to be relatively impermeable or if there are alternations of sand and clay, the movement of ground water is impeded, and rich ores cannot form except under special conditions. But if the greensand is sufficiently porous and permeable to allow free circulation of water, thick deposits of high-grade ore will usually be formed.

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[33] Hunt, T. S., The genesis of certain iron ores; Canadian Naturalist, vol. 9, pp. 431–433, 1880.

[34] Penrose, R. A. F., Jr., op. cit. pp. 79–81.

There are few obvious relationships between the iron ores and the local structural geology, but there is a tendency for the richest concentrations of iron ore to occur on or near structural highs rather than in synclinal areas. This is possibly due in part to the fact that many of the structural highs are also topographic highs and hence the greensands have been longer and better exposed to weathering. Apparently of much greater importance, however, is the fact that the greensand on structural highs commonly contains more quartz sand and is therefore more permeable and allows freer movement of ground waters.

That there must be transportation and concentration of iron during the formation of ore from greensand seems clear. The total volume of material seems to remain about constant during the alteration process, but the constituents are rearranged. Thus it is believed that much of the light-colored clay that occurs in the oxidized parts of the deposits is residual and due to the leaching of other constituents from the original greensands. In other words, the volume originally occupied by more or less homogeneous greensand is now occupied by oxidized greensand, clay, and brown iron ore, to which a considerable amount of iron has been added from other parts of the greensand beds.

SECONDARY CONCENTRATION OF ORE

In many places there is a secondary concentration of brown ore parallel to the present surface, and the surface ledge is commonly of higher grade than the lower layers of ore. One such example is sketched in figure 2, which also shows the lenticular character of the ore layers within the Weches greensand and demonstrates one of the possible errors that may be made in the estimation of ore reserves if the thickness of ore in outcropping sections is measured. Such surface enrichments show that there has been considerable transportation and redeposition of iron since the present topography was developed, although no explanation of the cause of the enrichment is obvious. The condition is by no means universal, but it is sufficiently widespread and of so great economic importance that it should be carefully looked for during the examination of all deposits. The possibility that there has been enrichment casts doubt on the results of surface sampling of the ores unless its presence or absence is definitely proved. Furthermore, estimates of tonnage based on surface exposures where a single rich bed may follow the topography are very likely to be erroneous if the ore beds are assumed to be horizontal.

Near Lassater, Marion County (pl. 2), hollow brown-ore concretions were found to be filled with liquid and gas, and it was hoped that they might throw light on the problem of the origin of the iron ores. A hole was drilled through the thick shell of one concretion by R. C. Wells, chief chemist of the Geological Survey, who collected the included gas and liquid over mercury under an inverted funnel. The results of his examination of the contents, as given below, do not afford any correlation between these and other known facts regarding the origin of the ores.

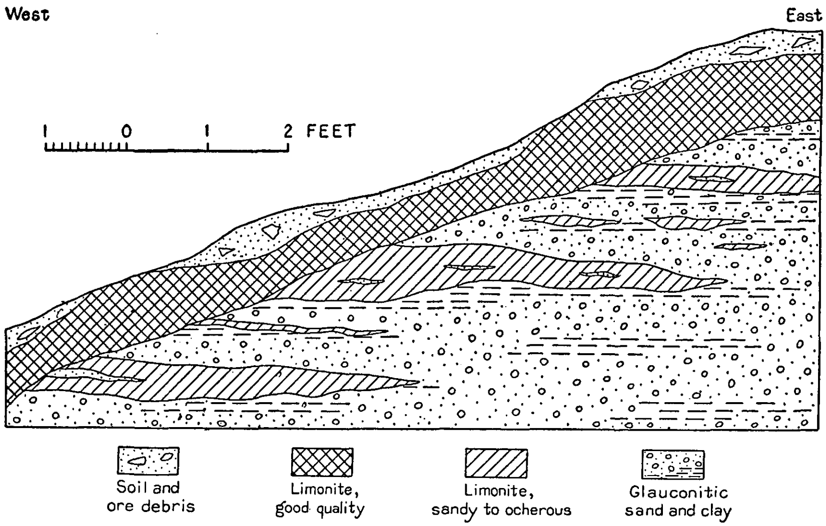

FIGURE 2.—Section showing secondary concentration of ore parallel to present surface, accompanied by increase in quality of the ore. This section also demonstrates the possible fallacy in basing calculations of ore reserves on apparent thickness of ore at outcrop. Sketched from a trench near the Harris tract, 5 miles southeast of Linden, Cass County.

Brown ore concretion found near Avinger, Cass County, Tex.

Total weight of original concretion .... grams ..	2,793.0
Weight of empty shell after opening .... do	2,604.75
Volume of cavity .... cc ..	175.55
Volume of solution from cavity .... do	59.7
Weight of contained fine siderite crystals .... grams ..	129.0
Volume of gas from cavity and solution .. cc. at 0°, 760 mm .	195.6
Calculated gas space .... cc .	84.6

Analysis of gas from concretion

[Percent by volume]

CO_2	91.1
O_2	1.7
N_2 (by difference)	7.2
	100.0

Analysis of water from concretion (59.7 cc)

[Reaction: Faintly acid to litmus]

	Grams per liter	Equivalents		Grams per liter	Equivalents
Fe''	1.973	0.0706	Cl	2.668	0.0752
Fe'''	.055	.0030	SO_4	1.234	.0257
Al	.085	.0095	HCO_3 (calc.)	.024	.0039
Mn	.350	.0127			
Mg	.039	.0032			
Ca	.093	.0046			
Na	.027	.0012			
		.1048			.1048

Analysis of siderite from interior of cavity

Organic matter	Trace
SiO_2	0. 58
FeO	61. 42
MgO	. 05
CaO	. 03
MnO	. 21
CO_2 (calc.)	37. 82
Total	100. 11

Another concretion, which was simply broken open, was found to contain a fine sediment of siderite and organic matter, and a little fluid, but this solution showed much less chloride and sulphate than the solution in the other concretion.

ORIGIN OF THE SOUTH BASIN ORES

The origin of the South Basin ores is apparently a special case of the situation outlined above and is related to the fact that the Weches of the South Basin contains much more clay and is in general finer textured than that farther north. A generalized section through the ore deposits of this basin is given below.

Generalized section through ore deposits of the South Basin

	Ft.	*in.*
1. Unconsolidated quartz sand (Sparta)	1–50	
2. Thin hard ferruginous sandstone, "frozen" to ore (basal Sparta)		1–6
3. Laminated brown ore. Iron-ore horizon		1–6
4. "Buff crumbly" or "curly" brown ore, with notably irregular and botryoidal lower surface. Iron-ore horizon		2–54
5. White clay, with upper and lower boundaries roughly parallel to lower contact of ore bed		2–18
6. Oxidized greensand, grading downward from nearly pure light-colored clay to fresh greensand and containing several thin beds of low-grade brown ore each of which is underlain by clay similar to overlying white clay	5–20	
7. Unaltered greensand, with occasional ledges or concretions of siderite near top of zone and containing a little pyrite in places	5–20	
8. Light-colored siliceous sand (Queen City).		

The chief distinction between the North Basin and South Basin ores lies in the fact that in the South Basin a single bed of ore occurs at the top of the Weches member near the outcrop. This bed is everywhere underlain by white clay. The few thin beds of limonitic material that occur in places below the top are sporadic in occurrence and generally too low in grade to be of interest as iron ore, but they, too, are underlain by white clay. In most places this clay grades downward to partly altered greensand. The clay exhibits relics of the oolitic greensand structure (pl. 14, *A*) and is believed to represent thoroughly leached greensand from which nearly all the iron has been removed by ground water.

The areal distribution of the persistent brown-ore zone at the top of the Weches and the relations that exist between this ore and the thickness of the overlying Sparta sand have been treated in the foregoing description of the laminated and buff crumbly ores (pp. 38–41). Any theory of the origin of the ore must take into consideration the persistence of the ore at the outcrop over an area of several hundred square miles and the virtual absence of ore where the greensand is covered by more than 10 or 15 feet of sand.

Water-table conditions in the South Basin are similar to those in the North Basin except that most of the hills are covered by so great a thickness of Sparta sand that the water table is more generally situated at or above the top of the Weches section. (See *a*, fig. 1.) The finer texture of the Weches in the South Basin makes it relatively less permeable to the flow of ground water, and lateral and vertical variations in the character of the greensand are not as marked nor as abrupt as those in the North Basin. This uniformity in mineral and chemical composition has apparently led to more uniformity in the grade and character of the resulting iron ores.

It seems reasonable to suppose that the brown ores were derived from the Weches greensands by weathering processes in a manner similar to that which formed the North Basin ores. The ground waters are probably of the same general character as those in the North Basin—that is, they contain carbon dioxide derived from the air and from decaying vegetation and sulphuric acid derived from oxidation of pyrite in the Sparta and Weches sands.

The waters probably begin to leach iron from the greensand at a considerable distance away from the outcrop and carry it toward the edges of the hills. However, instead of deposition during lateral or downward migration it is necessary to suppose that the complete leaching of the greensand to yield white clay and the deposition of the layer of iron ore must be effected by solutions that are carried upward by capillary force. During dry periods when the water table near the outcrop sinks below the top of the Weches for distances ranging from a few inches to 5 or 6 feet, water moves upward through the capillary fringe and finally deposits the iron as siderite or as brown ore, in part by escape of carbon dioxide and in part by evaporation or transpiration of the water close to the surface. The excess of silica and alumina over that left in the iron ore and white clay may be flushed out during periods of high water table, or it may possibly be drawn downward by the receding capillary waters when the water table drops to still lower levels. The thin beds and crusts of brown ore that underlie the top bed are probably formed by the same process during periods when the water table is at lower horizons.

The fine, even texture of the glauconitic clay and sand presents ideal conditions for the rise of water by capillarity, though it tends to prevent downward migration of water. The iron-bearing solutions cannot penetrate the Sparta sands and deposit limonite there because the relative coarseness and greater porosity of the quartz sand prevent capillary rise for more than a few inches at most. Though some investigators have presented evidence to show that the range of capillary movement is comparatively small,[35] it is fairly well established that in fine-grained material, such as that of the Weches greensand of the South Basin, water can rise by capillarity to heights of 5 to 10 feet.[36]

Both Robinson [37] and Harrassowitz [38] describe conditions similar to those outlined above, under which an inverted soil profile may be developed, the iron being carried toward the surface and deposited by capillary waters.

The theory of the deposition of iron ore during periods of capillary rise above a fluctuating water table appears to be the only one that fully explains the presence of ore underlain by thoroughly leached greensand at the top of the Weches and the presence of thinner but similar layers of ore beneath the top ore bed. No ore should be expected under heavy cover, because the water table occurs at or above the top of the Weches section where the cover of Sparta sand is thick. Again, even if the water table were low enough to allow capillary rise, the water would have no means of egress to the surface, and as it could not be removed the system would remain static, thus preventing the continued addition of iron from solution. Ore can therefore be formed only in areas close to the outcrop or where the overburden is light.

Whether all the ore has gone through the carbonate stage is not certain. The relatively greater density and lack of porosity of the South Basin ore suggests that it has not, but it is difficult to explain the transportation of large quantities of iron by other means than ferrous bicarbonate or sulphate solutions. Coarse crystals of siderite have been observed in a few places embedded in massive brown ore and, together with the sporadic occurrence of siderite in the lower greensand beds, show clearly that at least some of the brown ore has been derived from iron carbonate. Some iron may also have traveled

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[35] Keen, B. A., The limited role of capillarity in supplying water to plant roots: Internat. Cong. Soil Sci. Proc., vol. 1, pp. 504–511, 1923.

[36] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, pp. 31–38, 1923.

[37] Robinson, G. W., Soils, their origin, constitution, and classification, p. 59, New York, D. Van Nostrand Co., 1932.

[38] Harrassowitz, H. H., Laterit, Material und Versuch erdgeschichtlicher Auswertung: Fortschr. Geologie u. Paleontologie, Band 4, pp. 253–566, 1926.

in solution either as bicarbonate or as sulphate and been deposited in its present form, limonite, through oxidation and removal of the carbon dioxide at the time of deposition.

The vertical veins of ore that occur in places were probably formed by waters that abstracted iron from nearby greensand and deposited it along fractures or faults. The general absence of white clay along the walls of the veins suggests that the iron was transported for some distance laterally, rather than that it was formed from the immediately adjacent greensand; but the similarity in structure of the veins to that of the horizontal ore beds indicates that they have been formed by the same or similar processes.

No explanation of the origin of the laminated ore above the buff crumbly ore is apparent, but it may be suggested that the laminated ore was deposited first, by solutions somewhat richer in iron than those which later formed the crumbly ore. Such a difference in composition might lead to the formation of somewhat different products. Again, the uppermost part of the Weches greensand may possibly have consisted of thin-bedded or laminated materials including some clay, which were replaced more or less differentially.

It is hardly possible that the iron has been derived from overlying ferruginous formations, for the very thick overlying Sparta sand contains but little ferruginous material except locally.

The possibility that the iron ores are of bog origin is suggested by some of the field relations, but careful study of all the evidence makes this explanation seem extremely doubtful. The fact that the iron ore occurs only near the outcrop or under thin cover is of itself convincing evidence in opposition to the theory of bog origin. Furthermore, the existence of a plane surface sufficiently smooth to allow the formation of a thin film of bog ore from 2 inches to 3 or 4 feet thick over hundreds of square miles is possible but very improbable in a series of Coastal Plain sediments.

Penrose offered still another explanation of the origin of the South Basin ores.[39] He thought that the iron ore might have been formed from the decomposition of pyrite or iron sulphide and ascribed only a small part of the iron to the greensand. He said:

> The natural conclusion from these facts is that the presence of iron, the removal of shells, the alteration of glauconite, and the accompaniment of iron pyrites are closely connected phenomena; and everything goes to show that they are not only closely connected but are absolutely dependent on each other. The explanation seems to be that the change results from the decomposition of iron pyrites. The decomposition of this mineral gives rise to sulphate of iron and sulphuric acid. The sulphate of iron is either carried off in surface waters or decomposed on the spot into hydrous peroxide, the basis of the iron ore of the region. The sulphuric acid, set free by the decomposition of the pyrites, attacks the fossil shells, which are composed largely of carbonate of lime, and forms carbonic acid

[39] Penrose, R. A. F., Jr., op. cit., pp. 72-76.

and sulphate of lime (gypsum). It also attacks the glauconite, decomposing it either partially or wholly, and converts it into the yellow indurated mass seen everywhere in the iron-ore region. In many places, however, iron pyrite has not produced the whole of the iron-ore bed but has been assisted by the decomposition of the glauconite, which itself contains over 20 percent of metallic iron. When the pyrite is absent this does not decompose easily, but the continued action on it of sulphuric acid, from the decomposition of the pyrites, causes it gradually to break up into its various constitutents.

In support of his theory, Penrose recorded a section measured in a pit 2 miles east of Alto, Cherokee County, where the beds are but slightly altered and contain little or no iron ore. The section shows that the sand that immediately overlies the glauconitic sand and clay (at the top of the Weches?) contains an abundance of disseminated pyrite and considerable lignitic material.

The theory fits all the observed facts in regard to form and character of the iron-ore bed. Furthermore, it ascribes the ore to the action of downward-moving waters, a somewhat simpler concept than that advanced in this paper, which involves the rise of ground waters by capillary force. One almost insurmountable objection to Penrose's theory can be made, however. There is little or no evidence to support his thesis that enough pyrite is almost universally present at the top of the Weches or in the lower parts of the Sparta to explain the relatively large amount of ore that occurs at this horizon. Some pyrite is present here and there throughout the greensand, and some is probably also present in the Sparta sand. Very few of the many natural and artificial exposures that have been examined by the writer or by other geologists contain enough pyrite to yield even a thin bed of ore, to say nothing of beds 3 to 5 feet thick.

AGE OF THE ORES

There is much evidence to show that most if not all the ores are of very recent origin. Unquestionably the formation of brown ores has been going on since early Tertiary time. Water-worn pebbles of limonitic material in the Queen City sand indicate that either just before or during Queen City time iron ores were being formed from older greensand. The formation of ores from the Weches greensand has probably gone on intermittently ever since the Weches first emerged, with breaks due to later submergences. But the ore was formed only on exposed areas and was eroded almost as fast as it was formed. The presence of fresh greensand under heavy overburden and of carbonate at or near the present water table indicates this history clearly. As soon as the cover of Sparta sand became thin enough to allow the formation of iron ore, the older ore at the outcrop was eroded, thus producing an ever fresh exposure of greensand to the action of the weather.

SIGNIFICANCE OF GENETIC THEORIES

If the foregoing interpretations of the origin of the iron ores are correct, they lead to several conclusions that are of importance in prospecting or in making tonnage estimates. A close relationship between the best iron ores and the Weches greensand is established, and this fact alone sharply delimits the area in which commercial deposits can be expected, as well as fixing the lower limit of prospecting. That little ore is to be expected beneath heavy overburdens of sand seems rather clearly established both from field observations and from theoretical considerations. The facts that a granular phase of the greensand in conjunction with a low water table means in general a strong development of ore, and that clayey greensand, with a correspondingly high water table, means a weak development of ore are of the greatest importance. Thus a simple observation that springs issue from the top of the Weches greensand rather than from its base leads directly to the expectation that the associated iron-ore deposits are not likely to be as rich nor as thick as elsewhere.

QUALITY OF THE ORES

As the average quality of a given deposit of iron ore, including the character and amount of impurities, is the primary factor in determining the ultimate usefulness of the ore in the furnace, knowledge of the grade of actual shipping ore is even more important than estimates of available tonnage. If the ore is rich and contains a minimum of undesirable impurities, even a small deposit may eventually be used, but if the ore is of too low grade to justify beneficiation even very large deposits must remain untouched.

NORTH BASIN BROWN ORES

The results of analyses of samples of brown ore from various deposits in the North Basin are given in the following table, Nos. 1 to 35, inclusive. With the exception of two or three samples that were specially picked to show the grade or character of some particular type of ore, all the samples are believed to be truly representative. As less than half of them were washed, however, direct comparison is impossible. Where prospect pits or other openings were available the samples represent the entire section of brown ore, but where no such exposures were found, representative samples of the outcropping ore were taken. The unwashed samples are probably very similar to the lump ore that could be shipped without washing.

Chemical analyses of brown iron ores in North Basin and South Basin, eastern Texas

	1	2	3	4	5	6	7	8	9	10
SiO_2	20.14	7.77	8.03	11.91	12.40	8.24	9.74	10.04	22.83	13.31
Al_2O_3	5.23	4.61	4.88	2.31	4.58	4.21	5.46	4.85	4.62	6.45
Fe_2O_3	61.28	74.67	74.16	70.41	70.71	74.57	71.22	70.91	61.15	66.47
FeO	(1)	-------	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
MgO	(1)	-------	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CaO	(1)	-------	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
H_2O+	12.11	12.46	12.90	12.81	12.46	13.10	11.90	12.82	10.83	13.11
TiO_2	.15	.15	.15	.15	.14	.15	.15	.15	.16	.21
CO_2	.02	.02	.02	.02	.02	.02	.02	.50	.02	.02
P_2O_5	.23	.21	.25	.31	.17	.17	.22	.22	.22	.29
S	.03	.03	.06	.03	.05	.05	.03	.03	-------	.06
MnO	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Total	99.19	99.92	100.45	97.95	100.53	100.51	98.74	99.52	99.89	99.92
Metallic iron (Fe)	42.8	52.2	51.8	49.2	49.4	52.1	49.8	49.6	42.7	46.5
Phosphorus (P)	.10	.09	.11	.14	.07	.07	.10	.10	.10	.13

	11	12	13	14	15	16	17	18	19	20
SiO_2	18.20	13.54	2.24	20.28	23.07	23.03	11.10	15.72	15.88	19.72
Al_2O_3	4.33	5.26	1.04	6.42	3.41	5.16	4.88	8.73	3.91	3.99
Fe_2O_3	64.52	70.16	85.62	61.52	60.87	58.33	70.28	61.44	68.69	64.01
FeO	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
MgO	(1)	.11	(1)	(1)	(1)	(1)	(1)	(1)	.04	.06
CaO	(1)	.06	(1)	(1)	(1)	(1)	(1)	(1)	.06	.08
H_2O-	-------	1.19	-------	-------	-------	-------	-------	-------	1.00	1.09
H_2O+	10.88	9.67	10.72	12.01	11.33	11.67	12.80	13.39	10.42	11.08
TiO_2	.18	.10	.07	.12	.16	.21	.17	.19	.08	.08
CO_2	.02	Small	.50	.02	.02	.02	None	.02	Small	Small
P_2O_5	.25	.20	.15	.08	.18	.21	.24	.76	.14	.13
S	.03	.04	.05	.05	.05	.03	.09	.03	.04	.10
MnO	(1)	.06	(1)	(1)	(1)	(1)	(1)	(1)	.08	.06
Total	98.41	[2] 100.39	100.39	100.50	99.09	98.66	99.56	100.28	[2] 100.34	[2] 100.40
Metallic iron (Fe)	45.2	49.0	59.8	43.0	42.5	40.7	49.1	42.9	48.0	44.7
Phosphorus (P)	.11	.09	.07	.04	.08	.11	.03	.06	.06	.11

	21	22	23	24	25	26	27	28	29	30
SiO_2	15.96	19.76	14.92	9.98	13.10	13.70	12.64	19.60	3.08	19.53
Al_2O_3	4.51	4.42	4.94	6.38	7.65	6.13	3.64	4.04	2.41	3.93
Fe_2O_3	67.45	62.30	68.82	72.20	66.23	66.73	70.07	63.64	82.93	65.44
FeO	(1)	(1)	(1)	(1)	(1)	(1)	.14	.40	.27	.40
MgO	.13	.16	.21	.12	.08	.14	[3] None	[3] None	[3] None	[3] None
CaO	.14	.02	None	.10	.04	.08	[3] None	[3] None	[3] None	[3] None
H_2O-	1.51	1.04	1.19	1.27	1.23	1.75	1.12	1.12	.72	.82
H_2O+	10.44	12.15	10.23	10.33	11.56	11.59	[4] 11.55	[4] 10.53	[4] 10.60	[4] 9.76
TiO_2	.08	.30	.14	.14	.20	.16	.22	.11	.11	.09
CO_2	Small	Slight	Small	Small	Small	Small	[5] Present	[5] Present	[5] Present	[5] Present
P_2O_5	.26	.35	.21	.14	.46	.40	.20	.26	.11	.18
S	.04	.03	.10	.09	.03	.04	.06	.07	.12	.10
MnO	.09	.08	.11	.03	.05	.03	.10	.07	.06	.02
Total	[2] 100.61	[2] 100.61	[2] 100.87	[2] 100.78	[2] 100.63	[2] 100.75	99.74	99.84	100.41	100.27
Metallic iron (Fe)	47.4	43.5	48.1	50.4	46.3	46.6	49.1	44.8	58.2	47.9
Phosphorus (P)	.15	.15	.09	.06	.20	.18	.09	.11	.05	.08

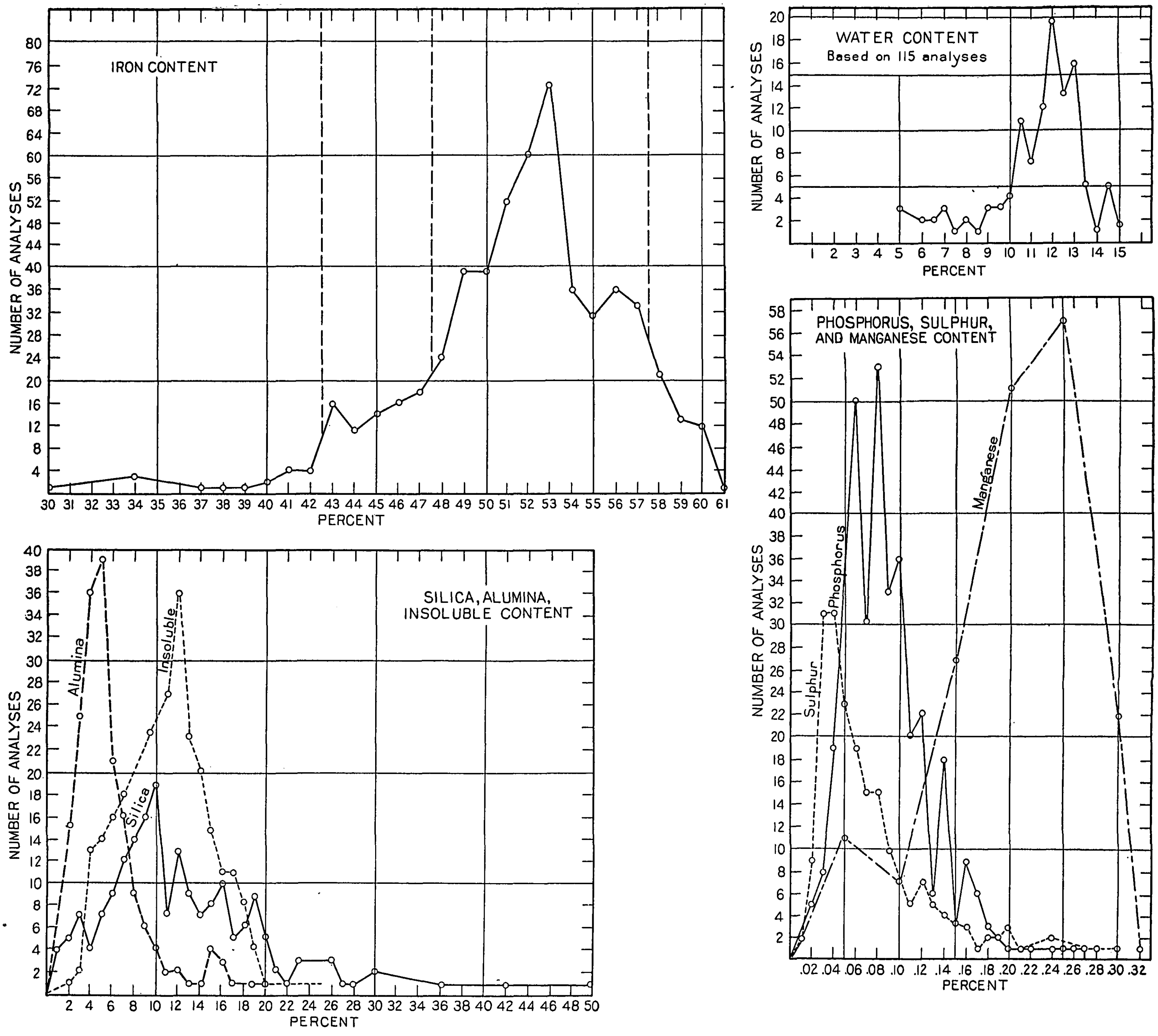
See footnotes at end of table.

Chemical analyses of brown iron ores in North Basin and South Basin, eastern Texas—Continued

	31	32	33	34	35	36	37	38	39	40	41
SiO_2	9.24	16.16	10.96	9.72	21.33	10.71	11.05	9.38	11.73	13.80	16.25
Al_2O_3	5.88	3.48	3.74	5.63	4.86	8.27	11.39	8.24	10.60	10.13	11.21
Fe_2O_3	69.40	67.88	72.45	70.29	59.06	68.03	61.46	67.02	63.10	60.05	51.83
FeO	(1)	(1)	.27	.51	.34	.07	.53	.32	.36	.27	2.63
MgO	.16	.11	[3] None	[3] None	[3] None	(1)	(1)	(1)	(1)	(1)	(1)
CaO	.08	.02	[3] None	[3] None	[3] None	(1)	(1)	(1)	(1)	(1)	(1)
H_2O-	1.58	1.07	1.07	1.30	1.98	.85	2.18	2.18	1.57	2.38	3.01
H_2O+	13.33	11.28	[4] 10.90	[4] 12.38	[4] 11.52	11.19	12.48	12.08	12.07	11.47	11.09
TiO_2	.10	.10	.14	.19	.30	.12	.24	.28	.12	.27	.18
CO_2	Tr.	Small	[5] Present	[5] Present	[5] Present	Tr.	Present	Tr.	Tr.	Present	.97
P_2O_5	.28	.56	.19	.18	.14	.46	.53	.34	.25	.53	.39
S	.03	.03	.09	.13	.19	(1)	(1)	(1)	(1)	(1)	(1)
MnO	.02	.01	.06	.03	None	Tr.	.04	None	None	.04	.14
Total	[2] 100.10	[2] 100.70	99.87	100.36	99.72	100.10	99.90	99.84	99.80	98.94	97.70
Metallic iron (Fe)	48.5	47.4	50.8	49.5	41.5	47.6	43.3	47.0	44.4	42.2	38.1
Phosphorus (P)	.12	.25	.08	.08	.06	.20	.23	.15	.11	.23	.17

[1] Not determined.
[2] The high totals are probably due to the fact that only 1 reprecipitation of Fe_2O_3 was made. Any error from retained soda would fall on the Al_2O_3.
[3] Qualitative tests showed that either MgO or CaO if present at all in any of the samples was very small, not over one- or two-tenths of 1 percent.
[4] From loss of weight on ignition and therefore including the small amount of CO_2 present.
[5] Identified by qualitative tests, which indicate presence of two- or three-tenths of 1 percent in each sample.

1. Typical unwashed brown ore from east end of Bowie Hill, 7.5 miles north of Atlanta.
2. Typical unwashed brown ore at surface of west part of Bowie Hill.
3. Unwashed brown ore from dump of large trench on Bowie Hill.
4. Buff crumbly ore, cleaned, from outcrops on Hickory Hill, 7.5 miles northwest of Atlanta.
5, 6. Typical unwashed brown ore from Bivins district, 1.5 miles west of Bivins. Ocherous and somewhat sandy, with streaks of very good ore.
7. Typical unwashed brown ore from central part of Waters district, 5 miles northwest of Atlanta.
8. Typical unwashed brown ore from Atlanta district, 1.5 miles northwest of Atlanta.
9. Low-grade unwashed brown ore from northwestern part of Surratt district, 4.5 miles north of Linden.
10. Typical unwashed brown ore from trench on west side of Bowman Creek, Surratt district.
11. Typical unwashed brown ore from near surface in eastern part of Prewitt district, 6 miles southeast of Linden.
12. Unwashed brown ore, average of six samples from various pits and trenches in central and western part of Prewitt district.
13. High-grade picked concretionary ore from near surface on Nigger Hill, Jurnigan Hill district, 5 miles south of Linden.
14. Typical cellular brown ore, unwashed, from southern part of Jurnigan Hill.
15. Representative unwashed brown ore from largest trench in Harris district, 9 miles southeast of Linden.
16. Representative sample from 7-foot thickness of brown ore near center of easternmost trench in Harris district, 9 miles southeast of Linden. Not washed.
17. Typical unwashed brown ore from Concord School district, 8 miles west of Linden. Average of samples from 10 pits.
18. Flinty laminated brown ore from largest hill in Concord School district. Picked sample.
19. Representative unwashed brown ore from John Davis district, 2 miles southwest of Linden. Average of samples from seven pits.
20. Representative unwashed brown ore from Lanier district. From outcrop in road 0.9 mile west of Lanier.
21. Unwashed brown ore from western part of Hagerty Hill, on Cass and Marion County line, 8 miles north of Jefferson.
22. Washed brown ore from small hill 2.75 miles northeast of Hughes Springs. Surface sample.
23. Washed brown ore from hill 2 miles N. 70° E. of Hughes Springs. Surface sample. Nos. 22 and 23 are representative of ore throughout the Chambers-Hughes district.
24. Washed brown ore from trench in western part of Ed West district, 2 miles northwest of Hughes Springs.
25. Washed brown ore from north end of Norwood Hill, 3.5 miles northeast of Hughes Springs. Surface sample.
26. Washed brown ore from gravel pit half a mile northeast of Hughes Springs. Representative of clean ore on Hooten Hill and adjacent areas.
27. Washed brown ore from small deposit 2 miles due east of Hughes Springs. Representative sample from pit.
28. Washed brown ore from vicinity of Harris Chapel, 4 miles south of Hughes Springs. Surface sample.
29. Washed brown ore from Spring Hill district, 4 miles south of Hughes Springs. Representative of surface ore.
30. Washed brown ore from hill 1.25 miles northeast of Avinger. Representative of surface ore.
31. Washed brown ore from gravel pit at Veals Switch, Morris County.
32. Washed brown ore from gravel pits on southeastern part of Daingerfield Hill, 1 mile northwest of Daingerfield
33. Washed brown ore from various parts of Morris County line district. Average of six surface samples.
34. Washed brown ore from main part of Gilbert tract, Marion County. Representative sample from old mine cut.
35. Washed light-brown flinty ore from small hill in southeastern part of Gilbert tract. Representative surface sample.



CURVES SHOWING RANGE IN CONTENT OF PRINCIPAL CONSTITUENTS OF NORTH BASIN BROWN ORES.

Based on 561 analyses and partial analyses, most of which represent washed samples of ore. Analyses compiled from all available sources. (See pp. 59–62.)

36. Laminated brown ore from west end of Mount Haven, 2 miles west of Jacksonville, Cherokee County. Representative of a solid 50-pound block of ore.
37. Buff crumbly ore from same locality as 36. Representative of a solid 50-pound block of ore.
38. Buff crumbly ore from road cut 4.8 miles northwest of Rusk, Cherokee County.
39. Typical brown ore, including laminated and buff crumbly varieties, from State ore mine, 2 miles northeast of Rusk.
40. Brown ore recovered by washing representative sample from 18-foot thickness of ore-bearing material. From road cut 1.3 miles north of Rusk.
41. Brown ore and carbonate ore recovered by washing representative sample from 28-foot thickness of ore-bearing material. From road cut 4.8 miles north of Jacksonville.
Analyses 1–11 and 13–18 by J. J. Fahey, Geological Survey, reported November 24, 1934; analyses 12, 19–26, 31, and 32 by E. T. Erickson, Geological Survey, reported November 2, 1934; analyses 27–30 and 33–35 by George Steiger, Geological Survey, reported November 2, 1934; analyses 36 to 41 by R. E. Stevens, Geological Survey, reported January 8, 1935.

"Unwashed" samples were taken by breaking off fragments of ore from exposed surfaces. They include sand and clay that occurred in cavities of the ore but not the sand and clay that occurred as layers between distinct ledges or masses of brown ore. The "washed" samples were crushed to about ½-inch mesh and washed by panning in water. No effort was made to remove lumps of hard oxidized greensand from the crushed samples, but all fine sand and clay were washed out.

An attempt was made to determine the average quality of the ores, using all available analyses. The results are shown on plate 15. In all, 561 complete and partial analyses were collected. Convenient percentage units of the various constituents are plotted on the horizontal coordinates. On the vertical coordinates are plotted the actual number of analyses for each of these units—not the percentage of the total number of analyses. For example, 73 of the 561 analyses showed 53 percent of metallic iron. Significant breaks and maxima appear in all the curves.

Of the 561 analyses used in compiling the iron content curve, 47, or 8.3 percent of the total, show 58 percent or more of iron. They probably represent carefully picked specimens of high-grade ore. Four hundred and twenty-three analyses, or 75.5 percent of the total, show from 48 to 57 percent of iron. They probably represent washed ore in large part. Seventy-five analyses, or 13.2 percent of the total, show 43 to 47 percent of iron and probably represent both low-grade washed ore and high-grade unwashed ore-bearing material. Seventeen analyses, or 3 percent of the total, show less than 43 percent of iron. They probably represent unwashed ore-bearing material or ferruginous sandstone. Two analyses that showed an iron content of 25.22 and 26.59 percent, respectively, were excluded from the compilation.

The silica content curve is based on 197 analyses, 128 of which, or 65 percent of the total, show 12 percent or less of silica. The alumina content curve is based on 194 analyses, 161 of which, or 83 percent of the total, show 7 percent or less of alumina. The insoluble content curve is based on 283 analyses, 244 of which, or 81 percent of the total, show 15 percent or less of insoluble material. The insoluble content, as commonly determined, is usually somewhat less than the sum of silica and alumina. In the analyses used for compiling this curve silica and alumina were not determined separately. The phosphorus content curve is based on 361 analyses, of which 235, or 65 percent of the total, show 0.10 percent or less of phosphorus. Twenty-six analyses, which reported "traces" of phosphorus were excluded. The sulphur content curve is based on 204 analyses, of which 163, or 80 percent of the total, show 0.10 percent or less of sulphur. Three analyses showing sulphur content of 0.46, 0.62, and 0.99, respectively, and 7 analyses which reported "traces" of sulphur were excluded in the compilation. The manganese content curve is based on 183 analyses, 131 of which, or 71.5 percent of the total, show from 0.15 to 0.30 percent manganese.

The curves do not show the relations between the various constituents, but with the exception of phosphorus and sulphur, which appear to vary independently, all the constituents may be said to vary inversely with the percentage of iron. This type of treatment seems much more desirable than an arithmetical average of all the analyses, as it shows the range in content of all the important constituents as well as indicating the average grade of the ore. The sources of the analyses are given below.

Source of analyses used in making up plate 15

Source	Character of samples	Number of analyses
Penrose, R. A. F., Jr., Texas Geol. Survey 1st Ann. Rept., for 1889, pp. 65–86, 1890.	Representative samples, unwashed, probably all from surface exposures.	14
Dumble, E. T., Kennedy, William, and others, Texas Geol. Survey 2d. Ann. Rept., for 1890, pp. 7–326, 1891.	Representative samples, unwashed, from all commercially valuable deposits in North Basin. Probably all from surface exposures.	57
Schoch, E. P., Chemical analyses of Texas rocks and minerals; Texas Univ. Bull 1814, pp. 199–201, 1918.	Samples, unwashed (?), from various localities. Also includes most of the analyses published by Penrose and Dumble.	9
This report; see table, pp. 57–59	18 unwashed and 17 washed samples representative of most of the commercially valuable deposits in North Basin. Unwashed samples contain some clay and sand but are typical of lump ores.	35
East Texas Brown Ore Development Co.; courtesy of Col. L. P. Featherstone.	Analyses of unwashed (?) samples from various properties in Morris, Marion, and southwestern Cass Counties as contained in reports of engineers to the company. Two of the analyses represent a 600-ton shipment of ore. Most of the others were made on surface samples.	143
East Texas Iron Co.; courtesy of Messrs. Charles Denby, Jr., and Brandon Barringer.	Thoroughly washed representative samples from all the company's properties in Cass County. Analyses made by company chemist.	276
Linton, Robert, Eng. and Min. Jour., vol. 96, no. 25, pp. 1153–1156, 1913.	Washed samples from various deposits in North Basin.	10
Other sources, mostly of a confidential nature.	In large part each analysis represents average of a number of analyses, which were made on carefully washed, truly representative samples of the entire section of brown ore. From Cass, Marion, and Morris Counties.	24

It is apparent that the analyses are based on samples selected by several groups with widely differing viewpoints. The State and Federal survey organizations presumably have a professional rather than a commercial interest in the grade of the ore. On the other hand, groups that are interested in both acquiring and disposing of ore lands are represented in the list. It is believed that the net result of a compilation of many analyses from these varied sources should approach a true picture of the range in grade of the ores. Elimination of any one group of these analyses would not appreciably alter the shape of the curves.

Some of the analyses were obviously made on unwashed samples of very low grade; others on carefully picked samples of high-grade concretionary ore. Most of them, however, represent either washed samples or lump ore such as would form the bulk of the shipping ores from the district. A study of plate 15 indicates that although there is a wide range in the composition of the North Basin ores, a large proportion of the analyzed samples fall within the limits indicated below.

Composition of average brown ore in North Basin

[Derived from plate 15]

	Percent
Iron	48–57
Silica	5–13
Alumina	2–7
Phosphorus	0. 04–0. 12
Sulphur	0. 02–0. 10
Manganese	0. 15–0. 30
Water	10–13

These figures are based on a great number of analyses, the antecedents of many of which are known only in a general way. Whether actual mining operations would yield a product within the range of composition indicated seems doubtful. The general experience in brown-ore mining is that the grade of ore indicated during prospecting campaigns is seldom realized in actual mining operations. This difference is due to many causes, some of which are common to all methods of sampling. One of the chief causes is perhaps the fact that the small prospect samples are likely to be more carefully washed than the shipping ores. Another factor of great importance in the Texas field is the general occurrence of enriched ore near the present surface. Without careful and expensive prospecting and sampling of the entire brown-ore section, the grade of the ores as indicated by analyses is almost certain to be deceptively high. According to a mining engineer who has had an exceptionally good opportunity to study the Texas deposits, the average shipping ore will probably contain about 45 percent of iron, with correspondingly high impurities. His figure is possibly closer to the truth than that indicated by plate 15.

Observations throughout the field lead the writer to the firm conviction that in general the iron ores in eastern and central Cass County are of somewhat higher grade than those farther west and southwest.

Detailed sampling by uniform methods throughout the district is essential in order to prove this statement, however.

Even though the ores may be somewhat lower in grade than is indicated by plate 15, there is no question that they are desirable from the furnace man's standpoint. The iron content is well within commercial limits; the manganese is relatively low, sulphur is somewhat lower, and phosphorus is considerably lower than is usual in this class of ores. Some of the ore, but by no means all of it, is of Bessemer quality. Alumina and silica are both somewhat higher than is desirable, however. Furthermore, the variation in content of all constituents, particularly of phosphorus and sulphur, indicates a serious lack of uniformity in the shipping product unless very large operations and thorough roasting of the ore to remove sulphur are adopted.

NORTH BASIN CARBONATE ORES

All available analyses of the North Basin carbonate ores are presented in the following table. The samples taken by the writer were carefully cleaned before analysis and are therefore probably of somewhat higher grade than could be expected in the average shipping ores. Most of the other analyses in the table represent washed samples of typical ore. The fact that much of the carbonate is partly altered to limonite accounts for most of the variation in the content of carbon dioxide and of ferric and ferrous iron. At first glance the carbonate ores seem to be of much lower grade than the brown ores, but this difference is due largely to the presence of 25 to 35 percent of carbon dioxide, which is easily removed by roasting the ores, leaving a product as high in quality as the best brown ores. The wide variation in the amount of sulphur shown by the analyses is probably due to the presence of pyrite in some of the carbonate samples. The sporadic occurrence of this element, which is undesirable in the furnace, is disturbing and indicates that thorough roasting of most of the ores to remove sulphur as well as carbon dioxide will be essential.

Analyses of North Basin carbonate ores

	1	2	3	4	5	6	7	8	9	10
SiO_2	15.60	11.69	4.39	9.59	5.23	1.64	1.98	4.07	1.10	2.5
Al_2O_3	3.09	1.22	3.15	4.03	3.66	1.98	1.40	.30	1.02	1.7
Fe_2O_3	13.38	47.65	4.96	3.67	2.05	3.02	4.49	5.23	--------	--------
FeO	37.95	19.06	51.63	48.63	52.94	56.96	54.03	55.30	--------	--------
MgO	.37	.02	--------	--------	--------	--------	--------	.03	--------	--------
CaO	.90	None	--------	--------	--------	--------	--------	None	.16	--------
CO_2	22.79	11.04	31.01	28.85	32.24	34.95	34.40	33.30	36.54	--------
P_2O_5	.94	.50	.19	.35	.32	None	.16	.20	--------	--------
S	.01	.01	--------	--------	--------	--------	--------	.02	.05	.096
MnO	.23	.23	--------	--------	--------	--------	--------	.16	--------	--------
C	--------	--------	.38	.31	.36	.23	.25	--------	--------	--------
H_2O	4.16	8.06	--------	--------	--------	--------	--------	.89	[1] .15 [2] 1.05	--------
Total	99.42	99.48	97.69	98.05	98.74	100.10	98.13	99.50	--------	--------
Metallic iron	38.88	48.14	43.66	40.37	42.68	46.40	45.19	46.76	46.44	48.1
Phosphorus	.04	.02	.08	.15	.14	None	.07	.09	.05	.043
Manganese	.18	.18	--------	--------	--------	--------	--------	.12	.10	.20

	11	12	13	14	15	16	17	18	19	20
SiO_2	10.58	8.01	4.85	10.34	4.26	10.73	10.37	8.25	13.09	10.15
Al_2O_3	3.33	2.73	2.94	6.00	2.38	4.49	4.00	3.16	2.93	3.00
S	.38	.231	.461	--------	--------	--------	.092	.200	.150	.90
Metallic iron	43.47	41.63	43.61	40.83	45.52	41.49	40.20	41.83	40.08	41.78
Phosphorus	.07	.078	.140	--------	--------	.130	.155	.106	.141	--------

	21	22	23	24	25	26	27	28	29	30	31
SiO_2	11.58	11.15	12.66	9.00	14.40	11.78	9.44	6.87	11.53	11.76	15.57
Al_2O_3	2.89	2.81	3.75	2.92	4.07	3.87	3.01	2.20	3.38	3.57	5.10
S	.338	.289	--------	--------	--------	--------	--------	--------	--------	--------	--------
Metallic iron	40.69	42.01	40.01	41.88	38.86	43.36	42.03	43.60	41.00	40.67	37.91

[1] Water driven off below 100° C.
[2] Water driven off above 100° C.

1, 2. Partly oxidized cleaned carbonate ore, southeastern Morris County, 5 miles S. 30° W. of Hughes Springs. Analyst, Charles Milton, Geological Survey, 1934.
3. Average grade cleaned carbonate ore, Surratt district, 4½ miles north of Linden, Cass County. Analyst, Jos. J. Fahey, Geological Survey, 1934.
4, 5. High-grade carbonate ore, same locality as 3.
6. Cleaned carbonate ore, Prewitt district, 6 miles southeast of Linden, Cass County. Analyst, Jos. J. Fahey, Geological Survey, 1934.
7, 8. Cleaned carbonate ore, 1½ miles southeast of Lanier, Cass County. Analysts, Jos. J. Fahey and Charles Milton, Geological Survey, 1934.
9. Average sample cleaned carbonate ore from vicinity of Linden. Burchard, E. F., U. S. Geol. Survey Bull. 620, p. 86, 1915.
10–31. Washed carbonate ores from various localities in Cass, Marion, and Morris Counties. Furnished by private companies.

SOUTH BASIN BROWN ORES

Several analyses of the main ore bed in the South Basin are given in the table on page 58, Nos. 36–39. Many other analyses are given by Penrose, Dumble, Kennedy, and Schoch in the publications already cited (p. 60). Analyses 40 and 41, page 58, were made on the material obtained by washing representative samples from the whole oxidized portion of the Weches greensand. They are further discussed in the description of the ore deposits of Cherokee County. It is not possible to compile curves similar to plate 15 showing the range in composition of the South Basin ore. First, too few analyses are available to obtain accurate curves. In such a compilation the greater the number of analyses the greater is the probable accuracy of the final results. Second, too much confusion exists as to the character of the samples. The term "laminated ore" may refer to the main ore bed at the top of the Weches, but it may also denote the thin sandy laminae of brown ore that occur in the lower Weches beds or in the Reklaw. Again, "massive brown ore" may refer to the typical buff crumbly ore or else to concretions or masses of ore in Weches or Reklaw beds. Trial curves that were prepared failed to show the maxima that characterize plate 15. It is believed that analyses 36 to 39, page 58, are typical of a large part of the main ore bed in the South Basin. If so, the approximate range in composition of the ores is probably represented in the table below. The figures for sulphur and manganese in this table are based on averages of the few published analyses known to be representative.

Probable range in composition of the South Basin laminated and buff crumbly ores

	Percent
Iron	42–48
Silica	10–12
Alumina	8–12
Phosphorus	0.10–0.25
Sulphur	.01–.20 (?)
Manganese	.15–.30 (?)
Water	12–14

Production figures for ore and pig iron suggest an even lower average grade of ore (pp. 14–15). It is clear that the South Basin ores are by no means as desirable as those of the North Basin. They contain less iron and more silica, alumina, and phosphorus. Doubtless low mining costs and the fact that the ores do not require washing offset the lower grade to some extent.

RESERVES OF IRON ORE

The eastern and northeastern parts of Texas contain a large and valuable reserve of brown iron ore, with some carbonate ore. The deposits have been known and worked sporadically for many years, and, as a result of examinations by numerous geologists and engineers, several estimates of available tonnage of commercial ore have been made. These estimates range from a few hundred million tons to more than a billion tons. In certain areas thorough prospecting campaigns have been carried on by private companies and have served to provide fairly accurate figures as to the ore reserves in those areas. Former estimates for the whole region were necessarily based in large part on reconnaissance studies of surface exposures only. Through the courtesy of officials of several of the companies that are interested in the eastern Texas iron-ore field, the results of much of the detailed prospecting that has been done were placed at the writer's disposal. In addition, he was able to map most of the important deposits in some detail and to make reconnaissance examinations of all the areas that showed even the least promise of containing valuable deposits of ore. The detailed mapping has made possible a rather definite limitation of the areas from which commercial production of ore can be expected under reasonably predictable conditions, although there are large and promising areas where further prospecting is needed before more accurate estimates of the probable reserves can be made.

The data used in estimating the available tonnage of ore in a given deposit are the average ratio of ore-bearing dirt in cubic yards to the ton of iron ore recovered; the average thickness of the ore-bearing material; the thickness of the overburden; the area of probable ore-bearing ground; and the average grade of the ore. Where the results of actual washing tests of the ore were available the data as to ratio of ore to waste were used directly. In most places, however, no such data were available, and estimates of tonnage were based on the volume ratio between ore and waste as actually measured in all available sections exposed in trenches, pits, or natural cuts. In still other areas, where little accurate information could be obtained, the figures as to ore thickness were arrived at by comparison of the surface showings with those of better-known areas.

The method of measurement outlined above involves an assumption as to the specific gravity of the ore in place. Experiments with large blocks of the laminated and buff crumbly ore of Cherokee County, whose volume could be measured accurately by displacement of water, showed that it weighs about 200 pounds to the cubic foot, which corresponds to about 3,890 long tons per acre-foot. This figure has been used in the estimation of the South Basin ores. The North Basin ores are almost without exception more porous and less dense than those of the South Basin. Estimates of the relative porosity of the two types, together with averages of the information furnished by several of the iron-ore companies, make it seem probable that the North Basin ores will weigh about 170 pounds to the cubic foot. This figure corresponds to about 3,300 long tons per acre-foot. In the estimation of the North Basin ores, 3,250 long tons per acre-foot has been used in order to provide a safety factor.

The carbonate ores are at least as dense as the South Basin brown ores, and their apparent specific gravity is probably about the same. As the carbonate ores appear to make up 20 percent or less of the total ore reserve, their difference in weight is almost negligible.

The average thickness of ore-bearing material is that obtained by measurement of all natural or artificial exposures. The ratio of ore to waste, by volume, exclusive of overburden, ranges in the North Basin from about 1:5 to 1:1, which would correspond, in terms more commonly used, to a range from 3 cubic yards of ore-bearing material to the long ton of ore, up to 1 cubic yard of ore-bearing material to the long ton of ore. In general, the permissible upper limit of stripping is considered to be equal to the total thickness of ore-bearing material at any place, but allowances have been made for areas where the ratio of ore to waste is very low.

In the South Basin, where the ore is confined to a single bed, probably no concentration other than removal of the overburden and the hard sandstone cap will be necessary.

During the field work in the South Basin measurements of minimum and maximum thicknesses of ore were made at all available exposures; and the averages of these measurements were used in computing ore reserves. Studies of many exposures such as that shown in plate 13, *A*, lead to the belief that the actual average thickness of ore at any locality is possibly somewhat greater than the mean of the maximum and minimum thicknesses. No area with an average overburden of sand of more than 10 feet is considered workable except under special conditions, such as where mining is to be carried through from one area of less stripping to another, and even this limit has been used in estimating the ore reserves only where there is good reason to believe that the sand is underlain by ore.

No material that would yield washed ore containing less than an average of 42 percent of metallic iron has been considered in making estimates of tonnage. In the North Basin no ore that averages less than 18 inches in thickness, exclusive of waste material that would be removed by ordinary washing methods, has been included as "probably available" ore. In the South Basin the lower limit of "probably available" ore is arbitrarily set at a thickness of 1 foot.

In several districts boulders and concretions of high-grade brown ore are distributed at or very close to the surface. Such boulders are frequently turned up by the plow in farming and are often accumulated in large piles in the fields. Though such areas could never be mined by large-scale machine operations, it seems probable that if a steady market for ore were established local farmers might supply considerable tonnages of high-grade ore during the seasons when farm work is slack. The estimates of reserves of "possibly available" ore in the North Basin refer largely to ore of this character, though certain deposits with a very high ratio of "dirt" to ore or of low-grade ore are also included. The figures as to "possibly available" ore in the South Basin refer to deposits with an average thickness of less than 1 foot. The estimated reserves of iron ore in the various counties, made with the limitations set forth above, are shown in the subjoined table.

Estimated reserves of iron ore in eastern Texas

County	Probably available now or in near future (long tons)	Possibly available but too thin or low-grade for large-scale operations (long tons)	Total reserves (long tons)	Area covered by probably available ore (acres)	Area covered by possibly available ore (acres)
North Basin					
Cass:					
East of 93°25′	41, 979, 000	5, 215, 000	47, 194, 000	8, 000	2, 200
West of 93°25′	18, 451, 000	3, 185, 000	21, 636, 000	2, 600	1, 500
Total	60. 430, 000	8, 400, 000	68, 830, 000	10, 600	3, 700
Morris	28, 338, 000	500, 000	28, 838, 000	3, 000	500
Marion	5, 313, 000	1, 819, 000	7, 132, 000	600	1, 600
Upshur (estimated)	4. 000, 000	1, 000, 000	5, 000, 000	800	200
Total, North Basin	98, 081, 000	11, 719, 000	109, 800, 000	25, 600	9, 700
South Basin					
Cherokee:					
Near Rusk	16, 503, 000			4, 250	
Near Dialville	12, 954, 000			3, 600	
Hassell Mountain	2, 626, 000			675	
Mount Haven	4, 376, 000			750	
Near Reese	1, 945, 000			500	
Other areas		7, 000, 000			2, 000
Total	39, 404, 000	7, 000, 000	46, 404, 000	9, 775	2, 000
Henderson:					
Near Brownsboro	1, 634, 000	3, 209, 000	4, 843, 000	280	1, 100
Other areas		2, 918, 000	2, 918, 000		1, 500
Total	1, 634, 000	6, 127, 000	7, 761, 000	280	2, 600
Anderson		12, 643, 000	12, 643, 000		6, 500
Other counties		5, 000, 000	5, 000, 000		500
Total, South Basin	41, 038, 000	25, 770, 000	66, 808, 000	10, 055	11, 600
Grand total	139, 119, 000	37, 489, 000	176, 608, 000	35, 655	21, 300

Comparison of the figures for the various counties and of the estimates that have been made by other engineers will no doubt raise questions as to the consistency and general accuracy of the above estimates. There are unquestionably inconsistencies and inaccuracies in the figures that cannot be eliminated without further intensive prospecting and field study, but an effort has been made to present estimates as fair and consistent as is possible in the light of present knowledge.

There is reason to believe that the figures for the North Basin reserves are accurate within a very few percent. They are based on detailed mapping and measurements of ore and on the results of extensive prospecting by private companies. The question as to whether the arbitrary limits as to workable thickness of ore and overburden that have been adopted are correct is possibly open to doubt, but it seems more likely that actual practice would raise these limits and so reduce the tonnage of available ore rather than increase it.

No provision is made in these figures for loss in mining or concentrating operations. This loss would probably amount to at least 10 percent of the total available ore. Furthermore, all the carbonate ore that has been included in the figures contains from 25 to 35 percent of carbon dioxide by weight. This would undoubtedly be removed by roasting before the ore was shipped. Part of this expected loss in weight is compensated in the estimates by the greater density of the carbonate ore. The proportion of the total ore reserve that occurs as carbonate is uncertain. There is no carbonate in many deposits, but in a few there is more carbonate than brown ore. Probably not over 20 percent of the ores in the North Basin are of the carbonate variety. All the brown ores contain from 10 to 14 percent of water, which might be removed by nodulizing before the ores were shipped.

It is a safe assumption that a deduction of at least 20 percent must be made in the figures for the reserves of ore in the North Basin to allow for losses in mining, concentrating, and roasting or calcining operations. The situation with respect to the South Basin ores is somewhat different. Several assumptions, the validity of which may be open to question, have been made in arriving at the figures for the probable ore reserves. First, the average thicknesses of the ore in various districts as measured by the writer are very much less than those reported by most other writers. So many exposures of ore were measured during the field work on which this report is based that it appears extremely unlikely that the average thicknesses as given can be very much in error. Second, it has been inferred that ore does not extend more than an average of 500 feet from the outcrop. Field evidence indicates that this inference is valid. That there are exceptions to this general rule is admitted; on the other hand, in many places the ore pinches out within less than 500 feet. Even if it could be shown that the ore is actually somewhat thicker than the writer's average, and that it extends in general much farther under cover than is here inferred, the total ore reserves in the South Basin could not by any stretch of the imagination be more than twice the figures given above, or about 134,000,000 tons; and even this greater estimate would still be far short of the figure assigned by some engineers to comparatively small portions of the ore deposits. As the South Basin ores do not contain carbonate and would not require washing, the necessary correction factor for the tonnage estimates to take care of mining loss and removal of water might possibly not exceed 12 to 15 percent.

There is apparently available in the whole of eastern Texas between 150,000,000 and 200,000,000 long tons of comparatively high-grade iron ore. These figures do not take into account an enormous tonnage of low-grade ferruginous material that might possibly be used in the distant future. Fresh greensand itself contains from 20 to 25 percent of metallic iron. It is probably too low in grade ever to be used as an ore, but the oxidized greensand with which all the brown iron ore deposits are associated contains from 35 to 40 percent of iron in places in the form of limonitic crusts, veninlets, small concretions, and ferruginous cement. Given a dearth of ore available elsewhere and other necessary economic conditions, such material might conceivably be used as iron ore. In this event, the reserves of possibly available ore would be raised by many millions of tons. If all the deposits of brown ore, both high and low grade, all the carbonate ore, all the high-grade conglomerate ore, and all the oxidized greensand are classed as possible ore, the total reserves in the Texas field will certainly approach if not exceed 1,000,000,000 tons. It is the writer's conviction, however, that the lower figures given above are more logical and that a production of ore in excess of those figures is hardly to be expected even in the very distant future.

DEVELOPMENT OF THE ORE DEPOSITS

PROSPECTING

During the early history of the Texas iron industry the ore needed to supply the small furnaces was obtained from the most favorably exposed ledges, and no thorough prospecting was necessary. Since early in the present century, however, most of the promising deposits have been carefully tested by several companies, and the existence of large reserves of ore have been proved beyond question. Burchard's description [40] of the prospecting methods adopted for most of this work is quoted below, with a few minor additions by the writer:

Systematic prospecting of a large tract of land bearing iron ore of the residual and nodular type, such as occurs in Cass and the adjoining counties, is by no means a simple and inexpensive operation. A preliminary study of the tract is first made, including examination of all the outcrops and natural sections of the iron-bearing sediments and tests by means of shallow pits and trenches in order to determine if possible whether the expense of further investigation is warranted. If the indications are favorable deeper prospecting may be done by means of test pits, open trenches, and drill holes.

The information to be derived from the prospecting, supplemented by concentration tests and chemical analyses, consists principally in determining the thickness of the cover, the total thickness of the ore-bearing ground, the section which will show approximately the volume ratio of ore to barren material, the weight ratio of ore to barren material, and the character of the ore itself.

The test pits are circular in cross section, about 3 feet in diameter, and as much as 35 feet in depth. They require two men—one for digging, the other for hoisting the excavated material to the surface by means of a windlass. Lump ore from a pit is usually piled at one side, and the sand and mixed fine ore and dirt are dumped on the other side. All the material from the pit is carefully preserved and forms a basis for the estimation of ratio of ore to dirt. The test pits are generally placed systematically a certain number of yards apart along lines which gridiron the tract except, of course, where surface features such as ravines, trees, or boulders may interfere. Records of the sections exposed by the pits are care-

[40] Burchard, E. F., op. cit., pp. 98–100.

fully kept. A valuable supplement to the test pit is the drill hole. Holes are now being drilled in Cass County ore fields by means of a Keystone drilling outfit. The drill is operated and moved from place to place by means of a traction engine. In the soft or partly consolidated sediments in which the ores are found the machine drills about 90 feet a day, so that two or three holes can be sunk in a day if not too far apart. Such drilling is much more rapid and is less expensive than the sinking of test pits by hand. The drillings are saved on a screen, and the ratio of ore to dirt is determined later. The drill hole does not, of course, yield a visible section, and in that respect is of less value than the pit or trench. By drilling holes close to a few test pits whose sections are on record, the relative value of the information afforded by the two types of openings soon becomes apparent, and the engineer in charge of prospecting learns to what extent he may depend on each type. The application of drilling to prospecting of this sort is a comparatively new feature, and its possibilities have probably not yet been fully realized. Drilling would seem to be a good method of preliminary prospecting, and drilling in connection with sinking of test pits greatly reduces the number of necessary pits and materially lessens the expense.

Prospecting by means of trenches, particularly if the trenches are large and deep, is very expensive, for the work is practically all done by hand. If a trench is driven into a hill there is an advantage in that the excavated material may be wheeled out on a level floor, or perhaps down grade, instead of having to be hoisted out. A prospect trench affords a much better idea of the character of the ore-bearing ground and of the relations of the ore deposits to the enclosing sediments and is probably not exceeded in this respect even by the face of an open-cut mine, for the face of the trench is cut down vertical and clean. For the sake of economy, especially where the ore deposit is largely a residual deposit just below the surface and where downward concentration of the limonite has resulted in the deposition of layers and masses of ore at a fairly even distance below and approximately parallel with the surface, a trench may be dug in steps and thus the extreme depth at the inner end, most of which might have to be dug in barren ground, may be avoided. If properties which contain important deposits of ore, of proved value, are to be displayed for sale or for financing, nothing is better than plenty of prospect trenches.

In connection with the prospecting work outlined above there should be carried on a thorough system of recording the results, preferably one which shall show them in as graphic a way as possible. This is effected by running careful levels over the property, making a large-scale topographic map with 5-foot contour intervals, and plotting each test pit or drill hole accurately on this map. Cross-section sheets are also made on which all the test openings are shown to scale in their relative altitudes, together with the materials passed through, distinguished by means of appropriate patterns. Later, when concentration tests and ore analyses have been made, these data can be added to the cross-section sheets, which, together with the topographic map, will then contain all the essential data concerning each tested point on the property and enable a reasonably close estimate to be made as to the reserves and grade of available ore.

Such systematic prospecting and recording of results is, of course, very expensive and cannot be undertaken unless the preliminary prospecting and natural indications are highly favorable, nor unless the property is large enough to warrant the expense, or several small properties may be prospected together. The engineering and mechanical corps necessary for such work must have a certain amount of special training and knowledge of the field, in order to produce the best results.

In prospecting laminated, bedded ore, such as occurs in Cherokee County, the problem is simpler than in prospecting the concretionary ores of the counties farther north. It is necessary to know the thickness of the cover above the ore, the thickness of the ore bed, its quality, and the altitude at which it lies. As the bed outcrops at a nearly uniform level around the plateau lands, generally on steep slopes, it is most conveniently prospected by pick and shovel on the outcrop. Drills might be used on the level upland, but in places where the cover exceeds 10 feet mining could hardly be carried on under present conditions; therefore systematic prospecting of such areas would be of little use.

As a pit 30 inches in diameter yields only about half as much dirt as one 36 inches in diameter, it is obviously to the operator's advantage to keep the pits as small as possible. The ground stands well in general and there is little danger of accident or loss of pits by caving. Some method of dewatering the pits is usually necessary, and bailing devices or small portable pumps should be provided. The writer found a rope ladder with wooden rungs almost indispensable in the examination of the test pits.

Washing tests to determine the ratio of ore to waste are much more accurate and instructive than measurements of the relative volumes of ore and waste in place, not only because the ore varies greatly in porosity and hence in weight, but because the results are more nearly comparable with those that might be expected in commercial mining and washing operations.

Except in certain localities the sinking of shafts or test pits seems to have several advantages over drilling. The character and mode of occurrence of the ore can actually be seen in the test pits. Furthermore, the small-diameter drill holes may give false impressions as to the quantity of ore present, either because they chance to strike a few unusually thick concretionary masses, or because they happen to penetrate an unusually lean area. In heavily wooded tracts, where there are few trails or roads, the physical difficulty of moving the drilling equipment becomes both serious and expensive. More important than these considerations, however, is the fact that there is apparently some discrepancy between the results obtained by the two methods. Where the writer had access to rather complete shaft and drill records, the drill records in general indicated a thicker section of ore-bearing material but a much lower ratio of ore to waste than the shaft records. A large part of the discrepancy is unquestionably due to the fact that most of the drilling was done on higher ground, where a full section of greensand was present but where the ore is usually leaner than close to the outcrop. According to some engineers who have examined the district, however, there is a marked difference in the results of drilling and shafting in identical material. This seems to be due largely to the fact that the fragments and masses of brown ore are pushed back into the soft clay and sand matrix and do not come up with the drill cuttings in the proper proportion. Core drilling would seem to have many advantages over churn drilling except as to cost, and even this may not be a very serious item.

Recent progress in the development of small-diameter portable core drills for use in geophysical and other forms of petroleum prospecting has been marked, and the costs of such work have been greatly reduced.

MINING

Former mining operations in the North Basin were confined to the richest outcrops of concretionary ore, and simple hand methods of mining were used. Wheel scrapers were used to some extent for stripping the sand overburden. Considerable quantities of ore could doubtless be recovered by similar hand-mining methods in the future; in fact, much of the ore included as possible ore in the present estimates of available tonnage reserves could be recovered only by such methods. For large and continuous operations, however, cheaper methods of handling both ore and overburden are necessary.

The existence of deposits of commercial ore that range from 5 to 30 feet in thickness and cover areas from a few acres to a square mile or more in extent is now well established. It seems possible that large-scale steam-shovel or dragline scraper operations may be used to advantage in most of the districts. Plate 13, *C*, shows a gravel pit in Marion County where shovel operations in material almost identical with that which would be mined as iron ore have been successful.

In the South Basin, it is probable that few improvements could be made on the mining methods formerly employed at Rusk. Burchard [41] describes these operations as follows:

> Mining of the bedded ore near Rusk, Cherokee County, at present not being worked, was carried on as follows: The cover, which is mainly loose sand, was removed by means of wheel scrapers and dumped into ravines or piled in banks on ground from which the ore had been mined. Areas of several acres were thus stripped at one time. The thickness of the cover stripped rarely exceeded 7 or 8 feet, but a maximum of 10 feet was noted. After the loose cover was stripped off, the "sand cap," or scale of ferruginous hard sandstone, half an inch to 4 inches thick, was split loose from the top of the ore and piled up where it would not interfere with the workings. Then the ore was blasted loose from the bed, and the lumps were pried up and broken to smaller sizes with sledges and picks and piled ready for shipment. The ore was loaded into carts by means of forks, and consequently much good ore in fine sizes was left on the ground. The ore of "curly" structure lying in the bed below the laminated top portion tends to crumble on weathering and is commonly referred to as the "buff crumbly" ore. Probably much ore was thus lost by being allowed to weather too long before it was carried to the furnace. The use of forks appears at first thought to be a wasteful method, but when it is considered that this ore contains a high percentage of alumina, the importance of getting it up free of any underlying clay, even at the sacrifice of some fine ore, is readily apparent. The State mines were operated by convict labor and when in operation were connected with the blast furnace by railroads and tramroads. The method of mining at the other mines near Rusk was similar to that at the State mines but on a much smaller scale.

[41] Burchard, E. F., op. cit., p. 102.

CONCENTRATION

Any method of mining that involves removal of both iron ore and waste material must be supplemented by concentration processes, and it is upon the success of this part of the work that the possibility of large-scale operations in the North Basin depends in large part. The concentration methods adopted will probably follow the lines usually practiced in other iron ore fields, the chief steps of which are summarized as follows: [42]

1. Hand-picking or cobbing, to separate that portion of the ore that is visibly of high grade from the poorer material.
2. Drying, to remove excess moisture.
3. Roasting, to remove moisture from hydrated ore and sometimes water combined mineralogically; to drive off carbonic acid from carbonate ores; to reduce the percentage of sulphur in some ores; to facilitate the removal of clay, rock, and sand by making a nonmagnetic ore magnetic; and to improve the physical features of the ore.
4. Washing, to reduce excessive amounts of clay, sand, and rock.
5. Jigging, to accomplish the same results as washing, but with finer material.
6. Magnetic separation, to separate the strongly magnetic particles from those that are nonmagnetic.
7. Agglomeration, to form finely divided material into lumps, either by briquetting, nodulizing, or sintering.

All these processes, except possibly the last two, would be necessary for complete success in the eastern Texas field. It may even be found necessary to agglomerate the roasted ores, as some tests have shown that roasting, particularly of the carbonate ores, produces a large amount of fines and dust, which are not only objectionable in the furnace but would cause much loss if discarded entirely.

In nearly all the districts some economy of water would be necessary, but by the erection of earth dams for reservoirs and settling ponds in ravines and the re-use of some of the water, a sufficient supply could probably be obtained within a short distance of most of the ore deposits. The fact that a number of natural gas and petroleum pipe lines traverse the area is important and should mean comparatively low roasting and drying costs.

Several of the interested companies have made fairly exhaustive tests of concentrating methods and costs, and some years ago, during the period of greatest development and prospecting in the district, it was the general consensus that the ore could be mined, washed, dried, and loaded on cars at the nearest shipping points for a cost of about $1 a ton of washed ore. The probable costs at the present time are not known, but the general adoption of motor-truck transportation, advances in mining methods and machinery, and the availability of oil and gas are probably factors favorable to similar if not lower costs.

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[42] Birkinbine, J. L. W., Beneficiating iron ores; the ABC of iron and steel, 5th ed., p. 22, Cleveland, Ohio, Penton Publishing Co., 1925.

FUTURE OF THE DISTRICT

In considering the future of the eastern Texas iron-ore district, two possibilities are evident. Either a local industry for the manufacture of iron and steel may be established, or the ore may be shipped to existing iron centers.

Iron-ore land in Texas is comparatively cheap, is more or less timbered, and present taxes are low—in fact the cost of prospecting a given tract of land and determining the ore reserves is in general a larger item of expense than the cost of the land itself.

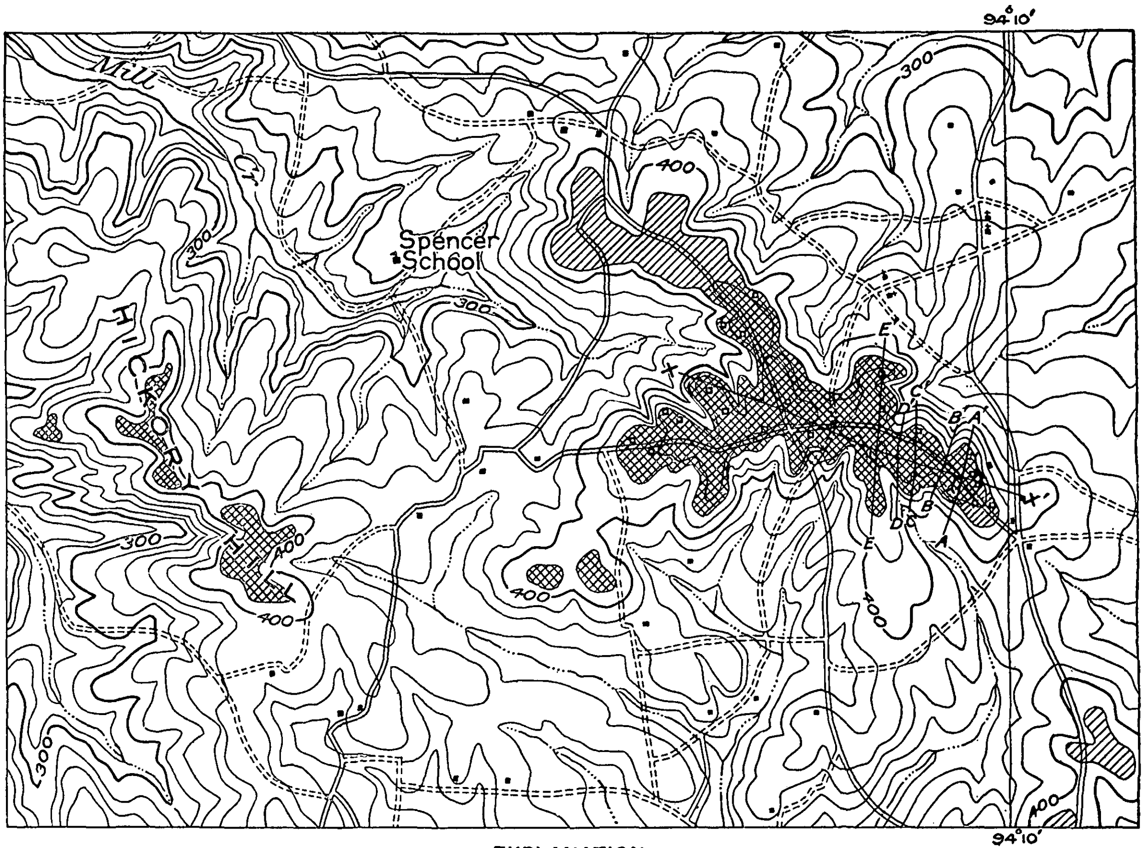
On the assumptions of a fairly uniform initial cost of iron-ore lands and mining costs per ton of recoverable iron and an expanding local market, the chief factors that must be considered in determining the location of a furnace are (*a*) cost of transportation of ore to the proposed furnace, (*b*) cost of transportation of fuel and flux to the furnace, and (*c*) cost of transportation of finished products to ultimate consuming points.

With respect to the cost of transportation of ore to the furnace, a local industry obviously possesses a great advantage. The following table summarizes the important facts relating to shipping distances between the ore deposits and possible points of fabrication in Texas.

Distance, in miles, to possible points of fabrication

District	Air-line distance from deposits to nearest railroad	Approximate distance from railroad shipping point to—			
		Jefferson	Texarkana	Rusk	Dallas
Bowie Hill	1. 5–3	33	18	135	193
Bivins	0. 5–3	18	33	123	178
Surratt	4–5	19	34	124	179
Prewitt	2–5	14	47	119	174
Jurnigan-Harris	3–4	14	47	119	174
Knight-Field	0. 5–4	12	63	117	172
Chambers-Hughes	1–2. 5	27	78	132	187
Hooten Hill	0. 5–1. 5	27	78	132	187
Daingerfield	0. 5–1	33	84	138	193
Oak Grove-Rock Springs	0–3	29	80	134	189
Morris County line	3–8	22	73	127	182
Gilbert	5. 5–6. 5	17	68	122	167
Orrs Switch-Lassater	0–3	12	63	117	162
Rusk	0–3	105	156	1–8	130
Dialville	1–5	100	150	8–12	120
Mount Haven	0. 25–2. 5	90	140	18–24	115
Brownsboro	0. 5–4	68	120	57	100

With regard to the cost of fuel and flux, the situation is less favorable for a local industry. It may be taken for granted that small charcoal furnaces will not be used to any great extent. The iron produced in such furnaces is of high grade, but the output is small, costs are high, and the supply of good charcoal timber is everywhere depleted. For some years there has been a marked trend away from small furnaces to large centralized operations. A supply of coking coal is therefore a necessity to the establishment of an iron industry.



EXPLANATION

Commercial ore-bearing

Barren of commercial ore

Weches greensand member of Mount Selman formation

Queen City sand member of Mount Selman formation

Pit examined

Trench examined

A——A′ Line of section shown in fig. 3

1 0 1 MILE

Contour interval 20 feet
Datum mean sea level

MAP SHOWING DETAILS OF BOWIE HILL DISTRICT, CASS COUNTY.

The plentiful supply of lignite that occurs in the Wilcox formation and in other formations of eastern Texas may be ruled out of consideration for the present, though in the future some method may possibly be devised to make them economically useful in the reduction of iron ores. The bituminous coals in the vicinity of Dallas might possibly make fairly good coke, but the sulphur content is too high to make them desirable for blast-furnace use.[43]

The nearest coking coals are those in Oklahoma and Arkansas, about 200 miles by rail from the center of the North Basin iron deposits and 100 miles farther from Rusk. A moderate-sized coke industry was carried on at McAlester, Okla., for several years, but no coke has been produced since 1910.[44] There is little doubt that a sufficient output of blast-furnace coke could be realized from this field if the coal were washed, sorted, and properly mixed, although there would probably be some difficulty in keeping the sulphur within acceptable limits.

Limestone for flux could be obtained from the Austin chalk or other Cretaceous formations that crop out in a semicircular belt west and north of the Tertiary deposits of the Coastal Plain. This belt passes through Austin, Waco, Dallas, and Greenville, Tex., whence it swings eastward through northeastern Texas and into Oklahoma and Arkansas. The nearest exposure of limestone in this belt is that at White Cliffs, Ark., about 60 miles north of Linden, Tex. An immense supply of limestone exists in this vicinity, but according to analyses given by Taff [45] the different beds vary between wide limits in their content of lime and silica. Some of the beds break into lumps when quarried, but most of them yield an excessive amount of fine material that would be objectionable for furnace use. It is probable that only a small proportion of the available stone could be used in the blast furnace. Purer limestone could be obtained from the Lower Cretaceous and Carboniferous rocks in north-central Texas and in Oklahoma and Arkansas, but these deposits are more than 200 miles distant, in an air line, from the iron ore. Oyster shells might be obtained from the Gulf coast, but the cost of the 300-mile rail haul would tend to offset the greater purity of this type of flux.

The limestone needed as flux might possibly be obtained from some of the interior salt domes in the South Basin, which are not far from

[43] Phillips, W. B., and Worrell, S. H., The fuels used in Texas: Texas Univ. Bull. 307, pp. 48–55, 1913.

[44] Hendricks, T. A., Geology and coal resources of the McAlester district, Okla.: U. S. Geol. Survey Bull. 874–A, pp. 81–82, 1937. For other data on the coals of Oklahoma and Arkansas, see Taff, J. A., The Southwestern coal field: U. S. Geol. Survey 22d Ann. Rept., pt. 3, pp. 367–413, 1901; Collier, A. J., The Arkansas coal field, with reports on the paleontology by David White and G. H. Girty: U. S. Geol. Survey Bull. 326, 158 pp., 1907.

[45] Taff, J. A., Chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements: U. S. Geol. Survey 22d Ann. Rept., pp. 687–742, maps, 1901.

the best South Basin ore deposits. The Austin chalk and other Cretaceous formations have been brought to the surface on several of these domes, particularly those in southern Smith County and central Anderson County.[46] By no means all of the stone is of fluxing grade, and the areas of outcropping limestone are relatively small. In addition, the complicated structure that characterizes the salt domes would necessitate careful and expensive mapping and prospecting in order to determine the tonnage available. Even if sufficient reserves of desirable stone should be discovered, the faulted condition of the rocks would tend to raise extraction costs considerably.

The third factor that must be considered, the cost of transportation of finished products to points of consumption, is a debatable one. The growth of industrial activity in the Southwest is unquestionably on the increase, but it may be reasonably doubted whether for several years in the future purely local demand will be able to support a large iron and steel industry. The petroleum industry alone, in Texas and other Southwestern States, consumes thousands of tons of iron and steel annually, which are brought in at high costs for freight. A local industry of moderate size could doubtless share in this market, provided constant production and uniformity of product were assured. The cost to local furnaces of fuel and flux would probably be too great to allow shipment of iron to other parts of the country where it would be in direct competition with iron from already established producing centers.

The cost of transportation of ore to furnace is the chief factor that will determine whether the Texas ores can be profitably shipped to furnaces elsewhere. Such furnaces already have supplies of fuel and flux, and their markets are established. High railroad freight rates have been and may easily continue to be the chief obstacle in the way of development of the Texas brown ores.

Present plans for development of inland waterways may change the transportation situation markedly. The proposed canalization of the Trinity River should provide cheap transportation to or from the main ore deposits of the South Basin, though rail hauls of at least 40 miles would be necessary to reach the canal. The proposal to open the Red River to navigation and to connect it with Jefferson by way of Caddo Lake and Cypress Creek bears much promise. Most of the rich North Basin deposits are less than 20 miles from Jefferson, and if this project were carried out, ore placed on barges there could reach the Birmingham, St. Louis, or Ohio River iron centers without unloading.

[46] Hopkins, O. B., The Palestine salt dome, Anderson County, Tex.: U. S. Geol. Survey Bull. 661–G, pp. 253–269, 1917. Powers, Sidney, and Hopkins, O. B., The Brooks, Steen, and Grand Saline salt domes, Smith and Van Zandt Counties, Tex.: U. S. Geol. Survey Bull. 736, pp. 179–220, 1922. Powers, Sidney, Interior salt domes of Texas: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 1–60, 1926.

If the transportation problem should be solved, either by waterways or by other means, or if the local demand for iron and steel products should expand considerably, there seems no good reason to believe that the Texas iron ores could not be developed commercially at a comparatively early date. Otherwise, it seems quite likely that they will remain dormant for many years.

DETAILED DESCRIPTIONS OF ORE DEPOSITS

DEPOSITS IN THE NORTH BASIN

CASS COUNTY

Cass County occupies the northernmost part of the eastern Texas iron region and includes within its borders more than half the available ore reserves in the North Basin. It has an area of 951 square miles and is drained by the Sulphur River, which forms its northern boundary, and by the Caddo Lake drainage systems. The population of the county in 1930 was, according to census figures for that year, 30,030, of which 20,090 were classed as rural farm dwellers. Of the total population 35 percent are colored, and the remainder native white. Most of the inhabitants are descendants of settlers who came from Tennessee, Alabama, and Georgia during the period between 1840 and 1870. The largest towns are Linden, the county seat (population 718), Atlanta (population 1,685), and Hughes Springs (population 736). The county is served by the Texas & Pacific, the Missouri-Kansas-Texas, and the Jefferson & Northwestern Railways. Several paved highways and numerous secondary roads, of varying degrees of improvement, traverse the county (pl. 2).

The chief products are cotton and lumber, though fruit and other crops are also important. Some pottery and brick clays are produced, largely for local use. Ferruginous gravel suitable for highway construction is widely distributed, and several deposits have been exploited, mostly for local use. One gas well was brought in near the eastern edge of the county in 1934, but numerous other efforts to discover oil and gas in commercial quantity have not yet met with success.

The topography of the ore-bearing part of the county, which trends in a general southwesterly direction from Bowie Hill, near Springdale, into Marion and Morris Counties (pl. 2), may be described as a series of long ridges and chains of ridges that rise from 50 to 150 feet above the intervening streams and have flat or gently rolling surfaces. The highest hills are more than 600 feet above sea level, and the lowlands about 200 feet. The ridges trend in a general northerly or northeasterly direction and are separated by steep-sided, narrow ravines, occupied by small spring-fed streams or by larger and more slowly flowing creeks and bayous. The flood plains of the larger streams are not infrequently flooded during the spring rainy season.

Except along the northern boundary of the county, where the Reklaw and Wilcox sediments and possibly the Carrizo sand are exposed along a narrow strip parallel to the Sulphur River, the whole area is occupied by the Queen City sand, Weches greensand, and Sparta sand. The character of the greensand and its transition in facies on approach to the Sabine uplift have been described in the section on stratigraphy. More complete descriptions of certain localities appear below.

Some of the 22 districts under which the ore deposits of Cass County are described below are purely arbitrary subdivisions, but most of them are distinct areas geographically or have been established as separate districts by local usage. The parenthetical numbers that follow the district names in the headings correspond with the numbering shown on the map (pl. 2).

BOWIE HILL DISTRICT (1)

One of the best-known deposits of brown ore in Cass County is on Bowie Hill, 7 miles north of Atlanta and about 2 miles west of the Texas & Pacific Railway (pl. 2). Bowie Hill is a small, flat-topped, steep-sided, irregularly branching plateau that reaches an altitude of about 460 feet above sea level, or 200 feet above the surrounding bayous (pl. 16). It forms part of the divide between the Sulphur River drainage system, to the north, and the Caddo Lake drainage system, to the south. The hill is typical of many of the uplands of eastern Texas where the ferruginous beds of the Weches greensand have successfully resisted erosion. In one or two places on the western part of the hill small landslides have occurred, doubtless owing to undermining of the Queen City sands from beneath a cap of iron ore. These areas are small and unimportant features but illustrate one of the ways in which the iron-ore deposits are gradually disintegrated and removed by erosion.

The Weches greensand is 30 to 35 feet thick on the main part of the hill but thins to 20 feet or less to the northwest. The greensand is thoroughly weathered throughout but apparently was once a typical mixture of oolitic glauconitic grains with minor amounts of quartz sand and clay. Where the Weches becomes thinner the proportion of quartz sand increases markedly, indicating that the thinning is due to difference in original deposition rather than to removal of the upper beds by erosion. In places the weathered greensand contains large quantities of reddish or yellowish clay, which may be in part original but is probably mostly residual from the break-down of the iron silicates. An apparent cross-bedding was observed in one trench, but it may have been due to alteration rather than to original cross-bedding.

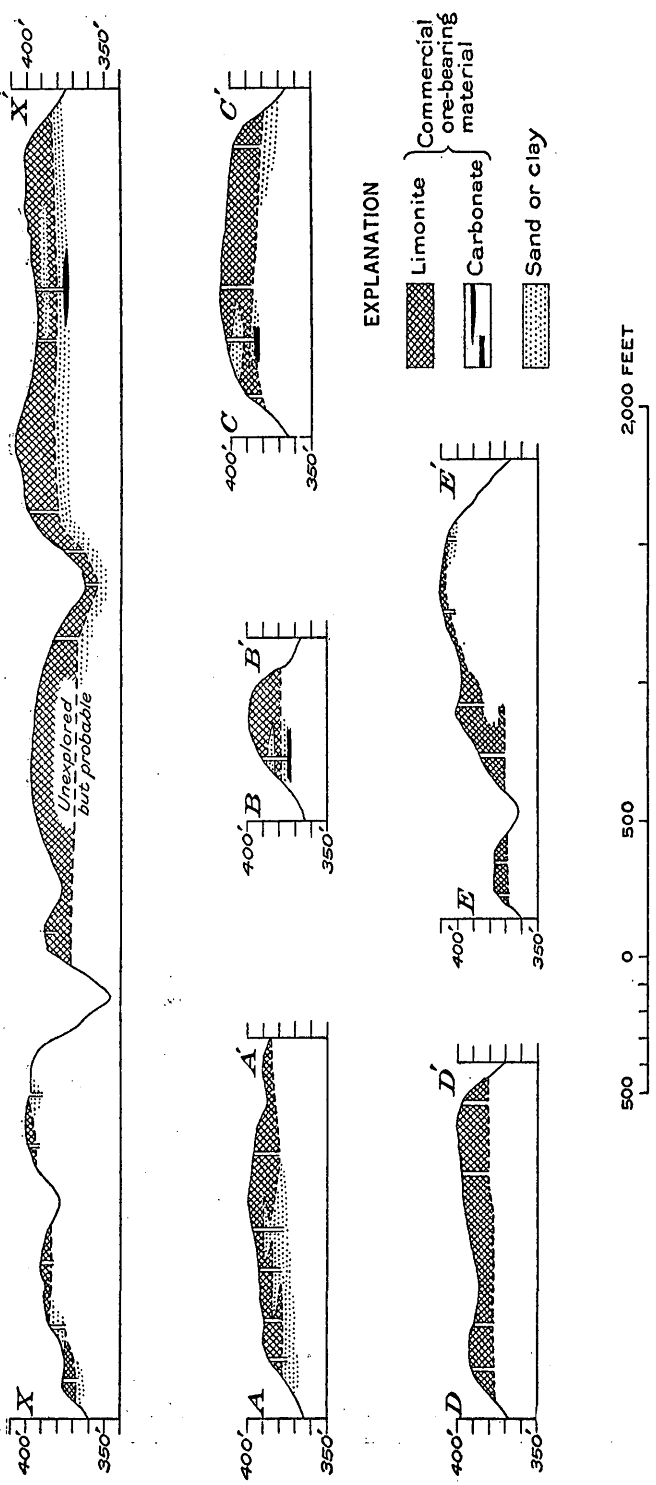


FIGURE 3.—Vertical sections of ore bodies on Bowie Hill, Cass County, showing location of drill holes and shafts. Sections prepared by East Texas Iron Co. and published by permission.

The base of the Weches occurs at an altitude of 420 feet on the northwestern part of Bowie Hill and at 440 feet near the east end (pl. 16).

There is no Sparta sand in place on Bowie Hill except for one or two small areas on the highest parts, where 4 or 5 feet of quartz sand and light-colored clay overlie the weathered greensands. A thin bed of hard ferruginous sandstone marks the contact. The overburden on the rest of the area consists in large part of sandy soil with fragments of iron ore or sandstone and ranges from a few inches to about 7 feet, but the maximum thickness is exceptional. Variations in quantity of ore are obviously not due to great variations in thickness of overburden, but it is of interest that even on this hill, where weathering conditions seem ideal, the ore is commonly thinner and of poorer quality near the central part of the hill than closer to the outcrop.

By far the larger part of the iron ore occurs as lenses, beds, or concretionary masses of brown ore, though according to company records a little carbonate ore was found in a few pits (fig. 3). The thicker beds of brown ore usually have a mammillary lower surface and range from masses of small concretions to laminated beds or lenses that show little or no evidence of concretionary structure. Veinlets of brown ore connect the horizontal beds in places. The ore is of good quality on the whole, but the presence of clay or sand within the concretions and the almost universal coating of oxidized greensand that adheres to masses of ore will tend to lower the grade of the final product.

The whole Weches section in the eastern part of the hill is rich enough in ore for mining, but farther west most of the ore is confined to a zone within 4 or 5 feet of the surface. The following sections, recorded by Burchard,[47] and figure 3 illustrate the mode of ore occurrence on Bowie Hill. Several other sections also have been recorded by Burchard.[47] (See also pl. 16.)

The brown ore on Bowie Hill is found in the top 15 to 35 feet of the highest land on the hill. A generalized section from many test pits and prospect trenches is as follows:

Generalized section of ore-bearing beds on Bowie Hill

	Feet
Residual fragments of limonite in top soil, in places practically solid ore gravel	1–3
Ledge of nodular limonite, more or less solid	½–1¼
Scales and thin bands of limonite, with a few thicker layers or ledges interlaminated with glauconitic sandy layers. The limonite in this condition ranges from pieces of the thickness of small chips up to masses 1½ feet thick and is scattered through yellowish to red sand and clay. It occurs in overlapping, roughly lenticular streaks, or broken and discontinuous seams. The limonite constitutes, in the sections observed, 20 to 30 percent, by volume, of the dirt. Thickness of limonitic sand and clay	12–15

[47] Burchard, E. F., op. cit., pp. 76–78.

Generalized section of ore-bearing beds on Bowie Hill—Continued

	Feet
Iron carbonate in nodular masses from the diameter of an acorn up to 6 inches, or in thin irregular lenses, embedded or interstratified in glauconitic sand and greenish-black clay called "buckfat" clay. The iron carbonate is in general partly altered to limonite or to reddish hydrated oxides of iron, which form a scale or crust of varying thickness around the carbonate nucleus and along cracks which intersect the masses. Thickness of exposed portions of the unoxidized beds	1–5

A section of the upper portion of the ore-bearing ground measures in detail as follows:

Section of cut at east end of washer trestle, Bowie Hill

	Ft.	*in.*
1. Soil, roots, and limonite debris	1–6	
2. Limonite in layers 1 to 4 inches thick		8–12
3. Reddish-yellow sand, in part glauconitic		9–15
4. Limonite ledge with wavy and crumpled layers		6–15
5. Yellowish-red glauconitic sand with ocherous nodules and flakes		½–11
6. Limonite ledge with wavy and crumpled layers interstratified with a little yellowish clay and glauconitic sand. (Nos. 4 and 6 come together, No. 5 forming a wedge between)		1–5
7. Reddish clay and yellow sand, mostly glauconitic, with ocherous nodules and lenses	1	1–3
8. Limonite in ½-inch to 2-inch bands, interstratified with glauconitic sand and running into ocher		2–3
9. Yellow glauconitic sand, with small ocherous lenses		10
10. Limonite streak running to ocher		¼–1
11. Yellow glauconitic sand		3
12. Ocherous clay		1
13. Yellow glauconitic sand		4
14. Limonite ledge, with slightly wavy laminae containing thin seams of ocher and glauconitic sand	1	9
15. Yellow sand, not glauconitic		1
16. Limonite ledge, base concealed		1

Other members besides No. 5 of this section are more or less wedge-shaped as exposed, and the great variability in thickness and extent of all the brown-ore members is easily demonstrated by the use of a pick.

Section in prospect trench south of road near east end of Bowie Hill

[Measured by E. B. Eckel]

	Ft.	in.
Surface soil and sand with about 40 percent of fragmental brown ore		18
Limonite ore, concretionary to laminated, dark brown, with sandy surfaces		8–12
Clay, red, slightly glauconitic in places		18
Limonite, massive, concretionary, somewhat cellular in places. Surfaces are coated with sand and very wavy. A few masses of oxidized greensand as much as 5 inches thick included in ore		8–14
Greensand, reddish, oxidized, with nodules of white clay and small irregular nodules or laminae of limonite		14
Limonite, like ore beds above, but somewhat sandier		3–5
Sandstone, reddish, indurated, glauconitic. Many veins of limonite, ¼ to ½ inch thick, connect ore beds above and below. Sand is tinted brown along walls of veins		18
Ore, like ore beds above, with considerable glauconitic sand in centers of concretionary masses		½–7
(Here the section begins 85 feet nearer the slope of the hill, near middle of trench.)		
Clay, red and white mottled, glauconitic, with some large masses of indurated greenish-brown oxidized sand		5–8
Limonite, concretionary, like beds above		3–5
Greensand, reddish, clayey, containing a few wavy veinlets and thin laminae of brown ore, averaging ½-inch thick	3	8
(Below this point the following beds are exposed along the trench toward the slope of the hill.)		
Greensand, yellowish, oxidized, with a few nodules of green clay. Reddish clay increases in amount at top and bottom of bed		12
Limonite with much oxidized greensand. Ore occurs as thin crusts and plates and grades laterally within a foot or two from nearly pure limonite to greensand with little or no ore		10–12
Greensand, reddish, clayey, oxidized		12–18
Limonite with oxidized greensand. Ore occurs in thin beds, 1 to 2 inches thick, alternating with thin layers of sand. Ore laminae pinch and swell, and in places whole thickness is ore of good quality		12–14
Greensand, somewhat clayey, oxidized	2	6
Limonite, concretionary, good quality, chocolate brown		6
Greensand and clay, reddish, glauconitic. Thickness unknown		?

The beds are accurately correlated between the different sections measured, but there is no means of determining whether or not the lower beds pinch out toward the central part of the hill. The whole 19-foot section shows about 5 feet 7 inches of ore, or 30 percent of ore by volume.

Section in pit on northwesterly spur of Bowie Hill

	Ft.	in.
Limonite, concretionary, dark brown, apparently of good quality		6
Clay and sand, glauconitic, predominantly red, containing a few thin laminae of sandy low-grade limonite	5	6
Limonite of good quality but containing much oxidized glauconitic sand		9
Greensand, oxidized, red, somewhat clayey throughout, but increasingly so toward base	1	10
Limonite, concretionary, dark brown but contaminated with much oxidized glauconitic sand	1	
Greensand, red, oxidized	1	
Sand, quartz, banded red and white. Top of Queen City sand. Exposed thickness	2	

This section shows a little more than 2 feet of ore in a total thickness of less than 10 feet, or 23 percent of ore by volume.

More than 125 prospect shafts have been sunk on Bowie Hill, and two trenches have been dug. In addition, an open cut along the northeast edge of the hill gives good exposures for a distance of 300 feet, and other small mining operations serve to show the quality and extent of the ore. The 25 pits and trenches that were measured in 1934 show an average of nearly 3 feet of ore in an average depth of about 8 feet, or nearly 32 percent of ore by volume. Company records for the same property, which are based on many more complete measurements and on careful washing tests, indicate an average thickness of 17.6 feet of ore-bearing material which in 10 washing tests gave an average recovery of 1 ton of ore from 2.6 cubic yards of material. The area of ore-bearing land is about 200 acres.

A spur line was graded from the eastern part of Bowie Hill to connect with the Texas & Pacific Railway in 1912, but the tracks were never laid. The haul would be downhill to the railway, with a drop of about 80 feet to the mile. Water is scarce in the vicinity of the hill and would probably have to be pumped from the Sulphur River, 5 miles to the north, or obtained from deep wells. A well near Bowie Hill, drilled some years ago for oil and gas, is said to have encountered a strong flow of water, which prevented an adequate test of the gas indications. A site for washing and concentrating works has already been excavated on the northeast side of the hill, and any of the small valleys might be dammed for settling ponds. There is some evidence of surface mining on the western part of the hill, and a large open cut has been dug along the northeastern edge. Some of this work may have been done to supply the old Sulphur Fork furnace, which was built near Bowie Hill in 1864, but most of the open-cut work was done to supply ore for test runs on an experimental washer and concentrating plant that was erected in 1911 or 1912 by the Texas Iron Association. Nothing remains of this plant except a concrete foundation and the shell of a rotary-kiln ore dryer.

OUTLYING DISTRICTS NEAR BOWIE HILL

Several small outliers occur within a radius of 2 miles of Bowie Hill. All of these are too small to work independently but they might be tributary to workings on Bowie Hill. (See pl. 16.) The two small knobs that occur half a mile south of the extreme west end of Bowie Hill are covered with blocks of concretionary ore from 6 inches to 1 foot in thickness. Although no prospecting has been done here, it is probably safe to assume that the two knobs, which have a combined area of about 10 acres, will yield about 1 foot of ore close to the surface. Hickory Hill, the two knobs of which are known locally as Hickory Nut Mountain and Rocky Mountain, is about 2 miles west of Bowie Hill. The highest parts of the hill, above the 420-foot contour, are covered with slabs of good-quality ore that range from 10 to 18 inches in thickness. Good float ore appears along the slopes in the uppermost 15 feet of the hill and several ledges of ore would probably be discovered by prospect pits. The area covered by ore is only between 30 and 40 acres, and transportation of ore would be a serious problem. On the flat spurs that jut out from Hickory Hill at an approximate altitude of 350 feet great quantities of conglomerate ore appear. This material, like all the conglomerate ore elsewhere in eastern Texas, is too siliceous to be of value.

The few small outliers of ferruginous material that appear along the highway south of Bowie Hill, toward Queen City (pl. 2), are too low in grade to be workable for iron ore, but they have already yielded many cubic yards of gravel for highway construction.

WATERS DISTRICT (2)

The Waters district, about 6 miles northwest of Atlanta, on the road between the Shadygrove and Anti School communities (pl. 2), contains a small but valuable deposit of brown ore. The distance to the Texas & Pacific Railway at Queen City is slightly more than 5 miles in an air line. Deposits of commercial ore are confined to the eastern parts of a sand-covered hill that reaches a maximum altitude of about 470 feet in the vicinity of Anti School. The iron ore occurs at altitudes between 375 and 410 feet, about 100 feet above the level of Black Bayou, the nearest large stream. Within the ore-bearing area the Weches greensand is composed largely of thoroughly weathered oolitic glauconitic material, but farther northwest and southeast it grades rapidly by increase of quartz sand to worthless material that contains little or no brown ore. Thus in the vicinity of Shadygrove School large quantities of ferruginous sandstone take the place of the good-quality iron ore of the Waters district. The greensand is fairly well indurated and forms blocks several feet in maximum diameter. The Weches is 30 to 40 feet thick, but only at the upper horizons has ore been formed. The beds dip gently toward the southeast in conformity with the regional structure. The sandy soil that thinly covers most of the ore-bearing area contains much fragmental brown ore of good quality, and except along the western edge of the area, where the Sparta sand attains a thickness of 40 feet or more and the ore is of poor quality, overburden is lacking.

Slabs and blocks of limonite from 2 to 6 inches thick cover much of the surface of the area, and several ledges of ore that reach a maximum observed thickness of 12 inches occur in the upper 12 to 20 feet of the greensand. Where only the lower parts of the greensand remain the ore is scarce and of indifferent quality. The ore in the upper beds is excellent brown limonite, with very little siliceous matter. Boxwork structures and the spongy, cellular type of ore predominate, though concretionary masses are not uncommon. In places the limonite preserves the oolitic structure of the parent greensand even down to the concentric shells of the oolites, and in one place a few fragments of limonitized wood were found (pl. 7, *A*). According to company records, a little carbonate ore was found in a few pits, but the percentage of ore of this type is small. The following section illustrates the typical mode of occurrence of ore in the central part of the area.

Section in pit near central part of Waters district

	Ft.	*in.*
Surface soil with much fragmental limonite of good quality	1	
Clay, red		8
Greensand, thoroughly oxidized		6
Clay, red, white, and yellow, with concretions of limonite as much as 4 inches in diameter, boxwork type	1	2
Limonite, dark, concretionary		5
Clay, red, with white specks		9
Greensand, oxidized and thoroughly indurated; contains a few seams of limonitic material	1	4
Limonite, dark, concretionary, with considerable associated sand and clay		4–5
Clay, white, with some iron stains		6
Limonite, dark, somewhat concretionary, associated with much clay and sand		8–9
Greensand, oxidized, with some red clay		6
Limonite, laminated, with much associated sand		1–2
Greensand, oxidized, with some red clay and a few seams of limonite, each of which is underlain by 1 to 3 inches of white clay	3	
Limonite, dark, concretionary, apparently of good quality	1	
Greensand, oxidized, very red	1	
Limonite, dark, extremely massive	1	
Clay, pinkish brown to pure white, with some bleached greensand near base	1	9
Limonite, dark brown, with much associated clay and sand		6
Clay, reddish, base unexposed	1	

This section shows about 4 feet of ore in a total depth of about 15 feet, or about 26 percent of ore, a somewhat higher ratio of ore to waste than the average for the district. The district has been thoroughly tested by means of pits and drill holes, which showed the average thickness of ore-bearing material to be about 16 feet. According to the records of the East Texas Iron Co. three washing tests showed a recovery of 1 ton of ore from 3.14 cubic yards of dirt. Measurements of four pits that were accessible in 1934 show an average of slightly less than 3 feet of ore in a total thickness of about 13 feet of ore-bearing material, somewhat more than is called for by the iron company's figures. The area of ore-bearing land, exclusive of the covered portion, is about 190 acres.

Abundant water could probably be obtained by damming Butler Creek, less than a mile east of the Waters district, and settling ponds could be located in the same valley. Timber is plentiful in this region. The deposit is relatively inaccessible, however, and is separated from possible shipping points by Black Bayou, which is difficult or impossible to cross during rainy seasons.

ATLANTA DISTRICT (3)

The Atlanta district is about 2 miles northwest of Atlanta, on Henderson Hill, the western part of a broad rolling upland that extends between Black Bayou and the vicinity of the Texas & Pacific Railway (pl. 2). The altitude of Henderson Hill ranges from 300 to 350 feet, less than 100 feet above the stream bottoms.

The Weches greensand has a maximum thickness of 20 feet and is a typical mixture of glauconitic grains with more or less sand and clay. The beds dip toward the west and south, away from a small domical uplift whose apex is apparently near the eastern part of Henderson Hill. Lateral variations in composition of the greensand are rapid, and except in the southern and western parts of the area the presence of large proportions of quartz sand has prevented the formation of commercial ore.

An overburden of Sparta sand and soil covers nearly half the area. The Sparta reaches a maximum thickness of 20 feet and contains an unusually large amount of clay in the thicker portions. It is not known whether the ore extends beneath the Sparta sand, but as the average thickness of cover is considerably less than 10 feet it probably does.

The ore is dark, hard limonite and contains but little sand or clay. It occurs mostly as laminated beds or botryoidal masses of concretions, but in a few places lenses of sponge ore appear.

Examinations of natural exposures and of the few pits that have been dug show a range of 1 to 4 feet of ore in 15 feet or so of ore-bearing material. The property has not been thoroughly tested, and as there is no means of knowing whether ore extends under the covered portions it seems safer to assume that the area will yield thicknesses of 20 to 24 inches of ore from 15 feet of ore-bearing material, corresponding to about 13 percent of ore by volume. This ratio of ore to waste is considerably lower than has been found in most of the districts where adequate tests have been made. The area of ore-bearing land is about 210 acres, of which half is covered by Sparta sand.

The Atlanta district is easily accessible by road from either Queen City or Atlanta. The ore is of good quality, but in view of the relatively large quantities of material that would have to be moved to obtain it, it seems likely that the district will not be mined until other and richer deposits have been exhausted.

The Berry Crawford mine, which supplied some of the ore for the Lone Star furnace, at Jefferson, is in the eastern part of the ore-bearing area. Nothing remains of the old workings but two or three overgrown shallow trenches or open cuts dug at slightly different levels and evidently working on separate beds of ore. The mine must have been located on an unusually rich deposit of ore, as Kennedy [48] says of it, "A broken bed of massive laminated ore 2 feet thick lies immediately under 3 feet of nodular ore."

BIVINS DISTRICT (4)

The Bivins district is 5 miles southwest of Atlanta and from 1 to 4 miles northwest of Bivins, a small sawmill town on the Texas & Pacific Railway (pl. 2). The ore deposits occupy parts of a branching heavily wooded hill that reaches a maximum altitude of nearly 400 feet, about 200 feet above the level of Johns Creek, which runs along the western edge of the hill. The slopes are steep on the western and southern sides of the hill, but become more gradual to the east and north (pl. 17).

The Weches greensand in the Bivins district contains more quartz sand in general than in any of the other areas where good ore occurs. This difference in composition is due in part to a natural gradation of facies toward the Sabine uplift and in part to the fact that the hill is situated at the top of a structural dome of some magnitude. Minor undulations in both the upper and lower surfaces of the Weches are the rule, and sudden lateral variations in composition are probably the cause of irregular distribution of the commercial iron ores as shown on plates 2 and 17 and in figure 4.

The variation in thickness of the Weches between limits of less than 20 to nearly 50 feet is typical of the formation, but the presence of more than 30 feet of greensand on a structural high of this character is unusual.

A few outliers of Sparta sand cover the higher parts of the hill to

[48] Kennedy, William, Texas Geol. Survey 2d Ann. Rept., for 1890, p. 77, 1891.

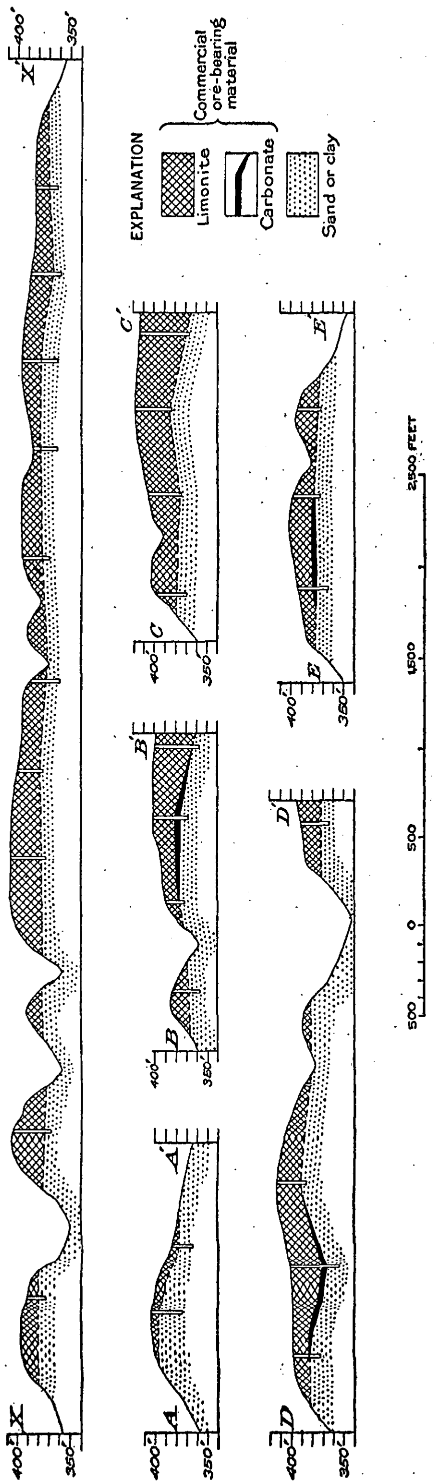


FIGURE 4.—Vertical sections of ore bodies in Bivins district, Cass County, showing location of drill holes and shafts. Sections prepared by East Texas Iron Co. and published by permission.

depths of as much as 15 or 20 feet, but none of these lie within areas containing probable ore. Much of the intervening land is covered by several feet of sandy soil, which in places contains abundant fragmental brown ore. The average thickness of overburden of this character is probably less than 5 feet.

With the exception of several feet of carbonate-bearing greensand near the base of the Weches, which was penetrated by a few pits, all of the ore in the Bivins district is brown ore. It occurs as laminated or massive beds, usually only a few inches and rarely over 1 foot thick. Small concretions are locally abundant, and some of the massive ores are made up largely of coalesced concretions. At the contact of the greensand with the overlying Sparta sand a little light-brown ore, similar in many respects to the buff crumbly ore so typical of the South Basin facies of the Weches greensand, was noted in one or two places.

The quality of the ore ranges between wide limits, and much of it is so sandy or ocherous that it can only be classed as of fair grade. The variation in quality is apparently related directly to variations in the proportions of quartz in the enclosing sand. Figure 4 shows typical cross sections through the central part of the hill.

The property has been thoroughly tested by means of shafts and drill holes, which proved an average thickness of 18.5 feet of ore-bearing material within the area classed as probable ore. The results of four washing tests indicate a recovery of 1 ton of ore from 3.06 cubic yards of ore-bearing material. Most of the shafts are now inaccessible, and the few that are open are not deep enough to give any knowledge of ore beneath the surface. Four shallow pits were measured in the westernmost part of the area. They range from 2 to 5 feet in depth and expose an average thickness of 18 inches of ore in an average depth of 4 feet. Only two pits were measured in the main ore-bearing area. One of these was only 6 feet deep and exposed but 1 foot of ore. The other, which was originally much deeper, is now filled within 12 feet of the surface. Slightly more than 3 feet of ore, or 26 percent of the total thickness, was measured. A few fragments of carbonate ore were found on the dump of this shaft.

Surface indications and observations of shallow pits and old mine cuts suggest that most of the area mapped on plate 17 as possibly ore-bearing will yield 1 foot or so of good ore from beds within 3 or 4 feet of the surface. The area of probable ore-bearing land is about 600 acres, and an additional area of possible ore, exclusive of the parts covered by Sparta sand, is about 500 acres.

The Bivins district is very close to the railroad, and the grade of an abandoned timber tramway, which might be rebuilt, traverses the ore-bearing area. A permanent supply of water could be obtained from nearby Johns Creek. The hill is heavily covered with second-growth pine, and sites for buildings and washing plants are plentiful. The ore varies in quality, and it seems probable that actual mining operations will prove the ore bodies to be spotty in character.

Small amounts of ore have been shipped from this district in the past to the Lone Star furnace, at Jefferson, and to a furnace in St. Louis. The mining was done by shallow pick and shovel methods and gave little indication of what might be expected from large-scale operations.

JOHN STONE HILL DISTRICT (5)

The John Stone Hill district, on the Linden-Atlanta highway, 5 miles west of the Texas & Pacific Railway at Bivins, occupies part of the irregular rolling upland between Frazier and Johns Creeks (pl. 2). The iron-ore deposits, though areally extensive, are of low grade and thin for the most part, and the whole area is only of minor importance.

The Weches greensand ranges from 20 to 30 feet in thickness and is covered in much of the area by 10 feet or more of Sparta sand or by sandy soil. The greensand is typical in appearance and composition. Along the highway the unconformable contact of the Weches with the Queen City sand is well exposed. Plate 6, *A*, shows this relation.

Wherever the Weches is exposed at the surface it contains great quantities of limonitic nodules. These are usually not larger than 3 or 4 inches in diameter, and most of them are hollow. The inner layers are good-grade dark-brown limonite, but nearly all the nodules are heavily coated with weathered greensand, which lowers the grade of the material very appreciably. Some nodules are ocherous, and crusts or laminae of ocherous material are locally abundant.

It seems likely that the area of exposed ore-bearing material, which covers about 390 acres, will yield 1 foot or more of ore from the uppermost 4 or 5 feet of beds, but without very careful hand picking the grade of the product is likely to be well below the permissible limit for iron ore.

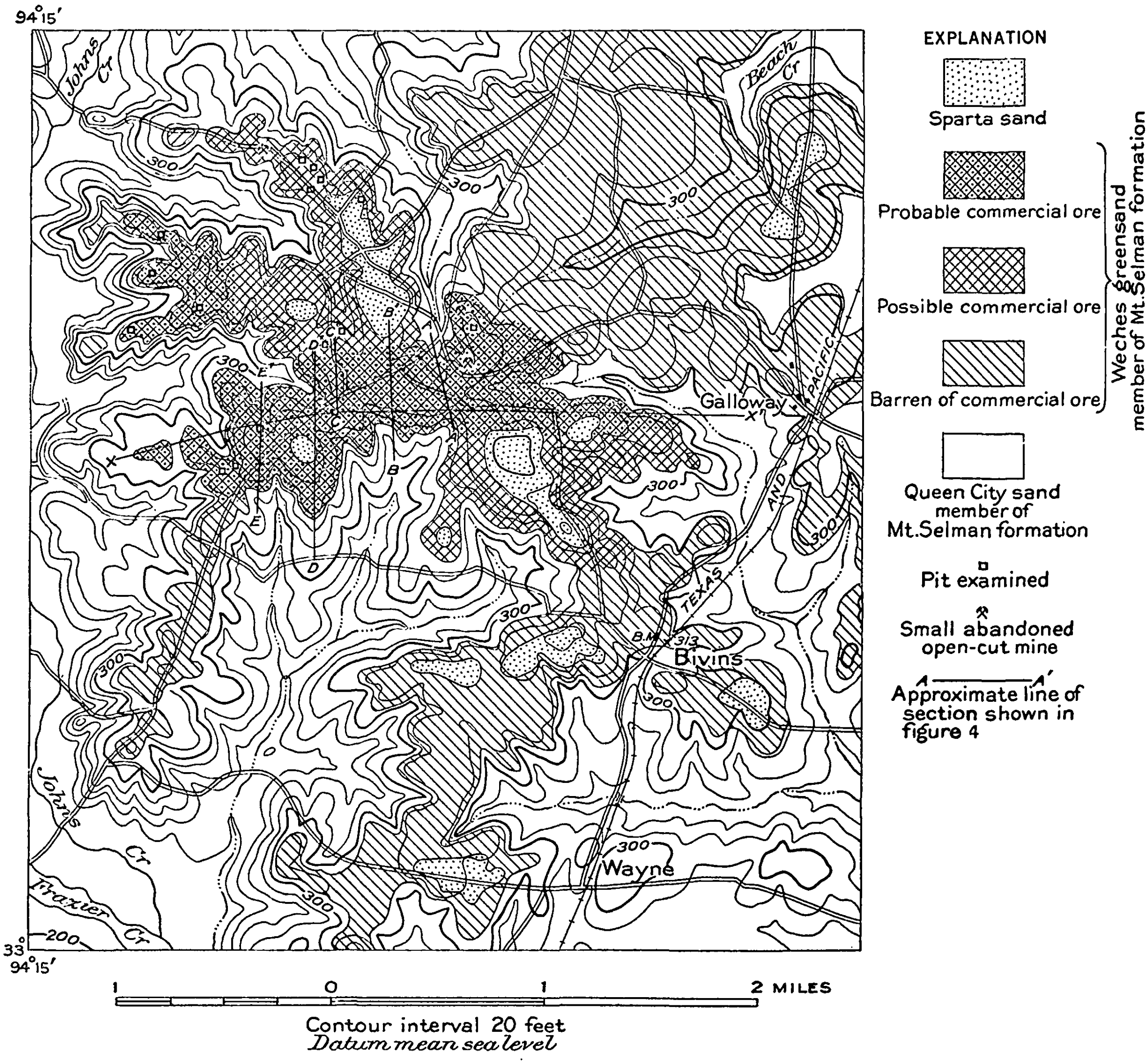
Thousands of yards of ferruginous material has been scraped from the western part of the hill for use in highway construction. The material is well suited for this use, and it is best to consider the whole area a deposit of road gravel rather than a potential iron mine.

SURRATT DISTRICT (6)

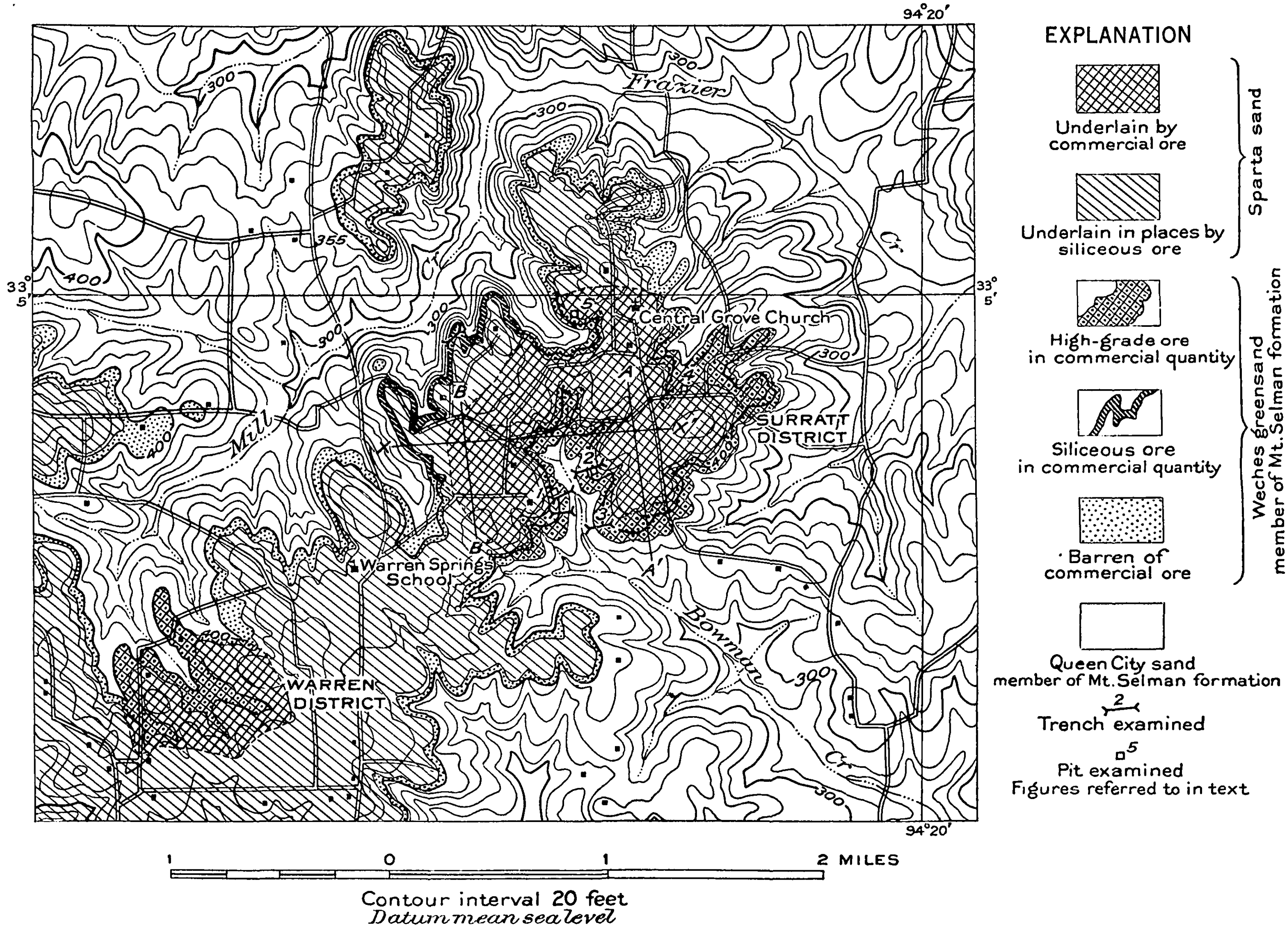
Besides containing a larger tonnage of proved ore than any other district in the North Basin, the Surratt district is of special interest because of the wide variety of problems presented there, the solution of which throws much light on the general problems of the relations of ore deposits to water-table conditions and to the original sediments. The district occupies an irregularly branching tableland in the vicinity of Central Grove Church, 4 to 5 miles north of Linden (pl. 2). This tableland, whose mean altitude is about 420 feet, is a northwesterly spur from the almost continuous area of Weches greensand and Sparta sand that extends northward from Marion County past Linden.

The usual rapid variations in thickness and in chemical and physical character are exhibited by the Weches greensand in this district. In the eastern and northern parts of the area the formation is from 35 to nearly 50 feet thick, but it is thinner and contains more quartz sand toward the west and south, where it is only 10 to 20 feet thick (pls. 18, 19). Immediately south of the Surratt district the Weches is composed of a thin series of chocolate-brown clays and sands, distinguishable from the underlying Queen City sand only by the presence of a few lenses of green glauconitic material. Where the formation is thick it is made up of glauconitic oolites or grains with relatively large proportions of greenish clay locally and only a little quartz sand. No lignitic material was seen in the greensand, but such material must be widespread, as much of the carbonate ore contains lignite. The greensands are cross-bedded in a few places, the false-bedding planes dipping in a southerly direction at angles of about 20°.

The overburden of Sparta sand ranges from a few inches to as much as 50 feet in thickness. In the northern part of the area the basal layers of the Sparta sand contain an abundance of small quartz

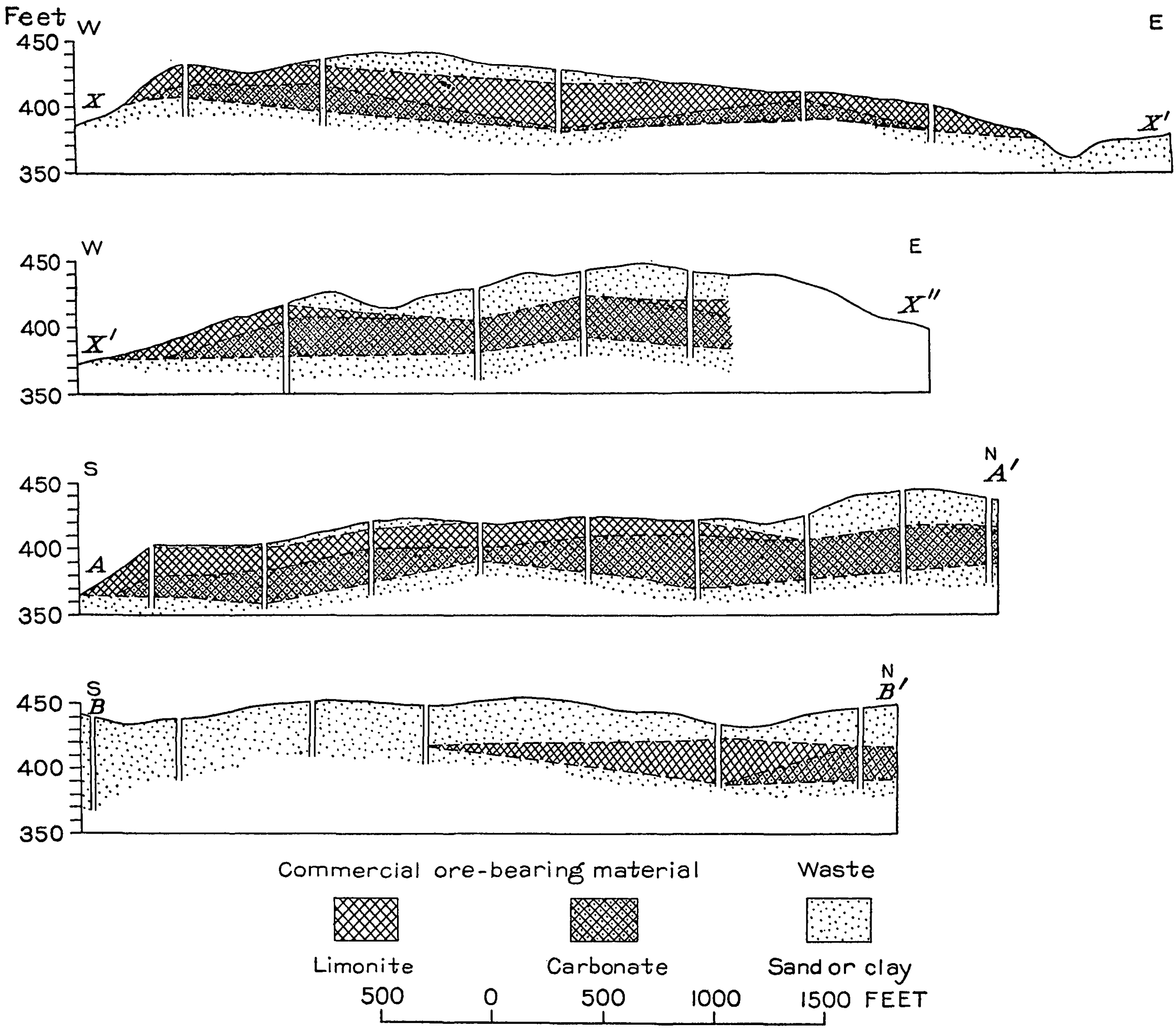


MAP SHOWING DETAILS OF BIVINS DISTRICT, CASS COUNTY.



MAP SHOWING DETAILS OF SURRATT AND WARREN DISTRICTS, CASS COUNTY.

A———*A′*, *B*———*B′*, *X*———*X′*, lines of sections shown in plate 19.



VERTICAL SECTIONS OF ORE BODIES IN SURRATT DISTRICT, CASS COUNTY.

Shows locations of drill holes and shafts. Sections prepared by East Texas Iron Co. and published with their permission.

pebbles, which when cemented by ferruginous material produce a fine-grained conglomerate of striking appearance. That rich iron-ore deposits extend beneath a heavy overburden of sand has been proved in this district by intensive drilling. This deviation from the general rule is probably due to a relatively high porosity in the greensand beds.

Almost the only surface evidence of the presence or absence of ore at depth is the position of the water table relative to the Sparta and Weches beds as shown by springs and wells, for where the water table is at the top of the greensand commercial ore is usually absent. Springs of more or less permanent nature occur in nearly every reentrant on the hill. Most of them issue from points within the greensand section, but where thick Sparta sand coincides with the presence of relatively large proportions of clayey material in the greensand,

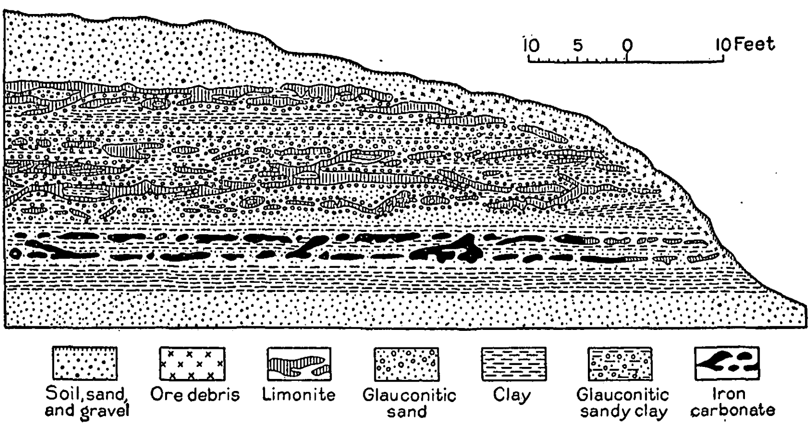


FIGURE 5.—Section showing typical association of iron ore in trench from edge of hill on Surratt tract, north of Linden, Cass County. (After Burchard, E. F., U. S. Geol. Survey Bull. 620, fig. 4, 1916.)

the springs issue from the top of the Weches member. A few springs in the western part of the area issue from the base of the Weches, obviously on account of the sandy, porous nature of the greensand there.

Both brown ore and carbonate are present in the Surratt district in more than usual abundance. The brown ore occurs as ledges or beds from a fraction of an inch to several feet in thickness and as concretionary masses. The carbonate ore occurs in similar masses below the water table. The thickest bed of carbonate seen was 9 inches thick, but one bed of solid carbonate 4 feet thick is reliably reported to have been penetrated by a drill. The ore is largely of good quality, as is shown by the analyses in the table on page 57, but in the northwestern part of the area it is in general much more siliceous and ocherous.

The best ore occurs along the slopes of Bowman Creek, which drains the central part of the district. Four large trenches have been opened there, and all show not only a very thick section of ore-bearing material but an unusually high proportion of ore. The following sections and figure 5 illustrate the mode of occurrence of the ore.

Section at west end of trench 1, on west side of Bowman Creek, Surratt district

	Ft.	in.
Soil and fragmental limonite. The limonite occurs as blocks as much as 6 or 8 inches thick and constitutes about 40 percent of the zone	1	6
Limonite, ranging from material of very good quality to indurated greensand		8
Greensand, brown, oxidized, containing a few concretions of limonite	1	4
Limonite, cellular or spongy to laminated. Irregular botryoidal lower surface. Very little sand and clay included		12–16
Greensand, red and white, clayey, containing a few concretions of limonite		5–9
Limonite, like bed above but containing thin partings of glauconitic sandy clay	1	2
Glauconitic sand and clay, varicolored, containing about 20 percent of limonite in streaks and concretions	1	4
Limonite, massive, dark brown, with very little included sand. Contains small beds of unreplaced carbonate in the basal half inch		12–18
(This point marks the approximate level of water in a well which when cleaned out showed the following continuation of the section.)		
Clay, light bluish green, containing scattered glauconitic grains throughout and a few small concretions of carbonate, slightly altered to limonite in places		12–20
Carbonate, hard irregular ledge, containing in places a little unreplaced glauconitic material		2–4
Greensand, dark green, with some admixed clay and a few concretions of carbonate		15–18
Carbonate, hard ledge, containing a few flakes of carbonaceous material		1–5
Greensand as above, with a few layers and lenses of carbonate which reach a maximum thickness of 10 to 12 inches	2	6
Greensand as above, but well indurated by carbonate between the glauconitic grains	1	9
Carbonate, hard ledge		1½
Greensand, partly indurated as above. A few nodules of carbonate	3	6
Carbonate, solid ledge		5–8
Carbonate, brownish gray, containing much sandy material		4
Greensand, some indurated by carbonate, containing less clayey material than beds above and a few thin lenses of carbonate	3	0
Ore-bearing material not bottomed.		

Section in middle of trench 2, on east side of Bowman Creek

	Ft.	in.
Sandy soil and fragmental limonite, constituting about 60 percent of the zone by volume	1	6
Limonite, laminated, with wavy surfaces; good quality		2–4
Clay and sand, glauconitic, reddish		4–8
Limonite, laminated to somewhat concretionary. Under surface wavy to botryoidal. Small streaks as much as 2 inches thick of brown to red glauconitic sand are included		11–13
Greensand, oxidized, coarse-grained, red to brown, containing many nodules and seams of white clay and a few concretions of sandy limonite, making up about 10 to 20 percent of the volume		12–14
Limonite, laminated, good quality, both surfaces extremely wavy		7–11
Clay, white, with red streaks and blebs of bleached glauconitic sand. Contains concretions of limonite with maximum dimensions of 3 by 14 inches. The bed is lenticular and wedges out against the limonite bed above		4–8
Limonite, laminated, with laminations parallel to the wavy upper and lower surfaces		1½–3
Greensand, oxidized, light brownish red, with many streaks and nodules of white clay and a few small concretions of limonite. A 1-inch band of limonite is intermittently present 2 inches from the top of the bed and is parallel to the lower surface of the limonite bed above		9–15
Limonite, laminated. In places inclusions of white clay make up 50 percent of the thickness		4–10
Greensand, brown, oxidized, fairly well indurated, containing a few concretions and lenses of limonite		8–14
Limonite, thinly laminated		1–6
Greensand, brown, oxidized, with very little clay. Soft and friable		2–7
Limonite, laminated, with considerable proportions of oxidized greensand. Here and there, especially toward the bottom of the bed, blebs of white unaltered carbonate are present		4–9
Greensand, green to brown, owing to partial oxidation. Contains a few lenses and concretions of limonite and carbonate		7–11
Greensand, same as last above, but well indurated by carbonate		6
Greensand, same as above, but soft, containing concretions of carbonate		6–12
(Water seeps from the top of this member, marking the top of the local water table.)		
Carbonate, wavy ledge, slightly altered to limonite in places		2–10
Greensand, mostly fresh and dark green, containing many bands and concretions of carbonate, over 10 inches in total thickness; base of greensand not exposed	3	3

The well noted in the section on page 92 is reported to have been 10 feet deeper, but was not cleaned out further. The section shows about 8½ feet of ore in a total depth of 24 feet, or about 35 percent of ore by volume. A few feet east of this point in the same trench the uppermost bed of limonite is from 3 to 5 feet thick.

The section on page 93 shows a little over 6 feet of ore in about 15 feet of ore-bearing material, or about 41 percent of ore by volume.

The trench is about 5 feet deeper at its west end, near Bowman Creek, but there the section shows only weathered greensand with

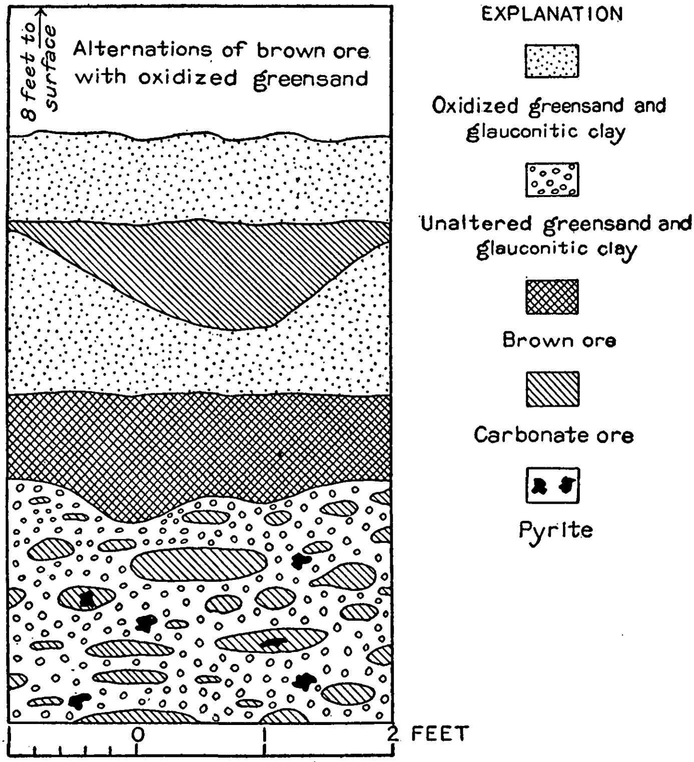


FIGURE 6.—Section at bottom of prospect pit near Central Grove Church, Surratt district, Cass County, showing brown ore beneath carbonate ore.

thin lenses and concretions of brown ore. The carbonate gives out in this direction on approach to the surface. Figure 5 represents the relations along the sides of this trench.

The carbonate masses are much like the limonite except that they are not as porous or cellular. The carbonate is white to gray and contains besides a few flakes of mica, an abundance of carbonaceous material in flakes and chips. Many of these pieces retain a woody structure and closely resemble charcoal.

Burchard [49] gives a section on another trench (no. 3, pl. 18) on the east side of Bowman Creek, which shows a total of almost 9 feet of ore in 40 feet of ore-bearing material.

In pit 4 (pl. 18) about half a mile southeast of Central Grove Church the carbonate zone extends to within 9 feet of the surface. It is reported that this shaft showed good ore throughout its entire depth of 47 feet. Pit 5 (pl. 18), a few hundred feet west of Central Grove Church and near a tributary to Mill Creek, is of interest from several angles. In the upper 8 feet of this pit are the usual alternations of laminated and concretionary limonite with oxidized greensand. Between the depths of 8 and 12 feet the relations sketched in figure 6 appear. The occurrence of brown ore beneath unaltered carbonate is reported to have been observed in several of the deeper shafts in the Surratt district. This relation is probably due to a combination of circumstances, in which fluctuations in the groundwater level and the relatively impervious nature of massive beds of iron carbonate must play important parts. The presence of pyrite in the fresh greensand and within concretions is not unusual in the vicinity of Hughes Springs, but it is uncommon in the eastern part of the North Basin. The oxidation of the pyrite may possibly have had something to do with the anomalous relations.

The large area north of Central Grove Church contains little or no ore in commercial quantities, although the Weches is very thick there and contains an unusually high proportion of glauconitic material. The greensand is well indurated in the beds of the streams, though not elsewhere, and the little limonite that is present is mostly of low grade. All the springs in this area issue from the top of the greensand, a fact suggestive in itself of the absence of any considerable bodies of ore. In the bed of one stream a little carbonate ore was found. It was partly altered to limonite and probably owed its preservation to the presence of sufficient water to retard oxidation.

Of 170 pits of which records are available, 133 showed ore-bearing material to an average depth of 12 feet. This material contained about 26 percent of ore by volume, equivalent to 3.1 feet of ore. The 15 pits and trenches measured by the writer in 1934 show an average of 5 feet of ore in 12 feet of ore-bearing material, or about 42 percent of ore by volume. On the other hand, the records of 92 drill holes show an average thickness of 32 feet of ore-bearing material, which in 26 washing tests yielded an average of 1 ton of ore from 3 cubic yards of material, corresponding roughly to 16 percent of ore by volume. The obvious discrepancy between the figures from the pits and the drill holes illustrates the necessity for extreme caution in estimating the ore reserves. The fact that the estimates of tonnage derived from the drill records and from measurements by the present party are

[49] Burchard, E. F., op. cit., p. 80.

of nearly the same magnitude suggests that perhaps the best ore is concentrated within the uppermost 10 to 12 feet of the greensand beds. If this is so, probably a large fraction of the total ore in the Surratt district could be recovered by mining only the upper beds, an operation that would cut both mining and washing costs considerably. The area of ore-bearing land is approximately 810 acres, fully one-half of which is covered by Sparta sand. All but a small fraction of the area, where the overburden amounts to 35 or 40 feet, can probably be regarded as workable.

The Surratt district is 4½ miles from the terminus of the Jefferson & Northwestern Railway at Linden. Bivins, the nearest station on the Texas & Pacific Railway, is 10 miles distant by air line but much farther over present roads. Sufficient water for mining and washing could probably be obtained by damming the headwaters of Bowman Creek, although the stream dries up completely during periods of drought. A large part of the timber that once covered most of the area has been removed in recent years. There is no record of shipments of ore from the Surratt district.

WARREN DISTRICT (7)

The Warren district, 1½ miles southwest of Warren Springs School and about 2 miles north of Linden (pl. 2), is small but might contribute some good ore to operations in the Surratt district.

On two small ridges near the headwaters of Mill Creek (pl. 18), the surface between altitudes of 400 and 420 feet is well covered with slabs and concretions of very good brown ore. The slabs are commonly 3 to 4 inches thick but are as much as 10 inches thick in places. The concretions range from 6 to 10 inches in diameter in general, though some larger ones occur. They are dark-brown limonite, some of it of the rich "needle ore" variety, and are commonly filled with ocherous material.

Surface exposures and a few shallow pits indicate that the area would yield about 1 foot of ore within 10 feet of the surface. Most of this would probably be recovered from the uppermost 2 to 3 feet. The area of exposed ore is about 78 acres, and there is about 74 acres of Sparta sand that reaches a maximum thickness of 20 feet which is probably underlain by ore. On account of its thinness the ore in this district can only be considered a possible rather than a probable reserve.

JOHN DAVIS DISTRICT (8)

The John Davis district, which receives its name from the headright that includes most of the ore-bearing land, is on the south side of James Bayou, from 1½ to 2 miles southwest of Linden (pl. 2). The higher parts of the broad ridge that contains the depoists are 350 to 400 feet above sea level and less than 100 feet above the level of the Bayou.

The fault that trends southwestward from the vicinity of Linden marks the southern extent of the ore deposits. North of the fault the Weches greensand is 20 to 25 feet thick and consists of typical glauconitic sand and clay, with a somewhat higher proportion of quartz sand than usual. On the south or downthrown side of the fault, which has a vertical displacement of about 45 feet, the greensand is only 3 to 4 feet thick and contains much more quartz sand and less glauconitic material than on the upthrown side. Little or no ore occurs where the greensand is thin, but less than a mile to the south, where it is again 20 to 25 feet thick and contains much coarse glauconitic material, an abundance of very siliceous limonite is exposed along stream beds and other exposures. West of the John Davis district the Weches again thins and becomes more sandy on its approach to the area of nondeposition shown on plate 2. Northward the relations are obscured by a heavy mantle of sand, but the greensand is probably thin or entirely missing, as no traces of it could be found on the slopes of the ridge about 2 miles west of Linden.

The overburden of Sparta sand reaches a maximum thickness of about 20 feet within the district. The average thickness of sand over the ore-bearing land is probably not much less than 10 feet.

Brown ore occurs as concretions or as ledges of coalesced concretions in large part, though thinly laminated, boxwork, and cellular varieties are also present. With the exception of one rich ledge that is usually present near the surface, nearly all the ore is prevailingly siliceous and is in many places only a ferruginous sandstone. The thinly laminated material is commonly ocherous. Oxidized greensand almost invariably adheres to the surfaces of masses of ore and tends to lower the grade materially. The zone of carbonate ore is thick in places and in one water well extended within 8 feet of the surface. The carbonate occurs as nodules or thin lenses distributed through comparatively fresh greensand. In contrast to most of the carbonate ore in the North Basin, the material in this district is impure and siliceous.

Nearly all of the 44 pits examined by Messrs. Stone and Williams were near the outcrop, where the ore usually reaches its maximum development. Nine of these showed no ore, but the remainder showed an average thickness of 14 inches of siliceous and ocherous ore in a depth of 5½ feet of ore-bearing material. This corresponds to about 21 percent of ore by volume. The district has been thoroughly prospected by means of shafts and drill holes. According to company records, 98 drill holes penetrated an average thickness of 17.8 feet of ore-bearing material, which was estimated to contain 1 ton of ore in 2.6 cubic yards, corresponding to about 20 percent of ore. The two sets of figures differ only in the thickness of ore-bearing material indicated, a difference due in part to the fact that the drill holes were put down in the higher parts of the area, where the full section of greensand is present, and in part to the fact that many of the shafts were partly filled with debris in 1934. The area of ore-bearing land is about 540 acres.

A large reserve tonnage of ore is indicated in this district, but the ore is siliceous and the overburden relatively thick.

PREWITT DISTRICT (9)

The Prewitt (Pruitt) district takes its name from the Reilly Prewitt headright, a small tract that includes some of the richest ore in the area. The district occupies part of a large irregular outlier of Weches greensand from 2 to 5 miles southeast of Linden (pl. 2). The area is traversed by the Linden-Kildare highway. Kildare, a station on the Texas & Pacific Railway, is 4 miles from the center of the district.

The highest parts of the area stand 350 to 380 feet above sea level, or 100 to 150 feet above the level of James Bayou, which drains the southeast side of the ridge. The upland is a gently rolling sand-covered surface, devoted extensively to cotton farming. At and below the Weches horizon the area is heavily timbered.

The Weches greensand is about 25 feet thick wherever the full section is preserved, but over large areas it has been beveled by erosion, and only a few feet remains. The greensand consists largely of oolitic glauconitic material, but clay is relatively abundant throughout the section, and quartz sand occurs locally in sufficient quantity to render the iron ores rather siliceous. The top of the Weches ranges in altitude from about 335 to 365 feet above sea level. The beds seem to be nearly flat, but a slight dip toward the west and northwest, away from the Sabine uplift, is indicated by a few random observations of altitude.

The overlying Sparta sand reaches a thickness of 30 feet or more in places, but over most of the area it is less than 10 feet thick. In one or two places in the southeastern part of the district the base of the Sparta is marked by abundant rounded pebbles of quartz and chert. In some localities the Sparta sand, as shown on plate 2, includes some reworked material that has been washed down over the beveled surface of the greensand. With the exception of a little sandy soil there is no overburden above the ore on most of the smaller spurs and ridges.

The water table is unusually high, and the water level in many wells and prospect pits is only 6 to 10 feet below the surface. The carbonate zone is in consequence not far from the present surface. In a few places limonitic material around the roots of fallen trees shows unmistakable evidence of recent carbonate parentage and indicates the presence of carbonate within 2 or 3 feet of the surface.

The iron ore in the Prewitt district shows a wide variety in quality, thickness, and character. Most of it is of medium to good grade, but in places it is too siliceous or ocherous to be of more than passable grade. Some concretions are made up in part of extremely high-grade needle ore, which closely approaches the theoretical composition of limonite. Most of the ore occurs as concretions of irregular shape and varying size or as lenslike beds that represent coalescences of such concretions. Some of the ore is massive or laminated and shows little or no evidence of concretionary structure.

On one of the larger ridges south of the main road a large amount of ore occurs at the surface. Some of this has been rendered magnetic by brush or forest fires, and a compass needle is deflected 20° or more in this vicinity.

Section in prospect trench, Prewitt district

	Ft.	*in.*
Sandy soil, containing about 40 percent of ore as fragments and concretions of variable size	2	6
Limonite, approximately parallel to present surface. Medium- to good-grade spongy ore, with a little interstitial oxidized greensand. Mammillary under surface		10–12
Greensand, reddish brown, with spots of white clay. A few small concretions of limonite throughout	2	2
Limonite as above, but of higher grade because of less included sand. This and lower beds dip into hill at low angles		7–11
Greensand as above, with a 1-inch bed of light-colored clay at top	3	5
Limonite, very good dark-brown laminated variety, but including as much as 20 percent of clay in places		5–7
Clay, red and white		3–4
Limonite, as above		½–3
Greensand, brown, with a few concretions of limonite		8
Limonite, good-quality concretionary ore in irregular zone of thin layers and concretions; much glauconitic sand included		11
Greensand, bleached, with very few concretions of limonite	1	
Limonite, laminated and ocherous; some glauconitic sand included		8–10
Greensand, as above		4
Limonite, as above, but containing little or no sand		2
Greensand and limonite in thin alternating beds	1	
Greensand containing a few concretions of limonite		8
Sand, greenish gray, mostly quartz but containing some glauconitic grains. Concretions of carbonate, averaging 2 to 3 inches in diameter, make up 20 percent of thickness	1	
Glauconitic clay, dark chocolate brown		4
Sand as above but barren of ore	1	

Iron ore occurs as nodules or as comparatively thin lens-shaped bodies. All gradations are to be seen from unaltered greensand through carbonate to the final product, brown ore. The centers of many masses of carbonate show shrinkage cracks, the first evidence of volume change during the alteration to limonite.

The section on page 99 is typical of the occurrence of ore on most of the Prewitt tract proper, which lies southwest of the point where the Kildare road turns abruptly from a southerly to an easterly direction (pl. 2).

This section shows about 5½ feet of ore in a total thickness of 14 feet, corresponding to 40 percent of ore by volume. This trench is on the east bank of a small ravine. Another trench on the opposite bank and a water well not far away show essentially the same relations except that in the well the water table and the zone of carbonate ore are less than 10 feet below the surface.

In the southeastern part of the district, east of the Prewitt tract, the greensand is thin, owing to erosion of the upper beds. One or two ledges of good ore occur near and approximately parallel to the surface in most of this area. A few crusts and thin laminae of ore lie below these ledges but probably do not constitute workable ore. North of the Kildare road the ore is in general thinner and of lower grade, though a little high-grade material occurs on several of the small ridges. The section given below is typical of the occurrence of ore in most of the southeastern part of the district.

Section in prospect in southeastern part of Prewitt district

	Ft.	in.
Sandy soil and limonitic debris, which makes up about 50 percent of volume	1	
Clay, yellow, with about 10 percent of ocherous limonite as small nodules	1	6
Limonite, concretionary, of medium weight and color. Apparently of good grade, but contains a seam of clay ½ inch to 2 inches thick near center		8
Oxidized greensand and clay, white to brown		11
Limonite, as above, but somewhat more ocherous		6
Clay, white		8
Sand, quartz, red and white, with thin clay partings. Typical Queen City aspect	4	

This section shows nearly 2 feet of ore in less than 5 feet of ore-bearing material, or about 40 percent of ore by volume.

Exposures in general are not good in the western part of the district, south of the Linden-Kildare road. Some of the smaller ridges are well covered with good ore, however, and two deep pits show alternations of ore, sand, and clay to a depth of at least 15 feet. The section measured in one of these pits follows.

Section in prospect pit in northwestern part of Prewitt district, south of Linden-Kildare road

	Ft.	in.
Sandy soil	2	
Limonite, of fair quality, but mixed with about 60 percent of clay	1	3
Glauconitic sand, red, with a few blebs of white clay	1	2
Limonite, dark, laminated, containing a little clay		2
Glauconitic sand	1	
Limonite		1
Glauconitic sand		11
Limonite		6
Glauconitic sand		10
Limonite		1½
Glauconitic sand		8
Limonite		3
Glauconitic sand	1	3
Limonite		3
Glauconitic clay and sand, bleached		3
Limonite		7
Glauconitic clay and sand, bleached	2	6
Limonite		8
Glauconitic clay and sand, bleached		6
Limonite		3

This section shows nearly 3½ feet of ore in about 15 feet of ore-bearing material, or 22 percent of ore by volume. Some of the beds of glauconitic sand are indurated. The ore appears to be of medium to good quality, though all of it is mixed with some sand and clay.

North of the Kildare road in the northern part of the district there are some areas that show good ore within 2 or 3 feet of the surface. In general, however, the ore is thin and sandy, and the deposits should be considered only as possible reserves.

The table below summarizes the information that is available regarding the quantity of ore in this district.

Comparative prospecting data in Prewitt district

Source	Number of measurements	Number of shafts containing no ore	Average depth of openings (feet)	Average thickness of ore-bearing material (feet)	Percent of ore by volume in ore-bearing material	Area of ore-bearing land (acres)[1]
Shaft records of East Texas Iron Co.	569	86	9.5	[2] 5.1	40	[3] 430
Drilling records of East Texas Iron Co.	62	----------	[4] 22.1	22.1	[5] 17	[6] 740
Measurements of shafts by E. B. Eckel, J. R. Stone, and E. C. Williams	41	----------	5.48	5.48	40	430

[1] Scaled from field maps made by present party.
[2] Average of ore-bearing material in 483 "good" shafts only.
[3] Outcropping ore only.
[4] All drill holes in upland where full section of ore-bearing material is present.
[5] Based on results of 5 washing tests which gave a recovery of 1 ton of ore from 2.87 cubic yards of ore-bearing material.
[6] Area of probable ore-bearing land; most of the drill holes were placed within this area.

The washing tests referred to were made by washing all material taken from pits sunk near selected drill holes to the same depth as the holes. The number of shafts that penetrated no ore indicates that a reduction of at least 10 or 15 percent should be made in the final tonnage estimates to allow for barren areas. The areas mapped as possible ore, which aggregate about 280 acres, should yield in the neighborhood of 1,500 tons to the acre.

The Prewitt district contains some of the most promising deposits in the region. It is large enough for large-scale operations to be continued for a long period. Water can be obtained from nearby James Bayou or by damming small tributaries to that stream. Kildare, on the Texas & Pacific Railway, is only 4 miles from the heart of the district, with a downhill haul, and the grade of an abandoned timber tramway, which could probably be rebuilt at moderate expense, connects most of the district with Kildare.

JURNIGAN DISTRICT (10)

The Jurnigan district is situated on the south side of James Bayou, 3 to 3½ miles east of Lanier and about 4 miles west of Kildare (pl. 2). It includes three distinct deposits, two of which are within the Curtis Jurnigan headright. The largest of these, known as Jurnigan Hill, occupies the southwestern part of the district (pl. 20). Nigger Hill lies northeast of Jurnigan Hill, from which it is separated by a shallow saddle. The Marett tract is in the northern part of the district and is separated from the other deposits by a deep, wide valley. The details of the main part of the district, exclusive of the Marett tract, are shown on plate 20.

The steep-sided, branching hills reach altitudes of about 410 feet above sea level, or 150 feet above James Bayou, which drains the whole area. Most of the district is heavily timbered, though a small proportion of the land is devoted to farming.

The Weches greensand is 20 to 25 feet thick over most of the area, but it thins locally to 10 or 15 feet. It is normally a typical mixture of glauconitic sand and clay and contains but little quartz sand. In a few places, however, particularly on western Jurnigan Hill, near Pine Hill Church, the proportion of quartz sand increases markedly, and in consequence ferruginous sandstone takes the place of ore. Cross-bedding was noted in one or two prospect pits. Local undulations interrupt the regional dip of the beds, which is toward the northwest, away from the Sabine uplift. As shown on plate 20, the top of the Weches ranges between altitudes of 330 and 375 feet.

The Sparta sand is nearly 50 feet thick on the higher parts of Jurnigan Hill, but on the ore-bearing spurs it is less than 15 feet thick and on Nigger Hill and the Marett tract even thinner. The typical basal sandstone is present locally, but on Nigger Hill and part of the

Marett tract the presence of many pebbles of chert, quartzite, and silicified wood at the Weches-Sparta contact has given rise to a coarse ferruginous conglomerate rather than to sandstone. These pebbles were probably laid down by ordinary sedimentary processes at the beginning of Sparta time, though it is possible that they are associated with a fault somewhere in the vicinity.

Burchard [50] says of the ore deposits in this district:

Jurnigan Hill has also been tested extensively by prospect pits from 9 to 44 feet deep. Some ore was found in nearly all the pits that were noted. Some of the top ore is too sandy to be of commercial value, but there is much good concretionary and nodular ore. There is generally a heavy ledge of limonite near the surface, irrespective of a difference in elevation of 25 to 30 feet, a fact that suggests a downward concentration, not only of the residual ore accompanying the degradation of the hill but also of iron hydroxide, thus continuing to build up ledges of ore a foot or two beneath the surface. Forest fires have partly dehydrated much of the surface ore, altering its color to a dark red. An ore seam 8 inches thick has been found at a depth of 45 feet below the highest part of the ridge. The test pits on Nigger Hill range generally from 6 to 10 feet in depth, but a few are 18 feet deep. A well being dug for water encountered only fragments of ore but cut through some pyritiferous green sandstone and dark clay at a depth of 40 feet. The ore shown by the shallow pits consists largely of rather rich "kidney" concretions, but some portions are sandy.

The following section, measured in a pit near the extreme southeastern extremity of the district, is typical of the areas where the ore is well developed.

Section in prospect pit in extreme southeastern part of the Jurnigan district

	Ft.	*in.*
Sandy soil and detrital limonite in thick ledges. Limonite, which makes up 65 to 70 percent of the volume, dark brown, cellular, and of good quality	3	6
Glauconitic sand and clay, red, containing two thin streaks of sandy limonite	3	9
Limonite, dark brown, laminated, somewhat siliceous		6
Glauconitic sand and clay	1	
Limonite, as above		3
Glauconitic sand and clay	1	6
Limonite, dark brown, of good quality		4
Clay, white to pink, alternating with 2-inch layers of hard, good-quality limonite, which makes up about 45 percent of the volume	1	6

This section shows about 4 feet of ore in a total thickness of 12 feet, or 33 percent of ore by volume.

In most of the pits that were examined the surface ledges are much thicker and richer in iron than the lower beds, which are in general too ocherous or siliceous to be very desirable as ore. A thin carbonate zone was penetrated near the bottom of a few of the deeper shafts, and some of the carbonate ore is to be seen on the waste dumps.

[50] Burchard, E. F., op. cit., pp. 84-85.

More than 400 shafts have been dug on Jurnigan Hill and Nigger Hill. Records are available of 230 of these, of which 44, or 19 percent, are reported as showing no ore. The remainder penetrated an average thickness of 3 feet of ore-bearing material, of which 50 percent was ore, in an average depth of 7.3 feet. These figures agree closely with the writer's measurements of 35 pits, which show 43.6 percent of ore by volume in an average thickness of 3 feet of ore-bearing material. Twenty-one drill holes in the higher parts of the area, where the full Weches section is present, showed an average thickness of 18 feet of ore-bearing material, estimated by company engineers to contain 1 ton of ore in 2.67 cubic yards, corresponding to about 18 percent by volume. The deposits on the Marett tract are very similar to those on Nigger Hill, and it is probably safe to assume the same thickness of ore there.

The area of exposed ore and of that beneath a maximum overburden of 5 feet is about 425 acres. The area which is believed to be ore-bearing but which is covered by more than 5 feet of sand is about 200 acres. The large number of shafts that showed no ore suggests that a correction factor should be applied to final tonnage estimates, but as at least some of these pits were not deep enough to reach the ore horizon, and as the drill holes indicate the occurrence of ore under cover, probably the correction factor should not be more than 10 percent.

Between the Marett tract and Salem Church, on the Jefferson-Linden highway (pl. 2), the Weches greensand is only 10 to 15 feet thick, but it contains many rich concretions of brown ore in places and deserves some consideration as a possible reserve. The concretions range from 6 to 10 inches in diameter and usually consist of pure black needle ore surrounded by outer layers of sponge ore. In places the concretions are coalesced to form thick ledges of rich ore. Some small-scale surface mining has been done in this vicinity in the past. In all there is about 120 acres which might yield 1,000 tons of ore to the acre with careful hand-mining operations.

An enormous amount of careful and expensive prospecting has been done in the Jurnigan district. A comparatively large reserve of ore has been proved to exist, and the district is otherwise desirable. Lanier and Kildare, the possible shipping points, are between 3 and 4 miles distant, and the grade of an abandoned timber tramway connects Jurnigan Hill and Nigger Hill with Kildare. Water could be obtained from James Bayou and the supply of timber is adequate.

HARRIS DISTRICT (11)

The Harris district adjoins the Jurnigan district on the south and is about the same distance from Lanier and Kildare (pl. 2). It occupies an intricately branching upland, covered with 15 to 20 feet of Sparta sand in the central portions, which are extensively devoted to farming. As is true in other districts, a large part of the ore-bearing area is heavily wooded. By far the richest accumulation of ore occurs in the northeastern part of the area, within the W. H. Harris and A. J. Dooley headrights.

The Weches greensand is similar in character to that in the Jurnigan district, though it apparently contains somewhat more quartz sand and is almost universally cross-bedded.

The iron ores are largely of the nodular and cellular varieties. Most of the ore appears to be of comparatively good quality, but nearly all of it is somewhat siliceous. The top ledges of ore are in general thicker and richer than those below. They conform to the present topography and in several places merge into the lower beds along the hill slopes. Figure 2 illustrates these relations as exposed in a shallow trench just west of the Harris tract.

Part of Burchard's description of the deposits on the Harris and Dooley tracts [51] is as follows:

An unusually large prospect trench has been excavated in this tract a short distance southeast of an old mine trench. This large trench is 6 to 7 feet wide, about 14 feet deep, and 130 feet long and connects with a narrower trench at right angles, which extends for 50 to 60 feet, to the brow of the hill, and affords drainage for the large trench. In addition to the material taken from the trench a block of the top ore-bearing ground about 50 feet square has been removed from one side of the trench, and the ore from the whole excavation has been stored in a large pile in a neighboring field. The following section indicates the character of the ore displayed in the large trench. The top 7 feet is especially rich in ore.

Section in large trench 9 miles southeast of Linden

	Ft.	*in.*
Soil rich in ore debris	1	
Ledge of limonite with a few seams of sand	4	10
Glauconitic sand and clay		7–10
Limonite, in part concretionary		3–8
Light-yellowish to reddish glauconitic sand		3
Limonite, in part concretionary		4–7
Reddish glauconitic sand and white clay, with a few small nodules of limonite; the sand is partly indurated by ferruginous streaks	1	9
Limonite		2–3
White and reddish glauconitic sand	1	11
Limonite lens, 3 feet long in sand layer		4
Limonite, with seams of indurated sand		10
Bluish-green clayey sand		3
Base concealed; iron carbonate reported below.		

The section outlined above thus shows about 8 feet of ore in 13 feet of sediments.

In contrast with the rich section just given is the following section, shown at the face of a cut about 200 yards east of the large trench:

[51] Burchard, E. F., op. cit., pp. 82–84.

Section in prospect trench 9 miles southeast of Linden

	Ft.	in.
Sand, light-colored, mostly silica	1	6
Limonite		14–18
Reddish glauconitic sand, with white clay streaks and five streaks of limonite, ¼ to ½ inch thick	1	6
Limonite, with streaks of sand		4–5
Reddish glauconitic sand, cross-bedded, containing white streaks	1	11
Limonite		7
Yellowish sand		5
Limonite		2
Yellowish sand, cross-bedded		10
Limonite		4
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	7
Limonite		3
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	6

According to this section there are about 3 feet 2 inches of limonite within 16 feet 3 inches of sediments.

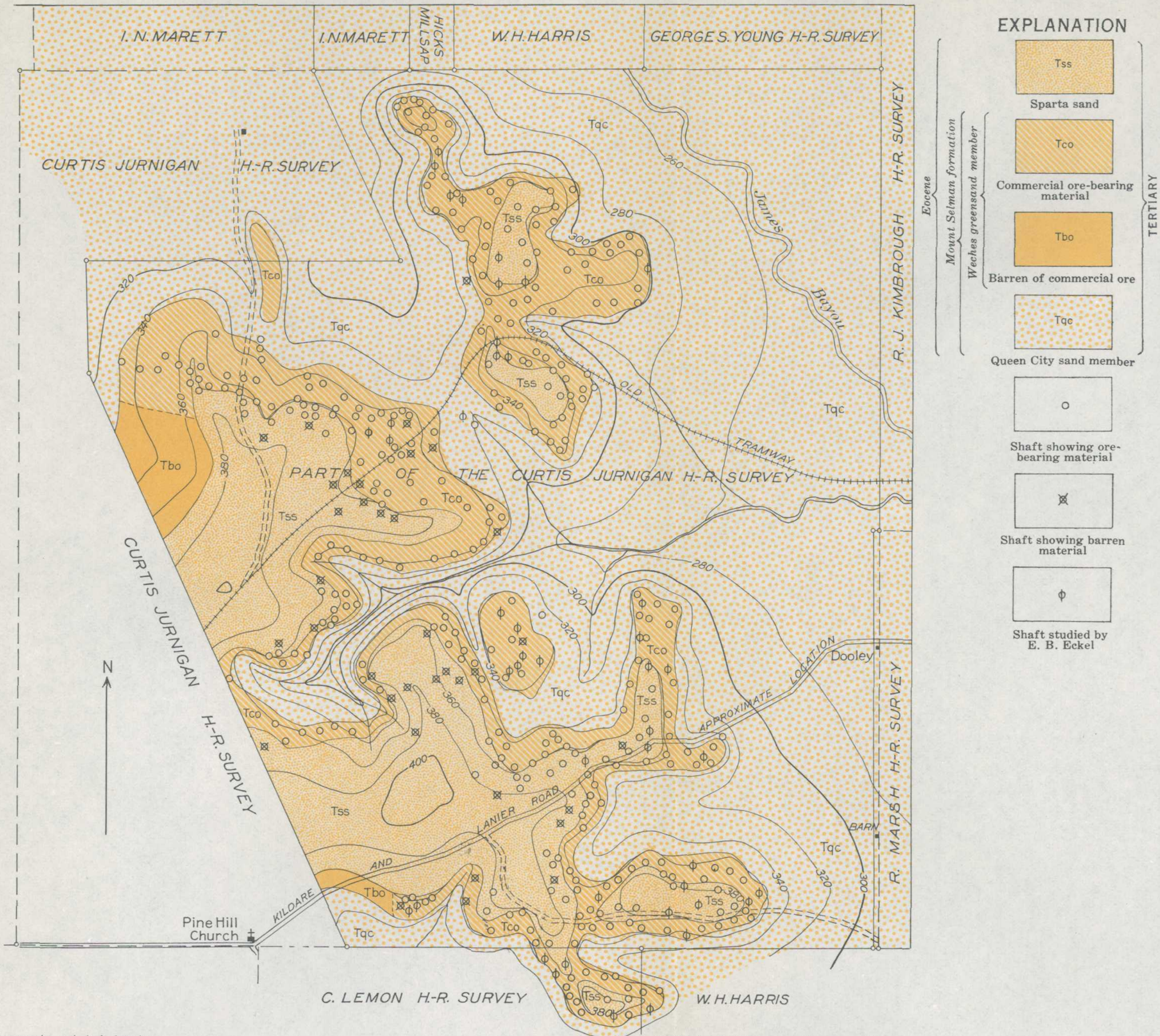
In this area one prospect trench has been cut entirely through a small hill and affords a view of the iron-bearing sediments for a distance of about 350 feet and to a depth of 10 to 20 feet. The richest ore-bearing material in this trench appears to be just about the middle of the hill.

The thick section of ore indicated in these and other trenches is likely to be misleading, as several pits in the same area show only a little ore in one or two ledges near the surface and very little in depth. The deposits are obviously very sporadic in occurrence. The 16 pits and trenches measured by the writer contained an average of a little more than 3 feet of ore in about 8 feet of ore-bearing material, corresponding to 40 percent of ore by volume. On the other hand, company records of 78 shafts show only 3½ feet of ore-bearing material, containing 50 percent of ore, in an average depth of 10 feet.

Aside from the northeastern part of the district, which includes about 100 acres of ore-bearing land answering the above description, the deposits in the rest of the Harris district are essentially confined to one or two ledges of ore close to the surface. The ledges are in general 6 to 12 inches thick and are of the same grade and character as the ore on the Harris tract. All the ore is within 3 or 4 feet of the surface and has an average thickness of about 1 foot over the whole 200-acre area where it is exposed or is covered by less than 5 feet of sand. Probably none of the ore that possibly underlies the central parts of the area can be considered workable, on account of the heavier overburden there.

DUNCAN DISTRICT (12)

Some ore is exposed along the sides of one of the main branches of Willow Creek, from 1 to 3 miles southeast of Lanier (pl. 2). Part of this area is included within the A. D. Duncan headright, which gives



Topography and shaft data by East Texas Iron Company

Geology by East Texas Iron Company, with additions and minor corrections by E. B. Eckel
Surveyed in 1912 and 1934

MAP SHOWING PART OF THE JURNIGAN DISTRICT, CASS COUNTY, TEXAS

1500 0 1500 FEET

Contour interval 20 feet

1938

its name to the district. The extreme southeastern portion of the district is known locally as Cyclone Hill. Surface showings of ore are not particularly encouraging, although a few thousand tons of excellent ore could doubtless be recovered by careful mining.

The Weches greensand is nowhere more than 12 feet thick and probably averages somewhat less than 10 feet in thickness over the whole area. The greensand contains much clay and relatively little siliceous sand, an unusual condition where the Weches is so thin. The resistance offered to weathering by the clay and the associated iron ores has operated to form pronounced benches at the greensand horizon. These are present along all the streams and reentrants but are most pronounced near the ends of the spurs that project from the main ridges.

The interstream divides are heavily covered with Sparta sand, which is 100 feet or more thick in places on the large upland east of Lanier. The upper parts of this formation contain a considerable amount of light-colored clay, but the lower parts are made up largely of quartz sand. Here and there the base is marked by a thin bed of ferruginous sandstone, which in places contains small masses of pyrite, but this bed is not universally present. The relatively great thickness of the Sparta sand and the impermeable nature of the Weches combine to form a perched water table, and nearly all springs issue from the contact of the two formations.

The ore deposits are well exposed naturally, and in addition there are a number of shallow trenches and pits in part of the area. Nearly all the ore is of the concretionary variety and occurs within 2 or 3 feet of the surface. The only exception is on a small part of Cyclone Hill, where several deep prospect pits have penetrated alternating beds of brown ore and glauconitic sand and clay to a depth of 9 feet. The concretions are thickly scattered over the surface in places and literally fill the beds of one or two small streams. Individual concretions range from about 3 to 14 inches in length, and from 2 to 8 inches in thickness. They are irregular in shape and are usually made up of several concentric layers of ocherous, spongy, or needle ore, which increases in purity toward the center. Where not filled with unaltered iron carbonate, the central part is usually hollow or partly filled with light-colored ocherous clay. The concretions occur at the surface on the benches, in stream beds, or close to the surface in a matrix of oxidized and bleached glauconitic sand or clay.

The volume percentage of ore in the dumps of several prospect trenches ranges from 5 to 25 percent. Probably the ore will not average more than 6 inches in thickness over the whole 300-acre area of exposed ore in this district. The position of the water table indicates that little ore is to be expected at any great distance from the outcrop.

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In any event, the overburden is in general so thick as to prevent mining of any but surface ore. Hand gathering of iron-ore concretions would seem to be the most practical method of mining in this area as the ore appears to be too thin and the deposits too scattered to make larger-scale operations profitable.

KNIGHT-FIELD (LANIER) DISTRICT (13)

The Knight-Field or Lanier district includes most of the large area that lies between Cunningham Creek and the Jefferson-Linden highway and extends northward from the Marion County line to a point about a mile north of Lanier (pl. 2). Many problems of scientific or economic importance are presented here, but their solution must await more detailed study and prospecting.

The district occupies the western part of the large area of Weches greensand and Sparta sand that extends almost uninterruptedly from Marion County to a point several miles north of Linden. The uplands, which are largely given over to farming, are heavily covered with sand.

Rapid lateral and vertical variations in the character and composition of the Weches greensand have produced scattered deposits of iron ore of varying degrees of thickness and purity. The greensand in general ranges from 10 to 20 feet in thickness. Random observations of the altitude of the Weches-Sparta contact indicate a gently rolling structure. In places the greensand is made up of coarse oolitic glauconitic material, which is locally indurated to a firm rock. Such material grades either laterally or vertically into siliceous sand that contains only small proportions of ferruginous material. In other places the greensand contains much clay.

The Sparta sand attains thicknesses of 30 feet or more in places but probably averages less than 10 feet in the vicinity of outcrops of commercial ore. The ore deposits are so sporadic in occurrence that it would be unwise to count on much ore beneath cover without further extensive prospecting.

The location of spring horizons varies, depending on the thickness of Sparta overburden and the character of the greensand. Where the greensand contains much clay or where the Sparta sand is relatively thick, the springs usually issue from the base of the Sparta formation.

The following descriptions of a few widely scattered exposures serve to illustrate the extreme variability in character of both greensand and iron ore.

A small deposit of rich ore occurs near the headwaters of a stream about a mile due west of Fairview Church (pl. 2). Several beds of ferruginous sandstone, each 12 to 16 inches thick, occur at the base of the greensand section. Above these beds is 10 to 15 feet of weathered greensand that contains a great concentration of brown-ore concretions. They average about 4 inches in diameter and are mostly of the spongy or massive varieties. In places, as in the stream bed where it crosses the main road, the concretions are made up of iron carbonate. Apparently from 15 to 20 percent of the section is ore.

The following section was measured along the road a little less than a mile due west of Lanier (pl. 2):

Section about 1 mile west of Lanier

	Ft.	*in.*
Quartz sand (Sparta), with thin clay partings	14	
Limonite, ocherous in large part, with coalesced concretionary structure; somewhat sandy in places		3–8
Glauconitic sand, pink, and white clay in irregular thin lenses. Many thin lenses of siliceous dark-brown limonite and small concretions (2 to 6 inches in diameter), usually of spongy ore surrounding a central part of heavy massive limonite. Ore is about 10 percent of thickness. A small spring issues at base of section	7	
Glauconitic sand and clay, as above, showing very little ore along ditch, but on hill slope alternations of thick lenticular beds of limonite with bleached sand and clay. The limonite is massive or spongy, coalesced concretionary in structure, and includes much oxidized greensand. It makes up nearly one-third of the section	10	
Quartz sand, with some clay, cross-bedded, light-colored, and of typical Queen City aspect	6	
Carbonate ore, dark gray, containing a few unreplaced glauconitic grains. Thin streaks of chocolate-brown clay included		4
Quartz sand, as above	2	
Clay and sand, black to chocolate-brown, with flakes of lignitic material. Thin, evenly bedded. Near base several thin beds of buff quartz sand interfingered with clay	13	

The fact that most of the ore beds penetrate the hill for only a short distance is a rather common feature and serves only as a warning against basing tonnage estimates on surface exposures. The presence of carbonate ore containing glauconitic grains in a series of sands and clays so typical of the Queen City is strongly suggestive of interfingering of the Weches and Queen City. The carbonate bed may represent the base of the Weches, but at no other place has the Weches formation been observed to contain cross-bedded sand and clay of the type described here.

Not far west of the exposure described above is a small quarry where a 4-foot bed of brown glauconitic sandstone has been worked to a moderate extent for building stone. This ledge is overlain by about 10 feet of weathered greensand rich in concretions and lenses of good-grade ore.

Along a stream bed near Antioch Church, half a mile west of Lanier (pl. 2), there is a remarkable concentration of carbonate ore in the greensand. The uppermost 5 to 6 feet of the 22-foot thick Weches section shows alternations of chocolate-colored or brown clays and sands. The sand is largely quartz but contains some dark-green glauconitic grains. Several ledges of carbonate crop out in the stream bed, and one of them marks the Sparta-Weches contact. Below the siliceous and sandy phase the rest of the section is made up of moderately coarse-grained greensand, which is usually dark green but is bleached locally. The greensand contains much greenish clay throughout, and in places there are thin layers of chocolate or gray clay with abundant flakes of lignitic material. Throughout the section ledges or concretions of carbonate ore are abundant. They are light-colored and of fairly good grade, although nearly all contain much unaltered glauconitic material. All stages in the formation of ore are exhibited. In places the greensand is merely cemented and hardened by the addition of siderite between the grains. In other places the alteration has gone one step further, with the development of concretions. Finally the concretions have grown together and coalesced to form rough, irregular ledges that in places retain some greensand in the interstices between the original concretions More than 7 feet of carbonate ore was measured in the entire section of about 22 feet along an exposure about 1,000 feet long. It is doubtful, however, whether any such concentration exists away from the outcrop. In fact, the presence of large springs at or close to the base of the overlying Sparta sand indicates that the bulk of the greensand is impermeable and probably contains but little ore.

The long ridge that extends westward toward Cunningham Creek, about 1½ miles due west of Lanier, is devoted to cotton fields, although the Weches apparently covers the whole ridge (pl. 2). The uppermost 8 to 10 feet is largely quartz sand, similar to the Sparta sand, but many rich solid concretions of limonite occur in places. This sand is probably a mixture of reworked Sparta sand and the upper, more siliceous Weches beds. Some of it, at least, would yield much good ore. Below the concretionary zone several thick beds of hardened greensand and ferruginous sandstone appear, but they are too low in iron and too high in silica to have any value.

A well at the east end of this spur exposes more than 2½ feet of ore in a 10-foot thickness of bleached glauconitic sand and clay. The limonite, which occurs in wavy beds from 1 to 8 inches thick, is apparently of rather good quality, though somewhat ocherous and coated in places with oxidized greensand. Some carbonate ore remains on the dump.

The large area mapped as probable ore that extends southwestward 2 to 4 miles from Lanier (pl. 2) appears promising. The greensand is about 15 feet thick and contains much brown ore in the upper part as ledges or concretions, usually from 2 to 6 inches thick, though some are larger. The lower 6 feet of the greensand contains a considerable amount of carbonate in places. Possibly the yield of ore from this area would be about 15 to 20 percent by volume.

In a region where the ore deposits are so variable in character any estimate of the reserve tonnage is quite likely to be in error. The areas shown on plate 2 as probable ore appear to be most promising. The total area is about 600 acres, which may possibly yield 15 to 20 percent of ore by volume from an average thickness between 10 and 15 feet. Some of the areas mapped as possible ore may be equally rich, but in general the symbol denotes areas where rich concretions appear close to the surface but where no appreciable thickness of ore is thought to exist. The 260-acre area of possible ore would probably not yield much more than 1,000 tons of ore to the acre.

None of the deposits in the Knight-Field district are more than 4 miles from the Jefferson & Northwestern Railway at Lanier. Water is readily available in nearby Cunningham Creek. A rather large reserve of ore is indicated, but the deposits are so widely scattered as to prevent large continuous mining operations, and much of the ore is only of fair or medium grade.

BEAR CREEK DISTRICT (14)

The Bear Creek district comprises the four small ore-bearing ridges that form part of the divide between Bear and Cunningham Creeks. They are 1½ to 2 miles east of Bear Creek School and about 3 miles west of Lanier (pl. 2).

The Weches greensand is only 10 to 20 feet thick here, probably on account of thinning about the edge of the area of nondeposition shown on plate 2, in the vicinity of Bear Creek School and Flag Pond Creek. The greensand grades rapidly from material rich in glauconitic sands to siliceous deposits that yield only ferruginous sandstone on weathering. The areas of commercial ore shown on the map correspond roughly with the areas of richest glauconitic material in the greensand.

The higher parts of the ridges are covered with a few inches to 10 or 20 feet of Sparta sand, but the average thickness of overburden is probably not prohibitive, even for these comparatively thin deposits of ore.

The mode of occurrence of iron ore on the largest of the four hills, immediately east of Bear Creek School (pl. 2), is typical of all the ore-bearing area. On nearly all exposed surfaces of the greensand many large and rich concretions of brown ore occur. They range in size from 2 by 6 inches to large masses that attain dimensions of 3 by 4 feet by 1 foot and are made up of three or four coalesced concretions. Over much of the area the individual concretions probably average 1 foot in diameter by 6 or 8 inches in thickness. They are generally very irregular in shape. The outer shell is commonly slightly earthy or spongy brown ore, with inner layers of glossy black needle ore. The centers may be solid ore, hollow, or filled with chocolate-brown to olive-drab clays. The concretions are apparently confined to a zone within 2 or 3 feet of the surface.

Probably the whole area of 275 acres would yield less than 1 foot of ore as an average, but the richness of the ore and its occurrence at the surface make this seem to be one of the most desirable areas of possible ore in the North Basin. Small-scale hand operations should recover a considerable tonnage of excellent ore with the expenditure of a minimum of effort.

West of the road on the main hill there are several long trenches and shallow pits. Information on their history is not available, but they seem to be evidence of very old small-scale mining operations rather than prospect openings.

The district is 3 miles in an air line from the Jefferson & Northwestern Railway at Lanier and fully twice that distance over present roads.

CONCORD SCHOOL DISTRICT (15)

The Concord School district, known also as the Fisher-Miller, Glass-Story, or Ryans Hill district, comprises the group of small, steep-sided rocky hills between Black Cypress Creek and Flat Creek, about midway between Hughes Springs and Linden (pl. 2). The hills range in altitude from 440 to 485 feet, or about 225 feet above the level of the streams.

The Weches greensand is 20 to 30 feet thick and is composed of glauconitic material with considerable quantities of clay and quartz sand. The beds are folded more strongly than in most of the North Basin, and differences of 20 to 50 feet in the altitude of the top of the Weches within short distances are the rule. The regional structure is obscure, on account of the scattered nature of the Weches outcrops in this region.

As most of the hills are capped by a little of the ferruginous basal Sparta sandstone, it appears that the full thickness of the Weches is represented. With the exception of this basal layer the Sparta is missing over all but a small fraction of the ore-bearing land, and the overburden consists of only a few inches to several feet of sandy soil.

Most of the iron ore is of the limonitic variety, though excellent carbonate ore is reported to have been penetrated in some of the prospect shafts. The brown ore is of medium to good quality and dark-brown color. Most of it occurs as laminated or cellular beds or lenses, from a fraction of an inch to more than a foot thick. The ore deposits are definitely related to the present topography, as without exception the best ore occurs close to the surface, irrespective of differences in altitude. The generalized section of all pits observed is about as follows:

Generalized section of pits in Concord School district

	Inches
Sandy soil and wash ore. The ore fragments are in general of high grade and constitute from 40 to 70 percent of the volume	18–36
Limonite, dark brown, laminated or cellular, with irregular to very wavy surfaces	8–18
Greensand, oxidized, with more or less quartz sand and clay and containing a few thin streaks of ocherous limonite	12–40
Limonite, like bed above	3–6
Greensand, with much clay and some quartz sand, containing a few thin streaks of limonite	36–120

The relations shown in this section appear in all pits, and it seems doubtful whether it would pay to mine below the second ledge of good ore. The 240 acres of ore-bearing land in this district should yield close to 2½ feet of ore from beds within 5 or 6 feet of the surface.

The combined area of all the isolated deposits is small, and transportation of ore would be a major problem in the exploitation of the district. Unless the recently abandoned Marietta line of the Jefferson & Northwestern Railway were rebuilt, ore would have to be moved to the railroad at either Linden or Hughes Springs, 6 to 8 miles distant.

NORWOOD HILL DISTRICT (16)

Norwood Hill, about 3½ miles northeast of Hughes Springs along the Linden Highway (pl. 2), should yield a small tonnage of medium-grade ore. The hill, which is drained by tributaries of Black Cypress Creek, attains an altitude of about 490 feet above sea level, 250 feet above the level of the creek.

The basal surface of the Weches greensand, which is about 25 feet thick, ranges in altitude from 435 to 460 feet, with local minor undulations. The greensand is made up of medium-coarse oolitic glauconitic sand with some clay and sufficient quartz sand to render the beds permeable to water. This results in the presence of springs at the base of the formation and favors rather thorough oxidation of the greensand. The proportion of quartz sand increases toward the south, and south of the Linden Highway the outcrop of the Weches is represented by ferruginous sands and sandstones, with little or no commercial ore.

The Sparta sand covers much of the area and reaches a maximum thickness of about 20 feet. The basal sandstone layer is well developed. In spite of the relatively heavy cover, it is probable that ore extends beneath most of the hill, as the springs at the base of the Weches indicate permeable conditions throughout the greensand.

The ore, as is shown in analysis 25 (p. 57), is only of medium quality. Most of it is a yellow ocherous oxidized greensand, well indurated locally, and containing sufficient limonitic material to form strongly pitted surfaces on weathering. From this material, which is heavy and of fair quality, the ore grades to spongy or cellular limonite of good weight and color but contaminated with some quartz sand. In a few places masses of heavy flinty ore, of medium-brown color, appear. Most of the ledges of brown ore range from 4 to 8 inches in thickness, and there are probably several such layers in the upper parts of the greensand.

The workable area is about 260 acres, of which more than one-third is covered by sand. The average thickness of ore-bearing material is probably not more than 10 feet and should yield 20 percent or less of ore by volume.

The district is not too far from the railroad at Hughes Springs for economical transportation of ore, but the reserve of ore indicated is small, and the overburden on most of the area is rather thick.

CHAMBERS-HUGHES DISTRICT (17)

The Chambers-Hughes district receives its name from the J. C. Chambers and R. Hughes headrights and comprises a group of ore-bearing hills about 2 miles northeast of Hughes Springs (pl. 2). All the deposits are small, and most of the ore is only of medium grade, but the aggregate tonnage indicated is large enough to be of interest. The hills, which are steep-sloped and irregular in shape, are heavily wooded in large part. They rise to altitudes of 450 to 500 feet, about 200 feet above the level of Black Cypress Creek, which drains the northern part of the area.

The Weches greensand is poorly exposed over most of the area but seems to be a normal mixture of oolitic glauconitic material with some quartz sand and but little clay. The formation ranges from 10 to 20 feet in thickness and is nearly flat, though minor undulations occur locally.

The contact of the Weches greensand with the Sparta sand, which overlies parts of the area to a maximum depth of 15 feet, is marked by the usual thin bed of ferruginous sandstone. The overburden is thin in general, probably averaging less than 5 feet in thickness.

The iron ore in this district is variable in both character and quality. Over much of the area the greensand is thoroughly hardened and forms thick ledges of massive ocherous material. In places this is obviously too sandy to have any value, but such material grades locally into heavy massive yellow ocher, streaked with dark brown, which though higher in alumina and silica than the typical brown ores of eastern Texas is at least of passable grade.

In places ledges of better-grade sponge ore, similar to that in the Ed West district (see below), take the place of the indurated greensand. They range in general from 6 to 10 inches in thickness, and slabs of float ore are locally abundant. In places rich masses of kidney ore, usually with an outer layer of sponge ore, are rather plentiful. Over most of the area the whole Weches section is thoroughly oxidized, as would be expected from its thinness and relatively porous nature, but one or two wells have penetrated a thin carbonate-bearing zone near the base of the greensand. This zone is not over 2 feet thick, and masses of carbonate ore are only sparingly present.

The differentiation between probable and possible ore-bearing acreage shown on plate 2 is in reality a distinction between the areas where concretionary or sponge ore predominates and those where most of the material is merely ocherous greensand. The total area, of which about one-fourth is of the latter type, is roughly 300 acres. The ore-bearing material is between 10 and 12 feet in thickness, in general, and should yield 20 to 25 percent of ore by volume.

The district is not far from Hughes Springs, the logical shipping point on the Missouri-Kansas-Texas Railway. The Marietta and Linden Highways cross the area. As in the Ed West district, water could be obtained from Cloninger Creek or Black Cypress Creek. Some good ore is certainly present, but mining costs are likely to be high on account of the scattered and sporadic nature of the deposits. In the matter of quality of product two alternatives are open. Only high-grade ore might be produced, but in that case rather costly crushing and washing operations would be necessary to separate the concretionary and sponge ore from the more ocherous material. On the other hand, if no such separation were made the final product would be much lower in grade and freight costs per ton of recoverable iron would be high.

ED WEST DISTRICT (18)

The Ed West district, so named from the headright survey within which most of the deposits occur, is 2 miles north-northwest of Hughes Springs (pl. 2). The principal deposits occupy a long, narrow ridge between the Black Cypress and Hughes Creek drainage systems. The highest part of the ridge is about 530 feet above sea level and 100 to 200 feet above the main streams.

The Weches greensand is typical in composition and general character. Its thickness appears to be about 20 to 25 feet on the western part of the ridge, but farther east the upper beds have been removed by erosion and only 10 feet or less of greensand remain. The beds dip toward the southeast with the base of the Weches at an altitude of about 490 feet on the western part of the ridge and only 460 feet at the east end.

The Sparta sand and reworked material from that formation covers only a small part of the ridge. In the western part the sand reaches a maximum thickness of about 15 feet, but the average for the whole ridge is considerably less than 5 feet.

The iron ore that covers the surface of much of the ridge is in large part dark-brown limonite of good quality. Sponge ore with little or no interstitial quartz sand predominates, but medium-brown flinty ore and thick-walled concretions are by no means rare. The spongy type of ore ranges in texture from very fine to coarsely cellular, with laminae as much as a quarter to half an inch thick. Nearly all surface exposures show uncommonly good float, which is probably as abundant as in the Harris and Bowie Hill districts. In an old shallow trench on the western part of the ridge 1 foot of gravel, very rich in fragmental ore, is underlain by a 2-foot ledge of ore, the base of which is not exposed.

The workable ore-bearing material is probably between 10 and 12 feet in average thickness and should yield about 25 percent of ore by volume. The area is about 210 acres. The small outlier north of the Ed West ridge contains a little good ore, but the Weches is thin and sandy, and only a few tons of ore could be expected.

This district is about 2 miles from the Missouri-Kansas-Texas Railway at Hughes Springs and a somewhat shorter distance from Veals Switch on the same railway. The upper parts of Cloninger Creek (pl. 2) could doubtless be dammed to furnish water and sites for settling ponds.

HOOTEN HILL DISTRICT (19)

Hooten Hill lies immediately north and northwest of Hughes Springs and is the east end of the large branching upland that extends westward from the vicinity of Hughes Springs to a point a mile or more beyond Veals Switch, in Morris County (pl. 2). As considered here the Hooten Hill district is limited on the west by the Morris County line.

Coarsely oolitic greensand makes up the bulk of the Weches section on eastern Hooten Hill, but toward the west the proportion of quartz sand increases markedly on account of the proximity to a structurally high area in the vicinity of Veals Switch. The actual thickness of the greensand is not much more than 20 feet, and it thins rapidly toward the west to about 10 feet. The abnormal thickness indicated by plotting the geology on a contour map is apparent rather than real, as the beds dip southeastward at a rate in excess of 35 feet to the mile. The base of the formation occurs at an altitude of 450 feet on the northwestern part of the hill, but in and near Hughes Springs it is at about 410 feet.

The few springs that occur on Hooten Hill, the largest and best known of which gives the name to Hughes Springs, issue near the base of the Weches section. As was noted in the discussion of origin (pp. 44–45), the waters of Hughes Springs contain more than the average quantity of iron, which occurs as bicarbonate and as sulphate. This fact suggests that the pyrite content of the unaltered greensand is somewhat higher in this vicinity than in many other parts of the area.

The Sparta sand covers the higher parts of the hill to a depth of 35 feet or more in places, and over much of the western part of the hill it is too thick to make the area desirable for mining. The average thickness over the whole minable area on eastern Hooten Hill, however, is probably considerably less than 10 feet.

The iron ores are in large part medium- to dark-brown limonite of fairly good quality. They occur as lenticular beds as much as 18 inches thick, as irregular veinlets or crusts, or more rarely as concretionary masses, some of which assume cigar-shaped or cylindrical forms and are hollow in places. Near the surface the ore-bearing gravel is unusually thick and rich in ore fragments. Near the tip of the hill just east of Hughes Springs there was noted an 18-inch bed of buff, crumbly ore, overlain by 5 feet of rich ore gravel. The gravel is commonly from 2 to 5 feet thick, and thousands of yards of it has been removed for highway construction from several extensive gravel pits. As the removal of gravel commonly ceases at the top of the first solid ledge of ore, it is apparent that much iron ore remains even in the pits.

The following section was measured along the road less than half a mile north of the central part of Hughes Springs (pl. 2). It gives a somewhat erroneous impression as to the thickness of ore-bearing material, on account of the southeasterly dip, and as in all other natural exposures the quantity of ore exposed is doubtless greater than would be found farther from the outcrop.

Section along road on Hooten Hill, a quarter to half a mile north of Hughes Springs

	Ft.	*in.*
Quartz sand, reworked Sparta, with a little ferruginous sandstone float	5	
Greensand, oxidized and hardened, with about 10 percent of sandy, flinty, brown ore in lenticular masses	3	
Limonite, dark brown, flinty, with notably botryoidal lower surface. Inclusions of reddish clay locally present		8
Greensand as above, with 15 to 20 percent of limonite by volume	7	
Limonite, dark brown, flinty, interbedded with light-colored clay and indurated ocherous greensand. Total of 32 inches of ore in beds 2 to 12 inches thick	4	
Greensand, poorly exposed, but apparently mostly oxidized, with about 15 percent of ore in thin lenses	8	
Limonite, like beds above		6–10
Greensand, oxidized and hardened, yellow and ocherous, containing veinlets and irregular masses of dark spongy ore. Apparently at least 25 percent of section is ore	14	
Queen City sand and clay (exposed portion)	20	

This section shows 10 feet of ore in nearly 40 feet of ore-bearing material, or about 28 percent of ore by volume.

The carbonate zone on Hooten Hill as shown in a few wells is less than 2 feet thick, and although rich in ore it is neither extensive nor thick enough to bear much promise. A large area in the west-central part of the district is almost entirely barren of iron ore, a fact doubtless due to a combination of heavy cover and the paucity of iron in the greensand.

The area of ore-bearing material on the eastern part of Hooten Hill, less than a quarter of which is covered with sand, is about 300 acres. The minable material is between 10 and 12 feet thick and should yield 25 percent or more of washed ore by volume. More than two-thirds of the 500-acre area of ore-bearing land on the western part of the hill, exclusive of the barren ground, is covered with Sparta sand. The combined thickness of the brown ore and carbonate zones is about like that on the eastern part of the hill, but the grade of the ore and the ratio of ore to waste are lower.

This district is so close to the Missouri-Kansas-Texas Railway that transportation of ore will not be a serious problem. Water can probably best be obtained from nearby Cloninger Creek. The ore is of fairly good grade, and the reserves indicated are sufficient to make this area of considerable interest.

GOODSON-PREWITTS LAKE DISTRICT (20)

The narrow discontinuous ridge that extends from the vicinity of Goodson School, about 5 miles east of Hughes Springs, nearly to Prewitts Lake School, 3 miles to the south (pl. 2), contains several comparatively small areas of distinct promise. This area is also known in part as the Blanton-Clark district. The ridge forms part of the divide between Black Cypress Creek and Turkey Creek and attains an altitude of about 425 feet in the highest parts.

The Weches greensand consists largely of coarse olive-greenish brown glauconitic sand, though some quartz sand and clay are distributed throughout the formation. In one or two places there are lenses of yellow quartz sand, similar to the underlying Queen City sand, that perhaps indicate an interfingering of the two members. The greensand, whose upper surface ranges in altitude from 390 to 430 feet on account of gentle and irregular local folds, has a maximum thickness of 20 feet. In some places, however, there is only 5 to 6 feet of greensand.

The Sparta sand covers most of the higher land to depths of 1 to 20 feet, with an average of somewhat less than 10 feet. Two wells show that ore extends under at least 8 feet of cover, and because of the permeable nature of the greensand it is probable that even the thickest cover is underlain by some ore.

Most of the iron ore consists of ledges of brown ore from 1 inch to 2 feet thick, though small concretions occur in places. The brown-ore zone is underlain in general by 3 to 4 feet of carbonate-bearing greensand. The brown ore is mostly dark and spongy, though light-brown flinty or ocherous material is present locally. The beds or ledges of ore commonly have uneven botryoidal surfaces and are made up in part of coalesced concretions. All the ore is contaminated with more or less quartz sand and oxidized greensand.

The best ore seems to be close to the surface, but there are usually several ledges of ore in the section, and in places a thin but rich bed marks the contact of the Weches with the Queen City.

The area mapped as containing probable ore covers about 430 acres, of which more than half is covered by Sparta sand. The brown-ore zone should average about 6 or 7 feet in thickness and yield about 20 percent of ore by volume. The carbonate zone is probably not over 4 feet thick in most of the area and contains a somewhat smaller proportion of ore to waste.

Much of the exposed area of Weches on this ridge that is not classed as probable ore shows many concretions or slabs of good ore at the surface. The ore is not sufficiently abundant to justify large-scale mining operations, but hand gathering of the ore fragments might possibly prove profitable in connection with larger-scale operations in the richer areas. The same statement is true of the small areas mapped as possible ore on the narrow ridge between Turkey and Hughes Creeks, 1 mile west of the Goodson-Prewitts Lake district.

The district is only about 2 miles from the Missouri-Kansas-Texas Railway at Patman. The area of exposed ore and the reserve of ore indicated are comparatively small, however.

AVINGER DISTRICT (21)

Several small deposits of more or less doubtful value occur within a radius of 2½ miles of Avinger, in the southern part of Cass County. They occupy parts of the outliers of Weches greensand northeast and southwest of Avinger and of the large upland that extends southward from Avinger into Marion County (pl. 2). The hills attain altitudes of 375 to 450 feet.

The Weches varies in thickness from place to place between limits of 10 and 25 feet, and lateral variations in composition are rapid. The beds dip eastward at rates of 30 to 50 feet to the mile.

Brief descriptions of the individual areas will serve to give a better idea of the district than an attempt at generalizations.

Limonitic float is very abundant on the eastern part of the ridge about 1 mile northeast of Avinger (pl. 2). The Weches greensand is about 20 feet thick and grades laterally from fairly rich glauconitic material on the east to ferruginous sand farther west. Most of the ore crops out as loose slabs or ledges from 3 to 8 inches thick. In one place a ledge 3 feet thick is exposed at the surface over an area of 200 to 300 square yards. The ore varies greatly in quality but is predominantly siliceous. Most of the material is dark-brown, hard cellular or spongy ore. Some slabs grade from ferruginous sandstone on one side to good ore on the other, and nearly all the ore contains considerable quartz sand, especially as coatings on the ledges. Hard oxidized greensand containing much ocherous limonite takes the place of the ore beds locally. Wells and prospect pits show that there is little or no good ore beneath the Sparta sand. Mining would be limited to the exposed portions of the Weches, which cover about 55 acres, but it seems likely that from 1½ to 2 feet of somewhat siliceous but otherwise desirable ore could be obtained from a thickness of 10 feet or less of ore-bearing material.

The small hill south of Sturdivant Branch, 1½ to 2 miles north of Avinger (pl. 2), bears promise of a possible small production of ore. The Weches is only 10 to 15 feet thick here, and the Sparta sand is missing except for the occurrence of fragments of the characteristic basal sandstone on the higher parts of the hill. The greensand is largely coarse-grained oxidized glauconitic material, usually rather hard in surface exposures. At or near the base of the greensand there is a persistent zone in which high-grade concretionary sponge or kidney ore is abundantly distributed. The concretions are in many places coalesced and form ledges 10 to 12 inches thick that are exposed on all the spurs from the main hill. In addition to this ore-bearing zone, the higher parts of the hill, particularly along the main road, are covered with 2 to 3 feet of sandy gravel that contains probably 75 percent of iron ore as fragments and concretions from 2 to 10 inches in diameter. It is believed that shallow stripping operations should recover 1½ feet or more of ore from an average depth of about 5 feet over the entire 80-acre area of this deposit.

Some ore is sporadically distributed over the small heart-shaped hill about 2½ miles northeast of Avinger (pl. 2), but the possible tonnage indicated is small and even so would necessitate selective mining. The Weches ranges from 10 to 15 feet in thickness and is covered by 8 feet or less of Sparta sand. Numerous slabs and concretions of sponge or kidney ore occur at the surface, and on the northern part of the hill, west of the main road, a small area is thickly covered with large masses of good ore. The concretions are in part filled with white clay. Ferruginous sandstone is associated with the ore throughout the area, and careful hand picking would be necessary to maintain an acceptable grade of product. This deposit might possibly yield an average of 1 foot of ore from beds within 3 or 4 feet of the surface, but the prospects are not very encouraging.

Part of the branching hill 1 to 2 miles southwest of Avinger (pl. 2) contains a small deposit of rich concretions, which, though too thin to justify large mining operations, might yield a few hundred tons of excellent ore to the acre with small-scale methods. The Weches is 10 to 20 feet thick and is covered in part by Sparta sand or by reworked material from that formation. The concretions, which are 4 to 8 inches in diameter, are composed of very hard chocolate-colored limonite and are evidently of high grade. They seem to occur at two or more horizons within the greensand and cover much of the surface on slopes near the central part of the hill.

Two miles southeast of Avinger, east of the point where the Missouri-Kansas-Texas Railway crosses the Marion County line (pl. 2), an eastward-flowing stream has exposed parts of what appears to be the most promising deposit of ore in the vicinity of Avinger. Burchard [52] describes the surface showings in this locality as follows:

Near Orr switch, at the south edge of the county, a ledge of limonite has been mined on the sides of the valley of a small creek, about a quarter of a mile northeast of the railway. The ledge is generally 1 foot 4 inches to 2 feet thick but attains in one place an exceptional thickness of 6 feet 6 inches in three reefs, separated by two lenses of glauconitic sand 4 inches to 1 foot 4 inches thick. At this place the ledge crops out at the surface, but where the ledge is thinner there are generally 2 to 3 feet of soil and loose ore debris above it. This ledge of limonite may be traced down the hill nearly to creek level. The ore is in rounded nodular masses, coalescing so as to form a ledge. Some of the ore is sandy and contains layers and coatings of glauconitic sand, but most of the ledge is limonite of good quality. It has been mined by pick and shovel along the outcrop in two or three places for a few hundred feet each. What is apparently the equivalent of this ledge has been mined at the top of the hill about a quarter of a mile southeast of the creek and about the same distance from the railway. Here a shallow trench extends around the crest of the hill and exposes ore generally from 1 foot to 1 foot 6 inches in thickness.

Much of the brown ore has been removed from this deposit, but there are indications that an area of 65 to 70 acres is underlain by a zone of carbonate ore about 10 feet thick which should yield 15 to 20 percent of ore by volume.

With the exception of the last-described area, none of the deposits in the Avinger district seem to be of high grade or to contain large potential tonnages of ore. Doubtless many thousand tons of ore could be recovered by careful mining, but the deposits are scattered, and the ore is sporadically distributed.

SPRING HILL DISTRICT (22)

The Spring Hill district, known also as the Stewart-Welch district, lies in southwestern Cass County, about 4 miles northwest of Avinger (pl. 2). Much of the surface of Spring Hill itself, in the vicinity of

[52] Burchard, E. F., op. cit., p. 85.

Spring Hill Church, is covered with concretions of brown ore, and careful hand-mining operations might possibly be rewarded with the recovery of a few hundred tons of ore to the acre. The most promising deposit, however, is about 1 mile west of Spring Hill, on the eastern part of the large hill that extends eastward from the county line in the vicinity of Harris Chapel. The ore-bearing part of the area attains altitudes between 375 and 450 feet.

The Weches greensand is about 20 feet thick and has the usual composition. The beds dip gently toward the east, the altitude of the Weches-Sparta contact being about 440 feet at a point about a quarter of a mile southeast of Harris Chapel and a little less than 400 feet along the eastern part of the hill (pl. 2).

Locally the Sparta sand is as much as 20 feet thick, but the average thickness of cover, exclusive of that part of the area where the Weches is exposed, is probably 10 feet or less.

Large boulders of high-grade ore appear at or near the surface over much of the area. The boulders are mostly heavy dark-brown concretionary masses, relatively free from sand, but some of them are ocherous. There are apparently several zones of such concretions in the weatherd portion of the greensand. In one water well a 6-inch bed of massive, hard gray iron carbonate was penetrated, and it is reliably reported that an abundance of carbonate ore underlies the brown-ore zone.

The distribution of the ore seems to be sporadic, owing perhaps to lateral variations in the character of the Weches sediments, but exposures are poor, and further prospecting is necessary to delimit accurately the areas of commercial ore. It is likely that the areas shown on plate 2 as probable ore, which aggregate about 180 acres, will yield from 7 to 10 feet of ore-bearing material, that contains an average of 20 percent of ore by volume. Surface showings on the areas mapped as of possible value are not so promising, but further prospecting might serve to show that they contain considerable ore.

The Spring Hill district is 3 miles in an air line west of the Missouri-Kansas-Texas Railway. Avinger, the nearest station on this railway, is about 5 miles distant over existing roads. The probable reserves are small, and the area could probably be worked only in conjunction with operations in the Morris County line district, farther west.

MORRIS COUNTY

Morris County adjoins Cass County on the west and contains in its southern portion the westerly extension of the iron-bearing region. With an area of 259 square miles, it had in 1930 a population of 10,028, of whom about 37 percent were colored and nearly 75 percent were classed as rural-farm inhabitants. Daingerfield (population 818), in the south-central part of the county, is the county seat and a station on the Missouri-Kansas-Texas Railway. Naples (population 843) and Omaha (population 506) are on the St. Louis-Southwestern (Cotton Belt) line farther north.

The first settlers came from Tennessee in 1839 and located on the high land near the present site of Daingerfield, where they built a fort to protect themselves against the Indians. During the fifties large numbers of people came from Tennessee, Georgia, and Alabama, and most of the present inhabitants are their direct descendants.

Farming and timbering are the chief industries. Some pottery clay is produced in the vicinity of Omaha and Naples, and the deposits of ferruginous gravel near Daingerfield are intermittently but extensively worked for highway and railroad ballast.

The surface of the county is gently rolling except in the southern part, where the Weches greensand member of the Mount Selman formation forms steep, rocky hills. It ranges in altitude from 245 feet to more than 600 feet. The divide between the Sulphur River and Cypress Bayou drainage basins crosses the county in an east-west direction in the vicinity of Omaha.

Southward from the Sulphur River the Wilcox, Carrizo(?), Reklaw, and Queen City beds appear at the surface in order.

The Weches greensand, capped in places by Sparta sand, occurs as a relatively large outlier that extends along the line between Cass and Morris Counties from Marion County to a point several miles northeast of Daingerfield. The long chain of narrow, disconnected ridges that extends southward from the vicinity of Daingerfield has also been carved from the Weches greensand.

The iron-ore deposits of Morris County are described below under four districts, although with the exception of the Daingerfield district the dividing lines are somewhat arbitrarily drawn. The Morris County line district extends a short distance into both Cass and Marion Counties.

DAINGERFIELD DISTRICT (23)

The iron deposits on Daingerfield Hill have been almost entirely neglected by those interested in acquiring Texas iron-ore lands, although they seem to compare favorably with the deposits in the vicinity of Hughes Springs. This prominent hill, which reaches an altitude of 612 feet, is about 1 mile northwest of Daingerfield, the county seat of Morris County (pl. 2).

The Weches greensand is here 90 to 112 feet thick, nearly five times its average in the North Basin. The base of the Weches, which is marked by a hard bed of ferruginous sandstone from 1 to 4 feet thick, occurs at altitudes of 500 to 520 feet, and the uppermost part of the hill, at 612 feet, is partly covered with thin slabs of the ferruginous sandstone that is typical of the Sparta-Weches contact.

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Surface exposures are good in general, and wherever seen the greensand seems to be made up almost exclusively of glauconitic oolites, with little or no clay and sand. The oolites are somewhat coarser in the western part of the hill, but with this exception the greensand is remarkably uniform in character throughout the hill.

The greensand seems to have been laid down in a deep, narrow trough, which probably subsided as deposition progressed. The Weches that is exposed on the ridges southwest of Daingerfield, shown on plate 2, is 50 to 60 feet thick and very similar in character to the material on Daingerfield Hill, although iron ore is almost entirely lacking. This indicates that the trough extended at least 6 miles in a north-south direction. That it was probably not much more than 2 miles wide is shown by the thinness and more sandy character of the greensands 2 to 3 miles east and southeast of Daingerfield.

The overburden over the whole of Daingerfield Hill is negligible and consists of thin sandy soil which itself contains large amounts of fragmental iron ore.

The only spring noted on the hill issues near the base of the greensand on the southeastern spur, but there is nothing to indicate whether or not the body of the greensand is permeable to ground water.

The whole surface of the hill is covered with a mantle of ore-bearing gravel, and thousands of yards of road-building material has been removed from several extensive gravel pits on the southeastern slopes. As exposed in the pits and in shallow prospect holes, the gravel is from 1 to 5 feet thick and consists of medium- to dark-brown, flinty, somewhat mottled limonite mixed with much indurated oolitic greensand. Individual fragments of ore range from some the size of a pea to slabs 6 inches thick by 18 inches long, with an average diameter of 1 to 2 inches. In most places the limonite makes up 40 to 50 percent of the volume of the gravel.

The gravel has been entirely removed in some areas, and in such places the flinty ore is seen to occur as a network of thin veins that connect horizontal beds of the same material. Both veins and beds have botryoidal surfaces in places (pl. 11, *A*). All the ore is very crumbly, and some of it strongly resembles the buff crumbly ore of the South Basin. Few of the horizontal beds are more than 6 to 8 inches thick, and apparently none of them are continuous for more than a few feet. Recent earth movements are possibly in part the cause of the broken nature of the ore and the unusually strong development of veins. The quality of the ore shown by a single analysis (no. 32, p. 58) is somewhat better than that of most of the deposits near Hughes Springs.

Quantitative data as to the depth of weathering and thickness of the ore-bearing zone are lacking for the most part. A well near an abandoned house on the southeasterly spur (pl. 2) exposes 30 feet of oxidized greensand that contains at least 25 percent by volume of ore as thin beds and veins. Below the oxidized zone, at the present water level, the greensand is comparatively fresh and dark green. Another well on the saddle between the southeasterly spur and the main hill, about 30 feet lower in altitude than the well just mentioned, was cleaned and pumped out to a depth of 10 feet. The section exposed consisted entirely of dark-green glauconitic oolites, all more or less firmly cemented by iron carbonate. No ore occurs in this well, although the carbonatized greensand itself contains about 35 percent of metallic iron, as shown by analysis 6, page 25.

Further prospecting is necessary on Daingerfield Hill before definite estimates of ore reserves can be made, but the indications are that the weathered zone is deep and that at least 20 feet of ore-bearing material, containing perhaps 25 percent of ore by volume, can reasonably be expected from the whole area of 330 acres.

The area is readily accessible to the Missouri-Kansas-Texas Railway at Daingerfield, and an aerial tram could be used to move the ore. Sufficient water for washing could doubtless be obtained from Brutons Creek, about a mile east of Daingerfield.

VEALS SWITCH DISTRICT (24)

The rolling sand-covered upland north of Veals Switch, in eastern Morris County (pl. 2), is a continuation of the western part of Hooten Hill in Cass County and is like that area in general character though even less promising as a potential producer of iron ore.

This area is apparently near the top of a structural high and the Weches is in consequence thin and sandy. It is in general 10 to 12 feet thick but thickens in places to 20 feet. The quartz sand, which occurs in sufficient quantities to give a greenish gray appearance to the fresh greensand, is sporadically distributed and accounts for the spotty nature of the ore deposits.

The Sparta sand is 35 to 40 feet thick over part of the area and covers nearly all of it to a considerable depth. In places, particularly at Veals Switch and near the northwestern extremity of the hill (pl. 2), the basal sandstone of the Sparta is very well developed and reaches several feet in thickness. The usual ferruginous character and dark color of the sandstone is lacking for the most part, and the grains of sand are apparently cemented with silica instead of iron hydroxide.

The northeastern spur of this area is separated from the Ed West ridge by only a shallow depression, and the ores are very similar in character to the deposits on that ridge (p. 115). Of this part of the area Burchard [53] says:

> Some surface mining was done 12 or 13 years ago [about 1902] to supply the blast furnace at Jefferson. Several shallow test pits dug in 1910 show limonite

[53] Burchard E. F., op. cit., p. 89.

in ledges from 8 inches to 4 feet 4 inches thick, the maximum representing an unusually thick mass.

West of this area the ore is for the most part so thin and scattered that it is doubtful if a yield of much more than 1,000 tons to the acre could be realized.

In a few places a fairly good grade of laminated or concretionary brown ore forms a ledge from 6 to 10 inches thick close to the outcrop, but the underlying beds are very lean.

A well not far from the outcrop, about a mile north of Veals Switch, penetrated 12 feet of Sparta sand, 1 foot of sandy low-grade limonite, and a 10-inch ledge of solid but very sandy iron carbonate. Below the carbonate 4 feet of greenish-gray greensand containing much fine quartz sand and some clay was encountered. A partial analysis of this material showed a total iron content of less than 7 percent, which explains the siliceous character of the resultant ores (analysis 7, p. 25).

The railroad cut immediately west of the siding at Veals Switch shows the following section:[54]

Section in railroad cut at Veals Switch

	Ft.	in.
Soil		6–12
Yellow sand and sandstone [Sparta, possibly reworked in part, E. B. E.]	3–8	
Iron ore	1	
Yellow sand		6
Iron ore		6
Sand		4
Iron ore		8
Sand	3–5	
Iron ore		1–2
Gray to chocolate-colored clay containing concretions of iron carbonate from 2 to 15 inches thick	8–10	

Nearly all the ore reported in this section is extremely ocherous and porous. There is much honeycomblike material with very thin walls of ocherous limonite. The intervening sands contain much quartz sand and clay, and apparently the original content of glauconitic material was relatively small. The chocolate clay and sand at the base of the section contains small greenish blebs of glauconitic sand, suggesting some interfingering with the underlying Queen City sand. All the carbonate ore is very sandy, but a few pieces found on the dump of the cut contain large bladed crystals of glassy siderite. Small springs seep out at the top of the dark clays and probably account for the preservation of carbonate at the surface of an artificial exposure for nearly 30 years.

[54] Eckel, E. C., The iron ores of northeastern Texas: U. S. Geol. Survey Bull. 260, p. 352, 1905.

The small area in the northeastern part of the Veals Switch district covers about 125 acres and should yield roughly 25 percent of ore from a 10- to 12-foot thickness of ore-bearing material, but the rest of the district is not considered capable of producing more than 1,000 tons of ore to the acre from the 475 acres that is covered by less than 10 feet of Sparta sand. Further prospecting is necessary, however, to prove the probable value of the district.

OAK GROVE-ROCK SPRINGS DISTRICT (25)

The Oak Grove-Rock Springs district is a somewhat arbitrary division, and comprises all the area south of the Missouri-Kansas-Texas Railway and west of the Cass County line as far south as Rock Springs School (pl. 2). This hilly, relatively inaccessible, and heavily wooded upland is part of the great ridge of Weches greensand and Sparta sand that extends southward along the Morris-Cass County line into Marion County.

The western slope of this ridge is drained by Brutons Creek and the eastern slope, which shows little promise as a source of iron ore, is drained by Hughes and Peacock Creeks. The ridge attains altitudes of 450 to 530 feet above sea level, in general less than 200 feet above the main streams.

The regional dip of the Weches is toward the southeast, though local undulations occur throughout the area. The greensand contains relatively little sand or clay except in the northern part of the district, where it grades into material of the type described above as occurring in the Veals Switch district. The thickness ranges from 10 to about 30 feet, with an average between 20 and 25 feet.

The district contains several streams and most of them continued to flow throughout the summer of 1934, toward the end of one of the longest droughts in local history. Most of the springs that feed these streams issue from the Weches greensand or from its base, but a few occur at the Sparta-Weches contact.

More than half the area is covered by Sparta sand, which reaches a maximum thickness of 35 feet on the highest ridges and probably averages 10 to 12 feet. Even the areas where the Sparta sand is thickest are commonly underlain by iron ore except in the general vicinity of Veals Switch.

Most of the ore that is exposed at the surface in this district is brown ore, though a rich and relatively thick carbonate zone underlies the brown ore away from the outcrops. All varieties of brown ore occur, and most of the material is of at least as good quality as the average ore in the Hughes Springs area. Ledges or beds of cellular or laminated ore range from 3 to 18 inches in thickness, and large concretions of rich needle and sponge ore are abundant in places

Exposures in the gravel pits near the Veals Switch siding show 3 to 4 feet of material rich in fragments of flinty and crumbly ore and much hardened greensand that contains more or less limonite throughout. Most of the ore is siliceous or ocherous, but rich concretions as much as several feet in diameter are sparingly distributed through the gravel. They are usually hollow, with linings of needle or kidney ore and outer shells of sponge ore an inch or more thick. In a cavity of one of these concretions a little light-green powder was found. This is probably the hydrous iron phosphate mineral allied to dufrenite noted by Burchard from this locality.

Near the ends of the small ridges that project southward from the vicinity of Oak Grove School some good ore occurs at or close to the surface in the form of concretions and cellular or spongy beds. The thickest of those seen by the writer were only about 6 inches thick, but Burchard [55] notes the occurrence of a ledge "a few inches to 6 feet thick over many acres." This statement was based on observations of several shallow pits and trenches that were not open in 1934.

The long sand-covered ridge about 2 miles southwest of Oak Grove School and the small outliers that intervene between this ridge and the main mass of Weches greensand contain ore of very high grade in places. It occurs as large concretions or thick ledges, but the distribution is erratic, and probably half of the area is barren.

Exposures along the westerly projections from the main ridge between Oak Grove and Rock Springs Schools show several 4- to 8-inch beds of slightly sandy brown ore, separated by weathered greensand that contains a high proportion of glauconitic material. Along the eastern slope of the main ridge very little ore appears except in the area just north of Rock Springs School, where a little good ore occurs as concretions close to the outcrop.

An area of nearly 1,200 acres in this district is believed to contain commercial ore. The oxidized zone probably averages 7 to 8 feet in thickness and should yield about 20 to 25 percent of ore by volume. The carbonate zone, which underlies the oxidized zone a few feet away from the outcrop and probably displaces it entirely where the cover is very thick, is probably about half as thick as the oxidized zone and should yield not more than 15 to 20 percent of ore by volume.

This district is from a quarter of a mile to 2½ miles distant from the Missouri-Kansas-Texas Railway, and even though it is heavily wooded and has poor roads, transportation of ore to the railway would not be so formidable a problem as in some other areas, such as those farther south in Morris County.

MORRIS COUNTY LINE DISTRICT (26)

The Morris County line district extends southward from Rock Springs School along the line between Cass and Morris Counties and

[55] Burchard, E. F., op. cit., p. 90.

a short distance into Marion County (pl. 2). Most of the area is in Morris County, though small parts of Cass and Marion Counties are included. The irregularly branching hill that parallels the county line and contains the iron ore attains altitudes of 475 to 525 feet, generally less than 200 feet above the levels of Brutons and Alley Creeks, which drain the area.

The Weches greensand is 20 to 35 feet thick in most of the area, but thickens locally to as much as 55 feet. Few deposits of commercial ore occur in the very thick portions, although the proportion of glauconitic material is there unusually high. The richest ores are usually formed where enough quartz sand occurs in the greensand to render it permeable to ground water. The top of the Weches occurs at altitudes of 435 to nearly 500 feet, and although local undulations of some magnitude are the rule, a structurally low area in the vicinity of Rock Springs School and eastward is indicated by scattered observations of altitude.

The Sparta sand, whose base is marked by the usual ferruginous sandstone, covers about one-third of the area to an average depth of about 10 feet. Its maximum thickness is about 35 feet, but on the other hand there are large areas where the ore beds are covered by only a few inches to several feet of sandy soil. Where the Sparta is thick the greensand is either barren or contains only carbonate ore.

In this district, as in the Oak Grove-Rock Springs district, farther north, there are numerous perennial streams fed by springs that issue from the Sparta-Weches contact, from Weches greensand, or from the contact of the Weches with the Queen City sand. The relation between quantity of ore and spring horizon is not as marked here as elsewhere in eastern Texas, but the relatively large amount of water available has undoubtedly played a part in the formation of the rich iron deposits of this district.

Iron ore occurs as both limonite and carbonate, and most of it appears to be of higher quality than the average of the ores in western Cass County. The brown ore is similar to that in the Oak Grove-Rock Springs district and occurs as ledges of cellular or massive ore from 6 inches to 1 foot thick or as concretions of varying size. The carbonate occurs in similar massive beds or as nodules and concretions. In many natural exposures fully half the iron-ore material is carbonate, which doubtless owes its partial or entire preservation to the permanent character of the streams. Probably no separation of the two types of ore could be made in mining, as the usual distinct zones of brown ore and carbonate are lacking for the most part and many of the exposed masses of carbonate are partly altered to limonite. On account of the covered areas, where carbonate ore is always relatively more abundant, this district should produce somewhat more carbonate than brown ore—a ratio that is probably unique among the deposits in eastern Texas.

The area classed as capable of producing commercial ore is about 2,500 acres, of which one-third is covered with Sparta sand. More than half of this area is rich in ore-bearing material, which appears to contain at least 50 percent of ore locally but a probable average of 20 percent or less by volume. The combined brown- and carbonate-ore deposits are between 17 and 20 feet in average thickness.

The district is 2½ to 9 miles from the Missouri-Kansas-Texas Railway at Hughes Springs and about 6 miles in an air line from Avinger, on the same railway. The distribution of the ores is not uniform, existing roads are poor, and the area is in general inaccessible. Notwithstanding these unfavorable circumstances, the district bears much promise on account of the high aggregate tonnage of good-quality ore that is indicated and the relatively thick section of ore-bearing material.

MARION COUNTY

Marion County lies just south of Cass County (pl. 2) and contains a few deposits of iron ore, though it has by no means the reserve of ore that is locally attributed to it. The county has a land area of 391 square miles and a population of 10,371, according to the census figures for 1930. Of the total population 62 percent are colored and 70 percent are classed as rural-farm dwellers. The Missouri-Kansas-Texas, the Texas & Pacific, and the Jefferson & Northwestern Railways join at Jefferson, the county seat (population 2,239), which is one of the oldest towns in Texas and the only one of any size within the county. The old Lone Star blast furnace was located on the outskirts of Jefferson. Three main highways cross the county, but much of the intervening area, particularly along the major streams, is relatively inaccessible. All the streams drain into Caddo Lake, part of which occupies the southeast corner of the county. Several years ago Jefferson was the head of navigation above Caddo Lake, but Cypress Bayou is not navigable at present.

The rolling surface presents the appearance of an undulating plain except along some of the major streams, which have cut steep cliffs in places, and in the northern part of the county, where several steep-sided hills that are held up by a cap of ferruginous material stand out above the general level. The altitude ranges between about 200 and 450 feet.

Agriculture, timbering, and petroleum production from the western part of the Caddo oil field are the chief industries. Much ferruginous gravel is produced for highway construction and railroad ballast. Most of this is used locally, but some gravel and rock are shipped to other parts of the State.

The southeastern third of the county is occupied by Reklaw, Wilcox, and possibly Carrizo sediments, which are brought to the surface by the Sabine uplift. The rest of the area is occupied by the Queen City sand, which is surmounted in the northern and western part of the county by relatively small outliers of Weches greensand and Sparta sand. These represent the southerly extension of the iron ore region of Cass County.

In addition to the Gilbert, Orrs Switch-Lassater, and Hagerty districts, described below, part of the iron deposits of this county have been included in descriptions of the Avinger district, Cass County, and the Morris County line district, Morris County.

GILBERT DISTRICT (27)

The Gilbert district is in western Marion County, about 6 miles southwest of Avinger (pl. 2). It comprises a group of comparatively small deposits, most of which are within the Walter Gilbert headright, and is of special interest as the site of the first Texas iron furnace. This was the Nash furnace, which was in operation before 1859. Furthermore, about 7,000 tons of ore, averaging more than 57 percent of iron, was shipped by steamer to Philadelphia from this district in 1913. The Port Bolivar Iron Ore Railway was built some years ago to transport ore from this field to Longview and thence over the Texas & Gulf Railway (Atchison, Topeka & Santa Fe system) to Port Bolivar, on Galveston Bay. The line has been abandoned, but most of the roadbed is in good condition, and the standard-gage tracks have not been removed.

The ore occurs at the flat tops of several small, steep, heavily wooded hills that reach altitudes of about 400 feet. They form part of the divide between Big Cypress Creek and Alley Creek, one of its tributaries. The largest of the group, which is known as 75-Acre Hill, resembles Bowie Hill, Cass County, in many respects, particularly in the flat top and the extremely irregular outline.

The Weches greensand is only 5 to 6 feet thick over the greater part of the area. That this thinness is due to original deposition rather than to later erosion is indicated by the regularity of the upper and lower contacts and by the presence of typical basal Sparta sandstone at the top of the greensand. This sandstone occurs only as residual fragments where erosion has cut below the top of the Weches.

Much of the ore-bearing area is covered by only a few inches of sandy soil, but in places there are remnants of Sparta sand from 2 or 3 to 10 feet thick. Because of the thin and permeable nature of the greensand, the springs that drain these hills issue from points well below the base of the Weches.

Burchard's description of the deposits on 75-Acre Hill is also applicable to the smaller hills in the district. He says:[56]

The ore is exposed along the brow of a high, flat-topped wooded ridge, known as 75-Acre Hill. The base of the main ore ledge lies about 80 feet above the railway spur and, according to company maps, is at an altitude of about 370 feet. In open cuts made in 1913 the ore is shown to be concretionary limonite, generally of high grade. In the cut which extends about 500 feet N. 30° W. from a point near the tipple the best ore forms a ledge 8 to 15 inches thick 2 to 4 feet below the surface and is overlain by sandy ledges of ore and ore debris in the soil. The ledge is concretionary in structure, and some of the ore debris consists of concretions. About a quarter of a mile northwest of the first cut another cut has been made along the brow of the ridge and around the head of a hollow. This cut is about 800 feet long and 3 to 6 feet deep and discloses a ledge of ore that is in places very thick. In one place 5 feet of excellent ore was measured, composed of two concretionary ledges and extending down from the grass roots. At another place a concretionary mass of ore measures 4 feet in thickness. At other places the good ore is only about 1 foot thick, with sandy ore and clay above it.

Aside from the mine cuts, 75-Acre Hill seems to have been fairly well tested by pits and other marginal and surface cuts. A contour map on a scale of 200 feet to 1 inch, with 10-foot contour intervals, has been made, and by its use it has been determined that there is on this hill perhaps 30 acres of ore-bearing land, besides 25 acres carrying float ore. Most of the test pits are shallow and show a moderate quantity of ore, generally not more than 10 to 15 percent by volume. Many ferruginous boulders are scattered about the surface, but these are mostly too sandy to be considered good ore.

In all, nearly 200 shallow pits were sunk in this district. Many of them are still open, and exposures along the margins of the hills are fairly good. The following section, measured in a deep water well in the central part of 75-Acre Hill, is typical of most of the pits that have been dug at any distance from the edge of the hill.

Section in water well on 75-Acre Hill

	Ft.	in.
Sandy soil	2	
Sparta sand, yellow and red, with thin bed of hard ferruginous sandstone at base	2	
Glauconitic sand and clay, varicolored	2	3
Limonite, light brown, flinty, of fair quality		4
Glauconitic clay, varicolored		8
Limonite, dark brown, spongy type, mixed with much glauconitic clay		13
Glauconitic clay, light-colored		5
Limonite, thinly laminated, light brown, and ocherous, of fair to medium grade. Small water seep at base		10
Queen City, thin-bedded quartz sand and clay	2	6
Sandstone, ferruginous		6
Sand, quartz, with clay partings, white or very light-colored	5	
To water level, not examined	30	

[56] Burchard, E. F., op. cit., pp. 87–88.

Field study of the larger deposits leads to the inescapable conclusion that the richest and thickest ores occur close to the margins of the hills. Away from the outcrop the ore is more commonly ocherous and sandy and is only of medium grade. Moreover, on 75-Acre Hill much of the best ore has already been removed. As would be expected, the good ore on the smaller hills apparently extends over the entire surface.

The total area of ore-bearing land in the Gilbert district is nearly 100 acres. The yield of ore should be 20 to 30 percent by volume from a uniform thickness between 5 and 6 feet. The total tonnage indicated is small, the deposits are scattered, and unless the Port Bolivar Iron Ore Railway should be revived, transportation of ore would be a serious problem. Nevertheless, some ore of very high grade exists, the ratio of ore to waste is comparatively high, and stripping is entirely unnecessary over most of the area.

ORRS SWITCH—LASSATER DISTRICT (28)

In the vicinities of Orrs Switch and Lassater, not far from the Missouri- Kansas-Texas Railway (pl. 2), there are several areas that contain good ore in commercial quantity. The topography is gently rolling, with rather smooth slopes that contrast with the more rugged ore-bearing hills farther west and north. The altitude ranges from 300 to about 400 feet above sea level.

The most pronounced geologic feature of this district is the Orrs Switch fault, which trends in an east-west direction and passes through the area just north of the Orrs Switch community. The vertical displacement of the beds along the fault is about 75 feet, with the downthrown side on the north. Close to the fault on the upthrown (south) side the Weches greensand is at least 65 feet thick and consists largely of glauconitic sand and clay with but little siliceous material. It thins rapidly toward the south to not more than 10 feet at Lassater and only 1 or 2 feet south and southwest of that town. Southeast of Lassater the greensand thickens gradually, until at the old Kelly mine it is about 20 feet thick.

North of the fault the Weches is 25 to 30 feet thick, and it maintains this thickness for some distance northward, where it again thins over the structural high in the vicinity of Avinger. Near the fault the beds are made up largely of glauconitic sand, with but little quartz sand or clay.

Deposits north of Orrs Switch fault.—On the north side of the fault the exposed portions of the greensand are rather rich in ore for a distance of somewhat less than half a mile. Concretions and lenses of medium-grade brown ore are distributed through the oxidized zone, which is 8 to 10 feet thick in general. In places beneath the oxidized zone the greensand contains an abundance of iron carbonate in thin beds and concretions. This carbonate zone is commonly 5 or 6 feet thick, but where the Sparta sand is thick little or no ore is present. The areas shown on plate 2 as ore-bearing amount to about 200 acres. The ore-bearing material averages about 15 feet in thickness and should yield less than 20 percent of brown ore and carbonate by volume.

Deposits south of Orrs Switch fault.—On the south side of the Orrs Switch fault, where the Weches is thickest, there is little or no ore exposed at the surface, and only a very small quantity of carbonate ore has been penetrated in deep wells and test pits. The greensand is indurated near the surface, and large quantities of fairly hard but ocherous material have been removed from the gravel pits south of Orrs Switch for use in highway and railroad construction.

From half a mile to a mile south of the fault and about 1½ miles due west of Lassater there is much good concretionary ore scattered over the surface. Some of the ore is ocherous, and some is crusted with oxidized greensand. There are several old shallow mine workings in this area. They are now largely filled in, but Burchard[57] describes them as formerly having showed ore from 1 foot 2 inches to nearly 5 feet thick. The latter thickness is exceptional. The overburden in this area consists only of a few inches to several feet of residual Sparta sand and sandy soil.

The areas shown on plate 2 as containing probable ore, cover about 160 acres. The oxidized zone is 8 to 10 feet thick. This is underlain away from the outcrop by 6 or 7 feet of greensand that contains carbonate. The yield of ore will probably be about like that on the north side of the fault, or a little less than 20 percent of ore by volume. The 250-acre area of possible ore, where concretions are fairly abundant at the surface but where little or no ore occurs in the lower beds, might possibly yield 1,000 tons of ore to the acre.

Deposits southwest of Lassater.—The road between Lassater and the Kellyville-Mim's Chapel road traverses a long, narrow ridge that is capped in most places by a thin covering of Weches greensand. The Weches is only 8 to 10 feet thick near Lassater, and on most of the ridge it is considerably less than 5 feet thick. The rolling topography apparently conforms to the structure.

There is no Sparta sand in place except near Lassater, where there are large blocks of the basal sandstone. These contain large fragments of what appears to be limonitized wood. Fragments of silicified wood are somewhat abundant locally in the thin deposit of residual sandy soil that covers the rest of the area to a depth of a few inches.

The ore in this area is apparently as high in quality as any of the ore in the North Basin. All of it is within 2 feet of the surface and occurs exclusively as concretions that range from 3 to 15 inches in diameter

[57] Burchard, E. F., op. cit., pp. 86–87.

and are thickly scattered over the surface. The concretions are for the most part very heavy dark-brown limonite. Nearly all are irregular in shape. Some are filled with light- to dark-colored clay, some are solid, and some are hollow. At one point about 1½ miles southwest of Lassater, several concretions were found to be partly filled with liquid. Analytical data regarding the contents of one of these concretions are presented in the section on the origin of the ores, pages 49–51.

The area includes about 575 acres. The yield of ore would probably be between 1,000 and 1,500 tons to the acre, but the exceptionally high grade should justify careful hand-mining operations. Stripping or extensive prospecting are unnecessary, as all the ore is within 2 feet of the surface.

HAGERTY (BERRY) DISTRICT (29)

The Hagerty or Berry district lies midway between Jefferson and Linden, on the line between Cass and Marion Counties, and is traversed by the Jefferson & Northwestern Railway (pl. 2). According to a large-scale topographic map generously furnished to the writer by Mr. Albert J. Jones, the ridge on which the deposits occur reaches a maximum altitude of about 385 feet.

The Weches greensand is about 20 feet thick over the whole area and is composed largely of glauconitic sand, though siliceous material is locally prominent. The top of the formation occurs at an altitude of 370 feet. The Sparta sand is not more than 15 feet thick at any place and over much of the area is represented only by a few inches of residual sandy soil.

J. R. Stone devoted 10 days to a study of this district and came to the conclusion that the ore deposits are thin, scattered, and of little more than mediocre quality. Several beds are rich in concretionary masses of brown ore, and in one pit nearly 3 feet of ore was measured in a total depth of about 8½ feet. In a well a 6-inch bed of concretionary brown ore was noted 5 feet from the surface. It was underlain by 16 feet of varicolored glauconitic clay, with a little ferruginous sandstone. At the base of this material was a 9-inch bed of solid iron carbonate.

The few pits and shallow trenches that have been dug in this district are insufficient to yield a reliable estimate of the ore reserves, but available data are rather discouraging. It is entirely within the bounds of probability that the 700-odd acres of ore-bearing land in this area might yield 1,000 tons of fair-grade ore to the acre with selective hand mining, but a larger reserve than is thus indicated can hardly be relied upon.

KELLEYVILLE DISTRICT (30)

The small deposit of ore that occurs along the highway about 2½ miles northwest of Kelleyville and 6½ miles from Jefferson (pl. 2) is of more historic than practical interest. It is the site of one of the oldest mines in the State and supplied the Loo Ellen furnace at Kelleyville with most of its ore for many years.

With the exception of a small area in the immediate vicinity of the old mine the Weches southeast of Lassater is thin, very sandy, and practically barren of ore. Near the mine, however, it is 10 to 20 feet thick and contains somewhat less quartz sand. The old mine pits are overgrown and poorly exposed, but here and there rich concretions of limonite are still to be seen. Apparently most of the ore that was mined was of the same type. Little or no stripping was done. The highest part of the hill, which is about 350 feet above sea level, is covered by 5 to 10 feet of Sparta sand, which may possibly be underlain by ore. Unless this is true there is little probability that more than a few tons of ore can ever be recovered from the district.

UPSHUR COUNTY

Upshur County is crossed by the zone that divides the North Basin from the South Basin (pl. 1). Lack of continuous exposures of the Weches greensand in critical areas makes an accurate delimitation of the two basins impossible, but there are certain essential differences in the character of the greensand in the northeastern and southwestern parts of the county that suggest a change in facies. The county has an area of 600 square miles, and according to the 1930 census a population of 22,297, of which 31.1 percent were Negroes. Gilmer, on the St. Louis Southwestern Railway, is the county seat.

The Reklaw member of the Mount Selman formation crops out in the vicinity of the Kelsey anticline, west and northwest of Gilmer, but over the remainder of the area the Queen City sand member, surmounted by small outliers of the Weches greensand member and the Sparta sand, appears at the surface.

In the southwestern part of the county, between Big Sandy and Rhonesboro, the Weches greensand is 20 feet or less thick and consists of soft weathered glauconitic sand and clay. In general character it resembles the facies of the South Basin but is nonfossiliferous. The topography is similar to that in the monoclinal area south of the eastern Texas geosyncline, and the gentle slopes cross the outcrops of Weches greensand, which are commonly covered with Sparta sand wash, with little or no regard to differences in character of the formations. In places concretions of brown ore that range from 6 to 18 inches in diameter occur in the greensand. They are in large part ocherous, soft, and sandy and are nowhere sufficiently rich or abundant to be classed as commercial iron ore.

The small outliers in the vicinity of Gilmer are capped with ferruginous sandstone and indurated greensand, with a small amount of flinty brown ore in places. The greensand is nonfossiliferous and resembles the facies of the Weches member that occurs in the North Basin in its general characteristics.

The only deposits of iron ore of any significance occur in the North Basin, in the northeastern part of the county. Within this area are numerous outliers of Weches greensand, which stand out as rugged, steep-sloped hills, locally called "mountains," that rise from 100 to 200 feet above the surrounding rolling country and characterize the topography in this region. Many of the outliers are simply small rounded knobs with scarcely an acre of Weches greensand as a cap, but some are long, narrow, rather sinuous ridges that are held up by caps of ferruginous sandstone and iron ore. The ridges and the chains of small knobs trend north and south in general.

The Weches greensand is 30 to 40 feet thick and is very similar in appearance to the oolitic glauconitic material that occurs on Daingerfield Hill, in Morris County. A broad bench commonly marks the contact between the Weches and the Queen City. At the top of the greensand the basal sandstone of the Sparta sand is unusually well developed and probably accounts in large part for the rugged topography. Remnants of Sparta sand and sandy soil cover some of the hills to a depth of a few feet, but in general the overburden is very light.

Most of the deposits were visited during a 3-day reconnaissance examination of the district, but as no base maps were available and time was limited, no detailed mapping was attempted. A few of the outliers contain a considerable quantity of rich concretionary or laminated ore, which makes surface showings as good as any of the deposits in Cass County. This is true of a ridge less than a mile west of Ore City, of the Camp Mountains, a group of small hills 4 miles southwest of that town, and of a long, narrow ridge just south of the Gilmer-Ore City highway about 8 miles west of Ore City. Except for the one nearest Ore City, which covers an area of several hundred acres, none of the deposits are large. The longest ridges are not much more than half a mile in length, and the average width is probably somewhat less than 200 feet. Some of the outliers are entirely barren of ore but are capped with ferruginous sandstone.

The largest outlier in the area is 11 to 12 miles west of Ore City and is crossed by the highway between that town and Gilmer. The southern part of this long, narrow chain of branching ridges, which is 8 or 9 miles long, is known as Barmer (Balmer?) Mountain, and the northern part as Long Mountain. A little flinty limonite and a very few concretions occur in places on this "mountain," but most of the material seen at the surface consists of ferruginous sandstone and well-indurated siliceous greensand. There are no artificial openings, and the natural exposures of the lower beds are obscured by talus material. Rich accumulations of ore may possibly exist beneath the surface, but this seems unlikely, because in all other parts of eastern Texas rich ores in depth are reflected by prominent surface showings.

Several comparatively large outliers occur in the vicinity of LaFayette, near the northern edge of the county. The surfaces of these outliers are literally covered with thick accumulations of ferruginous sandstone and indurated greensand, but little or no commercial iron ore occurs on any of them.

The examination of the deposits in Upshur County was too brief to form the basis for a reliable estimate of available ore reserves. It seems entirely possible, however, that about 4,000,000 or 5,000,000 tons of very good ore might be expected from the northeastern part of the county if the difficulties incident to working isolated, small deposits in rugged, sparsely settled country that lacks adequate transportation facilities can be overcome. Further study and detailed mapping are essential before the accuracy of this estimate can be verified.

DEPOSITS IN THE SOUTH BASIN

HENDERSON COUNTY

Henderson County contains a comparatively small reserve of iron ore of the South Basin type, and though the deposits of workable ore are small and scattered they seem to bear more promise than any others of the South Basin deposits except those of Cherokee County. The county is bounded on the east by the Neches River and on the west by the Trinity River (pl. 1). It includes an area of 946 square miles and had in 1930 a population of 30,583, of whom 18.9 percent were colored and about two-thirds were rural-farm dwellers. Athens (population 4,342) is the county seat and the largest town in the county. The Cotton Belt (St. Louis Southwestern) and the Texas & New Orleans Railways run diagonally across the county with a junction at Athens. Prior to the construction of the railways the Trinity River played an important part in transportation.

Farming is the principal industry, though stock raising, timbering, pottery and brick manufacture, and the production of lignitic coal are of considerable importance.

The nearly level prairie land in western Henderson County gives way eastward to the moderately rolling sand-hill area that characterizes the topography in the central part of the county. Steep-sided, flat-topped ridges and isolated hills, or "mountains," are the most outstanding features in the eastern part of the county. The altitude ranges from 250 feet along the major streams to more than 600 feet at the tops of the "mountains."

The Weches greensand occurs only in the eastern part of the county, where there are two large groups of small outliers in the northeast and southeast corners. Of typical South Basin appearance in the southeastern part, the greensand becomes more and more sandy toward the north. Along the north boundary of the county and extending a few miles into southeastern Van Zandt County, the Weches contains much more quartz sand and clay than glauconitic material and resembles the sandier portions of the facies in the North Basin. This progressive change in character of the sediments is believed to indicate an approach to shore-line conditions and seems to indicate that the basin in which the Weches was deposited did not extend very far west or northwest of the present outcrop.

SOUTHEASTERN HENDERSON COUNTY

In the southeastern part of the county, within a radius of 6 miles of Poynor, outliers of Weches greensand and Sparta sand occur as small, very steep-sided, flat-topped hills and ridges (pl. 1). The greensand is from 30 to 50 feet thick and has all the characteristics of the facies typical of the South Basin. All but the smallest hills are covered with 5 to 40 feet of Sparta sand.

The ore bed at the top of the greensand is of the laminated variety except in a few places, where it is somewhat thicker than usual and some buff crumbly ore has been developed beneath the laminated bed. All recorded observations give an average thickness of 4 to 7 inches of ore, but in most places it is only 2 to 3 inches thick, although there are several areas where the ore attains a maximum thickness of about 12 inches. Slabs of float ore occur on the hill slopes in places, but by no means as abundantly as in the vicinity of Brownsboro, farther north.

A small hill 1½ miles southwest of Poyner contains the only deposit that seems to have commercial possibilities. The entire surface of this hill, which includes an area of about 30 acres, is covered with ore that ranges from 10 to 24 inches in thickness, with an average of 16 to 18 inches. Except for a few inches to 2 feet of residual sandy soil the Sparta sand is missing. The total tonnage of ore indicated is too small to make the deposit particularly attractive.

NORTHEASTERN HENDERSON COUNTY

The group of outliers from 1 to 4 miles southeast of Brownsboro contains most of the deposits of iron ore that are considered workable. The Weches greensand is 30 to 50 feet thick and of normal South Basin appearance, except for the absence of fossils in all the poor exposures that were seen. The overburden of Sparta sand is thin in general but in places is as much as 25 feet thick. The characteristic ore bed at the top of the greensand is almost universally present. Where it is thin, only the laminated variety of ore has been developed, but in other places both the laminated and the buff crumbly ore are present. Slabs of wash ore occur in profusion on most of the hill slopes.

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The two large hills south and west of Pine Hill School, about 3½ miles southeast of Brownsboro (pl. 5), contain much laminated brown ore. The bed is 6 to 13 inches thick, with an average of about 9 inches. It crops out along the sides of the hills and forms huge slabs 8 to 10 feet in diameter that protect the hillsides from further erosion and tend to produce gentler slopes than is usual in the South Basin. The ore bed forms the surface of most of the smaller spurs, and along the sides of the hills it crops out as a nearly level pavement that ranges from 5 to 50 feet in width. The ore is locally rather siliceous but is largely of good quality. The overburden of sand has a maximum thickness of about 25 feet and averages from 10 to 15 feet. No wells or other openings were found, but it seems probable that all but the thickest sand is underlain by ore.

On New Hope Mountain, half a mile northeast of New Hope Church and 4 miles south of Brownsboro (pl. 5), the ore bed averages less than 6 inches in thickness. The Sparta sand is nowhere more than 5 feet thick and is entirely missing over most of the area. The top ore bed is here too thin to be considered workable by itself, but the lower slopes of the ridge are thickly covered with large slabs of ore which have worked their way down from the top bed. The ferruginous sandstone cap is in most places already separated from the ore, which is itself of good quality. Large quantities of ore could be removed from such slopes by selective hand mining.

On the large ridge midway between Pine Hill School and Friendship Church, about 2 miles southeast of Brownsboro (pl. 5), the top ore bed is 4 to 10 inches thick and of good quality. The higher parts of the ridge are covered with 10 feet or less of Sparta sand. Float ore is not as conspicuous or abundant here as on the hills described above.

On Zion Hill, less than 2 miles east of Brownsboro (pl. 5), the ore bed ranges from 12 to 24 inches in thickness and averages about 18 inches. Most of the ore is of the buff crumbly variety. The ferruginous sandstone cap rock is 2 inches thick, or less. The maximum thickness of Sparta sand is 10 to 12 feet, but the average is less than 5 feet. Some of the ore on this hill has been quarried for use in road building.

In the region southeast of Brownsboro there is about 250 acres of land that should yield ore 18 inches thick and about 1,100 acres where the ore averages 8 to 10 inches in thickness but is easily accessible. The deposits are all less than 4 miles from the Cotton Belt Railway. Trinidad, the nearest point on the Trinity River, is about 35 miles distant. The ore is thin in general and of no higher grade than any other South Basin ore. The accessibility of the deposits and the fact that nearly all of the ore is exposed at the surface or occurs as a heavy mantle of debris make it seem possible that eventually some iron ore may be obtained from this district. Should the canalization of the Trinity River be accomplished, the value of these deposits would be somewhat enhanced.

North of Chandler and extending into the southeast corner of Van Zandt County (pl. 5) the Weches greensand occurs as scattered outliers similar to those farther south, but the character of the beds is much different. The thickness of the member is about the same, but in all exposures seen it appears to be made up of alternating beds of greensand, reddish clay, and reddish quartz sand. In places the beds of quartz sand are very prominent and have many of the characteristics of the Queen City sands. Again, the red clays locally take on the appearance of Reklaw beds. The beds of greensand, which were originally made up of very fine-grained glauconitic material in a clay matrix, are as a rule strongly indurated. The sands and clays locally contain much shaly or concretionary, impure limonite, which gives rise to a very rocky soil that is suggestive of the exposures of Weches greensand in the North Basin.

The Sparta sand covers the larger hills to a maximum depth of 15 or 20 feet. The typical ferruginous basal sandstone is present in places but not universally.

The top bed of brown ore is in many places missing entirely, and where it does occur it is commonly very thin, averaging less than 3 inches. About a mile west of Concord Church, on the Van Zandt County line (pl. 5), the ore bed is 2 to 6 inches thick, but elsewhere on this ridge the ore is absent. At several points along the road near Saddler Springs School, 4 miles northwest of Chandler, the ore bed ranges from 6 to 18 inches in thickness and weathers out in huge slabs several feet in diameter. Close inspection shows this material to contain an unusually large amount of quartz sand, which renders it too siliceous for use as iron ore. In Van Zandt County the greensand is even more siliceous, and little or no commercial ore is present.

ANDERSON COUNTY

Anderson County lies immediately west of Cherokee County and south of Henderson County (pl. 1). The Neches River and the Trinity River form the eastern and western boundaries. Though some iron ore occurs at the top of the Weches greensand in the northern part of the county, none of the deposits seen in a rapid reconnaissance examination appear to be thick enough to warrant further consideration as possible reserves of iron ore.

The county has a land area of 938 square miles and had in 1930 a population of 34,643, of whom 33.2 percent were colored. Palestine (population 11,445) the county seat, is near the geographic center of the county and is the only large town. The International-Great Northern Railway and a branch of the Texas & New Orleans Railway serve most of the area.

Farming and timbering are the largest industries. Petroleum, lignitic coal, salt, and ferruginous gravel for highway construction are all produced in considerable quantity.

In the northeastern and central parts of the county the topography is characterized by steep-sloped rugged hills, but to the west and south these give way to more gently rolling uplands which slope toward the broad bottom lands of the larger streams.

DEPOSITS SOUTH OF PALESTINE

The character of the Weches greensand and of the iron ores is affected by the regional structure. Northward from the vicinity of Palestine the South Basin of the eastern Texas geosyncline is the dominant structural feature, and the greensand there is of normal South Basin character and composition. Not far south of Palestine the geosyncline broadens out into a great Gulfward-dipping monocline, and the influence of the synclinal structure becomes less marked. In this area the Weches is made up of glauconitic oolites in a matrix of greenish clay. In fresh exposures it resembles the facies typical of the South Basin except that fossils are in general much more abundant than they are in the South Basin and the member is much thicker, ranging from 75 to 100 feet in general. The greensand weathers to a soft, loamy soil of a brilliant red color and tends to form gently rolling hills or even stream valleys and broad bottom lands instead of the flat-topped steep-sided ridges that characterize the topography within the geosyncline. With the exception of two ridges about 5 miles southeast of Palestine, which contain some typical South Basin ore, all the greensand south of Palestine is essentially barren of ore. In places a little limonitic gravel occurs near the top of the beds. It has been used locally as road gravel but is ocherous and of too low grade to be classed as iron ore.

On the old Middle Crockett road, between Palestine and Elkhart, a long ridge of Sparta sand and Weches greensand projects southwestward from the main body of these formations. The Sparta sand is thick and averages about 20 feet over most of the hill. The basal ferruginous sandstone is rarely more than 2 inches thick. The bed of buff crumbly ore at the top of the greensand is about 10 inches thick. It seems to contain somewhat more clay than the Cherokee County ores but is otherwise of good quality. The whole area covered by ore is comparatively small, and the heavy overburden of sand would preclude removal of any of the ore that does not occur very close to the outcrop.

DEPOSITS NORTH OF PALESTINE

North of Palestine the Weches greensand occurs in areas ranging in size from small outliers that cover less than an acre to large plateaus several square miles in extent. The formation is ordinarily 30 to 50 feet thick, but in some areas, notably near the Neches River between Neches and Frankston, it thins to only 10 or 15 feet. It is made up of olive-greenish glauconitic oolites in a matrix of green clay and is nearly everywhere at least moderately fossiliferous. Thin seams and small concretions of ocherous limonitic material are commonly present in the weathered portions but are not sufficiently abundant to be classed as ore.

The thickness of the Sparta sand overburden varies almost directly with the area of the deposits involved. It may be missing on small outliers or projecting ridges but is 50 feet or more thick on the larger hills. The average cover over all the iron-bearing area is between 10 and 20 feet. The basal ferruginous sandstone is almost universally present and ranges from 1 to 6 inches in thickness.

The ore bed at the top of the greensand is uniformly distributed over nearly the whole area, though in a few places none was seen. Several inches of the laminated type of ore is nearly everywhere present, underlain in places by buff crumbly ore. About 2½ miles northwest of Palestine, where the Athens-Palestine highway crosses the Weches outcrop, both the laminated and buff crumbly ore have an oolitic structure which is almost certainly inherited from the original greensand.

The thickness of the ore bed varies greatly from place to place. The greatest thickness observed anywhere is 18 inches. Recorded observations at 21 places show a range of 4 to nearly 7 inches of ore, a range that is in accord with the impressions gained from dozens of unrecorded observations. In other words, except in a few very small localized areas, the average thickness of the ore should not be expected to be much more than 5 inches. Several inches of ferruginous sandstone would have to be mined with the ore bed and removed subsequently. The overburden is so thick as to prevent mining except from a narrow strip near the outcrop. Both mining and transportation problems are large. The only possibility of production from the deposits in northern Anderson County would seem to be by some sort of cooperative arrangement between the farmers and a centralized ore-buying organization. A fairly large annual tonnage of float ore or easily accessible ore in place might conceivably be attained by this means. The total area of ore-bearing land which might possibly produce an average of 5 to 6 inches of ore is about 6,500 acres.

CHEROKEE COUNTY

Cherokee County contains most of the deposits of commercial ore in the South Basin. The county includes a land area of 1,049 square miles and had in 1930 a population of 43,180, of whom 26.6 percent were colored. Jacksonville (population 6,748), Alto (1,053), and Rusk (3,859), the county seat, are the largest towns (pl. 1). The International-Great Northern, the Texas & New Orleans, and the St. Louis Southwestern Railways all traverse the county. Farming and timbering are the chief industries. Petroleum and road gravel are now the principal mineral products, though at one time iron ore was produced in considerable quantity in the vicinity of Rusk.

The county is drained by the Angelina and Neches Rivers and their tributaries. The topography is rugged in the northwestern and central parts, but to the east and south gently rolling sandy hills take the place of the steep, flat-topped hills and ridges. The higher hills attain altitudes of about 700 feet, about 500 feet above the level of the major streams.

Here, as in Anderson County, the character of the Weches greensand is related to the regional structure. The northern two-thirds of the county lies within the South Basin, and the greensand is typical of that region. It is made up of oolitic glauconitic material with much greenish clay, is moderately fossiliferous, and ranges in thickness from 40 to 60 feet in general. In the vicinity of Alto, however, the influence of the Gulfward-dipping monocline becomes dominant, and the Weches thickens, becomes more fossiliferous, and yields soft red soils and little or no ore on weathering.

Several eastward- and northeastward-trending faults cross the central part of the county. They extend from Mount Enterprise and New Salem, in Rusk County, to the vicinity of Palestine, in Anderson County (pl. 1). In places veins of limonitic material parallel the faults.

DEPOSITS IN THE VICINITY OF RUSK

The ore deposits in the immediate vicinity of Rusk have received more attention than other South Basin deposits. This was probably due in part to the fact that Rusk was for many years the site of the State penitentiary, where an ore mine, blast furnace, and pipe foundry were operated by convict labor, rather than to any great difference in the quantity of quality of the iron ores. The deposits occur near the top of an irregularly branching, nearly continuous ridge that lies east of the St. Louis Southwestern Railway and extends from a point near Dialville, 7 miles northwest of Rusk, to a point about 6 miles southeast of Rusk (pl. 3). The ridge forms part of the divide between the Neches and Angelina drainage systems.

The top of the Weches greensand ranges in altitude from 597 to 711 feet, as determined by surveying-aneroid observations. Inspection of the altitudes indicated on plate 3 will show that the upper surface of the greensand undulates considerably throughout the area, but that a structural high is present in the vicinity of Rusk. From that point the beds dip gently southward toward the Gulf monocline and northward toward the faulted area in the vicinity of Dialville. The greensand, which ranges from 45 to 60 feet in thickness, consists almost entirely of very small glauconitic oolites in green clay. Ordinarily the glauconitic material and the clay are more or less segregated, but nowhere is one constituent entirely free of the other. Fossils, usually small forms, are rather abundant but as a rule are well preserved only in the lower, unoxidized beds. In one well about 2 miles north of Rusk the normal greensand grades downward into a purplish chocolate-brown clay that contains a few "nests" of glauconitic material. This relation suggests an interfingering with the Queen City sand, but in other places where it is not obscured the contact between the two formations is sharply distinct.

Springs occur in nearly every draw and almost invariably issue from points just below the top ore bed or from the upper 10 feet of the greensand. Wherever the cover of Sparta sand is more than 10 or 12 feet thick the water level in wells occurs close to the contact between the Sparta and Weches beds.

The basal ferruginous sandstone of the Sparta sand is nearly everywhere present and ranges from 1 to 6 inches in thickness. The peculiar parallel furrows on the upper surface of the sandstone that are described by Burchard [58] were noted in many places, but exposures of this surface are very poor in general. This prevented the accumulation of any data as to the uniformity of the strike of these furrows over a larger area than was noted by Burchard. Their true significance is not known, but it is believed that the sandstone was formed in the same manner as that elsewhere throughout the North and South Basins—that is, it was formed through cementation of ordinary quartz sands by iron-bearing solutions that rose by the force of capillarity from the underlying Weches.

The lower 10 feet or so of the Sparta sand is in general much coarser than that of the North Basin. Above these beds of coarse sand are the usual sands, sandy clays, and clays of the normal Sparta sand. Clay becomes more abundant in the upper parts of the section. In nearly all places the sand is relatively thick and rises abruptly from the outcrop of the ore bed at the top of the Weches. On the highest ridges the sand is 40 feet or more thick. The altitudes of the iron-ore outcrops and of the land surface, as plotted on plate 3, show that at an average distance of 450 to 500 feet from the outcrop the overburden is 10 feet thick.

Immediately beneath the ferruginous sandstone that marks the contact of the Weches and Sparta, a layer of laminated brown ore is almost universally present. It ranges from 2 to 8 inches in thickness and adheres firmly to the sandstone bed. Below the laminated ore

[58] Burchard, E. F., op. cit., p. 91.

a relatively thick ledge of buff crumbly ore is commonly present, though it is missing in a few places. The lower surface of the buff crumbly ore is very uneven, and botryoidal protuberances extend downward into an underlying bed of white clay. The clay is rarely as thick as the ore bed, with which it varies in thickness directly.

Plate 3 shows all the areas where mining has been carried on to supply the furnaces near Rusk. In most areas the mining was confined to a narrow strip along the sides of the hills. At the back of most of the pits the overburden ranges from 5 to 10 feet in thickness, which was evidently considered about the economic limit for stripping, even with prison labor. The results of careful studies in all the pits and of inquiries among the inhabitants of Rusk who had first-hand knowledge of the old mines make it seem quite certain that at least some of the pits were abandoned on account of a decrease in the thickness of the ore bed rather than because of excessive overburden.

Every available complete exposure of the ore bed was measured in the course of mapping the deposits. In places where part of the buff crumbly ore had broken down to gravel, due allowance was made for the original thickness. The greatest thickness of ore measured was about 4 feet. A total of 118 recorded observations, each of which represents the average of all measurements at any one locality, shows average minimum and maximum thicknesses of 9.1 and 16.6 inches, respectively. As was pointed out in the general discussion of the South Basin ores (p. 66), the mean of these figures, or 12.82 inches, is possibly an inch or two less than would be recovered in actual mining. That some areas would yield ore several times as thick as the mean indicated above is obvious from an inspection of plate 3, which shows in a general way the horizontal variation in thickness of the ore bed. For purposes of determining the total reserve of iron ore in the vicinity of Rusk, however, it would be unwise to count on recovery of a much greater quantity of ore than is indicated by the above figures. The area enclosed by the boundary of iron-ore outcrop is about 7,500 acres. The area of land within 500 feet of the nearest outcrops—that is, where the ore is covered by less than 10 feet of sand—is about 4,250 acres.

At the outcrop the greensand is commonly weathered to a depth of about 20 feet. In some places several thin beds and nodular masses of limonitic material occur throughout this oxidized section. They are discontinuous and more often than not prove on close examination to be oxidized greensand cemented by a little limonite and hence not of commercial grade. In order to determine the possible value of such material, a channel sample was cut from the face of one of the best exposures, a cut on the Jacksonville highway 1.3 miles north of Rusk. This cut exposes 18 feet of oxidized greensand that is more than usually rich in limonitic material. The original sample weighed 42 pounds and contained proportionate quantities of all the beds, including the top bed of buff crumbly ore, which is here only 4 to 8 inches thick. The sample was crushed to about ½-inch mesh, and the soft and light material was washed out by panning in water. The final concentrate, air-dried, weighed 20.5 pounds, nearly half of the original weight. Analysis 40, page 58, shows the concentrate to be an acceptable iron ore, containing about 42 percent of metallic iron. The necessity for further prospecting and study of the lower beds is evident. It may be that a large reserve of ore is present that has been overlooked heretofore. It should be pointed out, however, that the section on which these tests were made is at least as rich in limonitic material as any of the other exposures in the area and is probably much richer than the average. Furthermore, there seems to be little cause to believe that the thorough oxidation necessary for the production of such deposits can extend very far from the edges of the hills.

Carbonate ore is rare to lacking in the greensand. At one point along the railroad cut about 3 miles north of Rusk a few concretions of pure-white iron carbonate that reach 6 inches in diameter occur in the lower beds. In other places the nearly fresh greensand contains a few nodular or bryozoanlike forms that are made up of glauconitic grains cemented with siderite, but these are all small and sparingly distributed.

Near the northwestern extremity of the district two parallel faults, separated by a narrow downfaulted block, are well exposed along the main highway between Jacksonville and Rusk (pl. 3). The central block is dropped about 15 feet, though the net displacement of the two faults is practically zero. Southeast of the faults the top ore bed is only about 6 inches thick, but a few vertical veins of limonite, as much as 1 foot thick, occur in the greensand. In the central block between the faults the top ore bed is 2 feet or more thick and of excellent quality. Veins are numerous and range from 6 inches to 4½ feet in thickness. They are nearly vertical and strike about N. 63° E., parallel to the trend of the faults. Such relations are probably not uncommon throughout the South Basin, but they are here unusually well exposed. The strong veins in this area are larger and more numerous than any seen elsewhere and have probably filled fractures in the greensand parallel to the faults. It seems reasonable to assume that where the greensand is not faulted the iron ore is more likely to be confined to the top bed instead of spreading out in the lower beds or forming veins. The importance of faults to the iron-ore producer is clear. Furthermore, the recognition of the relation that exists between veins and faults should be of use to petroleum geologists who are interested in the faults as structural features.

DEPOSITS WEST OF DIALVILLE

The highland just west of Dialville (pl. 3), which is known in part as Acker Mountain and in part as Gent Mountain, contains deposits of iron ore similar in most respects to those in the vicinity of Rusk. The hills attain altitudes of nearly 700 feet in a few places.

The Weches greensand is of about the same thickness and character here as it is near Rusk. Its surface shows many local undulations, but apparently there is a structural high in the central and southwestern parts of the region, where the top of the greensand occurs at altitudes of 650 to 680 feet. The beds dip northward toward a rather complicated system of northeastward-trending faults at the north end of the ore-bearing area. These faults have an aggregate downward displacement to the north of about 50 feet. Near the south end of the district a strong fault, which is possibly a continuation of the fault zone that occurs along the Jacksonville-Rusk highway, extends from a point near Dialville southwestward for several miles. The displacement along this fault, which is down on the north side, is about 75 feet. These faults are part of the system of faults that crosses the central part of Cherokee County (pl. 1). Further details of the structure in the vicinity of Dialville are evident from a study of the altitudes of the top of the Weches greensand, as plotted on plate 3.

The Sparta sand is 60 feet or more thick in places, but as in the Rusk area, the line that marks the limit of 10 feet of overburden is about 450 to 500 feet from the outcrop of the iron ore.

The ore bed, which consists of the usual laminated layer underlain by buff crumbly ore, ranges from an inch or so to as much as 4 feet in thickness, and 84 recorded observations give average minimum and maximum thicknesses of 6.87 and 15.45 inches respectively. The mean of these figures is 11.16 inches. Plate 3 shows the distribution of the ores of varying thickness. The whole area within the line of outcrop of the iron ore is 7,800 acres; that of probable ore beneath 10 feet or less of overburden is 3,600 acres.

DEPOSITS ON HASSELL MOUNTAIN

Hassell Mountain, also known as Mount Hope, is an irregularly branching plateaulike hill about 6½ miles west of Rusk and 2½ miles east and southeast of the community of Maydelle (pl. 3). The old Texas State Railway, now a branch of the Texas & New Orleans line, runs past the north end of the hill. The greensand and iron ore are in every way similar in character to the deposits near Rusk and Dialville. The higher parts of the hill are covered by unconsolidated Sparta sand to a depth that in few places exceeds 20 feet.

The greatest thickness of ore measured was 30 inches, but a local resident states that he encountered 4 feet of "ore" in his well at a depth of 20 feet. As his well is on a narrow ridge near the south end of Hassell Mountain, where ground waters would have an excellent chance to penetrate the greensand, the statement seems reasonable. The average of 50 recorded observations gives minimum and maximum thicknesses of ore as 6.76 and 15.8 inches, with a mean of 11.31 inches, almost exactly the same figures as were obtained in the region west of Dialville. The area of probable ore on Hassell Mountain is about 675 acres.

DEPOSITS NORTHWEST OF ALTO

The geologic map of Texas[59] shows several small outliers of Weches greensand from 4 to 8 miles west and northwest of Alto and about 8 miles south of Rusk. None of these were examined by the writer or by members of his party, because of lack of time. All the outliers are known to be small, but that some iron ore is present on some of them is indicated by the fact that the old Philleo furnace was located among these hills and used ore from the immediate vicinity. No doubt an adequate examination of the deposits in this area would serve to prove the existence of a considerable quantity of iron ore, but that this would materially alter the figures for the total reserve of ore in Cherokee County is doubted.

DEPOSITS NEAR IRONTON

The long, nearly continuous ridge that extends from a point near Ironton, in west-central Cherokee County, to a point about 9 miles south of Ironton (pl. 1) is known as Mount Tillman. It reaches an altitude of more than 600 feet in a few places and contains some ore of the type that is present in the vicinity of Rusk. The ore occurs as a series of comparatively small deposits near the tops of the highest ridges. In the saddles or depressions between these deposits the lower beds of the Weches are exposed. Where seen in several places during a rapid reconnaissance the ore ranges from 2 to 18 inches in thickness. Most of it is less than 6 inches thick, and it does not seem safe to estimate more than a very small reserve of available ore.

Just west of the community of Ironton, west of the International-Great Northern tracks, a small round, steep-sloped knob stands out above the surrounding lowland. The upper parts of the knob are made up of Weches greensand, and it is capped by a bed of iron ore a foot or more thick. The whole area covered by ore is not much more than 1 acre.

DEPOSITS WEST OF JACKSONVILLE

Mount Haven, a narrow, branching hill from 3 to 6 miles west of Jacksonville (pl. 4), contains some of the best ore seen in the South Basin, and it is rather surprising that more attention has not been

[59] Geologic map of Texas, prepared by the Geological Survey in cooperation with Texas Bureau of Economic Geology. See also plate 1.

given to it. The ore is of the usual South Basin type, with ferruginous sandstone cap, laminated ore, and buff crumbly ore all well developed. In several places the ore is 5 feet thick. Huge blocks as much as 5 feet wide, 10 feet long, and several feet thick are locally abundant on the surface. Plate 13, *B*, shows a typical occurrence of these blocks. The maximum thickness of the Sparta sand, which in places rises rather abruptly from the outcrop of the ore bed, is 40 feet. In general, however, the overburden is thinner than on most of the deposits near Rusk. This is especially true of the western part of the ridge, where over a large area the ore is covered by 10 to 15 feet or less of sand. Plate 4 shows the distribution of ore according to thickness. That in the northern part of the area, near Fry's Gap, is by no means as thick as that along the main east-west ridge. The average of 16 recorded observations indicates minimum and maximum thicknesses of 9.1 and 27.4 inches, respectively, with a mean of 18.25 inches. This average is considerably higher than that obtained for any other district in the South Basin. Because the ore is thicker and the overburden thinner than elsewhere, it is likely that a large part of the whole 750-acre area, exclusive of the northerly spur, is underlain by ore.

About 2 miles west of Mount Haven and not far north of Corine several small, narrow ridges are capped by a little iron ore in the form of gravel that has resulted from partial disintegration of the buff crumbly ore bed. This bed was apparently originally 18 inches thick or less. The deposits are small and relatively inaccessible and do not appear to warrant further consideration.

East of Reese and from 4 to 8 miles northwest of Jacksonville there is a large area of Weches greensand, capped by a thin bed of iron ore and overlain by considerable thicknesses of Sparta sand (pl. 4). Near the southeast extremity of the hill, at the point where the Jacksonville-Athens highway crosses the outcrop, the ore bed is well exposed in the road cut. Plate 13, *A*, shows the ore bed and its relations to the underlying clay and greensand. It ranges from 1 to 3 feet in thickness at this point, but unfortunately this is apparently the thickest ore in the whole area. A total of 32 recorded observations, each based on several measurements, indicates average minimum and maximum thicknesses of 5.25 and 11.92 inches respectively, with a mean of 8.6 inches. There are several comparatively small areas where mining might meet with success, but it is unlikely that more than 500 acres of land will be found to contain deposits of ore that average 1 foot in thickness.

DEPOSITS NORTH OF JACKSONVILLE

Between Jacksonville and the Smith County line (pl. 1) the Tyler Highway traverses a long, narrow ridge of Weches greensand which is well exposed in several road cuts. Between Jacksonville and a point 4 miles north of Mount Selman the typical ore bed at the top of the Weches greensand is fairly well developed, but north of that point it thins to 2 inches or less and in many places is missing altogether. In the southern part of this area the greatest thickness of ore seen at any point was 24 inches, and in most places the ore is less than 12 inches thick. As the total area covered or underlain by ore is relatively small, and as the ore is so thin, it is not likely that commercial production can ever be attained here. The lower beds of the greensand locally contain much ferruginous material which appears to be of as high quality as that near Rusk, described above. A channel sample was taken from a representative section of this nature 4.8 miles north of Jacksonville along the highway. The original sample, which represented a 28-foot section of material, weighed 67 pounds. After crushing and washing the concentrate weighed 32 pounds when air-dried. The chemical analysis of the concentrate (no. 41, p. 58) shows a metallic-iron content of less than 38 percent. This is too low in iron to be of much value at present, but the results suggest that the oxidized greensand below the top ore bed deserves further consideration as possible ore-bearing material.

In the northwest corner of Cherokee County (pl. 1) the Weches greensand contains little or no ore, either at the top or in the lower beds.

DEPOSITS IN NORTHEASTERN CHEROKEE COUNTY

In the northeast corner of Cherokee County, between New Salem, Rusk County, and Ponta (pl. 1), the Weches is exposed over a large area. As a rule a very thin bed of ferruginous sandstone marks the contact of the greensand with the Sparta sand, but this bed is in a few places underlain by 2 to 4 inches of iron ore. The maximum thickness of ore appears to be about 10 inches. Several faults occur in the area, and without adequate base maps accurate mapping of the deposits is almost impossible. The area is of interest structurally but there seems to be no reason for believing it to contain a possible reserve of iron ore.

DEPOSITS IN OTHER COUNTIES

In addition to the 7 counties described above, 16 counties in eastern Texas have been reported by various authors to contain commercial deposits of iron ore. Two of these, Hopkins and Franklin Counties, were not visited by the present party, but their general geology as represented on the geologic map of Texas is such that ore deposits of commercial grade are hardly to be expected. All the other counties—Camp, Gregg, Harrison, Houston, Nacogdoches, Panola, Rusk, San Augustine, Sabine, Shelby, Smith, Titus, Van Zandt, and Wood (pl. 1) were studied in reconnaissance, and each of the reported iron deposits shown on Phillips' map [60] was visited. It was found that the mapping of many reported deposits was apparently based on the presence of a few concretions of brown ore or carbonate. Some of these occur in Reklaw sediments, and others in the Wilcox or the Queen City. Although iron minerals exist in all the counties and localities noted by Phillips and other investigators, commercial production can probably be obtained from only a small fraction of them. Even if the ore itself were of high grade and occurred in thicknesses sufficiently great to permit large-scale mining operations, such features as small areal extent, inacessibility to existing lines of communication, and excessive overburden would debar many of the reported deposits from further consideration.

In places the ferruginous deposits in the Reklaw member of the Mount Selman formation might pay to work. This is especially true in Harrison County (pl. 1), where they contain an unusually high concentration of limonite. Most of the ore occurs as small concretions or thin lenticular beds, similar to those in the facies of the Weches greensand found in the North Basin. The limonite itself is at least of as high grade as any of the deposits associated with the Weches, but at no place were deposits seen that compared favorably with the Weches type in amount of ore or continuity. This is probably in large part due to the greater proportion of clay in the Reklaw beds, which tends to prevent the formation of rich ferruginous deposits. The total quantity of ferruginous material in the Reklaw beds in Harrison and other counties is enormous and is possibly nearly as great as that in the Weches greensand, but deposits of ore that are commercially available now or under reasonably predictable conditions for the future are extremely small.

In southern Rusk and northwestern Nacogdoches Counties (pl. 1), in the general vicinities of New Salem, Mount Enterprise, and Sacul, there are a few deposits of laminated and buff crumbly ore associated with relatively small outliers of Weches greensand. Near Sacul the ore ranges from 8 to 16 inches in thickness in general, and the deposits might conceivably be worked commercially. The ever-present ferruginous sandstone cap is nearly as thick as the ore bed, however, and its removal would increase production costs considerably. In addition the deposits are small and scattered. Elsewhere in this region the top ore bed is even thinner than at Sacul, and there seems little likelihood that iron ore could be produced profitably.

Nearly half of the 920 square miles of Smith County is covered or underlain by Weches greensand. Over much of this area the ore bed at the top of the member is missing or is only 1 or 2 inches thick. The best possibility for commercial ore is in the vicinity of Garden Valley,

[60] Phillips, W. B., Map of location of iron-ore deposits, blast furnaces, lignite mines in operation, and producing oil fields in east Texas, Texas Univ. Bur. Econ. Geology, September, 1912.

in the northwestern part of the county (pl. 1), where the typical top ore bed ranges from 2 to 10 inches in thickness.

A little laminated and buff crumbly ore occurs in parts of Houston and Van Zandt Counties, but none of the deposits seen are large enough or of high enough grade to be of value. One outlier of Weches greensand in southeastern Camp County and some of the outliers in central Wood County (pl. 1) contain small quantities of concretionary ore of the North Basin type. It is doubtful if further examination would serve to prove the existence of commercial deposits.

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