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THE BROWN IRON ORES OF WEST-MIDDLE TENNESSEE

BY

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Prepared in cooperation with the Tennessee Geological Survey

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THE BROWN IRON ORES OF WEST-MIDDLE TENNESSEE

By Ernest F. Burchard

INTRODUCTION

A study of the brown iron ore deposits of west-middle Tennessee has been carried on recently under a cooperative agreement between the Tennessee State Geological Survey and the United States Geological Survey. A detailed report on the subject was submitted in the spring of 1925 to the State Survey for publication as a bulletin, and the writing of the present report was completed in March, 1926. The field work was done mainly between October 22 and November 2, 1921, and April 26 and July 18, 1923; but in October, 1924, a visit was made to the mine at Napier. The writer was assisted in the field in 1921 by R. W. Smith, assistant geologist, and in 1923 by C. C. Anderson, topographer, both of the Tennessee Survey. Mr. Wilbur A. Nelson, State geologist at the time the work was in progress, visited several mines with the writer and on these occasions as well as many times during the preparation of the report rendered helpful suggestions and guidance. Mr. H. D. Miser, of the United States Geological Survey, State geologist from September 1, 1925, to July 1, 1926, who is especially familiar with the southern part of this area, also cooperated heartily in the preparation of this report; and Mr. H. W. Davis, of the United States Bureau of Mines, compiled the statistical data on iron ore and pig iron. To all these gentlemen the writer desires to express his appreciation. Acknowledgments are also due to the officials and employees of the iron mining and manufacturing companies and to people living in the vicinity of inactive mining properties for their courteous attention and for the large amount of information furnished.

In the present paper the general features of the region and of the iron-ore deposits are delineated, but only a few typical ore deposits in each county are described, as the State bulletin will contain detailed descriptions of all properties.

In order to facilitate the study of the brown iron ore deposits the State Geological Survey prepared maps of Hickman and Dickson Counties on a scale of 1 mile to 1 inch which show the culture and drainage, also special maps of the mining districts of Stribling, Stewart County; Marion, Montgomery County; Cumberland Furnace, Dickson County; and Aetna, Hickman County. For the location of ore deposits in Stewart County a rural-delivery base map on a scale of 1 mile to 1 inch, prepared by the Post Office Department, was available. For Montgomery County a base map on the same scale, prepared by the United States Bureau of Soils, was available; portions of Dickson and Hickman Counties are also covered by the topographic map of the Columbia quadrangle, prepared by the United States Geological Survey. For Lewis County a map on the scale of 1 mile to 1 inch, showing the roads, drainage, and iron-ore deposits, had been prepared by R. F. Rogers in connection with his studies of the deposits in 1912–13. The iron ore bearing portions of Wayne and Lawrence Counties are shown on the topographic map of the Waynesboro quadrangle, prepared by the United States Geological Survey. Geologic maps of the Columbia and Waynesboro quadrangles on a scale of 1:125,000 and a general geologic map of the State of Tennessee on a scale of 1:500,000 were also available.

The field work consisted of the examination of practically all the deposits of brown iron ore disclosed by mines, prospects, or outcrops in Stewart, Montgomery, Dickson, and Hickman Counties and of certain of the best-known deposits in Lewis, Wayne, and Lawrence Counties.

The deposits of brown iron ore in Wayne and Lawrence Counties and the southwestern portion of Lewis County have been described by H. D. Miser in Bulletin 26 of the Tennessee State Geological Survey, published in 1921, and those of Lewis County by R. F. Rogers in Resources of Tennessee, vol. 5, No. 3, published in 1915. The field work of Miser and Rogers, having been done very thoroughly, was not duplicated by the present writer except to visit certain active mines and to note their later developments. The report by Miser is available for distribution by the State Geological Survey, and so the data are not repeated here, although the locations of the iron-ore deposits in the Waynesboro quadrangle will be shown on the maps accompanying the forthcoming State Survey bulletin for the sake of completeness. As the report by Rogers has been for some years out of print and as it describes a large number of undeveloped deposits of brown iron ore in the western Highland Rim, it has been decided to reprint the data on Lewis County as a chapter of the State Survey bulletin.

It was not planned to map the areal geology of the region, as such work would have involved more time and funds than could be allotted to the purpose, and sufficiently detailed base maps were not available for the greater part of the area. Moreover, the detailed geologic mapping of this area will also require much more paleontologic work than has been done, especially in the areas where Mississippian rocks underlie the iron-ore deposits. Nearly all the deposits were reached in a Ford car, although in rainy weather the unimproved roads are in places difficult to travel. In the examination of individual deposits by the writer the following data were recorded, in so far as practicable, in accordance with an outline prepared by him for use in study of deposits of brown iron ore and bauxite:

Location.
Name and address of owner of property.
State of prospecting or developments.
Topographic situation: Position; altitude above nearest important drainage and above sea level; relation to peneplanation.
Outcrops or surface evidence of ore.
Extent and form of deposit; depth.
Overburden: Character and thickness.
Associated rocks: Age; character; dip and strike; general structure; relation to ore deposits.
Ore, character of: Appearance; principal minerals; principal impurities; probable grades; proportion of rock and waste; typical specimens.
Ore available: Blocked out; estimated; possible.
Conditions affecting mining: Accessibility, topography, sites for buildings, washers, dumps, settling basins, water supply, timber, fuel, distance to railroads and places of consumption.
Methods of mining, washing, transportation, and use of ore.
Representative chemical analyses of ores or products, property maps, and engineers' reports, if available.

EARLIER GEOLOGIC WORK

The State of Tennessee has carried on official studies of its geology and mineral resources during four periods—the first under Gerard Troost, State geologist from 1831 to 1850; the second under James M. Safford, State geologist, beginning in 1854; the third from 1870 under J. B. Killebrew, commissioner of agriculture, statistics, and mines, until well toward the end of the nineteenth century; and the fourth period, from 1910 to the present, under State Geologists George H. Ashley, 1910 to 1912; Albert H. Purdue, 1912 to 1917; Wilbur A. Nelson, 1918 to 1925; Hugh D. Miser, September 1, 1925, to July 1, 1926; and Walter F. Pond in 1927.

During these several periods of activity the State geologist or some member of his staff has devoted more or less attention to the subject of iron ore, for it early became recognized that Tennessee was liberally endowed with the two minerals most essential to civilization—iron and coal. In studying the iron-ore deposits Safford in 1855 divided the State geographically into four iron ore bearing regions, all differing more or less in geologic and mineralogic characteristics. They are:

1. The eastern region, which extends along the front of the Unaka Mountains and contains brown iron ore (limonite), red iron ore (hematite), and magnetic iron ore (magnetite).

2. The "Dyestone" region, which skirts the eastern base of Cumberland Mountain and Walden Ridge from Virginia to Georgia and extends laterally 10 to 20 miles into the valley of east Tennessee and also includes Sequatchie and Elk Valleys. It contains the principal deposits of bedded red hematite, typified by the ores mined near Rockwood.[1]

3. The Cumberland region, which is coextensive with the coal region in the northern part of the State and contains, interstratified with the shales of the coal measures, nodules, balls, flattened concretions, and bands of clay ironstone, or iron carbonate—sometimes called spathic iron ore. Ore of this type has not, however, proved of economic importance in Tennessee.

4. The western region, which occupies a wide strip of west-middle Tennessee from Kentucky to Alabama and which is characterized by the presence of large quantities of brown iron ore, or limonite. It is with this region that the present report is concerned.

In the interval between the publications of Commissioner Killebrew and the reestablishment of the State Geological Survey under G. H. Ashley in 1910 a detailed geologic study was made of the Columbia quadrangle by C. W. Hayes and E. O. Ulrich, of the United States Geological Survey, in 1899–1900, and the results were published in 1903 as Folio 95 of the Geologic Atlas of the United States. The Columbia quadrangle includes within its western portion a small strip of the southern part of Dickson County, the part of Hickman County from Centerville eastward, and the northeast corner of Lewis County.

Geologic work done in the western Highland Rim iron-ore area under the present State Geological Survey and prior to the study here reported consisted of a reconnaissance by A. H. Purdue of the deposits in Wayne and Lewis Counties in 1912, a detailed study of the deposits in Lewis County by R. F. Rogers in 1912–13, and a detailed study of the deposits in the Waynesboro quadrangle, embracing most of Wayne County and parts of Lawrence and Lewis Counties, by H. D. Miser in 1913, 1914, and 1920.

The following publications comprise the principal State and Federal Geological Survey papers that discuss the brown iron ores of west-middle Tennessee:

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[1] See Burchard, E. F., The red iron ores of east Tennessee: Tennessee Geol. Survey Bull. 16, 173 pp., 1913.

Troost, Gerard, Third geological report to the General Assembly of the State of Tennessee, October, 1835; Fifth geological report, November, 1839; Sixth geological report, October, 1841; Ninth geological report, November, 1847.

Safford, J. M., Geological reconnaissance of the State of Tennessee, Nashville, 1856; Geology of Tennessee, Nashville, 1869.

Killebrew, J. B., and Safford, J. M., Resources of Tennessee, Nashville, 1874.

Killebrew, J. B., Iron and coal of Tennessee, Nashville, 1881.

Hayes, C. W., and Ulrich, E. O., United States Geological Survey Geol. Atlas, Columbia folio (No. 95), 1903.

Purdue, A. H., The iron industry of Lawrence and Wayne Counties: Resources of Tennessee, vol. 2, No. 10, pp. 370–388, 1912.

Rogers, R. F., The iron ore deposits of Lewis County; Resources of Tennessee, vol. 5, No. 3, pp. 91–146, 1915.

Miser, H. D., Mineral resources of the Waynesboro quadrangle: Tennessee Geol. Survey Bull. 6, 1921.

THE EARLY IRON INDUSTRY

The iron industry in the western Highland Rim of Tennessee had its beginnings in the historical Cumberland Furnace locality, in Dickson County, where, in 1797, the first iron ore was dug and the first iron was made west of the Cumberland Mountains. It was at Cumberland Furnace that the cannon balls used by General Jackson in the battle of New Orleans were made. A furnace is reported to have been built on Yellow Creek, in Montgomery County, in 1802. All the early blast furnaces were small stone affairs using charcoal as fuel; some were supplied with blast from water power, but others had steam blast; both cold blast and hot blast were employed, one method often being changed to the other. During the first 30 years of the nineteenth century the iron industry expanded slowly in west-middle Tennessee, and in 1831 there were only six blast furnaces in operation; but four years later Troost[2] gives a list of 27 furnaces, of which 4 were in Stewart County, 6 in Montgomery, 6 in Dickson, 2 in Hickman, 3 in Wayne, 1 in Lawrence, 1 in Hardin, 2 in Perry, 1 in Humphreys, and 1 in Williamson. Of the output Troost says:

> Perhaps the number of furnaces in middle Tennessee is greater than that enumerated above. * * * Now if we suppose that each of them produces on an average 1,000 tons of metal per year, it will give the immense quantity of 27,000 tons of iron.

To these furnaces were attached bloomeries and refining forges, some of them on very extensive scales, and at two of them there were even rolling mills and nail factories. At this time a large rolling mill belonging to the Cumberland Iron Works was operated at Bear Spring, Stewart County, which was able to ship its products by way

[2] Troost, Gerard, Third geological report, pp. 28–29, 1835.

of Cumberland, Ohio, and Mississippi Rivers to Memphis, Vicksburg, and New Orleans. According to Killebrew [3] the first pig iron made in Stewart County was produced at these works in 1830, and the first cargo was shipped to Pittsburgh in 1831. It was the iron made here that obtained a high reputation through its subsequent successful use in the manufacture of plates for river-steamboat boilers. The report by Killebrew contains much interesting material for the student of early history of the iron industry. It gives good pen pictures of the character of properties essential for a large charcoal iron business and technical descriptions of early furnaces.

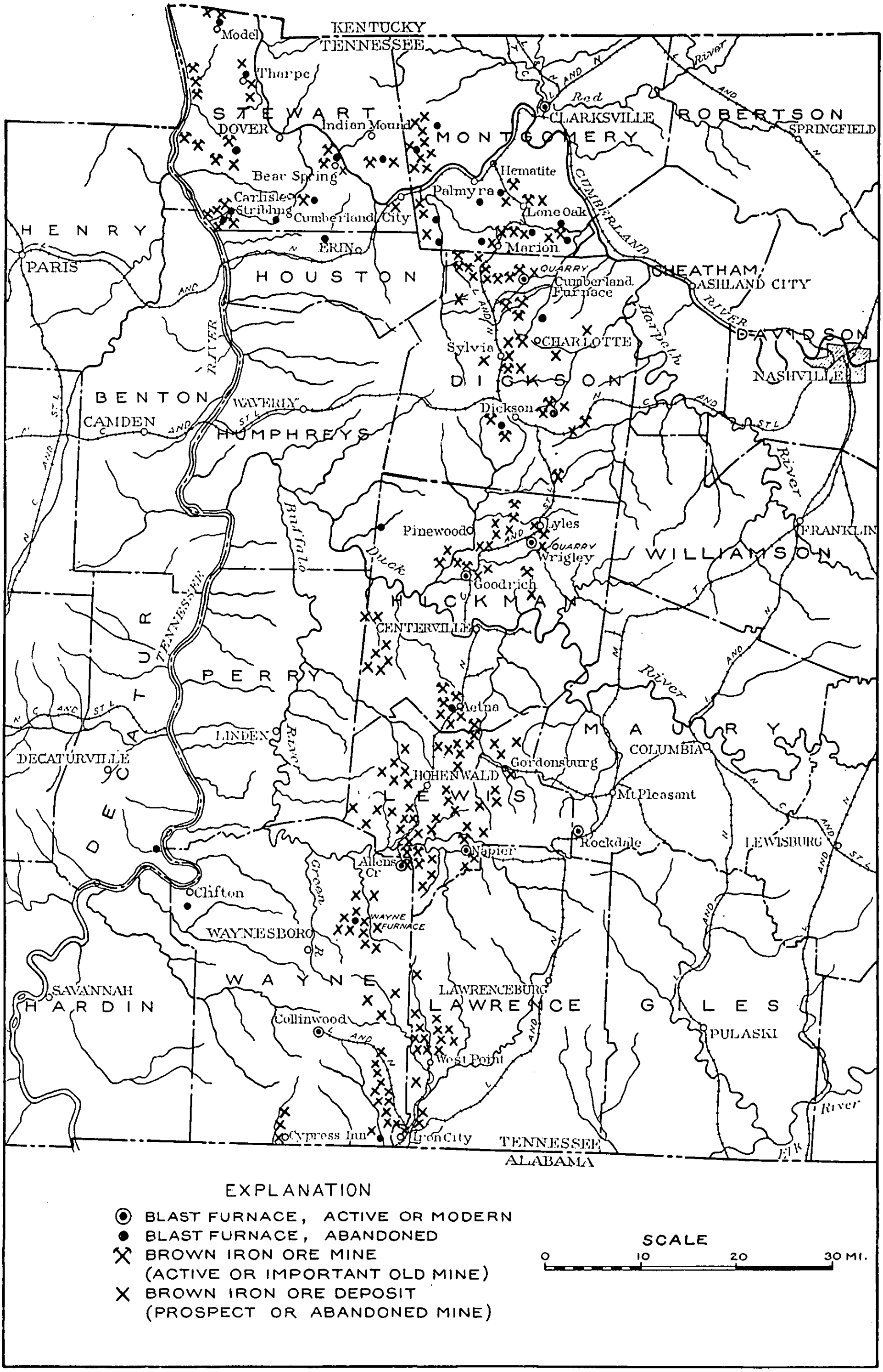
In commenting on economic conditions in the western iron belt Killebrew points out that the superior quality and great quantity of the iron ores, the vast supplies of timber, convenient and abundant limestone, and the cheapness of mining and production all combined to give the iron makers of the region a false sense of security, and they had continued up to that time to make iron according to ancient methods, although they really could not compete with more modern furnaces situated upon lines of transportation which, nevertheless, were using inferior ores. Therefore he hailed with delight the introduction of modern methods at the Warner furnace and the building of railway lines into the iron-ore territory.

Since Killebrew's report was published the operations of all the old stone-stack charcoal furnaces have been discontinued, and iron making has been concentrated on a larger scale at fewer places. The latest of the old charcoal furnaces to be operated is at Dover, Stewart County, and it is reported that iron was made here as late as 1920. Many of the old stone stacks are still standing, others are represented only by a few stones, and the sites of others can be identified only by the remains of piles of blue and green glassy slag now overgrown with underbrush by the side of some stream deep in the solitude of the woods. Modern blast furnaces have been erected at Clarksville, Cumberland Furnace, Wrigley, Goodrich, Aetna, Napier, Rockdale, and Allens Creek, but those at Clarksville, Goodrich, and Aetna have been dismantled.

GEOGRAPHY

The Highland Rim of middle Tennessee is a dissected plateau that surrounds the Nashville Basin and stands at a higher altitude. The western part of the Highland Rim, in which the deposits of brown iron ore are found, extends from south to north across Tennessee, west of the longitude of Nashville and Columbia and east of Tennessee River. (See pl. 4.) Two master streams control the drainage of the area—Tennessee River on the west and south and Cumberland River on the north. The two largest streams of the next

[3] Killebrew, J. B., Iron and coal of Tennessee, p. 99, 1881.



MAP OF THE WESTERN HIGHLAND RIM AREA OF TENNESSEE SHOWING LOCATION OF IRON-ORE DEPOSITS, MINES, QUARRIES, AND BLAST FURNACES order of size are Duck River and Buffalo River, and there are innumerable smaller streams, for the region is in general liberally supplied with rainfall.

The surface of this portion of the State has been rather intricately dissected by stream erosion and is consequently hilly, but there are large areas of the flat-topped ridge land in the north and smaller areas in the south, as well as some fairly wide bottom land along the larger streams throughout the area. The altitude ranges generally from 500 to 950 feet above sea level, but there are greater extremes from the level of Tennessee River, at about 350 feet, to the highest interstream area, at about 1,050 feet.

The largest towns are Clarksville and Dickson, and other important places are Centerville and Lawrenceburg. Three county seats—Charlotte, in Dickson County; Dover, in Stewart County; and Waynesboro, in Wayne County—are not on railroads, all being reached by automobile, and Dover also by launch or steamboat on Cumberland River. Iron-ore mining has not been extensive enough or steady enough to build up any large towns, but certain small villages such as Cumberland Furnace, Lyles, Nunnelly, Aetna, Allens Creek, and Iron City owe their existence chiefly to the mining industry, and other places have had alternations of activity and idleness. Aside from mining the chief occupations in this part of Tennessee are agriculture and lumbering. There are still many areas that produce hard woods, but most of them have been cut over many times. Farming is carried on in the northern part of the area on the upland and in the valley areas, but in the southern part, where there is less level upland, it is more generally confined to the flood plains of the streams. With the exception of a few highways between important places the roads are not well cared for, and in wet weather automobile travel is difficult on the ordinary country roads.

The railroads generally follow the ridges and are therefore in places somewhat circuitous. Two railroads cross the area, the Louisville & Nashville line that extends from Memphis to Louisville by way of Clarksville and the Nashville, Chattanooga & St. Louis line from Memphis to Nashville. Ore-bearing territory is tapped by branch lines of the Louisville & Nashville from Clarksville to Pond, near Dickson, with a spur from Van Leer to Cumberland Furnace, and of the Nashville, Chattanooga & St. Louis from Dickson to Allens Creek. The Columbia, Florence & Sheffield branch of the Louisville & Nashville Railroad passes close to iron-ore deposits at Iron City, Lawrence County, and maintains short branches to Pinkney and to Napier. A railroad known as the Tennessee Western was built from Iron City to Collinwood on account of the necessity for transportation facilities to Collinwood, where a charcoal by-product plant and blast furnace were constructed during the World War, but the activities of these plants were short-lived. This railroad was projected northward to the locality of the old Wayne furnace, in order to tap the local iron-ore deposits, but construction work did not progress beyond the preparation of the grade and laying of ties a few miles from Collinwood. It is reported that the original plan contemplated building this line on to connect with the Nashville, Chattanooga & St. Louis Railway at Allens Creek, an expensive piece of work because of the rough character of the country to be traversed.

In the northern part of the iron-ore area Tennessee River and Cumberland River afford potential water transportation for ore from deposits within easy wagon or motor-truck haul. None is being shipped in this way at present, but in very early days of the iron industry pig iron from local charcoal furnaces was transported extensively on these rivers, and later iron ore was shipped by boat down to blast furnaces in Kentucky.

GEOLOGY

STRATIGRAPHY

The rocks forming the surface of the western Highland Rim region are sedimentary and range in age from Ordovician to Quaternary. The Ordovician rocks are exposed along the eastern edge of the rim and extend down the valley of Duck River as far as Centerville. Other minor exposures occur in the valley of Shoal Creek northeast of Iron City, along Tennessee River near Clifton, and in a small upthrust area near Cumberland City. These rocks consist in middle Tennessee of unevenly bedded bluish-gray fossiliferous limestone and calcareous shale of various characters; the limestone is phosphatic at many horizons. Silurian rocks lie next above those of the Ordovician system. They are exposed also along the eastern border of the western Highland Rim and at the bottoms of portions of the valleys of Tennessee, Buffalo, Duck, Harpeth, and Cumberland Rivers and in Shoal Creek and many other tributaries of Tennessee River. The Silurian rocks consist of evenly bedded, in places dense, crystalline, massive to shaly fossiliferous limestone. The lower beds are variegated, and the upper part is gray and in places contains chert. The Devonian rocks, which are next in succession, crop out in the western valley of Tennessee River and consist of thick beds of chert, or novaculite, interbedded with thin pure-white limestone and siliceous limestone and shale. Overlying the Devonian chert is a thin sandstone and black shale (the Chattanooga shale), which is of Devonian or Carboniferous age. The rocks of Ordovician to Devonian age are not essentially associated with the deposits of brown iron ore and need not be described further. Their general distribution is shown on the geologic map of Tennessee, issued by the State Geological Survey in 1923, and descriptions of the formations with detailed mapping in portions of the western Highland Rim area will be found in publications written by Miser[4] and by Hayes and Ulrich.[5]

The essential features of the rocks later than the Devonian in the brown iron ore bearing area are summarized in the following outline, and their general distribution may be found on the geologic map of Tennessee referred to above.

Outline of post-Devonian geologic formations in western Highland Rim area of Tennessee

System	Series	Formation	Thickness (feet)	Lithology and distribution
Quaternary.	Recent.	Alluvium and terrace deposits.	1-30	Gravel and silt in stream flood plains. Gravel and loam on stream terraces.
Cretaceous.	Upper Cretaceous.	Eutaw sand.	0-50	Gray to red micaceous sand with some clay. Found on higher lands in southwest and northwest parts of area.
		Tuscaloosa gravel.	0-150	Gravel with small quantities of clay and sand. Gravel chiefly of chert derived from Mississippian rocks. Caps higher ridges and hills mostly in southwest and northwest parts of area.
Erosion interval.				
Carboniferous.	Mississippian.	St. Louis limestone.	50-200	Blue and gray massive cherty limestone, weathering to red clay and broken chert; underlies a large part of the upland north of Cumberland River and smaller areas south to Duck River. Overburden of red clay contains deposits of brown iron ore in many places.
		Warsaw formation.	150-200±	Massive pure and cherty limestone with a few sandstone beds. Probably occupies most of upland area south of Duck River. Weathers to deep-red clay containing fragments of chert and boulders of sandstone. The thick residual clay which underlies the general upland level contains deposits of brown iron ore in many places.
		Fort Payne chert.	100-200	Gray cherty crinoidal limestone, calcareous chert, and gray shale. Exposed on hill slopes not far below the general upland level.
		Ridgetop shale.	0-90	Gray platy siliceous shale, glauconitic near base. Recognized in Wayne and Lawrence Counties.
Erosion interval.				
Devonian or Carboniferous.	Upper Devonian or Mississippian.	Chattanooga shale.	0-37	Black platy shale with thin ledges of fine-grained phosphatic sandstone locally in basal part.

[4] Miser, H. D., Mineral resources of the Waynesboro quadrangle, Tennessee: Tennessee Geol. Survey Bull. 26, 1921.

[5] Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), 1903.

The consolidated rocks that are nearest the surface in most of the area containing the brown iron ore belong to the Mississippian series of the Carboniferous system. The three Mississippian formations most closely associated with the ore are, in ascending order, the Fort Payne chert, the Warsaw formation, and the St. Louis limestone.

The Fort Payne chert is a calcareous chert or highly siliceous limestone associated in places with some gray shale. Some of the chert contains an abundance of fossil crinoid stems, and here and there brachiopods are present. The formation is 100 to 200 feet thick in Wayne and Lawrence Counties but apparently becomes thicker toward the north. It is exposed on the hill slopes and in the upper parts of the valleys of smaller streams in the southern part of the region, but north of Duck River the exposures are not so extensive and are confined more to the vicinity of Tennessee and Cumberland Rivers. More or less tripoli, a soft, fine-grained porous material, is formed by the weathering of beds in the upper part of the Fort Payne chert, and the occurrence of this material, as well as the abundance of crinoid remains, aids in the identification of the beds. In places residual clay covers the outcrop, but clay from the Fort Payne can generally be distinguished from the red clay of the higher Warsaw and St. Louis limestones by its yellower color.

The Warsaw beds are considered to lie unconformably on the Fort Payne chert. They are composed of massive pure limestone and cherty limestone and contain also some sandstone beds. The limestone weathers to a deep-red cherty clay, and this clay contains in a few places residual boulders of a more or less saccharoidal sandstone which was probably originally calcareous. The residual clay, which is difficult to distinguish from that of the overlying St. Louis limestone, contains a large proportion of the deposits of brown iron ore in the area. The Warsaw beds and their residual clay underlie most of the upland area south of Duck River, and north of that river they extend back from the borders of the valleys for varying distances until they pass below the St. Louis beds. A piece of chert pronounced by Charles Butts to be typical of the Warsaw was found as far north as Slayden, Dickson County. The thickness of the Warsaw is not definitely known but is probably in excess of 150 feet.

The St. Louis limestone consists of blue-gray massive cherty limestone which weathers to reddish clay and loose fragments of chert. It forms the surface rock of most of the higher plateau lands north of Cumberland River and smaller areas southward to Duck River except in a few places where it is overlain by Cretaceous gravel, and thus it has been exposed to deep weathering, so that the whole thickness of the formation is probably nowhere present. The part still remaining north of Cumberland River may reach a thickness of 200 feet, but the formation is much thinner in the area between Cumberland and Duck Rivers, and, according to Charles Butts, it may not be present at all in the southern counties. H. D. Miser, however, believes that chert and clay residual from the St. Louis and possibly some limestone are present in places in Wayne and Lawrence Counties. Weathering has produced a residual mantle of clay and broken angular fragments of chert from a few feet to 100 feet thick. The characteristic red clay residual from the limestone contains a fossil coral, *Lithostrotion canadense*, which forms compact masses reaching a foot in diameter and which is considered to have been derived from the basal beds of the formation. Beds containing this coral in place have been noted only in a few localities in the northern part of the State. The residual clay, whether it is derived from the Warsaw or the St. Louis, contains a large proportion of the deposits of brown iron ore in the area.

Remnants of deposits of Upper Cretaceous rocks, the Tuscaloosa and Eutaw formations, overlie the Mississippian rocks and their residual clays in a few places east of Tennessee River. The Tuscaloosa, which consists mostly of gravel, contains partly rounded pebbles of chert derived from Carboniferous rocks, and in places the gravel has been cemented by iron oxide into a hard conglomerate. In Wayne County the gravel of the Tuscaloosa occurs as a mantle on the higher hills and ridges; it thins out entirely toward the north but thickens to as much as 150 feet toward the southwest corner of the county, where it is overlain by the Eutaw sand. This sand is red, weathering to gray at the surface, is extremely fine grained, contains flakes of mica and streaks of gray clay, and attains a maximum thickness of 50 feet. These Upper Cretaceous deposits are the lowest of the Gulf embayment and represent the eastern limit to which such deposits are now present in Tennessee. Evidently they were spread over most of the region and probably were formerly overlain by higher glauconite-bearing formations, such as the Selma and Ripley, which are present west of Tennessee River. In several places north of Wayne County, Tuscaloosa gravels are found on the interstream areas, as near Aetna and Coble, Hickman County; near Tennessee City, Dickson County; near Bear Spring and in the northwestern part of Stewart County, on the ridge between Tennessee and Cumberland Rivers. Here and there masses of the gravel conglomerate consisting chiefly of chert pebbles contain a few smoothly rounded pebbles of quartz or quartzite, and larger quantities of similar pebbles are commonly found lying loose on the highest hilltops in the southern counties of Tennessee and in northern Alabama. Gravel of this type in northwestern Alabama has been included with the Tuscaloosa by students of Coastal Plain geology, although the source of the pebbles is wholly different from that of the chert gravel and can not be traced to any of the older rocks exposed in the region. These quartz and quartzite pebbles may be of Tertiary or later age, and their presence in the ferruginous conglomerate in the Tennessee River valley may be accounted for by assuming that the materials of this conglomerate, which is found in detached masses not buried under heavy cover, have been reworked with later material and the whole cemented together in recent times by iron oxide from solution in surface waters. Conglomerates of this sort are being formed now where chalybeate waters are issuing into gravel fans near the levels of present streams.

The deposits of Quaternary age comprise terrace gravel, stream gravel, and alluvium, and these are not commonly associated with the brown iron ores.

STRUCTURE

The topographic features of middle Tennessee are directly related to the structural geology of the region. The outstanding feature of a geologic map or east-west cross section of this portion of the State is the Nashville uplift, an elliptical area that extends in a southwesterly direction across the State, in which the rocks, mostly Ordovician limestones, at the surface have been gently folded into a broad, low dome. Surrounding the Nashville uplift on all sides is the Highland Rim, a border of hills whose summits reach so nearly the same altitude that when viewed from a distance they present a comparatively even sky line. These hills, whose tops are more or less horizontal, represent remnants of an extensive plateau or highland developed on Mississippian rocks, below which the Ordovician beds dip gently away from the uplift.

The northern part of the Nashville uplift is drained by Cumberland River and its tributaries and the southern part by tributaries of Tennessee River which flow westward and southward, cut through the border of hills, and deeply dissect the country beyond. The rolling surface of the uplift, for the most part, slopes gently northward and westward, and it is lower at its borders than the Highland Rim, thus becoming more or less of a topographic basin, particularly in the vicinity of Nashville and Cumberland River.

In the western Highland Rim area the dips of the rocks are nearly everywhere so slight that locally the beds appear to be practically horizontal. A notable exception is the Wells Creek basin, just southwest of Cumberland City, where there is apparently an abrupt uplift, roughly circular in outline, about 1¾ miles in diameter, in which all the rocks down to the Ordovician are brought to the surface within the area of Mississippian rocks. The general dip as indicated by the geologic map of Tennessee is toward the west and southwest, away from the Nashville uplift; in some places the dips are measurable but they rarely exceed a few degrees. Where detailed geologic mapping has been done on a topographic base, as in the Waynesboro quadrangle, it has been possible to delineate several gentle anticlinal and synclinal folds, and these have been shown on the geologic map [6] by means of structure contours on the Chattanooga shale. Many of the larger streams in the Waynesboro quadrangle occupy synclinal folds, and thus most of their tributaries flow toward the axes of these folds, with the dip of the rocks. The relation of this folding to the distribution of the iron-ore deposits is probably significant, although not thoroughly worked out because of the lack of detailed topographic maps or accurate levels.

THE IRON ORES

DISTRIBUTION

The deposits of brown iron ore that are described in this bulletin occur in a belt that lies east of Tennessee River and extends from the north to the south boundary of the State, a distance of 115 miles. This belt is generally about 15 miles wide from east to west, but in the northern part of the State, in Stewart and Montgomery Counties, it is about 40 miles wide, as shown in Plate 4. Some of the deposits, as in Stewart County, are near Tennessee River, but most of them are in the second tier of counties east of the river, 15 to 40 miles distant from it. The counties which contain most of the iron-ore deposits are, beginning at the northwest, Stewart, Montgomery, Dickson, Hickman, Lewis, Wayne, and Lawrence. Minor deposits in Benton, Decatur, Hardin, Houston, Humphreys, and Perry Counties have been noted in State Survey reports or reported by local residents. Iron ore of similar character is also found toward the north in the vicinity of Tennessee and Cumberland Rivers in western Kentucky, and toward the south in the vicinity of Russellville, Colbert County, Ala., and as a whole this may well be considered the western Tennessee River valley area of brown iron ore. There are no large towns close to any of the iron-ore deposits, but Clarksville, Mount Pleasant, Columbia, and Nashville are not far beyond the border of the iron-bearing area.

[6] Miser, H. D., Mineral resources of the Waynesboro quadrangle, Tennessee: Tennessee Geol. Survey Bull. 26, pl. 1, 1921.

OCCURRENCE AND CHARACTER

POSITION AND FORM OF DEPOSITS

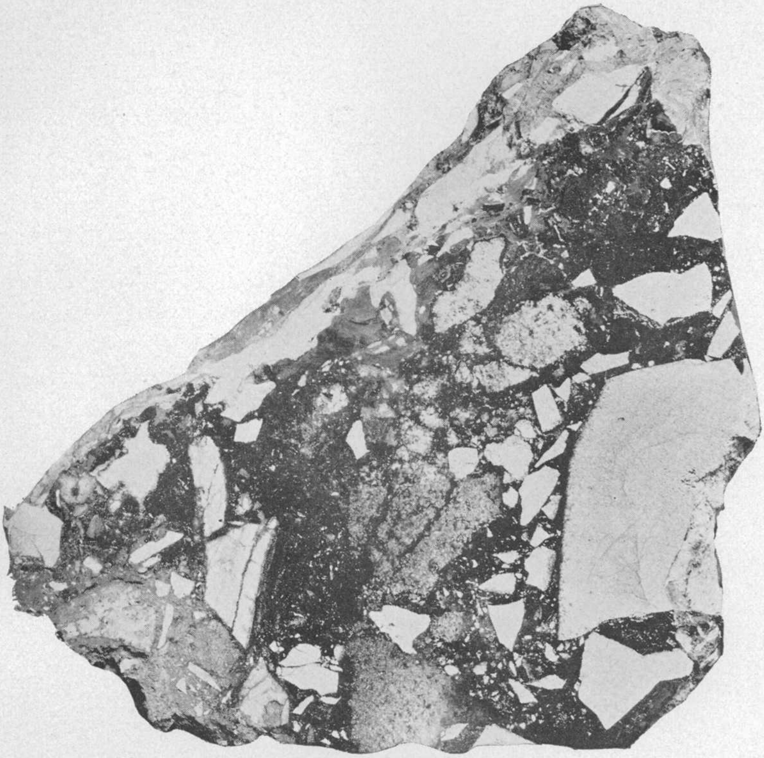
The deposits of brown iron ore throughout the western Highland Rim area of Tennessee display considerable similarity in their general form and position. The ores are inclosed in clay and chert débris lying above beds of cherty limestone that have been subjected to deep weathering, so that the upper and lower limits of the ore bodies are uneven. Many of the deposits occur on the borders or near the crests of narrow ridges and tend to conform to a certain extent to the upper hill slopes, so that they can not be said to lie in a horizontal position, although locally there is a certain degree of uniformity in the altitude of the deposits. Other deposits occur on the slopes or well down toward the levels of the valleys, but even in such positions there is a considerable thickness of residual clay or chert, or both, between the ore and the underlying consolidated rocks. Near the surface the ore occurs in loose fragments from the size of shot to boulders several feet in diameter; at greater depth it is in large irregular-shaped masses and veins, some of them forming branching networks and large clay-filled crusts. Where erosion on a hillside has been rapid a solid mass of ore or of ferruginous conglomerate may become exposed before being broken down into loose lumps, but the best place in which to study the ore is in an active mine cut.

In places the presence of good ore is indicated by outcrops of lumps and scattered boulders and fragments of limonite and by the presence of fine gravel of limonite, or " shot ore," scattered over the surface and embedded in very red subsoil. In places ledges of chert-gravel conglomerate cemented firmly by brown iron oxide crop out prominently on the hillsides, but these masses do not constitute very rich ore. Most commonly the ore is covered with soil, clay, gravel, sand, and other unconsolidated material to a depth of a few feet to 30 feet or more, so that in mining the overburden of barren material must first be removed.

The deposits are extremely variable in size, ranging from a pocket containing a few hundred tons of ore, or hardly enough to pay to mine even by hand methods, to groups of deposits extending over hundreds of acres and to depths of 30 to 100 feet and originally capable of yielding more than 1,000,000 tons by means of steam-shovel stripping and mining.

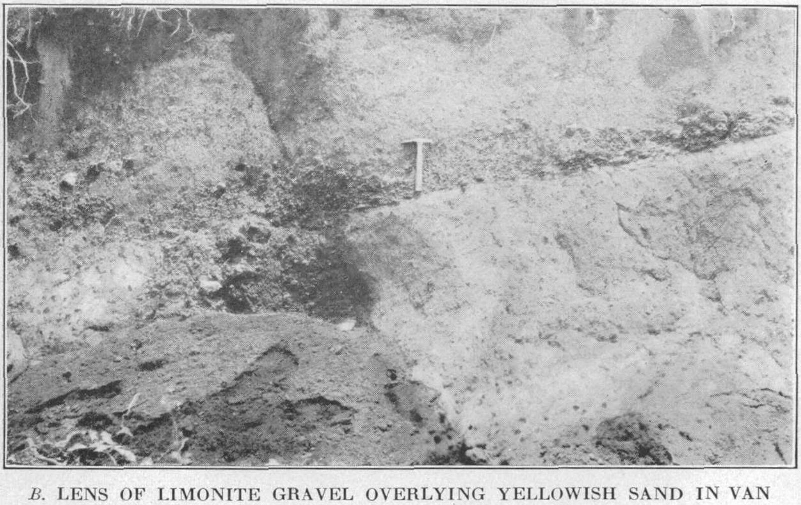
TYPES OF ORE

The ore consists principally of limonite, and the great variety of forms assumed by this mineral is of interest. The shot ore is fine-



A. FRACTURED CHERT PARTLY REPLACED AND CEMENTED BY LIMONITE

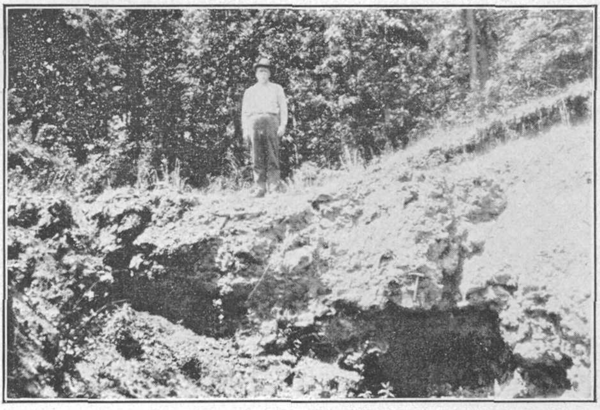
Faint gray areas show fragments of chert in various stages of replacement, but the dense brown areas of limonite have resulted from almost complete replacement of chert. From Napier mine. Two-thirds natural size



B. LENS OF LIMONITE GRAVEL OVERLYING YELLOWISH SAND IN VAN LEER BROWN IRON ORE MINE OF TENNESSEE PRODUCTS CORPORATION, NEAR IRON CITY, TENN.

A. STACK OF BEAR SPRING FURNACE, AT BEAR SPRING, TENN.

Erected in 1873



B. FACE OF BROWN IRON ORE LEDGE IN SWAMP BANK OF LA GRANGE PROPERTY, STRIBLING, TENN.

Right end of ledge at hammer handle shows a band of chert grained material, usually more or less rounded, that has been derived by the natural disintegration of larger fragments and masses of ore. The individual fragments are rich in iron, and where they occur in abundance in the clay they are mined and recovered by washing. Many large lumps and boulders of limonite are found to be hollow, like geodes, and to contain clay, sand, gravel, or chert within the cavity. Frequently the cavities are lined with glossy black limonite. The ore exhibits great differences in texture, ranging all the way from dense and solid to earthy, porous material. "Honeycomb" ore consists of hard limonite in thin webs with open spaces between, and there is much ore containing irregular-shaped small cavities. According to the mode of its deposition the ore shows certain characteristics. So much chert has been replaced by iron oxide in this field that the term "chert-replacement ore" is suggested (pl. 5, *A*). At first glance ore of this type appears to be a breccia in which angular fragments of chert are cemented together by limonite, but close observation shows that limonite has replaced the chert to a greater or less extent, proceeding along the angular fractures in the rock. The natural breaking down of material of this type has yielded a great deal of limonite in the form of fragments of crusts and gravel and shot ore (pl. 5, *B*), and crushing and washing are employed to recover this material artificially. Clay has also been replaced by iron oxide to a small extent, with the formation of a low-grade ore. More or less commonly the limonite, where deposited from solution in an open cavity, is botryoidal and stalactitic. This ore is generally of relatively high grade, as is also the massive, compact type.

MINERAL COMPOSITION

The brown iron ores appear to consist of a mixture of hydrous iron oxides in which the iron is present in the ferric form as the sesquioxide (Fe_2O_3). As the great bulk of the material is hydrated, there is probably very little hematite, or nonhydrous ferric oxide, present. The more common hydrated ferric oxides are limonite, goethite, and turgite, but in this field limonite and goethite seem to be the principal minerals. It is not unlikely that there is more goethite present than has been formerly suspected. Examination under the microscope by C. S. Ross of a specimen of powdered ore, clean and well separated from gangue material, indicated that it was mostly crystalline material with the indices of refraction corresponding to goethite, a result which confirmed a chemical analysis made at Wrigley Furnace that showed more metallic iron than is contained in limonite, or about the percentage necessary for goethite.

The principal impurities in the ore are clay, chert, sand, and gravel. The clay and chert are residual from the Mississippian limestone, and the sand and gravel from the Cretaceous formations, although some may have been derived ultimately from the Mississippian beds. Some rather rare iron phosphate minerals, strengite, beraunite, cacoxenite, and dufrenite, have been found in boulders of chert breccia cemented with iron oxide at the Van Leer mine, in Wayne County.

A statement of the relations of the iron oxide minerals may be of interest here. Beginning with hematite, which contains no water, the formulas of the other oxides may be so arranged as to show a close relationship in which, if the ferric oxide is regarded as constant, the proportion of chemically combined water steadily increases and the iron decreases.

Character of certain ferric-oxide minerals [a]

Name of mineral	Chemical formula	Composition		
		Iron oxide (per cent)	Water (per cent)	Iron (per cent)
Hematite	$2Fe_2O_3.0H_2O$	100.0	0	70.0
Turgite	$2Fe_2O_3.1H_2O$	94.7	5.3	66.2
Goethite	$2Fe_2O_3.2H_2O$	89.9	10.1	62.9
Limonite	$2Fe_2O_3.3H_2O$	85.5	14.5	59.8
Xanthosiderite	$2Fe_2O_3.4H_2O$	81.6	18.4	57.0
Limnite	$2Fe_2O_3.6H_2O$	74.7	25.3	52.3

[a] Eckel, E. C., Iron ores, their occurrence, valuation, and control, p. 25, New York, McGraw-Hill Book Co., 1914.

In his report on the brown iron ores of the Waynesboro quadrangle, which is an important part of this ore field, Miser [7] in using this table commented on the composition of these iron oxide minerals as follows:

From this table it will be seen that the first [five] minerals in question make up a perfect series with respect to their percentages of combined water, beginning with hematite, which contains no water, and showing gradually increased amounts to the other end of the series. The table also shows a decrease in the percentages of iron from hematite toward the other end of the series. The percentages of iron as given in the table are theoretical and will never be found in the ores in the Waynesboro quadrangle, because all of the ores contain more or less impurities.

The four hydrous oxides, turgite, goethite, limonite. and xanthosiderite, are commonly grouped under the name of brown iron ores, or limonite. It is probable that if the product from any particular brown-ore deposit in the Waynesboro quadrangle be carefully examined, it will be found that much of the ore is limonite proper, with much goethite and smaller proportions of the other two hydrous oxides. Hematite, if present in the quadrangle, occurs in very small quantity. In the present report the iron oxide minerals are called simply brown iron oxides or red oxides according to their color.

Limonite is not crystallized; most of it is massive, though some of it has botryoidal surfaces and has a fibrous structure. It has a brown or nearly black varnishlike surface, and the color of freshly fractured surfaces ranges from light to dark brown. The streak is yellowish brown.

Goethite resembles limonite and has a brownish-yellow to ocher-yellow streak, whereas both hematite and turgite, which often resemble limonite, have

[7] Miser, H. D., op. cit., p. 49.

red streaks. Xanthosiderite occurs as fine needles or fibers and as ocher and is golden yellowish or brown to brownish black in color.

CHEMICAL COMPOSITION

No complete chemical analyses of specimens of the brown iron ore from this field are available, but there are many partial analyses of prospect samples and of the ore as prepared for the blast furnace, either by washing and screening or by hand picking and dry screening. Local ores that have been used in the blast furnaces of the region generally range as follows in the constituents that are ordinarily determined in commercial analyses: Metallic iron (Fe), 38 to 52 per cent but averaging not more than 46 per cent; insoluble material, mostly silica (SiO_2) and alumina (Al_2O_3), 10 to 38 per cent and averaging about 25 per cent; phosphorus (P), 0.12 to 1.30, mostly between 0.30 and 0.50 per cent (the percentage of phosphorus appears to increase from north to south through the field); manganese (Mn), 0.10 to 1.30, mostly between 0.20 and 0.50 per cent; combined water, about 10 to 12 per cent. Analyses have been made of specimens of hydrous iron oxide, separated from gangue material, that showed more than the percentage of iron required for limonite, thus suggesting the presence of goethite, a suggestion which has been confirmed by microscopic examination.

The run of mine washed ores generally range lower in iron and higher in insoluble material than prospect samples. This is probably unavoidable, because the prospecting is done by hand and the greater part of the clay, chert, and sand are eliminated, whereas mining by means of steam shovel can not be done so selectively and involves the incentive toward obtaining a large quantity production by speeding up work and advancing into leaner ore bodies, and moreover the limitation of efficiency in the ore washers affects the product. This difference between the character of prospect samples and the run of mine ore as it reaches the furnace will be apparent to anyone who examines the records of analyses at the blast-furnace laboratories, and it should be taken into consideration in interpreting the analyses of prospect samples when planning new or additional mining developments. The optimistic frame of mind induced by the generally high quality of prospect samples has been impressed upon the writer by an examination of a number of analyses of brown iron ore recorded in an unpublished report on the ores of the western iron-ore region, made by Maj. G. D. Fitzhugh to the vice president of the Louisville & Nashville Railroad Co. in 1890. This report was based on a very thorough study of a large number of the ore deposits, many of which have since yielded a large quantity of ore. Wherever it was found necessary test pits were dug to determine the thickness of the ore, and samples were taken for analysis that were believed to represent the average quality of the ore that might be recovered. The report recorded 67 analyses, and of these 57 showed metallic iron higher than 50 per cent. The range was between 35 and 60.5 per cent, and the average for these 67 analyses was about 53 per cent. It is probably safe to say that the average yield of iron for the mines in this region since 1890 has by no means reached this figure.

The first table below presents analyses of samples of iron ore from different parts of the ore-bearing region, and the second table consists of representative analyses of ores from the mines as prepared for use in the blast furnaces. Several of the analyses in the two tables represent ores from the same deposits, and they bring out clearly the contrast between the quality of prospect samples and that of mine-run ore. Other analyses will be found among the descriptions of typical iron-ore deposits on pages 83 and 104.

Analyses of prospect samples of brown iron ore from western Highland Rim area, Tennessee

Locality	Authority [a]	Fe	Insoluble	Mn	P	S
Carlisle, Stewart County	B	53.18	9.00	0.24	0.23	--------
Louise, Montgomery County	F	51.77	[b] 7.16	1.82	.10	0.02
Mount Vernon, Montgomery County	F	53.03	[b] 6.12	Tr.	.29	.12
Charlotte, Dickson County	F	55.60	[c] 9.86	.36	.26	.09
1.3 miles northwest of Hortense, Dickson County	T	52.69	10.36	.18	.31	--------
Iron Hill, Dickson County	F	52.89	[b] 8.85	1.65	.058	.052
Nunnelly, Hickman County	T	52.73	[c] 11.31	.41	.38	--------
Aetna, Hickman County	F	57.85	[b] 3.99	.58	.31	Tr.
Napier, Lewis County	F	56.40	[b] 5.35	.46	.602	.037
Nixon bank, Lewis County	M	47.07	[b] 18.42	--------	.64	.042
Grinders Bank, Lewis County	M	50.46	[b] 12.39	--------	.841	.221
Allens Creek, Wayne County	M	56.89	[b] 4.21	--------	1.372	.007
Wayne furnace, Wayne County	M	52.28	[b] 9.41	--------	.88	--------
Pinkney mine, Lawrence County	M	54.17	[b] 6.01	--------	1.302	.004
Seavy-Lull mine, Lawrence County	M	54.02	[b] 6.98	--------	1.07	.014

[a] B, Bon Air Coal & Iron Corporation; F, Maj. G. D. Fitzhugh, unpublished manuscript; M, Miser, H. D., Tennessee Geol. Survey Bull. 26; T, Tennessee Geol. Survey, D. F. Farrar, chemist.
[b] Silica (SiO_2).
[c] Silica (SiO_2)+alumina (Al_2O_3).

Analyses of run of mine, washed, and screened brown iron ore from western Highland Rim area, Tennessee

Locality	Authority [a]	Fe	Insoluble	Mn	P
Stribling, Stewart County	B	40.21	33.49	--------	0.43
Louise, Montgomery County	W	44.09	23.60	--------	--------
Do	W	38.67	31.30	--------	--------
Cumberland Furnace, Dickson County	W	40.08	28.38	0.20	.62
Stokes, Dickson County	W	42.79	27.36	.42	.14
Iron Hill, Dickson County	B	51.67	11.52	.27	.195
Do	B	43.47	26.60	.40	.116
Nunnelly, Hickman County	B	49.27	18.70	.20	.36
Do	B	44.04	22.42	.20	.44
Aetna, Hickman County	B	48.61	18.47	.22	.27
Do	B	43.69	21.64	.49	.176
Napier, Lewis County	[b] R	50	--------	--------	.50
Allens Creek, Wayne County	M	[b] 47	15 to [c] 18	.25 to .30	.80 to 1.25
Van Leer, Wayne County	W	48	[c] 10	.40	.50+
Pinkney, Lawrence County	[b] M	47	[d] 17.50	.70	--------

[a] B, Bon Air Coal & Iron Corporation; M, Miser, H. D., Tennessee Geol. Survey Bull. 26; R, Rogers, R. F., Resources of Tennessee, vol. 5, No. 3, July, 1915; W, Warner Iron Co.
[b] Average.
[c] Silica (SiO_2).
[d] Silica (SiO_2)+alumina (Al_2O_3).

TOPOGRAPHIC RELATIONS

The iron-ore area is largely within the western part of the Highland Rim, the dissected plateau that surrounds at a higher altitude the Nashville Basin in west-middle Tennessee. The region is very much dissected by streams, the altitude ranging from about 350 feet at Tennessee River in Stewart County to about 1,050 feet on the flatwoods in Lewis County. Locally, of course, there is less relief, the altitude of the smaller stream valleys ranging from 500 to 750 feet and that of the ridge crests from 850 to 1,000 feet or more. These ridge crests probably represent the remains of a peneplain of Tertiary or Pleistocene age, to which the name Highland Rim peneplain has been applied.

A feature of many of the iron-ore deposits is the occurrence of the ore-bearing clay, chert, and gravel on or near the crests of the ridges and on the borders of flat interstream areas. An inspection of the general map (pl. 4) will show the large number of ore occurrences that are remote from the streams and consequently on the upland, particularly in Dickson, Lewis, and Wayne Counties, but the same map shows also in these counties and in all the others many deposits that are close to good-sized streams and consequently well below the level of the old peneplain. In fact, in Stewart County large deposits are found practically at the levels of the flood plains of Tennessee and Cumberland Rivers, which have cut to the lowest altitudes found in this part of Tennessee, or considerably below 400 feet. The highest altitudes at which the brown ore has been found are more than 1,000 feet in Lewis and Wayne Counties, and thus there is an extreme vertical range of about 650 feet, which represents the difference between the lowest stream channels and the highest interstream areas in this part of the Tennessee River valley.

A study of the barometric altitudes of more than 200 deposits recorded by Miser, Rogers, and the writer shows the following range by counties. More careful instrumental work might modify some of the data.

Range in altitude of deposits of brown iron ore in west-middle Tennessee

Area	Number of deposits	Altitude (feet above sea level)
Stewart County	22	365–650
Montgomery County	10	475–700
Dickson County	32	550–900
Hickman County	20	600–900
Lewis County	30	700–1,050
Waynesboro quadrangle (portions of Lewis, Wayne, and Lawrence Counties)	90	750–1,000

The figures may be summarized in another way as follows:

Percentage distribution of deposits of brown iron ore according to altitude

Approximate range in altitude (feet above sea level)	Approximate percentage of deposits	Approximate range in altitude (feet above sea level)	Approximate percentage of deposits
350–400	1. 2	701–750	9. 8
401–450	2. 0	751–800	13. 9
451–500	3. 3	801–850	16. 3
501–550	1. 6	851–900	16. 7
551–600	4. 1	901–950	10. 2
601–650	4. 1	951–1, 000	8. 2
651–700	7. 3	1, 001–1, 050	1. 2

This summary shows that 57 per cent of the deposits, or the major part of those studied, are between altitudes of 750 and 950 feet; many of these, together with those above 950 feet, amounting to 9.4 per cent additional, are at or near the crests of the ridges, and about 33 per cent are lower than 750 feet and are for the most part not on the crests of ridges.

The first table shows that the highest deposits are in Lewis County, and these happen to be surface showings of limonite near the Lewis Monument, which stands near the north border of the extensive flatwoods area north of Buffalo River, one of the largest high, flat interstream areas in the region. The table also shows that there is a gradual decrease in altitude of the deposits from south to north, which happens to be the direction of flow of Tennessee River. The decrease in altitude of the deposits, however, is very much greater than the fall of the river and is not directly related to the local drainage, except that the general level of the old peneplain, represented by the hills of the Highland Rim, descends slightly northward toward Cumberland River. The deposits in Lewis, Wayne, and Lawrence Counties are more commonly on the crests of the ridges than those in the counties farther north, but detailed studies when more topographic maps become available may indicate that some of the lower deposits of ore have been developed on lower erosional areas. The topographic relations of many of the lower deposits, however, indicate a downward migration of the limonite, and some deposits are even now being formed through the action of spring waters. Erosion has probably greatly reduced the size of the areas of iron ore that formerly occupied the high levels and is probably now carrying away more iron than is being deposited.

GEOLOGIC RELATIONS

The deposits of brown iron ore in the western Highland Rim of Tennessee overlie areas of nearly horizontal Mississippian rocks, chiefly cherty limestones, of which the Fort Payne, Warsaw, and St.

Louis formations have been recognized. Of these the St. Louis is the latest, or stratigraphically the highest. The ore deposits themselves are generally found in the upper part of a mantle, in places 100 feet thick, of cherty clay residual from the weathering of the calcareous parts of the limestone and in a few places in fragmentary deposits of sand and gravel of Cretaceous age overlying the residual clay. In northern Alabama, near Russellville, deposits of brown iron ore belonging to this general belt are found in clay residual from Mississippian limestone and in the overlying unconsolidated Cretaceous and Tertiary (?) deposits, in very close proximity to the surface of the limestone, but nowhere in this part of Tennessee was any ore noted less than about 50 feet above the underlying limestone. In some mine pits, as at the Red River mines, west of Lyles, and at the Nunnelly and Aetna mines, a light-colored clay termed "white horse" by the miners underlies the ore in places or forms pinnacles that extend upward into the reddish ore-bearing clay and thus form walls at the sides of many of the ore deposits. It might even happen that some of this "white-horse" clay, through the slumping down of a sharp pinnacle or through the falling of a mass of ore into a depression resulting from a cave or solution channel in the limestone below, has reached a position on top of some of the ore. Such a relation is not normal, however, for the "white horse" is residual from a portion of the Mississippian limestone and belongs below the iron ore. This clay may represent a general horizon in the limestone, but, if so, the fact can not at present be established. In places where the pinnacles of white clay are present the solid limestone may be less than 50 feet from the ore. In other districts where brown ore is mined, such as Russellville and Woodstock, Ala., a cut through a clay "horse" often reveals hard limestone within, but the writer has not observed this in the Tennessee area under discussion. Associated with the brown ore in the Red River and Napier mines and overlying the clay that is residual from the limestone is a reddish clay mottled with thin, wavy fragments or streaks of greenish-gray sandy clay. This mottled clay is associated with red loam and gravel and is believed by the writer to be of Tuscaloosa (Upper Cretaceous) age. In the other brown-ore districts mentioned above the corresponding clay of the Tuscaloosa carries mottlings similar to those of the Tennessee material. The important fact to be distinguished in connection with these clays is that when the "white horse" is encountered in mining it is useless to explore this material in search of further ore, for experience has shown, both here and elsewhere, that it marks the limit of ore-bearing material in that direction.

The clay that contains the deposits of ore has probably been derived through weathering of all three of the Mississippian formations mentioned above. In some places fossils characteristic of the St. Louis limestone, such as the coral *Lithostrotion*, are found in the residual chert; in others the residual material contains lumps and boulders of saccharoidal sandy rock characteristic of the Warsaw beds; elsewhere the predominant residual chert may contain fossil crinoids and brachiopods characteristic of the Fort Payne chert; but there are places where the associated clay appears to contain fossiliferous material from all three of the limestone formations, thus indicating that a very long period of weathering and a considerable thickness of rock have been involved in the production of this clay. The clay from the St. Louis limestone generally displays a deep-red color in surface exposures.

SUGGESTIONS AS TO ORIGIN

The occurrence of the brown iron ore in the residual clay in the western Highland Rim area as well as in other similar brown-ore fields of the South can not be easily or simply explained. Several modes of origin have been suggested by different writers. Some of the ideas advanced may possess elements of probability, and the true explanation of the origin of the ores may involve portions of several hypotheses. One hypothesis that has many adherents is that the iron oxide, now found in lumps, veins, and masses in the clay, was once disseminated through the limestone beds that have weathered to form the clay, the insoluble portions of the limestone, such as the chert and clay minerals, having remained together with the iron oxide which has been concentrated in this residual material. Iron is a very widely distributed element and is found in practically all rocks, and, although the total quantity present in these limestones was doubtless considerable and probably contributed to the iron oxide now found in the clay, the deposits can not reasonably be ascribed wholly to this source. Even if the quantity of iron oxide originally present had been adequate—which is open to question—much of the disseminated iron oxide, which is somewhat soluble, would have been carried away in solution and in suspension during the long periods of weathering that were required to remove several hundred feet of limestone and would thus have been lost. It is necessary, therefore, to seek a larger source of supply of iron, and this, it is believed, may be found in the ferruginous sediments of Cretaceous and Tertiary age that formerly overlay this region but are now present east of Tennessee River only as isolated remnants. The ferruginous character of the sediments of the Coastal Plain in many places in the Southern States is well known, and the influence of such material upon the formation of iron-ore deposits is readily apparent at such localities as Woodstock[8] and Russellville,[9] Ala.; Shreveport, La.;[10] Atlanta, Tex.;[11] and Hickory Flat, Miss.,[12] and the deposits of the western Highland Rim area of Tennessee are probably no exception to this class.

The close association of iron ore, both limonite and iron carbonate, with glauconite in Tertiary sands and clays in northeastern Texas, described in Bulletin 620, points strongly to the possibility that glauconite was the mineral that originally contained the iron in those deposits. Glauconite, or greensand, is a hydrated silicate of potassium and iron. In a series of five analyses of glauconite given by Clarke[13] the percentage of iron (Fe) calculated from the contents of ferric and ferrous iron ranges from 16 to 19.7 per cent. Glauconite is widely distributed in several formations of the Coastal Plain, and in western Tennessee and northeastern Mississippi the Ripley and Selma beds, of Upper Cretaceous age, contain more or less of the mineral. It is believed that the glauconite in these and other associated formations is a possible and adequate source of the iron in the iron carbonate and limonite associated with the bauxite found in northeastern Mississippi.[14] There is evidence that these glauconite-bearing formations formerly extended farther east into Tennessee and Alabama and overlay the Mississippian rocks in the area that is now the western Highland Rim, and so it seems entirely possible that during the leaching and weathering of the glauconite-bearing beds surface waters gathered and distributed large quantities of iron salts in solution until finally they became concentrated in the clay and chert that are residual from the Mississippian limestones. This process was not direct or simple, however, for it doubtless was closely related to the physiographic history of the region, and the iron oxides may have passed through several stages of concentration before arriving at their present condition and position.

In his discussion of the iron-ore deposits of the Waynesboro quadrangle Miser[15] recognizes the importance of the formations of the Coastal Plain as contributors of iron minerals. He states that the

[8] Burchard, E. F., Iron ores in the Brookwood quadrangle, Ala.: U. S. Geol. Survey Bull. 260, pp. 321–334, 1905; Geology and development of the brown ores of the Woodstock and Champion districts, Ala.: U. S. Geol. Survey Bull. 400, pp. 150–169, 1910.

[9] Burchard, E. F., Brown iron ores of the Russellville district, Ala.: U. S. Geol. Survey Bull. 315, pp. 152–160, 1907.

[10] Burchard, E. F., Iron-bearing deposits in Bossier, Caddo, and Webster Parishes, La.: U. S. Geol. Survey Bull. 620, pp. 129–150, 1915.

[11] Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee Counties, Tex.: U. S. Geol. Survey Bull. 620, pp. 69–109, 1915.

[12] Lowe, E. N., Iron ores of Mississippi: Mississippi Geol. Survey Bull. 10, 1913.

[13] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 522, 1924.

[14] Burchard, E. F., Bauxite in northeastern Mississippi: U. S. Geol. Survey Bull. 750, p. 115, 1925.

[15] Miser, H. D., Mineral resources of the Waynesboro quadrangle, Tenn.: Tennessee Geol. Survey Bull. 26, pp. 61–62, 1921.

source of the iron is not known but that it is believed to have been either the St. Louis limestone or rocks of Upper Cretaceous age, or both. He observed few or no iron minerals in the exposed portions of the St. Louis limestone, and he cites the fact that at numerous places iron oxide forms a cementing material in Tuscaloosa gravel, producing hard conglomerate. The occurrence of this iron cement in the gravel indicates that the gravel or the Eutaw or higher beds are the source of this iron and also that they may have contributed to the brown iron ores of the Waynesboro quadrangle.

Miser[16] has noted the relationship of many of the brown-ore deposits in the Waynesboro quadrangle with the Highland Rim peneplain, stating:

> In a region of low relief such as that on a peneplain rock decay and solution would probably be more active than rock disintegration and removal, whereas in a region with considerable relief rock decay and solution would be less important in comparison with rock disintegration and removal. It therefore appears probable that the deep weathering of the St. Louis limestone to form as much as 100 feet of residual materials took place in large part during the existence of the Highland Rim peneplain, though it has doubtless continued to some extent down to the present.

It appears very probable that much ferruginous material derived from glauconite-bearing beds was concentrated in swampy places on this peneplain and that the present deposits within the residual clay and chert have come from a further downward migration of the iron-bearing solutions into the residual material. Possibly the downward movement was halted by more impervious limestone beds which have subsequently, through weathering agencies, been reduced to still lower levels, leaving a considerable thickness of comparatively impervious clay or "white horse" between the ore and the present limestone surface. Also it would seem that in all of the western Highland Rim area, including the Waynesboro quadrangle, the solubility of the limestone along joint openings and the porosity of the residual chert and clay of the Mississippian formations have afforded easy access for surface waters bearing iron in solution, and these waters in percolating downward have deposited iron minerals in places wherever conditions favored precipitation. Masses of ore thus formed in cavities have been left as residual deposits in clay when the surrounding limestone has weathered away.

A detail in deposition that is more pronounced in the brown iron ore of the western Highland Rim than in other similar ores of the South is the large extent to which chemical reaction has taken place between the residual chert and the hydrous iron oxide. Replacement of chert, sand, and clay by iron oxide has been so extensive as

[16] Miser, H. D., op. cit., pp. 57–59; unpublished paper read at meeting of the Society of Economic Geologists, New York City, May 18–19, 1923.

to indicate a thorough saturation of the residual materials with iron-bearing solutions, which further strengthens the view that the iron has been concentrated from an external and more abundant source that lay above rather than segregated within the beds themselves.

The broader features of geologic structure have probably influenced the localization of the deposits of brown iron ore. Synclinal troughs might be expected to direct the flow of iron-bearing waters, but, on the other hand, surface valleys developed on anticlinal axes may have been even more influential. The areal geology of the western Highland Rim of Tennessee, except in the Waynesboro and Columbia quadrangles, has not been worked out in sufficient detail to show more than the broader features of the structure of the Mississippian rocks, and a study of the distribution of the brown-ore deposits as plotted on the geologic map of the State printed in 1923 on the 1:500,000 scale affords only vague suggestions of gentle synclinal or monoclinal structure in the vicinity of the ore deposits.

A correct interpretation of the geologic relations of the deposits of brown iron ore is of more importance than a theory as to their origin in making explorations for ore. The geologic relations can be ascertained fairly definitely, but the questions of origin will always involve more or less uncertainty and grounds for disagreement.

TYPICAL DEPOSITS

STEWART COUNTY

The deposits of brown iron ore in Stewart County lie mainly near Cumberland and Tennessee Rivers. None are being worked at present, but up to a very few years ago some of the deposits have supplied ore for the use of local blast furnaces. The deposits appear to be grouped in certain areas, one of which is in the northwestern part of the county, where a few deposits yielded ore that was used in the Great Western furnace at the village of Model. Another furnace existed at Tharpe in the early days and derived its ore from deposits in the vicinity. Along Tennessee River deposits have been noted near the mouths of Byrds and Baileys Creeks, also south of Fort Henry, and in the vicinity of Stribling, on Leatherwood Creek about 1½ miles from Tennessee River. Two blast furnaces utilized the ore in this vicinity, the La Grange furnace at Stribling and the Clark furnace 1½ miles farther up Leatherwood Creek. Near the south boundary of the county, also on Leatherwood Creek, about 6 miles east of Stribling, is the site of the reported Eclipse furnace, which was said to have derived its ore from near-by ore banks. Between Stribling and Cumberland River are several deposits of iron ore that were mined for the old Peytonia furnace, which was situated on the headwaters of Bear Creek about 6½ miles west of Dover. In the vicinity of Bear Spring a furnace was operated for many years. The latest blast furnace to be operated in this county was the Dover furnace, at Carlisle, where, it is reported, iron was made during and even after the World War. Another group of deposits lies north of Cumberland River near the site of the Rough and Ready furnace, about 3 miles south-southeast of Indian Mound. The Stribling furnace was once connected with the Louisville & Nashville Railroad at Danville by a branch line 6 or 7 miles long, but that line has long since been abandoned. The furnaces at Carlisle and Bear Spring were likewise on a branch railroad which connected with the Louisville & Nashville at Tennessee Ridge, but this branch has been taken up since the World War. Other charcoal furnaces, reported to have been operated in early days but not located in the course of this survey, are the Randolph furnace, on Lick Creek, south of Dover, and the Bellwood furnace, the location of which could not be ascertained. Besides these blast furnaces there were numerous forges, and an establishment known as the Cumberland rolling mills is reported to have been situated near Dover. In Houston County, to the south of Stewart County, were the Brunson furnace and the Wilcox furnace. In addition to the ore that was consumed locally some ore from the vicinity of Tennessee River was transported by water to furnaces near Paducah, Ky.

It seems probable that there is more ore in this county than is indicated by the scattered groups of deposits mentioned above. The only deposits that could be mined were those within wagon haul of the furnaces to which the ore was delivered, and therefore in areas more remote from the furnaces ore may very well exist that was not drawn upon in the early days of iron making.

DEPOSITS NEAR BEAR SPRING

The Bear Spring locality has been one of the largest iron producers in Stewart County. The old charcoal furnace (pl. 6, *A*), built of rock in 1873, still stands on the south side of the road west of the spring. When it was active it derived its ore supplies chiefly from deposits within a radius of 1¼ miles. The Bear Spring locality was at one time connected with the Louisville & Nashville Railroad by a branch line from Tennessee Ridge, Houston County. This branch has now been entirely removed.

The high portions of the ridges south of the Bear Spring furnace nearly all contain ore, and many large and small openings are still available for inspection. One of these is the Grave Yard ore bank, at an altitude of about 550 feet. The ore here lies from 10 to 20 feet below the surface and may have a thickness of 25 to 30 feet. The ore is generally a limonite of fair grade, mostly of the chert-replacement type, but in places it contains a good deal of cherty conglomerate. There is considerable wash ore in the screened dumps all around the Grave Yard workings, and some ore shows in the sides of the pits. Talus, however, covers much of these walls, so that the ore can not well be seen. There are masses of lean chert-replacement ore and ferruginous material of the clay-replacement type which is of too low grade for the blast furnace but contains here and there very rich streaks of limonite. Systematic prospecting by drill is reported to have been done on the areas between the pits and to have shown ore corresponding to that already mined. It is reported locally that the early mining was very carelessly done and that for every ton of ore recovered 2 or 3 tons was buried or rendered inaccessible by the reckless and greedy methods of mining whereby the miners, working on a tonnage basis, sought only the most easily obtained and best ore. The ore from these openings was hauled by wagons to a small washer near the Bear Spring furnace. Some was mined by steam shovel, but much was won by hand. There is probably a large quantity of ore still in the ground here, and much might be recovered by rewashing the old dumps. At the time of visit water stood in the bottoms of some of the old pits, probably owing to heavy rains that had fallen shortly before. Most of these pits could be drained easily in case mining should be resumed.

A little more than half a mile north of Bear Spring, on a ridge between Bear Spring and Cumberland River, are three or four mine pits, known as the Skunk Hollow workings, where ore lies under a cover of 25 to 30 feet of chert débris, gravel, and clay, at an altitude of 450 to 475 feet. The ore found here is reported to extend below the bottoms of the pits but apparently is rather cherty. A similar deposit of ore was formerly worked at the head of a hollow on the opposite side of the road and a little west of the blast furnace. This was known as the Hotel ore bank, and the ore was delivered by wagon to the small washer near the furnace. A large washer was erected several years ago near the head of Skunk Hollow and was supplied with water piped from Bear Spring, about 1 mile distant. The washer consisted of two 25-foot logs, rotary rougher screen, picking belt, ore bin, ore box and elevator, rotary screen, 4-celled jig, elevator for ore and waste chert, and loading bin over the railroad siding. In 1923 this washer had not been operated for two or three years, possibly longer, but was in fair shape, and the principal machinery could be removed to another site and used again. If not enough ore should be found in the Skunk Hollow banks to supply a washer, ore from the other mines in the locality might be washed here and shipped to Hematite by barges on Cumberland River. The washer is about three-quarters of a mile from the main Bear Spring road, and a railroad spur ran to it over which washed ore was shipped to the blast furnace at Clarksville. Some ore carrying 48 per cent of iron was shipped in 1920. The rails have since been removed from this spur.

About 1¼ miles south of the Bear Spring furnace is the Potato Patch Hollow mine, owned by persons in Clarksville. The old mine pits and prospects are of irregular branching plan and are situated near the tops of the ridges and spurs at altitudes of 530 to 570 feet, about 150 feet above the level of Bear Spring. The main pit extends about 500 feet in a direction N. 30° E. and is 60 to 80 feet wide and 20 to 30 feet deep. Mining is said to have begun here before the Civil War, and there were extensive operations with steam shovel and washer between 1900 and 1903, followed by "wagon mining" on a small scale about 1912–13. Before the railroad was removed ore was shipped from this mine to the blast furnace at Clarksville and to the Bear Spring furnace. The overburden consists of pockets of clay and chert débris, from a few feet to 10 or 15 feet thick. A fine-grained siliceous limestone resembling "cotton rock" crops out about 50 feet lower than the bottom of the workings. The ore is limonite of fair grade, mostly of the chert-replacement type, but contains considerable angular chert in a matrix of limonite resembling a conglomerate. The impurities are chert, silica, and ocherous clay. Conglomeratic and cherty ferruginous material crop out in places. From the evidence afforded by prospects and by the walls of the old mine openings considerable ore still remains in the areas between the old pits, and there is probably some ore below the bottoms of the pits and some that might be recovered from the old dumps. Conditions are favorable for mining except that water for washing must be piped from South Cross Creek, about three-quarters of a mile distant. The hardwood timber suitable for making charcoal has practically all been exhausted from this vicinity, so that none of the charcoal furnaces may be expected to resume operations, but it might be feasible to ship ore from this vicinity by barge up Cumberland River to the railroad at Hematite. Navigation on Cumberland River is aided by Lock D, below Dover.

DEPOSITS NEAR STRIBLING

Pig iron was produced from local ores more than 30 years ago at the La Grange furnace, at Stribling, on Leatherwood Creek about 1½ miles from Tennessee River, and at the Clark furnace, on the creek about 1½ miles above Stribling. Neither of these furnaces is now standing. When active the La Grange furnace was connected by a spur with the Louisville & Nashville Railroad at Danville, on Tennessee River 6 miles to the south. This branch line has long since been removed.

In May, 1923, the property was reported to be owned by the La Grange Plantation Co. (Inc.). The plantation is said to comprise 27,000 acres of land mostly timbered, but 350 acres, more or less, is bottom land in the valleys of Tennessee River and Leatherwood Creek which is farmed, soy-bean hay being the principal crop. Five or six large mine pits and many smaller ones were noted. Some of these pits are in the low foothills of chert that border the

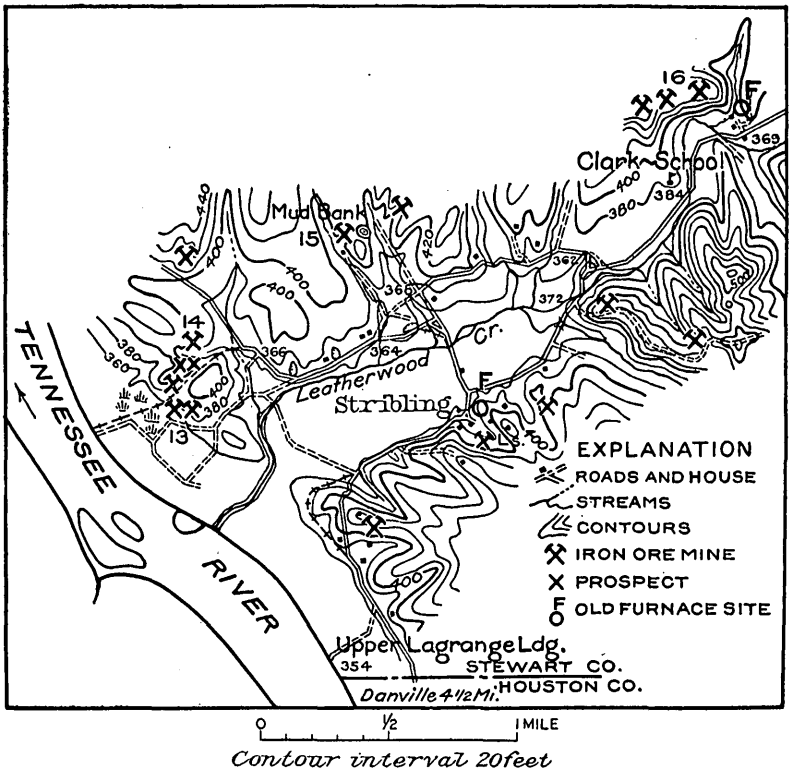


FIGURE 3.—Map of Stribling, Tenn., and vicinity, showing location of iron-ore mines and former blast furnaces. By C. C. Anderson, Tennessee State Geological Survey

valleys, and some of the pits are at the base of the foothills, practically at flood-plain level. Considerable mining was done in this area, as is shown by the size of the pits, some of which are as much as 400 feet long, 200 feet wide, and 40 feet deep. The local topography and the location of these pits and furnaces are shown in Figure 3.

The Swamp Bank mines (No. 13, fig. 3) consist of three or four large old pits, two of which were 350 to 400 feet long and 25 to 40 feet deep, excavated in a worn-down spur of the upland west of Leatherwood Creek and less than half a mile from its mouth. The altitude of these pits ranges from 365 to about 390 feet. At the time of visit water stood in the lowest pits, which were poorly drained, inasmuch as they border a swamp on the flood plain of Tennessee River. The rocks associated with the ore are clay and disintegrated chert, some of which is white and passes over into the "white horse" clay so common in certain other brown-ore deposits in this region. No limestone could be found closely associated with the ore, although some was quarried for flux at about the same level in a pit a short distance south of the La Grange furnace. The ore in the Swamp Bank is not generally of high grade, as sandy crusts are common, but some good needle ore was noted. As these deposits are among the lowest topographically of the brown ores of this region the question naturally arises whether they were formed in this situation at the same time and in the same manner as the deposits which are on higher levels. There seems to be some evidence that waters carrying iron in solution descending from higher levels have formed mammillary sheets of ore, generally sandy but rich in spots. In places a mass of horizontally bedded limonite 6 to 10 feet thick has been exposed by open cuts (pl. 6, *B*). In one cut this mass of ore contains an interbedded layer of chert 6 to 8 inches thick, and the relations suggest that the limonite has been deposited here through the replacement of chert. Ferruginous conglomerate is also present, and pockets of angular to subangular creek gravel show in the banks and talus. Although many masses of ore are exposed in the pit banks, it is probable that the greater part of the ore reserve lies below water level, where pumping would be necessary in mining. Part of the La Grange property in this vicinity was prospected in 1916 or 1917 by a small drill, holes having been put down at nearly every corner of 30-foot squares. It is reported that most of these holes showed iron ore, presumably penetrating the horizontal ore ledge mentioned above, which appears generally to lie 4 to 10 feet below the surface covering of clay, soil, and chert débris. The drill holes were 16 to 24 feet deep.

North of the Swamp Bank pits is an old "tunnel" mine (No. 14, fig. 3) on the point of a ridge at an altitude of about 420 feet. This opening is about 20 by 25 feet and 6 to 8 feet high and was excavated by hand. The deposit appears to cover about an acre, with a thickness of 6 to 15 feet. There is a light covering of soil, chert, and clay. The ore is very bouldery and contains much chert and clay. As in most of the other deposits some high-grade needle and botryoidal limonite is present here. The ore appears to be mostly of the chert-replacement type, and the proportion of ore to waste appears to be favorable. Probably if the other mines were reopened in the Stribling locality the deposits in the vicinity of this tunnel would contribute their share of ore, but they are not considered sufficiently large to open independently.

The Mud Bank mines are also among the large openings in this vicinity. They are in a branching hollow northeast of Leatherwood Creek, about three-quarters of a mile northeast of the site of the old La Grange furnace, at an altitude of about 400 feet. A few pits were dug 20 to 30 feet above the floor of the hollow on the chert hillsides, but the deep pit of the mine is not so far above the floor of the hollow. The large pit is about 175 by 350 feet, with banks rising to a height of 35 feet above the water, which occupied a good part of the area of the pit when visited. Ore is exposed in the west end of the pit. This ore is good in spots but is generally sandy and appears to be of the sand and chert-replacement type. Very little gravel of the Cretaceous deposits which are ordinarily found on the high hills in the vicinity was noted in this locality.

The mines north of Clark School supplied the Clark furnace with ore. The ore bank is on a spur of the ridge that has an altitude of about 500 feet, and the pits are 25 to 30 feet deep. The overburden comprises reddish sandy clay and disintegrated chert. The old ore dumps appear to consist of waste material from which practically all the ore had been separated. The ore is said to lie under considerable overburden, and as slumping of the sides of the pit would effectually conceal any possible showings, very little ore can be seen. The Clark furnace is reported to have been shut down in 1891 or 1892, and there has been no mining since that time.

The ore reserve in the vicinity of Stribling is indefinite but is probably of economic importance. Mining would be handicapped in places by heavy overburden and generally by water in the lower deposits. Plenty of water would therefore be available for washing the ore.

The following analyses reported to represent "Stribling" ore were obtained from undated records of the Bon Air Coal & Iron Corporation laboratory at Wrigley Furnace. If this ore came from this locality in carload lots it must have been transported before the railroad from Danville to Stribling was removed, for the expense of hauling to the railroad material so high in silica and so low in iron would hardly have been justified. Each of the analyses was stated to represent one carload.

Analyses of brown iron ore from Stribling (?) mine

Fe	Insoluble	P	Mn
40.04	35.78	0.43	----------
40.21	33.49	.43	----------
33.70	37.37	.43	----------
33.79	39.90	.44	0.23

MONTGOMERY COUNTY

The iron-ore deposits in Montgomery County are confined to the southern third or half of the county, and most of them are south of Cumberland River. The sites of eleven old blast furnaces were noted during the inspection of the deposits, and these do not represent all that have been in existence. Beginning at the northwest the Blooming Grove furnace site is about 2 miles southeast of Oakwood, or 10½ miles southwest of Clarksville. The Poplar Spring furnace site is about 5 miles south of Oakwood. These two sites are the only ones north of Cumberland River. South of the river the Steele furnace stood on Yellow Creek about 3½ miles southeast of Sailors Rest station on the Louisville & Nashville Railroad, and the site of the Sailors Rest furnace was on Yellow Creek about 6 miles southeast of the station. Another old furnace known as the Montgomery was about 2 miles south-southeast of Palmyra. The O. K. Furnace was on the East Fork of Yellow Creek about 1¾ miles northwest of Marion station on the Louisville & Nashville Railroad. The Vernon furnace still stands about 1½ miles south-southeast of Hackberry station, beside the Louisville & Nashville Railroad tracks. One mile northeast of Lone Oak station on the same railroad is the site of the Washington furnace, and 1½ miles southeast of Louise station is the site of the Louise furnace. The Lafayette furnace was on the north fork of Barton Creek about 1¾ miles northeast of McAllisters Cross Roads, and the Tennessee (Watson?) furnace was about 2 miles east of McAllisters Cross Roads on the middle fork of Barton Creek. Other furnaces reported are the Robinson furnace, near Palmyra, and the Jones furnace, on Budds Creek, somewhere near the Vernon furnace.

The iron-ore deposits in this county are in scattered localities tributary to the furnaces above mentioned. None of them were being worked at the time of visit except the deposits near Louise.

DEPOSITS NEAR LOUISE

Seven-tenths of a mile southeast of Louise station on the Louisville & Nashville Railroad are brown-ore deposits on property of the Red River Iron Co., of Clarksville. The ore was being mined under lease by the Warner Iron Co. at the time of visit in May, 1923, and was shipped to Cumberland Furnace. These are the Louise mines, where mining has been carried on at intervals since a time before the Civil War. The ore occurs on the uplands and borders of hollows that open into the drainage basins of the forks of Barton Creek. The altitude of the ore deposits seems to range from 565 to 675 feet, or from 75 to 185 feet above the neighboring drainage level. The deposits show depths of 30 to 50 feet and are reported to extend over more than 200 acres. The overburden is soil, gravel, clay, and chert débris, 5 to 20 feet thick; the chert débris lies mainly in pockets. Limestone is exposed in the north fork of Barton Creek and north of Louise station at an altitude of 490 to 510 feet. The ore then worked in the main pit, about a quarter of a mile northwest of the washer, occurs in a mass of tabular form 20 to 30 feet thick. It consists of light to dark brown and nearly black limonite in crusts within clay. When broken down by blasting and pick and shovel the ore is very fine grained but is said to yield a product of good quality when washed. The light-brown crusts of limonite and the light-brown claylike masses, which readily break apart, are not acceptable ore, so that it is necessary to confine shipments to the darker material. In the ore there is also considerable pebble material, mostly of chert but including some quartz. The active mine pit is connected with the washer by a mule tramway, and the washer discharges into railroad cars. The washer is in a hollow about 3,500 feet from Louise station and is connected with the railroad by a standard-gage track. Analyses of the ore shipped from the Louise mines in 1923 showed 38 to 44 per cent of iron and 23 to 32 per cent of insoluble matter. The output from these workings was said to be limited by a scarcity of labor. It is reported that much good ore was covered in the old workings by careless mining in earlier days.

An estimate of the cost per ton of the ore at Cumberland Furnace in 1923 is as follows:

Royalty to owners	$0.35
Mining and washing	2.00
Rail haul	.60
	2.95

The old pit 500 feet up the hollow south of the washer is an irregular-shaped opening 30 feet or more deep, 70 to 80 feet long, and 40 to 50 feet wide, which shows walls containing much gravel and clay with lean ferruginous masses of chert and conglomerate. Talus on the slopes obscures the base of the walls, and there is very little workable ore in sight above this talus. This pit has evidently not been worked for a long time, and the tramway that passes the pit is no longer in use. Some openings high on the hill to the southeast of this pit show evidence of later working. A large "horse" of gravel and clay has been left in the old pit. The ridge south of the washer contains six or seven large pits ranging from 10 to 40 feet in depth and covering a total area of 2½ to 3 acres, and there are also several prospect pits on top of the ridge. The ore deposits ranged from drainage level (altitude about 540 feet at the washer) to 80 to 100 feet higher. This ridge extends eastward to and beyond the Taber ore banks and, according to reliable local report, is spotted with ore in many places, but the depth and area of the deposits are very irregular and uncertain. The overburden consists mainly of chert gravel and soil ranging from 1 to 20 feet in thickness. The gravel contains many large pebbles of chert, 2 or 3 inches in maximum diameter, and also many large pebbles of quartz and quartzite. The ore is associated with chert gravel, "horses" of light-colored clay, and boulders of iron-cemented conglomerate. The ore seems to have been chiefly light brown in color, of the clay-replacement and conglomerate-cement types. Some scattered pieces of rich needle ore and dark limonite were noted, but not much lump ore of this kind is present. Little ore remains in the dumps, and much of the workable ore seems to have been removed in mining, so that what is left consists of widely scattered bits of good ore or of conglomeratic material.

DICKSON COUNTY

The brown iron ores in Dickson County are grouped mainly in six localities—near Slayden; near Cumberland Furnace; near Sylvia and Hortense, northwest of Dickson; southwest of Dickson, near the site of the old Worley furnace; northeast of Dickson, in the old Laurel furnace locality; and southeast of Dickson, near Iron Hill. A few scattered deposits were noted in the vicinity of Charlotte, near the Houston-Dickson county line west of Vanleer, south of Tennessee City, and near Herbertson School. Other blast furnaces reported to have been in Dickson County are the Carroll furnace, on Bartons Creek, about 4 miles south of Cumberland Furnace, the Piney furnace, on the headwaters of Piney River, and the Bell furnace, 3 miles south of Charlotte, besides several forges, among them the Steam forge, on Cumberland River near Betseytown.

DEPOSITS NEAR CUMBERLAND FURNACE

The deposits of limonite directly tributary to the Cumberland furnace occupy a triangular area extending about 4 miles west and southwest of the furnace and having a maximum north-south width of about 2½ miles. The distribution of the deposits in the immediate vicinity of the furnace is shown in Figure 4. In general the ore lies near the crests of the ridges and part way down their slopes. There were several active mining operations here in 1923, and the salient features of several of these deposits will be described.

From half to three-quarters of a mile northwest of Cumberland Furnace are extensive old mine pits belonging to Clarksville persons. These pits are on top of the ridge at an altitude of about 745 feet, or about 250 feet above Furnace Creek at Cumberland Furnace. The ore deposit follows the crest of the ridge, is irregular in width, and is cut through in places by gaps or notches in the ridge. The depth of the ore may be greater than is indicated by the pits, but prospecting would be necessary to prove this. The overburden is made up of soil, clay, and broken chert 2 to 5 feet thick above masses of cherty limonite interspersed with more chert and clay. Limestone is exposed in the neighboring valleys 100 to 120 feet lower than the ore horizon. The limestone shows slight

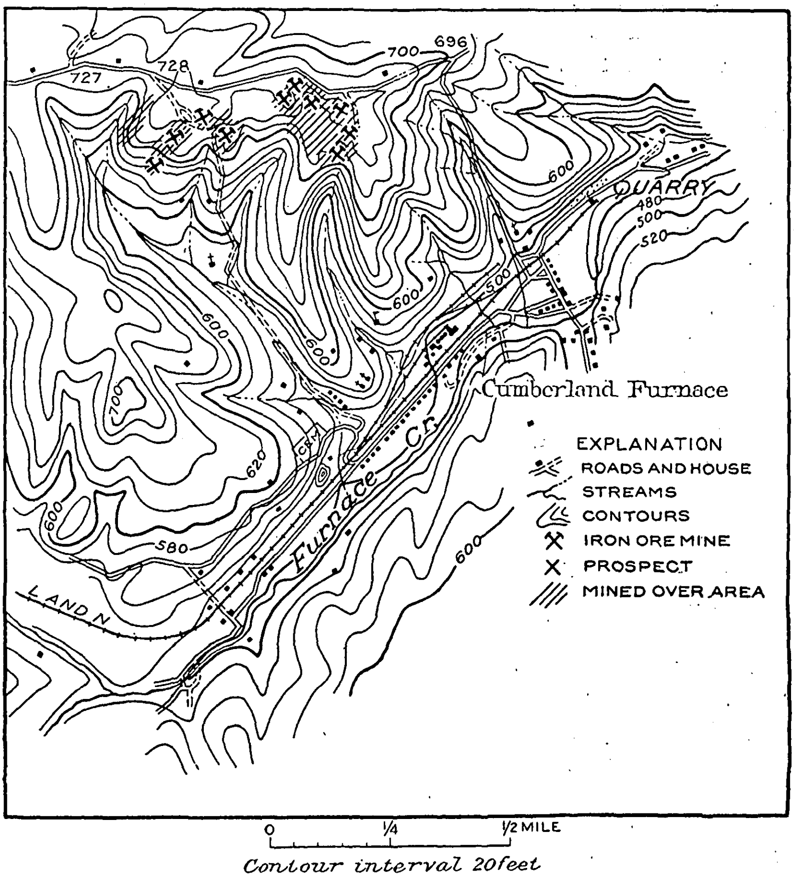


FIGURE 4.—Map of the vicinity of Cumberland Furnace, Tenn., showing relation of ore-bearing land to the topography and to the blast furnace. By C. C. Anderson, Tennessee State Geological Survey

local dips, 3° N. 70° W. having been noted in one place. The ore here is of several types. Some is laminated nearly pure limonite, some is cherty, some is soft and ocherous, and some is spongy, containing much clay and decomposed chert. In the old pit masses of " white horse " clay disintegrated from white chert occur. These pits are many years old and are reported to have been worked entirely by hand. When they were visited mining was being carried on in a small way by hand methods in which the ore is screened and forked and the product hauled in wagons to the furnace. In May, 1923, ore of this sort brought $2.25 a ton at the furnace, out of which a haulage charge of 75 cents a ton was paid by the miner. For about half a mile west of this locality erosion has removed the ore-bearing ground, as may be observed from the ridge road that borders the abrupt southern slope. According to miners who have worked in this locality for 30 or 40 years, ore is considered to have extended downward 30 to 35 feet below the principal level, but it does not extend down to the limestone, which is invariably overlain by hard clay and sand. The possible reserve of ore in this immediate locality is uncertain but not great. The locality is convenient to the furnace, the haul is downhill, and the general conditions warrant the conjecture that if an easily movable steam shovel could be used here it might be possible to get more ore by working the deposits on a larger scale.

The map (fig. 4) shows the topographic relations of these ore deposits, also those of the industrial settlement known as Cumberland Furnace. The limestone quarry from which fluxing stone is obtained is on the north side of Furnace Creek about three-eighths of a mile northeast of the blast furnace.

About 1¾ miles west-northwest of Cumberland Furnace, on land owned by Clarksville people, are a number of old pits similar to those just described. They were dug around the heads of hollows opening to the southeast and on the margin of a spur of the ridge. Several acres of old workings here are now overgrown with trees as much as 8 inches in diameter. The altitude of the ridge along the road is 720 to 740 feet, and the drainage goes to the southeast into Dry Hollow Creek, a branch of Furnace Creek. The plan of the deposit is irregular and branching, following the axis and southern spurs of the ridge, and the depth of the ore may be 30 to 50 feet, or possibly more, but there are barren spots where no ore has been found. The character of the ore is so similar to that of the deposit described above that no further description is necessary.

From a quarter to half a mile southeast of the last-mentioned workings and 1½ to 1¾ miles west of Cumberland Furnace, a quarter of a mile north of the Louisville & Nashville Railroad, are several old mine pits long since abandoned. These pits are on the top and south borders of ridges directly north of Dry Hollow Creek, at altitudes of 700 to 735 feet, or about 150 feet above the creek. The principal old workings extend about a quarter of a mile east and west and 750 feet north and south and have a depth of 20 to 35 feet. Ore is also shown in prospects toward the northwest and on the east side of a hollow across from the old mines. The overburden consists of soil, chert, and gravel a few inches to 3 or 4 feet thick, and unconsolidated chert, clay, and gravel are associated with the ore. The ore is conglomeratic and mixed with much clay, chert, and gravel, some of which consists of quartz. The ore does not appear to have been very rich at this place. Some large masses of cherty, sandy ore are exposed in the sides of the pits. A noticeable quantity of red hydrous oxide of iron is scattered about. If washed, it would probably require 4 to 5 cubic yards and possibly more of this ore-bearing dirt to yield 1 ton of commercial concentrates. Some good ore is present, but the average would be of low grade. Little can be said regarding the definite reserve of ore still available at this locality, but it is believed that prospecting should be done in order to ascertain whether ore may not occur here in quantities that would pay to work at greater depths. In and around the hollows that open into Dry Hollow Creek in this vicinity there is considerable float of cherty limonite that has been washed out from its inclosing clay by erosion, and this may be a sign that further deposits may be expected.

About a mile west of the locality last described, or 2½ to 3 miles west of Cumberland Furnace, are still more mine pits on the crest and south border of the ridge north of Dry Hollow Creek, at an altitude of 730 to 750 feet, or about 170 feet above the creek. The old workings extend from east to west along the ridge and are also on both sides of a large branch hollow opening into Dry Hollow Creek. The depth of the ore-bearing material exposed by the pits is about 25 feet. The overburden ranges from 1 foot to 10 feet or more in places where pockets of barren chert extend down into the ore-bearing ground. Chert, clay, and a little gravel, some of which consists of quartz, are mixed with the ore. The ore consists of limonite cementing masses of chert and occurring as isolated fragments in clay, and there is some that is conglomeratic. The proportion of ore in sight seems small, not more than 1 part in 10. Some of the ore is sandy, as if it represented a partial replacement of sandy layers of Warsaw (?) chert. It seems possible that there may be a little more ore below the present levels. Mining conditions are favorable here, and at the mouth of the hollow, half a mile to 1 mile south of the openings, is the site of an old ore washer formerly operated by the Red River Iron Co. Some ore was being obtained at the time of visit from two or three places in this locality, on the east side of the hollow, by hand methods of mining, hand cobbing, and wagon hauling to the railroad, over which it was shipped to Cumberland Furnace. The ore as hand cobbed is of higher grade than the average washer ore, and the operators will gladly buy it at market prices if the furnace is in operation. The mines are therefore likely to be operated in a small way so long as men can make wages at mining of this kind. Miners report that there is too much barren ground and too much "knot" ore or masses of chert containing but little limonite to permit mining by steam shovel in this immediate vicinity.

Three miles southwest of Cumberland Furnace and about one-third of a mile south of Dry Hollow Creek is the Stokes ore bank, operated in 1923 by the Warner Iron Co. to help supply the Cumberland furnace. These workings are situated on the top of the hill west of a branch flowing north into Dry Hollow Creek. Considerable mining and prospecting by pits of various sizes has been done all around the hill. The base of the workings is about 50 feet above the level of the branch, and the hilltops are about 60 feet higher, or at an altitude of about 750 feet. The ore deposit as opened by the pits is roughly circular and about 1,200 feet in diameter, and the ore appears to occupy a zone 40 to 50 feet thick as opened, but it may go deeper. The overburden is variable in thickness. In some places ore masses come to the surface, but in others there is much clay and disintegrated chert above the ore. Gray crystalline fossiliferous limestone crops out in the railroad cut near the washer about 40 to 50 feet lower than the ore workings. The surface of the limestone is overlain by red clay, but no ore is present in this clay immediately above the limestone.

The ore is composed principally of cherty limonite surrounded by chert, clay, and gravel. The grade of the ore appears generally to be fair, but a large quantity of dirt and waste must be moved in order to obtain the ore. Here and there a cherty or conglomeratic mass crops out, but most of these masses lie a few feet below the surface and continue downward 5 to 8 feet or more. The situation seems favorable for mining, washing, and transportation. The washer has been built on the east slope of the hill, and water is brought to a tank in a 4-inch pipe from Dry Hollow Creek across the hill toward the west. The settling pond is in the hollow on the east side of the railroad spur. Mining was done by means of blasting, and the ore was loaded by hand on mule tramcars, which carried it to the grizzly. At the time of visit, during a period of considerable rainfall, it appeared as if much waste material was being mined. necessitating throwing a great deal of chert from the picking belt; and also much fine ore was being lost because no jigs were in use. The mine is connected with the Louisville & Nashville Railroad in Dry Hollow by a spur that extends southward to the Bell mine, described below.

On the south side of Bell Hollow 3½ miles southwest of Cumberland Furnace is the Bell mine, which in the spring of 1923 was operated by the Warner Iron Co. The deposit extends east-northeastward along the narrow ridge south of Bell Hollow Creek for nearly half a mile and is 500 to 1,200 feet wide and 40 feet or more deep. In places there is practically no overburden, and lumps of ore are exposed on the surface. The ore is associated with reddish and yellowish clay and considerable chert. Nearly flat-lying limestone is exposed in the bluff of the stream about 75 feet below the bottom of the mine. The ore is the characteristic material of this field, consisting of solid lumps of limonite and also of conglomeratic and cherty material cemented by limonite. The mine consists of large cuts in the top of the ridge, at an altitude of more than 750 feet, or 155 feet above Bell Hollow Creek (pl. 7, *A*). Ore is excavated by a steam shovel and carried by tramcars drawn by a dinkey engine to a grizzly at the top of the hill, from which it goes to a gravity washer at the top of a 100-foot bluff facing Bell Hollow. The material associated with the ore can not all be run through the washer. There are pockets of barren clay, for instance, which are excavated by steam shovel and dumped into hollows where mining will not be done. The average of the material being excavated at the time of visit was reported to be 3 to 4 yards of dirt to 1 ton of ore, although some of it appeared to the writer to be leaner. The ore seems by no means to be exhausted in this tract, as the present pit is adjoined on all sides except the south by land reported to be ore-bearing, and the beds at this horizon should extend along the ridge both east and west of this property, thus indicating a reserve of more ore than has been mined. It is also reported that there is ore below the level of the deepest cuts, but this was not demonstrated at the time of visit.

At 2.3 miles southwest of Cumberland Furnace are some old mines on the property of J. N. Stokes. They consist of several old pits at the border and end of the ridge, which trends in a south to southwest direction, and are said to have been worked about the time of the Civil War. The altitude of these pits is about 650 to 730 feet, and the richest parts of the ore-bearing material are about 50 feet above drainage level. The overburden consisted of broken chert and clay a few feet thick. There is no bedded rock in place, the associated material being residual chert and clay, but flat-lying limestone crops out in Bell Hollow Creek. This deposit seems to have been composed of irregular pockets of limonite, partly of spring-deposit origin, as it appears to occur at comparatively low levels topographically and is in places almost down to the level of the branch. The depth of the deposits in the highest faces of the pits was 60 to 70 feet. The ore was largely pebbly conglomerate cemented by limonite. There has been some replacement of chert and also of clay by limonite. The limonite is varied in composition. Masses of conglomerate and chert, only sparingly ferruginous, crop out at the sides of the pits, but there is little ore in sight. Some reddish hydrous oxides of iron are present. Conditions for mining, washing, and transportation of ore are favorable, as there is plenty of water available, and the railroad spur might be extended from the Bell mine, about 1½ miles distant.

Analyses of brown iron ore representative of the material obtained from the vicinity of Cumberland Furnace and the Louise mine, Montgomery County, being smelted into pig iron in 1923, according to laboratory records at Cumberland Furnace show the content of metallic iron to range from 34 to 49 per cent, the insoluble matter from 18 to 41 per cent, phosphorus from 0.22 to 0.62 per cent, and manganese from 0.20 to 0.42 per cent. The sulphur is reported to range between 0.002 and 0.006 per cent and is so low that it is seldom determined. The general tenor is a moderate percentage of iron with high insoluble material and indicates perhaps that it has not been feasible to wash the ore as thoroughly as might have been desired, especially when the insoluble material exceeded the content of metallic iron. Some ore from the Allens Creek district was also consumed at Cumberland Furnace. In the spring of 1923 the product was a high-silicon pig iron, carrying 4 to 8 per cent of silicon. Alabama by-product coke and local limestone were used as fuel and flux. For a short period in the fall of 1924 ferrophosphorus was made at this furnace from local brown iron ore and ground phosphate rock from Mount Pleasant, Tenn.

Fluxing material for the Cumberland furnace is obtained from a large quarry on the north side of Furnace Creek about half a mile northeast of the furnace. The rock exposed consists of about 30 feet of high-grade limestone in the lower part of the bluff, overlain by beds about 50 feet thick that contain more or less chert, above which is an overburden of rock débris, clay, and soil from a few feet to 8 or 10 feet thick. The best rock is crystalline gray high-calcium limestone with stylolitic markings parallel to the bedding planes. It is reported to carry about 97 per cent of calcium and magnesium (mostly calcium) carbonates. The base of the quarry is about at creek level, and the maximum height and length are respectively about 90 feet and 1,250 feet. The quarry floor has been worked back about 150 feet, and a large quantity of rock has been obtained here, as the quarry has probably been worked for more than 30 years. The rock is drilled and shot down and is broken where necessary by sledges, the chert is separated from the material from the upper portion, and the suitable fluxing stone is loaded by hand into mule carts, hauled to a skip, hoisted to a crusher where it is broken to about 2-inch size, and fed into a bin that empties into railroad cars bound for the furnace. The full capacity of the plant is said to be about 100 tons a day, but this is seldom reached. Analyses of the stone from this quarry as used for flux are reported as follows:

Analyses of limestone from Cumberland Furnace quarry

	1	2
Total fluxes ($CaCO_3$+$MgCO_3$)	91.36	95.86
Insoluble matter (mostly SiO_2)	6.92	2.67
Iron oxide and alumina (Fe_2O_3+Al_2O_3)	1.08	.88
Moisture (H_2O)	.64	----------

HICKMAN COUNTY

The deposits of brown iron ore in Hickman County fall into four groups—between Lyles and Pinewood, near Nunnelly, and near Dry Creek (Johnson mines) and Jerry Branch 5 to 7 miles south of Lyles, all in the north half of the county, or north of Duck River, and near Aetna, in the southern part of the county. The mines near Nunnelly rank among the largest ore producers of this region. In the western part of the county southwest of Coble large tracts of land show signs of brown ore, but no intensive prospecting or mining has been done there. The only active blast furnace is that of the Bon Air Chemical Co. at Wrigley, but furnaces were formerly situated on Sugar Creek, in the northwestern part of the county, at Goodrich, near the middle, and at Aetna, in the southern part.

DEPOSITS NEAR AETNA

West and north of Aetna, a village on the Nashville, Chattanooga & St. Louis Railway, in the southern part of the county, are extensive brown-ore mines of the Tennessee Products Corporation. The principal opening is half to three-quarters of a mile north of Aetna, on the high land west of the valley of Piney Branch, a tributary of Beaverdam Creek, at an altitude of 820 to 850 feet. The lower part of the ore deposit is about 110 feet above the valley level. The deposit as disclosed by the open cuts underlay 4 or 5 acres and was irregular in form, both in plan and in cross sections. A special map of the Aetna locality (fig. 5) shows the topographic position of the ore deposit, the outlines of the workings, and the relations of the mines, washer, and railroad. The overburden consists of thin soil, loam, red clay, and chert débris 1 to 10 feet thick, grading down into wash-ore dirt, and in places this ore dirt extends almost up to the surface. The materials associated with the ore are Tuscaloosa red loam and clay, light-colored sandy clay with ferruginous streaks which may also belong to the Tuscaloosa, and light-colored clay and chert débris residual from the Mississippian St. Louis limestone and possibly from the Warsaw beds. The residual chert associated with the ore has caved and warped to a great extent on account of solution of the limestone with which it was originally interbedded. Bedded limestone exposed in the creek valley 2 or 3 miles downstream from the mines lies nearly horizontal. Similar exposures also occur in a creek half a mile east of Aetna. The reddish clay loam is mixed with ore or overlies the brown ore, and the residual "white horse" underlies and borders the ore in the hollows and pinnacles. (Pl. 7, *B*.)

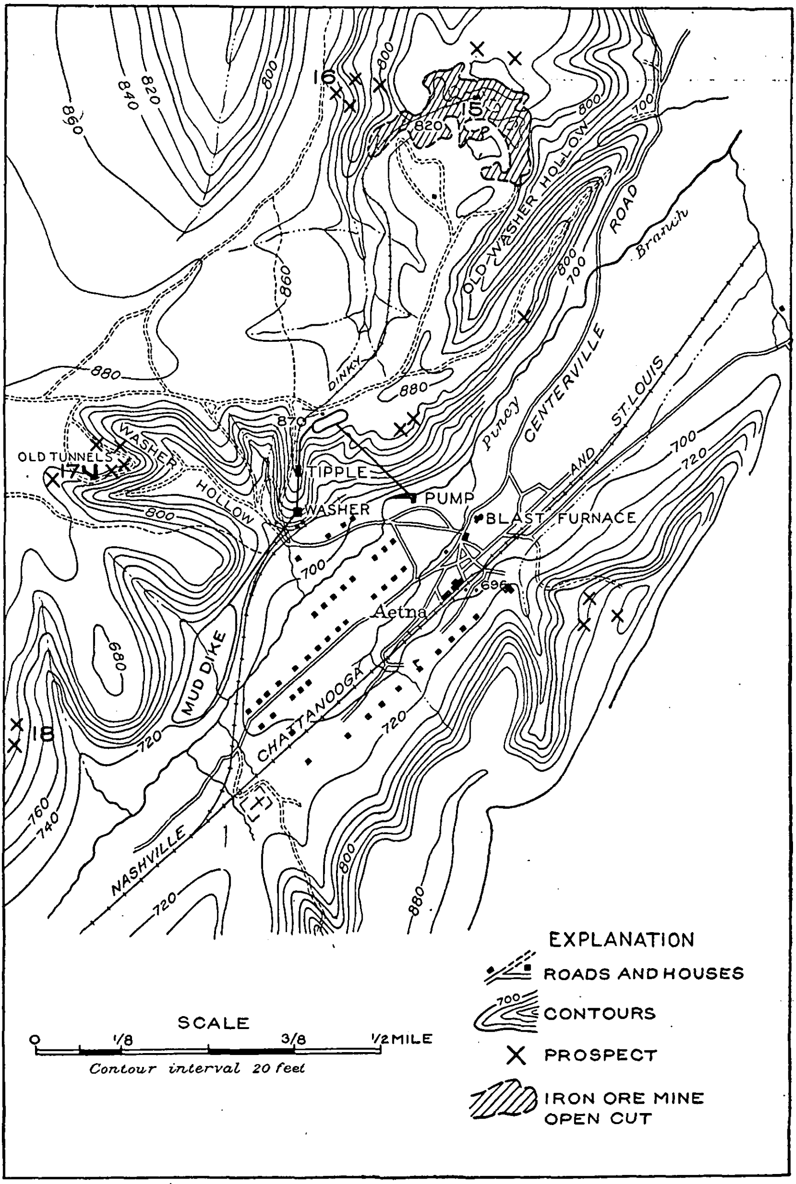


FIGURE 5.—Map of Aetna, Tenn., and vicinity showing relation of ore deposits to topography. By C. C. Anderson, Tennessee State Geological Survey

The ore is limonite of the usual types of this region. It appears to be fairly rich in some places and rather lean and cherty in others.

There are good illustrations of cherty conglomerate cemented with more or less limonite of the chert-replacement type of ore in which the chert fragments are angular and the mass simulates breccia; and in other places, chiefly near the upper limit of the deposit, the mass contains rounded pebbles of chert. At one place rounded chert nodules were found cemented by limonite which had partly replaced the chert. Some ore has the appearance of having been formed by the replacement of sandy clay. This material is of a lighter brown color than the better grade of limonite and contains more or less sand. In places it shows purplish-red colors.

The principal mine cut is connected with an ore washer on the hillside just northwest of Aetna by a tramway about 3,500 feet long. This open cut has been mined by steam shovel, but it was idle at the time of visit. The recovery in 1923 was about 1 ton of ore to 5 tons of dirt mined and washed. In places good massive ore is still exposed in the banks. The ore is apparently very pockety, and a more readily movable and more efficient steam shovel was needed in mining this deposit to the best advantage. It appears as if the Aetna banks have not been worked as carefully as possible, for considerable good ore lies about the cuts mixed with poor ore and is now difficult of recovery. When the demand for iron becomes acute much of the cherty débris might be cleaned up and put through the concentrator and a fair recovery made.

Other brown-ore deposits near the main open cut of the Aetna mine are on both sides of Black Hollow, which opens northward into the Brushy Creek valley. On the east side of Black Hollow are some old workings and a few old drifts, known as the Ward tunnels, in which ore of fair grade mixed with considerable hard chert was noted. In addition to the cherty ore there is some of the clay-replacement type. The altitude at the surface is about 800 feet, and the ore appears to extend through a vertical distance of about 60 feet on the hill slope. These cuts are about 2,700 feet from the washer tipple. It is reported that they were opened about 1891 and reworked in 1918.

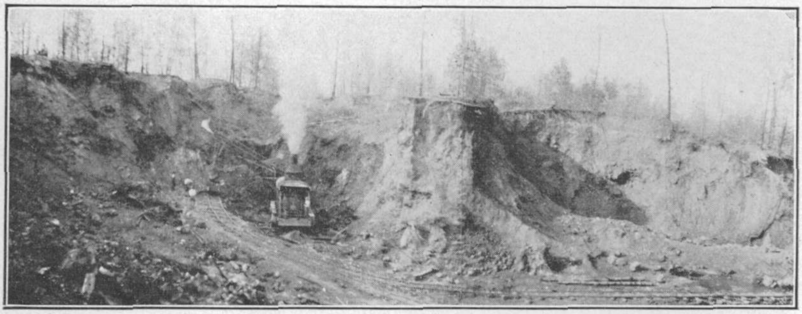
On the west side of Black Hollow, about 1,000 feet from the Ward tunnels, are some open cuts on the land of Brice Milam. The prospects and hillside outcrops show ore in places over an area of 2 or 3 acres. The ore is at an altitude of 800 to 850 feet, and the hillside pits indicate a vertical range of about 40 feet. Chert débris and clay are associated with the ore, and the nearest bedded rock is a variety of leached siliceous limestone resembling tripoli, which is exposed in thin horizontal beds about 100 feet lower in Black Hollow and may represent the upper part of the Fort Payne chert. Boulders of ferruginous conglomerate containing a few smooth rounded quartz pebbles crop out on the slope. The ore deposit is on a spur running northward toward Brushy Creek from the ridge on which the Aetna mines are located. Ore of good grade was disclosed around the largest opening, but in general the ore is of the usual type, containing considerable chert and clay. There is also some ore débris on the ridge and slope, and as only a little mining was done here in 1891 and 1918, the ore is far from being worked out, and the showing on the surface and in the pits may be said to be fairly promising. The route for haulage from this place to the Aetna ore washer would be fairly level.

About 1,600 feet west of the washer at the head of Washer Hollow near the top of the hill are some underground brown-ore workings known as the Washer Hollow Tunnel mine. The level of the ore here is about 180 feet above Piney Branch near the Aetna station, and the altitude is about 850 feet. The hill rises 25 to 50 feet higher than these tunnels. Limonite of medium grade mixed with chert and clay was obtained here as late as 1918, and earlier mining is said to have been done about 1891. The ore appears to be largely of the clay-replacement type. The old tunnels are badly caved, so that no accurate idea could be obtained as to the richness of the ore-bearing ground, but a number of test pits on the hilltop 150 feet or more back from the face of the hill indicate the presence of ore.

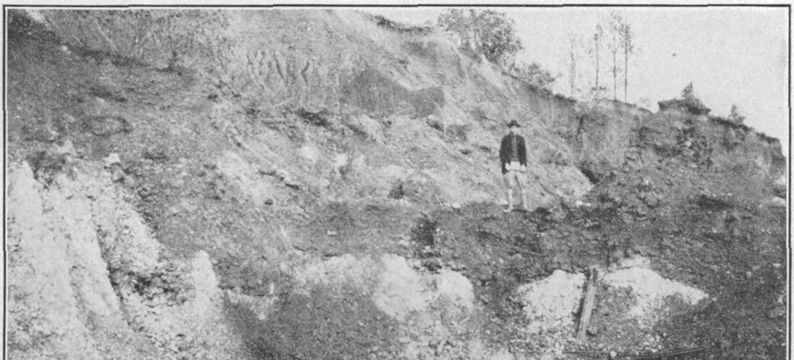
Near the top of the northwest escarpment of Piney Branch about half a mile southwest of the ore washer, on lands of the Tennessee Products Corporation, are some open cuts extending for a distance of about 600 feet. These cuts are about 20 feet high and run back 10 to 40 feet into the hill, and some of them end in short tunnels. The ore that attracted attention here is chiefly chert gravel cemented by limonite, and there are bands of nearly pure limonite between bands of chert and also veins of limonite ramifying through the chert masses. Prominent ledges and boulders of chert and gravel cemented by limonite crop out on the face of the escarpment, some of them 10 to 12 feet in thickness. The deposits are apparently about 30 feet thick and are 120 to 150 feet above Piney Creek at an altitude of about 820 feet. Prospects on top of the hill at an altitude of about 880 feet show ore, and it is possible that this deposit extends back well into the ridge. The average ore disclosed by these prospects contains considerable chert, but a good separation of the chert and the ore may be made by cobbing. The position of the deposit seems to suggest that it originated on an old stream terrace.

Some ore is reported to have been obtained for the Aetna furnace by hand mining from deposits on the ridge about a quarter of a mile east of Aetna. It is reported that some ore has been left here and that there is a similar deposit on the same ridge about 1 mile southwest of Aetna.

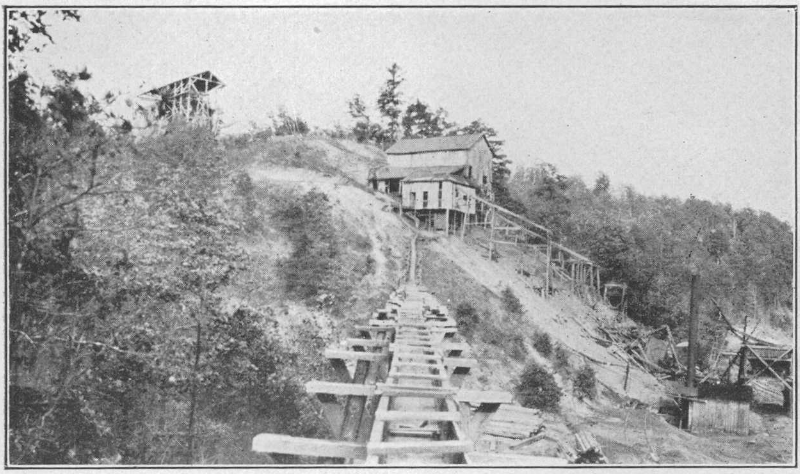
Analyses of ore from the Aetna mines, made by the Bon Air Coal & Iron Corporation at the Wrigley furnace, indicate a general range in metallic iron between 36 and 48 per cent, in insoluble



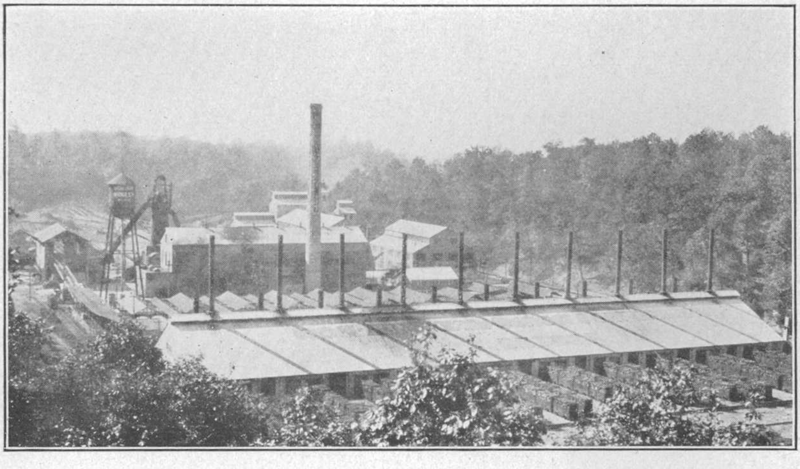
A. BELL BROWN IRON ORE MINE, 3½ MILES SOUTHWEST OF CUMBERLAND FURNACE, TENN.



B. CUT IN AETNA BROWN IRON ORE MINE, AETNA, TENN., SHOWING ORE OVERLYING WHITE CLAY



A. TIPPLE, ORE WASHER, ORE BIN, AND WASTE FLUME AT AETNA BROWN IRON ORE MINE OF TENNESSEE PRODUCTS CORPORATION, AETNA, TENN.



B. COKING AND BY-PRODUCT PLANT OF BON AIR CHEMICAL CO. AT WRIGLEY, TENN.

Viewed from the north

material between 18 and 36 per cent, in phosphorus between 0.27 and 0.33 per cent, and in manganese between 0.20 and 0.22 per cent, although there are a few percentages that are higher and lower than these figures.

Ore from the Aetna mines was concentrated in a modern plant built on the hillside overlooking the village of Aetna. The tramway from

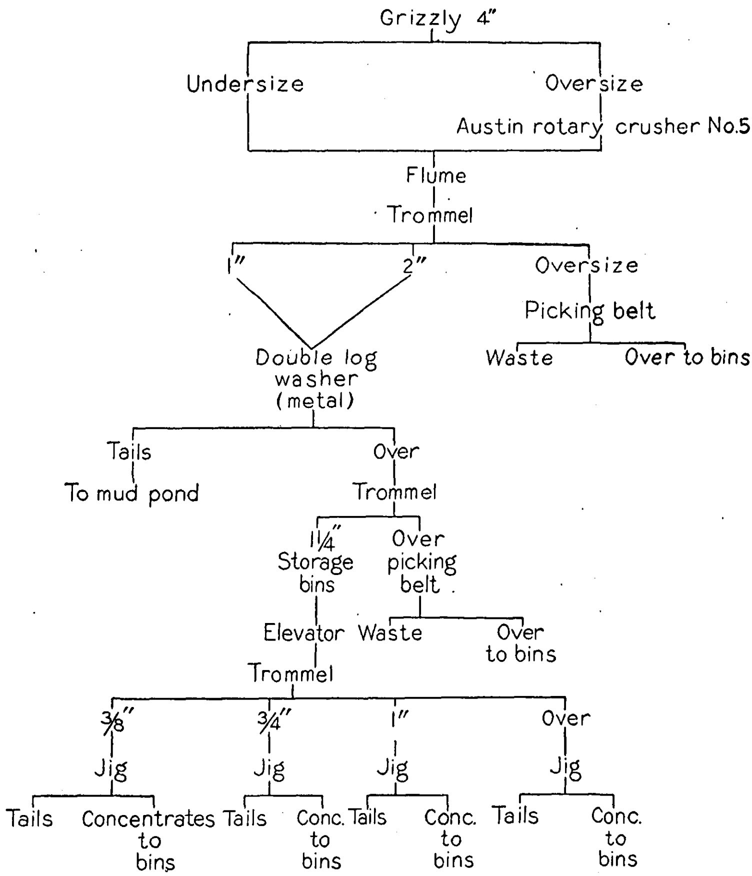


FIGURE 6.—Flow sheet of washer at Aetna mine of Tennessee Products Corporation, Aetna, Tenn. By R. W. Smith, Tennessee State Geological Survey

the large open-cut mine terminates in a tipple and grizzly, from which the ore is carried into a flume leading down to the washing plant. The capacity of the washer is reported to be 200 tons of concentrates in 10 hours, but probably this maximum could be produced only under the most favorable conditions. An ample supply of water is available from Piney Creek and from a large spring near the creek level at Aetna. A photograph of the washer plant is shown in Plate 8, *A*, and the flow sheet is given in Figure 6.

BLAST FURNACE AND BY-PRODUCT PLANT AT WRIGLEY

The largest blast furnace and incidental industrial development in Hickman County is at Wrigley, 1¼ miles south of Lyles. The former Warner furnace, now the Wrigley furnace of the Bon Air Chemical Co., is situated here. It is a single-stack 80-ton skip-filled modern charcoal furnace, operated in connection with a large by-product plant for the recovery of wood alcohol, acetic acid, and tar. The blast furnace and by-product plant and the limestone quarry one-third of a mile toward the south are connected with the Nashville, Chattanooga & St. Louis Railway at Lyles by a spur track. (See pl. 8, *B*.)

In the Wrigley plant the "by-product" is actually charcoal pig iron, as the products of wood distillation are the more valuable, and there is many times as much capital invested in the recovery plant and forests as in the blast furnace. In such a plant the charcoal would be a surplus product, and so its use in the blast furnace becomes the most natural outlet. The general principles involved in the wood distillation are the heating of hardwood in retorts until all the liquid and gaseous contents are expelled, the collection and fixation of these liquids, and the use of the carbonized wood, or charcoal, in the blast furnace. The essential features of the operation of the plant, of which a view from the north is shown in Plate 8, *B*, are as follows: Cord wood, mostly of oak, cut into 4-foot lengths is placed in steel buggies holding 2½ cords each, and trains of four buggies are pushed into the retorts by means of an electrically driven shifting table and sealed within. There are 20 retorts 53 feet in length, 9½ feet high, and condensers and pipe lines for liquid and gaseous products. Each retort has two outlets into the condensers. They are fired with coal in double-end fire boxes and also use the gas from the wood that can not be condensed to liquid. The condensation produces pyroligneous acid, which contains alcohol, acetic acid, oils, and tars. These products are collected in a central tank and pumped into holding tanks in the still house for further distillation and fixation. It requires about 24 hours for the carbonization of a charge of dry wood and 36 hours for green wood. When the wood is carbonized the steel cars of charcoal are drawn out of the end of the retort opposite to the end at which they entered and are quickly shut into the first set of cooling chambers, and later they are moved into the second cooling chambers. This is necessary in order to prevent the combustion of the charcoal which would take place if the red-hot material from the kilns were allowed to stand in a free supply of air. Eventually the buggies of charcoal are drawn out of the cooling chambers into sheds and are gathered by an electric shifter similar to that used in charging the retorts and moved to the coke storage house, where their contents are dumped.

The production of raw liquor is reported as approximately 250 to 260 gallons per cord of oak or hickory, but beech or maple will yield about 300 gallons to the cord. Figures obtained at the plant of the Wayne Wood Products Co. at Collinwood indicate that under favorable conditions 200 cords of wood will produce 10,000 bushels of charcoal and 45,000 gallons of crude pyroligneous acid, from which are obtained 2,000 gallons of methyl alcohol, 2,000 gallons of tar and oils, and 40,000 pounds of dry acetate of lime.[17]

At the time of visit about 160 cords of wood was used daily in the Wrigley plant. The distilling plant, equipped by E. Badger & Sons Co., of Boston, contains tar-settling tanks, digesting tanks, distillation tanks, lime mixers, and acetate of lime tanks, and the dryer building is equipped with an evaporator drum, a chain conveyor for calcium acetate slime, a woven-wire dryer, storage bins, and acetate baggers. The acetic acid is fixed as calcium acetate by the addition of lime and water, and the crude dried calcium acetate carries about 80 per cent of this salt. This material is placed in bags holding 120 to 125 pounds. In the spring of 1923 shipments of calcium acetate were being made to the Netherlands, where it was to be converted into methyl acetate for use in the manufacture of lacquers. It is also used in the chemical industries to produce acetic acid, other acetates, and acetone.

The principal uses for charcoal iron[18] are in the manufacture of chilled rolls, car wheels, chilled surfaces for crushing and grinding machinery, and general castings that require a specially fine metal, such as small or medium-sized cylinders, or thin castings that require great strength with sufficient softness to machine well.

Analyses of charcoal pig iron made at the Wrigley furnace prior to May, 1923, show a range in silicon from 0.63 to 2.78 but mostly between 1.5 and 2.35 per cent, sulphur 0.014 to 0.025 per cent, phosphorus 0.56 to 0.72 per cent, and manganese 0.22 to 0.72 per cent.

LEWIS COUNTY

In Lewis County the best-known deposits of brown iron ore are in the southern part of the county near Napier and near Riverside, just across the line from the Allens Creek district,[19a] Wayne County; also in the northern part of the county not far from the Aetna district, Hickman County. The ore deposits are, however, by no means confined to these three localities, for Rogers[19] has shown that surface indications of ore or partly prospected deposits are fairly well dis-

[17] The Wayne plant is described in Bulletin 26 of the Tennessee State Geological Survey, pp. 169–171.

[18] Moldenke, Richard, Charcoal iron, Lime Rock, Conn., Salisbury Iron Corporation, 1920.

[19] Rogers, R. F., The iron ore deposits of Lewis County, Tenn.: Resources of Tennessee, vol. 5, No. 3, pp. 91–146, 1915.

[19a] The Allens Creek district is now in Lewis County. (See p. 103.)

tributed over the whole county with the notable exception of the Flatwoods plateau, in the southeastern part, where there are large areas in which no deposits have been indicated on the map. Lack of discovery of ore here may be due to the fact that there are few settlements or roads. Many of the known deposits are near the Nashville, Chattanooga & St. Louis Railway, which crosses the county from south to north; those near Napier are reached by the Louisville & Nashville Railroad.

NAPIER MINES

The mines and blast furnace of the Napier Iron Works are in the southern part of Lewis County near Chief Creek, a tributary of Buffalo River. This locality is connected with the Louisville & Nashville Railroad at Summertown by the Napier branch line. The principal mine workings are three-quarters of a mile to 1 mile north of the village of Napier, on the east-west ridge that forms a divide between Buffalo River and Chief Creek, and there is a small opening about half a mile east of Napier, between Chief Creek on the south and the railroad track on the north. The main workings north of Napier were examined by E. F. Burchard and R. W. Smith October 23, 1924. The relations of the open cuts to the topography are substantially as shown in the maps by Rogers, although considerable extensions to cut No. 3 have been made since these mines were examined by him in 1913.

The main ore body is well toward the highest part of the ridge, a remnant of the old plateau that represents the peneplain developed on a surface of cherty limestone in this part of Tennessee. Rogers shows that the altitude of the ridge is above 900 feet and that the principal ore deposits are a little more than 150 feet above the level of Chief Creek, figures which coincide with barometric observations made during the writer's visit. The deposit east of Napier, according to Rogers's map, appears to be about 50 feet lower. A property map made by Robert H. McNeilly, of Vanderbilt University, dated 1921, evidently having the same base as the Rogers map, was available at the time of the recent visit and shows the principal iron-ore deposit as occupying an irregular branching area 6,250 feet in length from southwest to northeast, with a maximum width of about 2,100 feet, and a small outlying deposit about 2,000 feet west of the principal area.

According to this map only portions aggregating less than half of this area have been mined out, but the map does not appear to be strictly up to date in this respect. The old mine pits and many new prospect pits, mainly at the north, show that the overburden is clay and chert débris, the chert disintegrated in places to gravel and sand, and that the thickness ranges from a few feet to 15 feet or more. On steep slopes and in the heads of hollows boulders of ore and ferruginous conglomerate crop out, and in places lumps of loose ore are found on the surface. Much ore occurs, however, in pockets below a heavy cover where no ore shows at the surface. No bedded rocks are exposed in association with the ore deposits, but flat-lying cherty limestone crops out in the vicinity of Buffalo River and Chief Creek. The ore is embedded in broken chert, clay, and sand. Where the surface material closely overlies ore the soil is reddish and ferruginous, but over places barren of ore it appears of lighter shades. In the mines and test pits fine-grained hard fossiliferous chert similar to the Fort Payne is common, but there are also large blocks and boulders that are somewhat porous and inclined to weather sandy, like the chert of the Warsaw formation, and the presence of this material suggests a mixture of material residual from these two chert formations, which is inconsistent with the view taken by Rogers that the upper portions of the underlying cherty limestone beds belong to the St. Louis formation. In places near the top of the bank in cut No. 2 red sandy clay mottled with bluish-green clay was noted, a type characteristic of what may represent Tuscaloosa clay in this region.

The cuts numbered 1 and 2 are 10 to 30 feet deep, and some ore has been indicated by prospects below their present floors. Cut No. 3 is much deeper, reaching more than 60 feet in places. The ore in this cut evidently was pockety and probably required the moving by steam shovel of considerable barren ground between the pockets.

The old mine openings did not show much ore at the time of the recent visit, as the walls are weathered and much talus has accumulated, obscuring the ore horizon and the bottoms of the workings, but from what could be seen there and on the surface in connection with a large number of prospect pits north of the old mines the ore appears to be of fair grade, somewhat better than that seen at some places south of this locality and superior to that at many places to the north in showing less ore of the chert-breccia type, although there are masses and boulders of this material in places. Many specimens, however, are of a lighter shade of brown than is characteristic of the best grade of ore, and this suggests a higher content of disseminated silica and alumina. In a few places the ore contains manganese above the average for brown ore of this region, and such ore is darker than the average. The content of phosphorus is said to be about 0.50 per cent, which is near the average for this part of the region.

The test pits on the ridge between cuts No. 1 and No. 2 and north of No. 2 are from 10 to 20 feet deep. Samples of ore are displayed about these pits, each representing the recovery by washing and screening 1 cubic foot of dirt from each 5 feet of depth in the pits. The quality of the ore thus recovered generally appeared good, some being dark and slightly manganiferous, and the limonite fragments do not show a large proportion of adherent chert. The proportion of rock and waste in the ore as a whole, however, appears fairly high, to judge by the ore recovered in the new test pits, the appearance of the mine openings, and the rock pile at the site of the former washer. It was reported that about 4 cubic yards of the ore-bearing dirt would yield 1 ton of ore.

The latest period of operation of these mines was from August, 1912, to August, 1917, when 208,550 long tons of ore is reported to have been delivered to the blast furnace. This compares closely with the probable recovery of 200,000 tons estimated by this company in 1912, as reported by Purdue.[20] According to the blast-furnace records for this period the average yield of metallic iron in the ore consumed was about 50 per cent. The latest period of operation of the blast furnace was from 1912 to 1923, except for a few periods of inactivity lasting less than a year. The blast furnace was supplied from 1917 to 1923 in part by ore from the Corning mines, in Wayne County, also owned by the Napier Iron Works, and in part by red hematite from the Birmingham district, Alabama. The product was No. 2 foundry iron, fracture graded. On the closing of the mines at Napier the ore washer was moved to the Corning mines, which were operated at intervals from 1917 to 1923, when they were considered to be worked out. If it is decided to reopen the mines at Napier the ore washer will probably be moved back to this locality. There seems to be a fair chance that enough ore is contained in the extensions of the ore body disclosed by recent prospecting to warrant reopening the mines in times of strong demand and high prices for pig iron, but as these periods are of erratic occurrence and uncertain duration the undertaking involves an element of speculation.

Revenue from an unusual source was being obtained on this property in October, 1924, through the shipment of chert gravel from the old washer dumps to the blast furnace at Rockdale, Tenn., where ferrophosphorus is manufactured from Tennessee limonite and phosphate rock. This gravel, which is accompanied by a small percentage of limonite lost in the washing, is added to the blast-furnace burden for the purpose of introducing a definite proportion of silica.

WAYNE AND LAWRENCE COUNTIES

The brown iron ores of Wayne and Lawrence Counties occur mainly within the Waynesboro quadrangle, an area of 974 square miles that lies in latitude 35° to 35° 30′ north and longitude 87° 30′ to 88° west. The greater part of Wayne County and the western 5 miles of Lawrence County are within the quadrangle.

[20] Purdue, A. H., The iron industry of Lawrence and Wayne Counties: Resources of Tennessee, vol. 2, No. 10, p. 376, 1912.

Practically all the brown-ore deposits in these two counties have been described by Hugh D. Miser in Bulletin 26 of the Tennessee State Geological Survey, published in 1921. As that bulletin with its geologic map and other data of scientific and economic interest is available for distribution at the time the present paper is being prepared, Miser's description of these deposits will not be republished here, but certain of the larger deposits were visited by the present writer in order to note the latest developments, and supplementary notes are therefore available regarding some of them. Most of the deposits in Wayne County are grouped near Allens Creek [20a] and the old Wayne furnace site, in the northeastern part of the county, and near Iron City, in the southeastern part; those of Lawrence County are in the southwestern part of the county near Pinkney and Iron City. Mining was active in 1923 and 1924 at Allens Creek and 1½ miles northwest of Iron City. Of the prospects and mines shown on Miser's map 46 are in Wayne County and 22 in Lawrence County. Two of the deposits, one at the Cedar Point mine, half a mile north of Iron City, and the other near Clifton, are of a bedded type instead of the residual-concentration type of brown ore common to this locality. The bedded type of ore is not of consequence as regards the future production of ore in this region, as apparently it consists of ferruginous limestone in which there has been a little more than the usual deposition of iron in the sediments, and the extent of such deposits is small.

DEPOSITS NEAR ALLENS CREEK

The deposits of brown iron ore near Allens Creek (Ruppertown post office) occupy an irregular crescentic area probably aggregating more than 1 square mile along the former border of Wayne and Lewis Counties. The deposits of ore are on the upland ridge a quarter of a mile to 1 mile south of Buffalo River, at an altitude of about 900 feet, and they extend out half a mile or more toward the north on the crests of several spurs of the ridge. The deposits are on the property of the Tennessee Products Corporation. They have been mined for many years and until recently produced ore.

The ore is exposed at the surface here and there, but it is mostly covered by a few feet of soil, gravel, clay, and disintegrated chert. In places there are disclosed in the banks of the open-cut mines distinct channels, due to former erosion, filled with gravel. In this gravel, as well as in masses of limonite-cemented conglomerate, there are a few rounded quartz and quartzite pebbles, but most of the gravel consists of subangular chert pebbles, more or less leached or altered to a pale yellowish or whitish color part way through.

[20a] The Allens Creek iron-ore area has recently been transferred to Lewis County through change of the county boundary.

The ore is underlain by chert and yellowish sand, but in no place has it been found to rest on limestone. The nearest beds of limestone are exposed in Allens Creek a short distance upstream from the blast furnace. The massive chert layers that lie below the ore form a distinct ridge in one place where they are exposed by mining, and they show partial replacement by limonite along joint and bedding planes but generally not to such an extent as to form an ore. In one of the lower mine cuts warped layers of chert were observed underlain by a pocket or lens of yellowish sand. Near by this sand was encountered at a depth of 60 feet in a test drill hole. This sand may fill an old solution channel or cave, or possibly it may represent a sandy layer within the chert. The thickness of the ore-bearing material, which consists of clay and disintegrated chert in association with limonite, is 40 to 60 feet, as indicated by the open cuts, and there may be ore at greater depths, as indicated by drilling below some of the pits. The limonite occurs in lumps that may be nearly solid or else geodal and in irregular masses and ramifying streaks. In places the ore is exceptionally rich, but the tenor of the product depends, of course, on the character of the bank in which the steam shovel is excavating. The limonite is largely of the chert-replacement type, but some that is apparently of the clay-replacement type was noted below a surface gully. Some of the chert-replacement ore is cavernous and honeycombed and suggests that the replacement of silica by limonite has been accompanied by a loss of volume, but this is not universally true, because lumps of nearly solid limonite are found which indicate that the limonite has almost entirely replaced loose lumps of chert. The geodal lumps may represent partial replacement and partial removal of silica. A specimen of the clay-replacement ore obtained below a surface gully, represented by the following analysis by D. F. Farrar, of the Tennessee State Geological Survey, shows both alumina and silica present in considerable quantities.

Analysis of impure brown iron ore from mine near Allens Creek

Iron (Fe)	32.11
Silica (SiO_2)	32.76
Alumina (Al_2O_3)	9.28
Phosphorus (P)	.84

It was stated at the mine that the ore-bearing material might range from 4 to 12 yards of dirt to 1 ton of ore. The washed ore in 1922 ranged in iron from 42 to 53 per cent, but generally from 42 to 45 per cent, and in insoluble material from 25 to 10 per cent. Phosphorus ranges from 0.80 to 1.25 per cent and is said to be least in the lowest levels. Manganese ranges from 0.10 to 0.50 per cent, and sulphur is practically negligible, generally below 0.01 per cent.

The Allens Creek mines are among the largest in this ore field, several of the cuts extending out spurs of the ridge for half a mile or more from the middle of the area. The old cuts are in places 40 feet deep, and in one of the active cuts a lower level is being mined 20 feet below the former level. Four steam shovels were on the property at the time of visit, one excavating waste in a cut through barren ground toward an ore body that had been disclosed by prospecting, one loading ore, one under repair, and a fourth temporarily inactive. The old pits have been so dug as to leave islands and ridges of barren or low-grade dirt, but considerable systematic prospecting has been done between, beyond, and below the old cuts, with the result, according to Superintendent Deaver, that a supply of ore sufficient for 10 years at the present rate of production has been disclosed.

In 1923 the deepest cut was worked by drilling holes by hand or gasoline churn drill 8 or 10 feet back from the face and blasting the ore-bearing material loose, then loading it by steam shovel into tram-cars, which are drawn by dinkey engines to the ore washer. The best prospects for ore appeared to be at the level of the lowest cut and below one of the east branches of the largest cut. The ore exposed in fresh faces of the cut and in prospect openings appears to be of good quality and in good proportion to the waste material.

The ore washer, which is built on the east side of Allens Creek above the blast furnaces, consists of a tipple and grizzly high on the valley side, a long flume down which the ore is carried by water and partly separated from the adhering clay, a coarse rotary screen, two steel logs, a picking belt, a sand screen, and a set of 4-cell jigs. The output was reported to be from 150 to 300 tons of ore a day, all of which was used at the local blast furnace.

The blast furnace, known as the Mannie furnace, consisted of two stacks, although only one of them has been operated for several years, and the inactive stack has recently been taken down. The daily output was reported to range from 80 to 100 tons of pig iron, depending to some extent upon the grade of ore available. Limestone for flux was brought from the quarry of the company at Wrigley, as the stone obtainable at Allens Creek is less suitable. Foundry pig iron, containing 2.25 to 6 per cent of silicon, was the staple product of the furnace.

DEPOSITS NEAR IRON CITY

Large deposits of brown iron ore occur on the ridge 1½ miles northwest of Iron City. The area occupied by these deposits as outlined by Miser on Plate 1 in Bulletin 26 of the Tennessee State Geological Survey is about three-quarters of a mile in length from southeast to northwest and about half a mile in maximum width. The altitude of this tract ranges from 800 to 864 feet, approximately the maximum upland level in this vicinity, and is typical of the occurrence of many brown ore deposits in the Waynesboro quadrangle.

The only mine in the vicinity of Iron City that was active in 1923 and 1924 was the Van Leer, operated by Dr. L. J. Gray. The ore deposit is on the edge of the upland and is reported to underlie an area of about 14 acres but not to extend throughout the width of the chert ridge. The overburden, generally 3 to 15 feet thick, is composed of red clay and chert débris with some sand and gravel in places. Ore rarely crops out at the surface. The ore-bearing ground ranges in thickness from a few feet to 30 or 40 feet and comprises red clay, chert débris, gravel, a little sand and light-colored clay, and limonite. The excavations have disclosed no limestone immediately underlying the ore, but limestones of Laurel, Lego, and Ridgetop ages crop out extensively in the valleys of Shoal Creek and its tributaries near Iron City, 250 to 300 feet lower than the ore horizon.

The iron ore is limonite of the chert-replacement and conglomerate type. Most of the available limonite is in fragments in the clay and chert débris, and the quality of these limonite fragments appears generally good. Some of the limonite cements angular or rounded chert débris into large masses, and it is probable that the loose limonite débris found in the deposit has been derived largely from the breaking down of such masses of rock. Several uncommon iron minerals have been found by Doctor Gray in this deposit, among which beraunite, cacoxenite, dufrenite, and strengite were identified by C. S. Ross and the writer. All these minerals are hydrous phosphates of iron. The beraunite occurs in obscure thin crusts and minute tabular masses of dark-reddish crystalline material. The cacoxenite occurs in radiated finely fibrous tufts of a bright golden-yellow color and is in places associated with the beraunite. The dufrenite occurs in radiated fibrous masses similar to those of the cacoxenite, but of a dull olive-green to dark-green color. The strengite occurs in small spherical and botryoidal clusters of pink to white crystalline material. These phosphate minerals have been formed on the linings of cavities within limonite, appear to be later than the iron oxide with which they are associated, and show alterations from one form to another. The occurrence of iron phosphate here in definite minerals is of interest but difficult of explanation. The deposit in general carries a little more than the normal percentage of phosphorus for brown ores of the region. The Mississippian rocks immediately associated with the iron ore are not high in phosphorus, but the Ordovician limestones, lower in the geologic section, are distinctly phosphatic, and whether they have contributed phosphate material to ascending waters which have deposited it in the brown ores is an interesting speculation.

A lens of limonite gravel overlying yellow sand was noted in the side of one of the old mine cuts (pl. 5, *B*). This gravel is rounded and waterworn, like ordinary creek gravel, and is apparently a placer deposit of limonite fragments reworked from the ore associated with clay and chert residual from Mississippian formations. The gravel is within deposits that are of Tuscaloosa (Upper Cretaceous) or later age.

The Van Leer mine consists of several open cuts, 15 to 20 feet deep and about 1,000 feet long. The stripping and removal of barren ground as well as the mining of ore is done by steam shovel. Prospecting is done by hand drills to a depth of 10 or 12 feet. The ore is loaded into 4-yard cars and drawn to the washer by a dinkey engine. At the time of visit preparations were being made to mine ore from levels beneath the first mine cuts, as prospecting is reported to have indicated considerable ore in the lower levels. By selective mining and careful washing ore carrying 45 to 48 per cent of iron, 10 per cent of silica, and 0.5 to 2 per cent of phosphorus [21] was produced, which was shipped to the blast furnaces of J. J. Gray, jr., at Rockdale [22] and Clarksville. The proportions of rock vary greatly from place to place. Besides the waste material which is too lean to go through the washer there was being produced at the time of visit, according to local report, 0.22 ton of ore from each yard of dirt washed, but at times the proportion of ore was twice as great. The ore is used in the manufacture of ferrophosphorus, and for this purpose it may carry a little higher percentages of silica and phosphorus than for charcoal pig iron. The ferrophosphorus is reported to carry 18 to 22 per cent of phosphorus. The burden of the furnace at Clarksville is reported to have consisted of 80 tons of lump phosphate rock and 55 tons of iron ore, in addition to small quantities of iron borings, mill cinder, etc.

BENEFICIATION OF IRON ORE

An iron ore is said to be beneficiated if its quality is in any way improved by physical or chemical treatment. Thus the elimination of more or less of the foreign accessories, such as sand, clay, and water, with the result of increasing proportionately the percentage of iron, not only beneficiates the ore directly but, if done at the mine, lowers the cost of transporting the ore to the furnace. Merely changing the physical character or the chemical composition of the ore without eliminating any of the impurities may so improve its quality that it is more suitable for use in the blast furnace; therefore processes that produce such results may also properly be said to beneficiate the ore. There are many methods of improving the

[21] Barr, J. A., Manufacture of ferrophosphorus: Am. Inst. Min. Met. Eng. Trans., vol. 71, pp. 507–511, 1925.

[22] The new blast furnace at Rockdale is described in the Iron Age, Dec. 24, 1925, pp. 1731–1732, and the Iron Trade Review, Dec. 24, 1925, pp. 1595–1596. Since the field work of the writer the Gray furnaces have been sold to the Tennessee Products Corporation and the furnace at Clarksville has been dismantled.

quality of iron ores, some of them very simple and even primitive and others rather complex and depending for their efficiency on large and expensive mechanical equipment, with all manner of gradations between the extremes. The methods and equipment employed depend, of course, largely upon the character of the ore and the nature of the problem to be solved.

An early method of treating the brown ore of the western Highland Rim area was to pile it on "ricks" of wood and set the wood on fire; the resultant roasting loosened the clay, drove off some moisture, and through decrepitation loosened considerable of the chert so that it could be more easily separated by hand. The early mechanical means of treating the ores was a log washer, or inclined trough, in which was rotated a log 10 to 20 feet in length having metal paddles attached to its sides at such an angle that the iron ore was churned and gradually moved up the trough against a flow of water that washed away the sand and clay. The ore then went on a picking belt, from which the coarse rock and lumps of clay were picked by hand. Steel posts have now to some extent replaced the wooden logs. As the art of washing the ores progressed other devices were introduced both before and after the log washer, such as the grizzly, a coarse grating, usually of railway rails, on which the ore is dumped, broken by sledges to pass the openings, below which it is washed in a flume and sized in trommel screens. Rotary or jaw crushers are also used after the grizzly. As the log washer is an inefficient apparatus, which saves coarse impurities and wastes fine ore, pulsating jigs have been introduced toward the end of the process that take advantage of the difference in specific gravity of the brown ore and the chert and sand. The jigs require close sizing of the material and are usually built as a series of cells in which material of one size is treated in each cell.

As now developed the ore washer, as it is called, has become a fairly complicated plant involving crushing, sizing, washing, picking, and jigging of the ore. The most graphic representation of apparatus used, its arrangement, and the course followed by the ore is furnished by the flow sheet, and such a sheet for the washer at the Aetna mine is shown in Figure 6.

A good supply of water is necessary to a successful ore-washing plant and also a large area of lowland below the plant site for settling ponds and dumps for the finely divided waste that is carried away from the washers. The plant should be built if possible on a hillside lower than the ore deposit, to have the advantage of gravity in the movement of ore from the mines and through the plant.

The ratio of crude ore, or "dirt," exclusive of stripping and barren ground, that must be treated to the ore recovered varies considerably in the practice in the western Highland Rim area. Good ground will yield 1 gross ton of ore for 2 or 3 cubic yards of dirt, and as much as 16 cubic yards of dirt has been reported as being washed in order to recover 1 ton of ore, but probably this ratio was not maintained as an average. Just what the limiting ratio may be can not be stated, as it would depend on many diverse factors, not all of which are operative at any one place.

The problem of beneficiation of the brown iron ores in the western Highland Rim is of prime importance. A hundred and thirty years of mining has necessarily exhausted much of the highest grade ore, and future mining will necessarily involve handling ores with increasing proportions of clay, chert, sand, and gravel, and in places the reworking of ground that has been carelessly mined and even of old gravel dumps. In the writer's judgment it would seem that the present local methods of ore treatment have been developed about as far as practicable and that radical departures from present practice may be required in order to treat successfully cherty brown iron ore of lower grades. It is his belief that the next logical step in the beneficiation process, wherever there is lean hematite or limonite in large quantity convenient to transportation and markets, should be to endeavor to develop a commercially successful process for reducing the hematite or limonite to a magnetic condition, in which the magnetic ore may be separated from the nonmetallic impurities by electromagnetic action.

PRODUCTION

IRON ORE

Statistics of mineral production in the United States were collected by the United States Geological Survey from 1882 to 1924; since that date they have been collected by the Bureau of Mines. In the earlier years the records were not kept in a form sufficiently detailed to permit the separation of iron ore produced by counties in the western Highland Rim area of Tennessee from iron ore produced by the whole State. Beginning with 1896, however, the reports of the State mine inspector of Tennessee contain data on production by counties, and, beginning in 1906, those of the Federal Survey are fairly detailed and complete, but those of the State mine inspector show a hiatus for the years 1915 to 1919, and so in order to arrive at the most complete detailed record beginning with 1896 these two official sources of information have been drawn upon. In the bulletin already cited H. D. Miser has recorded the production of the mines in the Waynesboro quadrangle from 1835 to 1920, as ascertained mainly from the owners of the mines, and from those figures totals for 1835 to 1895 for Wayne and Lawrence Counties and part of Lewis County are derived. The figures used for the years prior to 1896 for the counties north of Wayne are necessarily rough estimates and are subject to revision. The following table summarizes the available data, without reference, however, to the recent change in boundary between Lewis and Wayne Counties:

Summary of production of iron ore in western Highland Rim area, Tennessee, by counties, 1797–1926, in gross tons

Period	Stewart	Montgomery	Dickson	Hickman	Lewis	Wayne	Lawrence	Total
1797–1895 [a]	95,000	42,000	113,800	376,000	550,000	-----------	1,441,300	2,618,100
1896–1926	172,365	77,588	183,368	785,979	742,897	1,437,626	2,401,351	5,801,174
	267,365	119,588	297,168	1,161,979	1,292,897	-----------	5,280,277	8,419,274

[a] Estimated.

PIG IRON

The records of the United States Geological Survey and the Bureau of Mines show the production of pig iron, including ferrosilicon and ferrophosphorus, in the counties of the western Highland Rim by years from 1910 to 1926, and Safford's report, issued in 1855, gives a table of blast furnaces and their products in 1854. The report of the Tenth Census, volume 2, 1883, gives for the year 1880 figures for Stewart, Dickson, and Lawrence Counties.

The data derived from these sources are to be published in detail in the complete bulletin by the State Geological Survey, but a summary of the figures is given below.

Summary of production of pig iron, including ferrosilicon and ferrophosphorus, in western Highland Rim area, Tennessee, 1797–1926, in gross tons

1797–1909 (estimated)	2,700,800
1910–1926	1,239,014
	3,939,814

If the grand totals of iron-ore and pig-iron production are compared they indicate an average yield of 46.79 per cent of metallic iron from the ore, which is not inconsistent in view of the facts that in the early days the ore was hand picked and that in recent years some iron ore from outside the area and some scrap iron have been added to the furnace burdens. It is a question, however, whether so high an average yield will be maintained in the future, because of the increasing quantity of siliceous ore that will have to be mined.

RESERVES OF IRON ORE

The western Highland Rim area contains a valuable reserve of brown iron ore, notwithstanding the fact, which must be apparent to anyone who is acquainted with local conditions, that a large proportion of the easily accessible and rich ore has already been mined.

The ore that remains must therefore be won at greater expense and with greater capital outlay and consequently at greater risk to capital than was involved in the earlier days of mining. The principal factors affecting the availability of a bank of ore are its situation with regard to mining and washing, its accessibility and location with respect to transportation facilities and markets, the demand for and prices of iron ore and pig iron, and the possibility of successfully beneficiating the ore. The process of beneficiation is susceptible of improvement, and upon its improvement the future of this brown-ore field probably depends to a greater extent than on any other single factor to-day.

In attempting a rough estimate of ore reserves in the areas examined the present processes of recovery have necessarily been taken for granted, but the possibility of better demand and prices have had to be assumed, for otherwise it is not likely that the incentive for greater effort and expenditure for the recovery of ore would be forthcoming. The difficulties in making satisfactory estimates of ore tonnage are obvious. Few deposits have been prospected sufficiently to enable their owners to make close tonnage estimates, and no such data were available to the writer. The data used in estimating the ore that might possibly remain in a partly mined-out deposit were the average ratio of ore-bearing dirt in cubic yards to the ton of iron ore recovered; the average thickness of the deposit, exclusive of overburden; and the area of probable ore-bearing ground corresponding to these averages that remains. For deposits that had not been mined the best information as to these factors that could be obtained was used, or assumptions were made based upon comparisons with other deposits in the locality that appeared to be of similar character.

The writer attempted estimates based on personal study only for Stewart, Montgomery, Dickson, and Hickman Counties, but for Lewis County north of Allens Creek a general estimate was made from the descriptions in the report by Rogers,[23] and for Wayne and Lawrence Counties including the area near Allens Creek recently transferred from Wayne to Lewis County the estimate by Miser [24] has been accepted. In computing the reserves in the four northern counties the writer made estimates for each individual deposit examined by him, but as he probably did not see all the ore-bearing territory additions have been included in the estimates for each county in order to compensate for areas not considered. The totals for the several counties are as follows:

[23] Rogers, R. F., The iron ore deposits of Lewis County, Tenn.: Resources of Tennessee, vol. 5, pp. 91–146, 1915.

[24] Miser, H. D., Mineral resources of the Waynesboro quadrangle: Tennessee Geol. Survey Bull. 26, p. 57, 1921.

Estimated reserves of brown iron ore in western Highland Rim area, Tennessee, by counties, in gross tons

[Subject to revision]

Stewart	450,000
Montgomery	400,000
Dickson	600,000
Hickman	750,000
Lewis (north of Allens Creek)	700,000
Wayne and Lawrence, including area near Allens Creek recently transferred from Wayne to Lewis County	6,000,000
	8,900,000

This estimate is fairly consistent with an earlier rough estimate, prepared in part by the writer for C. W. Hayes, of the tonnage of brown iron ore in the western Tennessee River valley embracing the deposits in northern Alabama, west-middle Tennessee, and western Kentucky, which assigned 10,000,000 tons to the available supply and 15,000,000 tons to the nonavailable supply of ore.[25] Of the available ore 5,300,000 tons was credited to the Russellville district, Alabama.

Comparison of the figures by counties may raise questions as to their consistency and also as to whether they are conservative or liberal. The writer has no doubt that there are inconsistencies in these totals that can not well be eliminated without giving the subject much more study, but he has endeavored to make the estimates as fair and consistent as possible.

Some property owners doubtless feel that there are in single properties greater quantities of ore than have been estimated for the whole of certain counties. When it is considered, however, that the estimated total production of brown iron ore from this area since the beginning of mining is about 8,420,000 tons and that the estimated total reserve of ore yet unmined amounts to 8,900,000 tons, the latter estimate may even be suspected of being too liberal. If the quantities already mined and yet to be mined stand in relation to each other as indicated in these estimates it means that practically every mine will have to yield as much ore in the future as it has yielded in the past, for there are not many large areas that have not already been developed to some extent. It will be difficult to obtain from some of the old and abandoned mines as much ore as they have produced, but it is the belief of the writer that if the prices of pig iron and iron ore should rise and be maintained at a high level for a long term of years and if experimentation can devise improvements in beneficiating the cherty brown iron ores of this area, the western Highland Rim of Tennessee will resume its place as an important producer of brown iron ore and high-quality pig iron.

[25] Hayes, C. W., Iron ores of the United States: U. S. Geol. Survey Bull. 394, p. 96, 1909.

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