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Review of Southeastern (United States) Iron Ores exclusive of the Birmingham district, with emphasis on the Silurian hard red ores

by the

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Introduction

Mining and smelting of iron ore in the Southeastern States began shortly after the Revolutionary War but did not attain any substantial rate until the middle of the Nineteenth Century, when numerous furnaces were erected, particularly in and near Birmingham, which continues to be the principal steel-making center of the region. The industry is based on three principal ore types--red ore, brown ore, and gray or magnetite ore--of different geologic occurrence and vastly different resources. The red ores are by far the most abundant, accounting for a large part of the total production, but except for the area around Birmingham the ore beds are relatively thin and low-grade. As enriched near-surface, easily mined ores were exhausted in other parts of the region, and as transportation improved, small local furnaces were shut down and mining declined sharply. (See production statistics, tables 4-9.)

This report reviews the evidence and attempts to evaluate the present and future potential of the red ores in the light of modern technology and economics, both for "normal" conditions and as a possible strategic reserve for wartime.

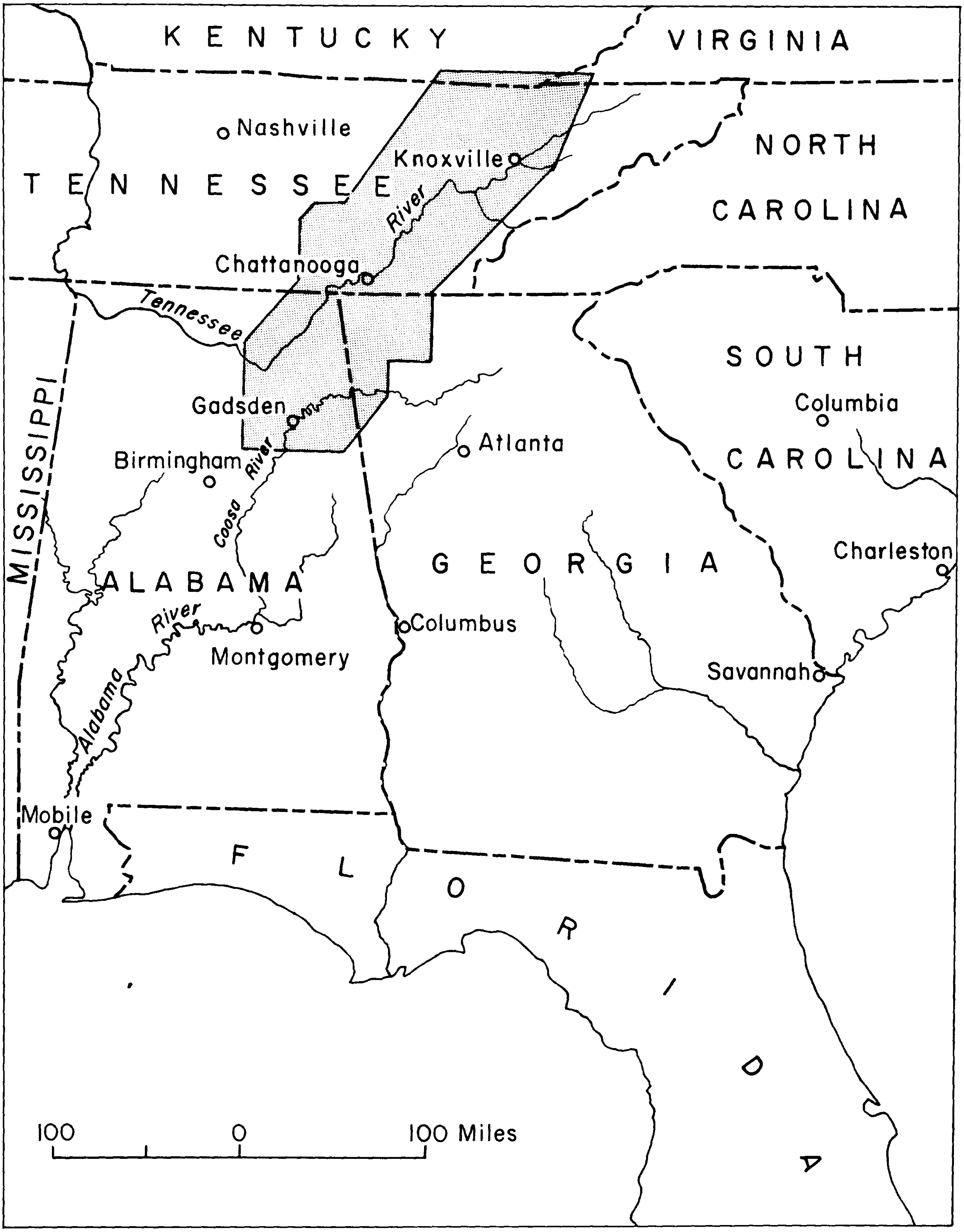
Geological investigations long ago established the general nature and extent of the red iron ores and provided background for the relatively small-scale operations that constituted the iron-ore mining industry everywhere but in the Birmingham district. In the latter area, detailed studies have been carried out both by Government agencies and private companies. Elsewhere, however, little has been done in recent years, and to a considerable extent our knowledge of these ores is based on the old reports and scattered fragmentary information.

Technical personnel of the Department of the Interior have assembled the available information on the red iron ores in eastern Tennessee, Georgia, and Alabama exclusive of the Birmingham district. The information has been summarized graphically on the accompanying figures 1 and 3, which are based on the Army Map Service 1:250,000-scale map series (about 4 miles to the inch), and figures 2 and 4, geologic cross sections along lines indicated on the maps. The exact areas covered are shown in the index maps in the corners of the large maps. The general location of the area and its geographical relationship to major industrial and commercial centers of the Southeast are shown in the index map on the following page.

Although particular attention was directed toward the red ores because of their preponderant potential importance, the brown ores and magnetite ores are described briefly for completeness. They are not shown on the maps, and in general they lie outside the areas shown in figures 1 and 3.

Principal responsibility devolved on Jesse W. Whitlow of the U. S. Geological Survey for assembling the geologic information and on James L. Vallely and Avery N. Reed, Jr., of the Bureau of Mines for the production statistics, mining and beneficiation data, and economic analysis. Published and unpublished reports were freely consulted; sources of information are given in the section on Selected References. The assistance of many organizations and individuals who cooperated with the Department of the Interior is gratefully acknowledged. Among the many, special mention must be made of the following:

In Georgia, Captain Garland Peyton, Director of the Georgia State Department of Mines, Mining, and Geology and Dr. Vernon Hurst of the same organization; Dr. A. S. Furcron, State Geologist; Dr. Arthur Allen and



INDEX MAP, SHOWING AREA STUDIED FOR THIS REPORT

Prof. Romeo Martin of the Department of Geology of Emory University; and Messrs. Abernathy and Jay, who furnished a description of the mines on Dirtseller Mountain.

In Alabama, Messrs. Arthur J. and Charles S. Blair, geologists at Birmingham; Dr. Walter B. Jones, Director of the Geological Survey of Alabama; and Mr. H. D. Pallister of the Department of Geology at the University of Alabama.

In Tennessee, Stuart W. Maher, Herbert A. Tiedemann, and Robert C. Milici of the Tennessee Department of Conservation, Division of Geology in Knoxville; Dr. George E. Swingle, Department of Geology at the University of Tennessee; B. C. Moneymaker and J. M. Kelberg, geologists for the Tennessee Valley Authority at Knoxville; and Charles Wilson, miner and quarryman at Rockwood.

Red ores

The so-called red iron ores of the Southeast are sedimentary geologic strata of iron oxides (principally hematite, Fe_2O_3) containing varying amounts of calcium carbonate ($CaCO_3$), quartz (SiO_2), alumina (Al_2O_3) as clay, phosphorus (P), manganese (Mn), and minor amounts of other elements. By far the most important beds were laid down in Silurian (mid-Paleozoic) time, when iron was being deposited more or less simultaneously from New York State to Alabama. The name Clinton, often applied to these ores, comes from New York; in Alabama and Georgia the name Red Mountain formation is used for the ore beds and the Silurian rocks enclosing them. In Tennessee the name Rockwood is ordinarily applied.

Red hematitic beds also called red ores occur in the Tellico sandstone of Ordovician age in Georgia and Tennessee but are not considered in this report because of their low grade and complete lack of economic potential.

The Silurian ore as deposited and solidified is a dark reddish rock, commonly speckled white and brown from calcium carbonate and limonite, respectively. The hematite often occurs either as rounded oolites (flaxseed-like particles) or as casts of fossils (crinoid stems, bryozoans, corals, etc.) replaced by iron oxide. Where unweathered (i.e., below the surface zone), the ore is compact and hard.

Soft ore is derived from the hard ore by leaching of the calcium carbonate. In the process, the content of iron and insolubles (chiefly quartz) is increased so that the soft ores are higher grade but more siliceous. The physical structure of soft ore varies from friable, unconsolidated material to a rather hard, closely compacted mass. As the soft ores are both more accessible and higher grade, they have furnished the bulk of the production outside the Birmingham district and have, to a large extent, been mined out.

Chemical composition.--Analyses from the literature have been assembled on the maps (figs. 1 and 3). Analyses of soft ores predominate because these ores were more extensively mined; however those of the hard ore are far more significant as representing the bulk of the remaining material.

The hard ores range downward in grade from 47.7 percent iron (McCaulie, 1908, p. 91) and pass into ferruginous limestone and sandstone containing less than 20 percent iron. Most have less than 40 percent iron; the average may be less than 30 percent iron.

The manner in which the hard ores pass into semihard and soft ores is illustrated in table 1, after Burchard (1913, p. 76), who had an opportunity to sample an ore bed both from below the weathered zone and progressively higher toward the original surface. The increase in combined water, due to hydration of some of the hematite to limonite, is accompanied by color change from dark red to yellowish brown.

Table 1. Analyses of hard, semihard, and soft "Rockwood" iron ore from Chamberlain, Tenn., after Burchard (1913, p. 76).

	Hard	Semi-hard	Soft, near dividing line	Soft
Fe	27.22	37.32	52.55	50.79
SiO_2	5.00	7.92	7.63	7.62
Al_2O_3	2.82	3.07	3.64	4.31
$CaCO_3$ a/	44.40	24.50	3.00	0.70
P	0.44	0.57	0.74	0.53
H_2O +	4.72	5.52	8.15	9.35

a/ Recalculated from CaO.

Thickness.--Individual ferruginous Silurian beds range in thickness from an inch or less to 30 feet, but except in the Birmingham district most are at best only a few feet thick. Commonly several ore beds are present, separated by varying amounts of shale or sandstone. The separate ore beds are not continuous; rather they lens out to be replaced by others.

In most places only one ore bed is thick enough to be workable, but locally three separate beds have been mined. Where mined the principal bed varies from about 18 to 48 inches except for a few places such as Greasy Cove, near Gadsden, Ala., where it is 90 inches thick.

The thicknesses of the principal ore bed, of the total ore in the section, and of the total ore-bearing section have been shown at numerous places on the maps. In addition, the outcrop of the ore beds has been shown in a solid line where the principal bed is 18 inches or more thick and a dashed line where it is thinner than this.

Distribution.--The red ores were originally deposited in shallow seas that covered this part of the country in Silurian time. Later, during the deformation that led to the building of the Appalachian Mountains, the beds were folded into anticlines (arches) and synclines (troughs), and also were broken by faults. Erosion has since removed the ore beds from most of the anticlinal areas, so that for the most part only the downfolded parts of the total area of iron deposition are preserved today. On figures 1 and 3 these areas have been indicated by a ruled pattern.

Cross sections (figs. 2 and 4) along lines indicated on the maps show graphically the geologic structure of the area and the probable subsurface position of the ore beds. Depths below the present surface, which in general range from about 2,000 to 3,500 feet in the centers of the synclines, are based on knowledge of the thicknesses of the overlying rocks and careful identification of the beds during geologic mapping. The only drill hole known to penetrate the ore far back from the outcrop is that near Pine Knot, just north of the Tennessee-Kentucky boundary (figure 3).

The southeasternmost outcrops of red ore in Georgia, too thin to be minable, are shown by short dashed lines in Floyd, Gordon, Walker, and Whitfield Counties. Thicker beds, still only 1 to 2 feet in aggregate, crop out on Taylor Ridge in Chattooga, Walker, Whitfield, and Catoosa Counties; some soft ore was formerly mined by stripping at a number of places, and a little underground work was done near the southwest end of the ridge. No analyses of hard ore are known; presumably all the production was of soft ore that ranged in grade from about 49 to 57 percent iron (analyses B1-6, fig. 1).

Thin red ore beds, in general aggregating two feet or less, crop out on Dirtseller Mountain, which lies across the State boundary in Chattooga County, Ga., and Cherokee County, Ala. Production, now entirely ceased, was principally by stripping with some underground operations, and a good grade of soft ore was mined (analyses C1-3). Thin beds southeast of Gadsden, Ala., were stripped.

The ore beds crop out almost continuously along both sides of Lookout Mountain for about 80 miles, from Gadsden to Chattanooga. In Walker County, Ga., Pigeon Mountain projects as a spur separated from the main mass by the anticline in McElmore Cove which brings older, less resistant rocks to the surface (see section B-B', fig. 2).

The ore beds dip below the surface from both sides of this mountain and are covered by younger, more resistant rocks, chiefly sandstones, that contain some coal horizons. The width of the belt presumed to be underlain by ore beds in the Lookout Mountain syncline and Pigeon Mountain spur ranges from about 5 to 10 miles; the area is nearly 620 square miles in Alabama and Georgia, and 17 square miles in the Tennessee extension of the zone.

The aggregate thicknesses of the ore beds vary from less than a foot to four feet or more. In places the proportion of ore to rock in the section is high, so that the beds could be mined as a unit without extracting an undue proportion of waste, in others the beds are separated by considerable waste.

Sand Mountain lies northwest of Lookout Mountain and is separated from it by Wills and Lookout Valleys except for a narrow connection near the Georgia-Alabama border. The red ore beds underlie the entire area from the outcrops along the west sides of these valleys to the line of the Tennessee River and the valley extension southwest of Guntersville (see fig. 1). In southernmost Tennessee (fig. 3) the Tennessee River cuts through this mountain belt and turns northeastward again to parallel the east flank of the ore-bearing area, while Sequatchie Valley continues northeastward some 65 miles along the west side, here called Walden Ridge. Ore thicknesses vary even more widely, and the proportion of shale, sandstone, or limestone in the total ore section tends generally to increase northwestward. Relatively little mining has been done along most of this belt; analyses are scarce, but those available show a progressive decrease in iron content northwestward. The series of analyses M1-9, fig. 1, along the west flank of Sand Mountain, are of ferruginous sandstones and limestones of no potential value. In Marion County, Tenn., however, substantial quantities of ore were mined prior to 1905 along the west edge of Walden Ridge (Inman mine, table 9). Although the analyses (H1-2, fig. 3) show that the hard ore is fairly low in iron (24-28 percent), leaching of its high carbonate content (32-54 percent) probably yielded a high-grade soft ore.

North of the head of Sequatchie Valley, Walden Ridge merges with the Cumberland Plateau. The abrupt bend to the northwest near the line of section C-C' (fig. 3) is due to faulting that carried older rocks northwestward. The red ore beds crop out again along the front of Cumberland Mountain, where they are some 3 to 4 feet thick and of moderate grade (analysis E-1). They dip to perhaps 3,850 feet below Walnut Mountain (section B-B', figure 4), reappear only briefly in Pine Mountain, and do not come to the surface again. Fifteen miles northwest, in Kentucky, a drill hole encountered six feet of moderately good ore (analysis J-1) at a depth of 1,720 feet.

East of the Walden Ridge-Cumberland Plateau mass in Tennessee, only isolated small areas of red ore have escaped erosion by being down folded or faulted. By far the largest of these is in White Oak Mountain, the northern continuation of Taylor Ridge in Georgia. In general the beds are thin, two feet or less, but in the area near Watts Bar Reservoir aggregate thicknesses range up to 8 feet. Many of these isolated patches were formerly mined, as shown on figure 3.

Southwest of Gadsden the red ore beds underlie Blount and Chandler Mountains, coming to the surface along the northwest edge of Canoe Creek Valley and around Greasy Cove. The ore-bearing area merges into Sand Mountain to the north and west, and extends southwestward beyond the map area toward Birmingham. Aggregate ore thicknesses also vary widely, ranging upward to 90 inches in Greasy Cove (Burchard 1933, p. 5).

Reserves.--In the strict sense, ores are materials that can be extracted and sold at a profit under the conditions obtaining at any given period, and reserves are composed only of ores. In this sense, there is little red iron ore in the area under consideration and almost no reserve. Most of the ferruginous material in the Clinton formation, except for a little around Gadsden, Ala., and near Rockwood, Tenn., falls in the general category of resources, material that would have potential value under improved conditions of price or technology.

Grade, amenability to beneficiation, thickness and attitude of ore beds (which affect cost of extraction), and cost of transportation to market are major factors in determining the value of a raw material. Implicit in any economic evaluation of a resource is the competition from alternate sources of supply, which themselves have costs based on the same factors.

Careful reserve estimates of the Southeast red ores have been made in the past, and no significant new data have been developed that alter the picture presented earlier. However, the present report attempts to analyze the data in a somewhat different, perhaps more refined manner, as is explained below. For comparative purposes an earlier estimate is given first, including the figures for the Birmingham district.

Table 2. Red iron ore reserves in the Southeast, after H. D. Pallister and E. F. Burchard, in Chapman, 1953, p. 50.
(in millions of long tons)

District	Available ore [a]	Potential ore [b]	Total
Birmingham	1,855	2,680	4,535
Northeastern Alabama	51	2,120	2,171
Northwest Georgia	19	1,820	1,839
Tennessee	36	1,310	1,346

a/ Available ore is near-surface material, generally not more than 1,000 or 1,200 feet down dip. Seams down to 2 feet thick included. Original workers cautioned that this material was not economic when the estimate was made, except at Birmingham and near furnaces at Gadsden, Ala., and Rockwood, Tenn.

b/ Material lying at distances from outcrop greater than limit of the "available ore." For northeastern Alabama, based on assumption of 3 feet of "ore" underlying 341 square miles. Presumably similar assumptions made for Georgia and Tennessee.

For this report it has been assumed that a minimum thickness of 30 inches of ore might be economically minable (granted that the other problems were solved), so long as it occurs in one bed or in a group of closely spaced beds that could be extracted as a unit. It has further been assumed that the proportion of area underlain by ore beds at least this thick is the same as the proportion of linear outcrop meeting this minimum condition. Where greater average thicknesses occur, correspondingly larger figures were used. This is obviously one of the weakest links in the tonnage calculations, particularly where relatively few sections have been measured and the areas involved are large.

Areas were measured from the maps. No split between States has been made for the parts of Sand and Lookout Mountains that lie in Alabama and Georgia.

Burchard made many determinations of specific gravities of the red ores, which vary rather widely according to their grade and the amount of pore space. The hard red ores generally range from 11 to 12 cubic feet per long ton, except for the best Birmingham ores that run about 10 cubic feet per long ton. In this report a figure of 12 cubic feet (Burchard and Andrews, 1947, p. 100-101), is used, which is believed to be reasonably conservative for the better ores and is the factor used by Burchard and Andrews (1947, p. 367) for the Lookout Mountain area. Obviously this factor is another of the uncertainties that vitiates any attempt to be precise in the calculations that follow. At 12 cubic feet per long ton, a square mile of ore one foot thick weighs 2,323,200 long tons.

Table 3. Estimated potential resources of Silurian red iron ore in Georgia, northeast Alabama, and Tennessee.

Location	Thickness, inches a/	Area, square miles		Long tons c/
		Total	Having thickness shown in first column b/	
Ga.-Ala. (See fig. 1)				
Lookout and Pigeon Mtns.	30	619	248	1,441,000,000
Sand Mountain	30	1,360	258	1,500,000,000
Blount and Chandler Mtns.	30	210	72	418,000,000
Tenn. (See fig. 3)				
Walden Ridge-Cumberland Plateau:		1,791		
Cumberland and Pine Mtns.	48		87	808,000,000
Other areas	36		91	635,000,000
	30		29	167,000,000
Area 5 mi. SSW of Kingston	90	0.654	0.654	11,400,000
Area 4 mi. S of Barnardsville	42	0.426	0.426	3,465,000
Area W & N of Maple Grove	36	5.29	5.29	36,880,000
From Chattanooga N to Falling Water Creek	36	17.1	3.03	21,130,000
				5,020,745,000

a/ Minimum thickness considered, 30 inches.

b/ Based on assumption that outcrop thicknesses reflect thickness over total area in proper proportion.

c/ Volume converted to weight at 12 cubic feet per long ton; a square mile of ore 1 foot thick equals 2,323,200 l.t.

The results in table 3 agree reasonably closely with the 5,356,000,000 given in table 2 for the area outside the Birmingham district, although the methods used and assumptions differed in detail. It seems entirely probable that some 5 billion tons of ferruginous material may be taken as a round figure for the resource of potential iron ore contained in beds aggregating 30 inches or more in thickness and capable of being extracted as a unit without undue proportions of waste. This figure may, indeed, be conservative.

However, two notes of caution must be emphasized. The first is that very little or none of this material can be mined profitably at present or at any foreseeable future date. This is dealt with in detail in a later section of this report. The second is that the statistical approach used does not pinpoint the areas under cover of younger rocks that have these presumably minable thicknesses. Far more exploratory drilling would be necessary to prove the existence of these thicker sections and outline their limits before plans could be made for mining.

Brown ores

The brown ores are essentially nodules and fragments of limonite (hydrous iron oxide) that occur mixed with clay and rock fragments on or near the eroded, irregular surface of older rocks. The deposits commonly are covered by unconsolidated sand or gravel from a few feet to 30 feet thick. The ore nodules, lumps, and boulders vary from dense, solid limonite containing well over 50 percent iron to hollow shells incorporating clay, sand, gravel, and chert. Honeycomb ore consists of hard limonite in thin webs with open spaces between them.

Brown ores do not occur as continuous regular layers, like the red ores, so that it is not possible to predict the size of a deposit from geological studies. On the contrary, test pitting or drilling is needed to outline the ore limits. The deposits range from small pockets to areas covering hundreds of acres with ore as much as 100 feet deep and containing more than a million tons. In location, the deposits occur from the crests of narrow ridges to well down the slopes toward the valleys.

In Alabama, the most important brown ore-producing areas have been the Woodstock, Champion, Russellville, Eastern Alabama, and South Alabama districts.

Brown ores in Georgia are classified into four groups: 1) deposits of the area of typical Paleozoic rocks, 2) deposits on metamorphosed Paleozoic rocks, 3) deposits on crystalline rocks, 4) deposits of the Coastal Plain area. The most important are those in the first category; some ore is also being produced at present from Coastal Plain deposits.

Two areas have brown ore deposits in Tennessee. The more important one is the Western Highland Rim area in west central Tennessee, west of the mapped area. Minor amounts occur in eastern Tennessee also.

Because of the irregular, unpredictable nature of the deposits, the ultimate resources of brown ore are particularly difficult to estimate. On the other hand, reserves that have been proved by drilling are normally extracted in a relatively short period. Pallister and Burchard (Chapman 1953, p. 50) estimated brown ore reserves in the Southeast at 54 million short tons available and 23 million short tons potential. The total, 77 million, is equivalent to about 69 million long tons. Some 10 million long tons have been mined since the estimate was made; some new ore has probably been found, or potential ore transferred to the "available" category. As the Department of the Interior has no basis for revising this estimate, nor could a more accurate one be obtained without a considerable expenditure of time, the figure of 60 million long tons is used here to indicate the order of magnitude of the Southeast brown ores.

Magnetic ores

Gray or black ores consisting in part or entirely of magnetite (Fe_3O_4) occur in a number of places in the Southeastern States. They are, however, the least important of the three ore types because only small quantities are known to be available, and these are at considerable distances from existing furnaces. Siliceous magnetite ore was formerly mined in the mountainous area along the North Carolina-Tennessee border, particularly at Cranberry, N. C. Titaniferous magnetite deposits are known in North Carolina, Tennessee, and Georgia that are not suitable for iron production. Mixtures of magnetite and gray, specular hematite occur along the North Carolina-Tennessee boundary and in eastern Alabama, especially in Talladega County, but there has been only small production many years ago, and the deposits are not believed to be either large enough or rich enough to have any present interest. (Chapman and others, 1953, p. 45-47; Haseltine, 1924, p. 183-198.)

Pallister and Burchard (Chapman 1953, p. 50) estimated reserves of magnetite and hematitic magnetite at 30 million short tons available and 33 million short tons potential. Of the 63 million tons total, 44 million are in the Talladega gray ores. As no magnetic ores are known to have been mined in recent years and there is no new information on them, the above figure, equivalent to about 56 million long tons, is used here.

Mining

History and production

No statistics are available on mine production during the early days of the iron industry in the Southeast, but the output in that period could not have been large. Tables 4-6 give ore production for Georgia and Alabama north of the Birmingham district since 1890, and for east Tennessee since 1881. The total is slightly over 36 million tons distributed as follows: Georgia, 41 percent; northeast Alabama, 29 percent; and east Tennessee, 30 percent. By far the greater part of the Georgia output has been brown ore, but in the counties within the map area of figure 1 (shown by an asterisk in table 4) red ore has predominated. Table 5 shows that relatively little ore has ever been mined in Alabama north of the Gadsden area in Etowah County. Nearly all the Tennessee production has been red ore; in fact, the Tennessee production of red ore has exceeded the total output of this ore type from all other areas of the Southeast except the Birmingham district.

Table 4.--Production of iron ore in Georgia, by counties, 1890-1957
(long tons)

County	Hematite	Limonite	Total
Bartow................		5,519,082	5,519,082
Chattooga *	108,090	334	108,424
Cherokee..............		229,643	229,643
Dade *	111,772		111,772
Fannin................		115	115
Floyd *	36,165	116,788	152,953
Gilmer................	120	27,606	27,726
Gordon *		80,690	80,690
Haralson..............			247 a/
Meriwether............		12,013	12,013
Muscogee..............		2,615	2,615
Polk..................		5,355,218	5,355,218
Quitman...............		123	123
Stewart...............		164,842	164,842
Walker *	989,764	7,328	997,092
Webster...............		5,161	5,161
Whitfield *		31	31
Undistributed.........	684,598	1,271,508	1,956,106
Total............	1,930,509	12,793,097	14,723,853

* County within area shown on figure 1.

a/ Magnetite.

Table 5.--Production of iron ore in Alabama northeast of the Birmingham district, by counties, 1890-1957
(long tons)

County	Hematite	Limonite	Total
Blount............	---------	2,934,507	2,934,507
Calhoun...........	42	---------	42
Cherokee..........	13,829	1,313,833	1,327,662
De Kalb...........	15,592	---------	15,592
Etowah............	5,989,971	---------	5,989,971
Jackson...........	---------	3,258	3,258
Marshall..........	---------	7,614	7,614
St. Clair.........	32,101	48,472	80,573
Total........	6,051,535	4,307,684	10,359,219

Table 6.--Shipments of iron ore in east Tennessee, by counties, 1881-1957
(long tons)

County	Hematite	Limonite	Total
Anderson..........	184	---------	184
Bradley...........	703	---------	703
Campbell..........	592,363	---------	592,363
Claiborne.........	78,603	---------	78,603
Hamilton..........	6,331	---------	6,331
Marion............	1,551,619	---------	1,551,619
McMinn............	---------	11,418	11,418
Meigs.............	233,443	---------	233,443
Roane.............	5,595,979	---------	5,595,979
Undistributed.....	2,866,696	---------	2,866,696
Total........	10,925,921	11,418	10,937,339

Tables 7-9 give the production of the leading individual iron ore mines of the area under discussion. The column labeled "Active period" shows the known initial and terminal dates of mining and does not necessarily mean that production was continuous throughout the period shown.

All mining of red ores has ceased in Georgia; in fact very little has been produced since the mid-twenties except during the World War II period. In northeast Alabama only the mines near Gadsden continue to yield red ores. In Tennessee only the Chamberlain mine has been actively producing red ore in recent years for smelting in the Rockwood furnace nearby, and it is believed to have about reached the limit of its ability to compete.

Table 7.--Production of leading iron ore mines in Georgia

Mine	County	Active Period	Total Production (long tons)
Limonite:			
Bartow..............	Bartow	1891-	2,233,000
Iron Hill...........	Bartow	1910-	1,895,000
Woodstock...........	Polk	1885-1938	1,207,000
Oremont.............	Polk	1881-	682,000
Grady...............	Polk	1881-	581,000
Hematite:			
Estelle.............	Walker	1901-1955	977,000
Rising Fawn.........	Dade	1902-1940	112,000
Taylors Ridge.......	Chattooga	1907-1921	56,000
Dirtseller Ridge....	Chattooga	1903-1941	52,000

Table 8.--Production of leading iron ore mines in Alabama northeast of the Birmingham district

Mine	County	Active Period	Total Production (long tons)
Limonite:			
Champion............	Blount	1891-1946	2,018,686
Taits Gap...........	Blount	1922-	838,748
Auxford.............	Calhoun	1923-1953	614,467
Rock Run............	Cherokee	1906-	293,645
Woodward............	Cherokee	1909-1953	283,779
Hematite:			
Attalla.............	Etowah	1904-	2,761,960
Crudup..............	Etowah	1899-1921	1,464,059
Etowah..............	Etowah	1890-	1,170,093
Portersville........	Etowah	1904-1908	142,400
Citico..............	Etowah	1906-1924	126,541

Table 9.--Production of leading iron ore mines in east Tennessee

Mine	County	Active Period	Total Production (long tons)
Limonite:			
Nonaburg...........	McMinn	1957	11,418
Hematite:			
Cardiff............	Roane	1896-1921	3,729,932
Inman..............	Marion	1891-1905	1,551,619
Chamberlain........	Roane	1907-	854,704
Clymer.............	Roane	1921-1930	674,343
LaFollette #3......	Campbell	1901-1924	471,052

Future potential

The future outlook for mining of the red iron ores of the Southeast is not promising, except for the Birmingham district, because iron and steel apparently cannot be made from them as cheaply as they can from other raw materials. Only special circumstances, such as a protracted disruption of normal trade by war or artificial stimulus through Government action, are likely to promote utilization of any substantial quantity of this material. The reasons for this competitive disadvantage are set forth below.

Iron and steel can be made from virtually any iron-bearing material. The profit that makes production attractive for investment of capital depends, of course, on the spread between costs and the price for which the products can be sold. Costs include the expense of mining and beneficiating raw materials, transportation of raw materials to the furnaces, smelting costs, and transportation of the product to the consumer. Grade of the iron ore is a basic factor because the impurities of low-grade ore not only increase the per-unit transportation cost to the furnace but also increase the quantities of other raw materials, principally coke and limestone, required to smelt the ore. Furthermore, the furnace capacity is reduced relative to the output attainable with good ore.

In special cases, as in the Birmingham district, ores of 35 to 40 percent iron content from captive mines can be used because their lime content reduces the quantity of limestone that must be added to the charge--they are, in blast furnace terminology, "self-fluxing." The materials discussed in this report range downward from 48 percent iron, but most have less than 40 percent, and the average may be less than

30 percent iron. Although some of this material is "self-fluxing" and therefore might be marketable under special conditions, essentially all run-of-mine material would have to be upgraded to find a market under normal conditions.

Mining problems and costs.--As only a minor amount of near-surface ore remains that could be extracted by strip mining, most mining would have to be by underground methods. Because the beds are thin, unit costs would be high. Considerable excess rock would have to be removed where the ore thickness is insufficient to permit haulage. The advantages of large-scale mechanization could not be applied to ore extraction. Lack of efficient working room would hold down production per man and result in high labor costs.

The roof conditions are not good because the thinly laminated ore-shale-sandstone sequence would require strong support for safety and to avoid undue contamination of the ore zone through overbreaking and slabbing.

The particular mining method employed would depend on the attitude of the ore beds. Near the outcrops they dip moderately to steeply; close folds and minor faults would require deviations from a regular pattern of workings. Down dip the attitude is believed to be nearly horizontal (see figs. 2 and 4) and less complicated, so more regular operations might be possible. Details are obviously not known in these deeper areas, however, and local irregularities are entirely possible.

Most of the potential ore lies below the ground water table where there is danger of flooding. Pumping would add to the cost. Although the shale beds should seal much of the water out of the workings, fractures could form channelways for large volumes of water under considerable pressure. Large pumps were needed at mines near Gadsden, Alabama.

An estimated mining cost for these ores is attempted in table 10, based on the costs of reopening a small iron ore mine near Gadsden in 1947 and on the costs of somewhat similar but much smaller operations in uranium mines on the Colorado Plateau, adjusted to 1958 prices where practicable. These are given for comparative purposes. Obviously it is impossible to predict accurately, as to a considerable extent the costs would depend on the scale of operations, ore thickness, attitude, etc.

The hypothetical operation used here is a mine producing 1,000 tons of ore per day (300,000 tons per year) over a period of 20 years. Recovery of 80 percent of the ore is planned for by the method outlined below, so the minimum reserve needed would be 7.5 million tons. On the assumption that this is contained in a bed 2½ feet thick, the area would be about 1.3 square miles and the average haul to the surface would be 3/4 mile. Further assuming a dip of 20 degrees, a modified room and pillar method would be used in which haulage drifts would be driven in ore (with the bottoms lowered to provide head room) from an incline at 200-foot intervals down the dip. Rooms would be started from 7 X 6-foot raises between levels at 60-foot intervals. Each block, bounded by the drifts and raises, would contain slightly over 1,600 tons of ore, of which about 1,300 tons would be mined and the remainder

Table 10.--Detailed estimate of costs of hypothetical typical mine in the southeastern red ore of Silurian age and actual costs of similar but smaller operations

	ESTIMATED COSTS		ACTUAL COSTS							
	Typical Mine (1958 prices)		Gadsden, Ala. 1947 1/		Big Buck Uranium 1955 2/			Calyx No.8 1955-57 3/	Calyx No.3 1955-57 3/	Average of 10 Salt Wash Mines 1956 4/
	Cost/ft. 6' x 7'	Cost/ ton	Units/ft.	Cost/ft. 6' x 7'	Cost/ ton	Percent of total	Cost/ft. 6' x 7'	Cost/ton	Cost/ton	Cost/ton
Indirect cost										
Engineering and sampling	------	$0.035	----------	------	$0.09	-----	------	$0.03	$0.08	---------
Service operation, maintenance, depreciation	------	.020	----------	------	.24	-----	------	.17	.18	---------
Depreciation, mining equipment .	------	.030	----------	------	.74	-----	------	.18	-----	$0.75
Depreciation, mine plant	------	.050	----------	------	.09	-----	------	-----	.03	-----
Payroll, taxes and workman's compensation	------	.210	----------	------	.22	-----	------	.74	.62	.58
Miscellaneous	------	.100	----------	------	.46	-----	------	-----	.06	.07
Administration	------	.077	----------	------	.25	-----	------	.06	.41	.15
Subtotal		$0.522			$2.09	27½		$1.18	$1.38	$1.50
Development										
Labor	$9.07	------	22.84 mhrs	$21.70	$0.13	-----	$19.30	$0.51	$0.44	$1.25
Supervision	.71	------	1.55 mhrs	------	.01	-----	------	.10	.09	.20
Drill steel and bits	1.10	------	1.96 ea	.68	.01	-----	------	.03	.03	.06
Power and electric supplies . .	.31	------	205.2 kw	.41	-----	-----	9.60	.06	.08	.13
Supplies - other	------	------	----------	------	.04	-----		.14	.11	.30
Timber	3.04	------	----------	------	-----	-----	------	-----	-----	-----
Ventilation	1.65	------	----------	------	-----	-----	1.65	-----	-----	-----
Air and water pipe	2.11	------	----------	------	-----	-----	2.11	-----	-----	-----
Explosives	3.14	------	10.02 lbs	------	.09	-----	3.30	.11	.09	.17
Subtotal	$21.13	$3.44		$22.72	$0.28	4	$35.96	$0.95	$0.84	$2.11
Mining										
Labor	------	$0.80	----------	------	$1.15	-----	------	$3.40	$3.51	$5.40
Supervision		.05	----------	------	.25	-----	------	.53	.59	.85
Drill steel and bits	------	.28	----------	------	.45	-----	------	.20	.15	.23
Power and electric supplies . .	------	.55	----------	------	.19	-----	------	.27	.37	.53
Explosives	------	.56	----------	------	.73	-----	------	.63	.83	.69
Diesel fuel, oil and grease . .	------	1.16	----------	------	.31	-----	------	.16	.18	-----
Supplies - other	------	-----	----------	------	.26	-----	------	.87	.83	1.36
Timber	------	-----	----------	------	-----	-----	------	-----	-----	-----
Subtotal		$3.40			$3.34	45½		$6.06	$6.26	$9.06
Haulage	------	-----	----------	------	$0.38	-----	------	-----	-----	-----
Maintenance	------	-----	----------	------	1.23	-----	------	-----	-----	-----
Subtotal					$4.95	67½				
Total		$7.36			$7.33			$8.19	$8.48	$12.67

1/ Feeley, J. C., 1949, Reopening and developing a small red-iron-ore mine, Gadsden, Ala.: U. S. Bur. Mines Inf. Circ. 7499, p. 25-28.

2/ Dare, W. L., and Durk, R. R., 1956, Mining methods and costs, Standard Uranium Corp., Big Buck Mine, San Juan County, Utah: U. S. Bur. Mines Inf. Circ. 7766, 51 p.

3/ Dare, W. L., 1957, Mining methods and costs, Calyx Nos. 3 and 8 Uranium Mines, Temple Mountain district, Emery County, Utah: U. S. Bur. Mines Inf. Circ. 7811, 36 p.

4/ Dare, W. L., 1959, Uranium mining practices of ten Salt Wash mine operations of Union Carbide Nuclear Co: U. S. Bur. Mines Inf. Circ. 7922, 71 p.

left behind as a central pillar to support the workings.

The cost shown, \$7.36 per ton at the mine for this imaginary operation, is believed to be as low or lower than the cost for any other underground mining method, and may be taken as a minimum average for the region. In those relatively restricted areas where the ore zone exceeds the $2\frac{1}{2}$-foot figure used, the development costs per ton (the major single item, table 10) should be correspondingly lower.

As most of the ore is too low grade to be sold regardless of price, it would have to be upgraded to find a market, which would add greatly to the cost (see below). For the part that could possibly be sold, however, the contrast between the valuation of \$6.53 placed on Alabama direct-shipping ores in 1958 and the mine-head costs shown above clearly demonstrates why these ores could not be mined successfully under present day economic conditions.

Beneficiation.--Although no tests have been made on the ores discussed in this report, the Bureau of Mines Southern Experiment Station at Tuscaloosa, Ala., has made extensive beneficiation tests on red iron ores from the Birmingham district (Thoenen, Reed, and Clemmons, 1953). Several methods are technically feasible; flotation is considered preferable to magnetic separation because it does not reject the calcite to the same degree as does the latter method and thereby yields a concentrate that is approximately self-fluxing.

Costs would naturally vary with the grade of the crude ore, grain size and nature of the impurities present, method used, and grade of concentrate obtained. Although no firm figures can be assigned, an approximation is given in table 11, adapted from the Bureau of Mines work (Thoenen, Reed, and Clemmons, 1953, p. 62), in which the mining cost derived above has been used as a starting point. The average feed taken for this estimate was 28 percent iron; a higher grade feed should reduce costs, as should a higher plant capacity. Costs exclusive of mining are about $2.00 per ton of crude ore, whereas Clemmons estimates that in concentrators larger than the 500-ton per day plant used in table 11 they might be as low as $1.05 (at 1953 prices).

Regardless of the economies that might be effected, the need to mine approximately 2 tons of ore for each ton of concentrate makes it unlikely that costs for a saleable product could be reduced much below $15 per ton, and $20 is perhaps more nearly realistic.

To this would have to be added the freight, which for example, is $1.55 per ton from northeast Georgia to Birmingham, and a profit margin. Concentrates containing 47 percent iron were valued in Birmingham at about $8 per ton in 1958.

<u>Smelting</u>.--The cost per ton of smelting the hard red ores of the area under consideration would equal or exceed the cost for Birmingham ores, if shipped there. Although it might at first glance seem attractive to smelt them locally, experience indicates that iron and steel made from them could not compete with products shipped in from the major steel-making centers, for the furnaces at Rockwood, Tenn., and Gadsden, Ala., have used very little local ore after exhaustion of the nearby soft ores. Instead they have

Table 11.--Estimated cost of concentrate from the hypothetical mine, based on estimated milling and beneficiation costs for surface hematite in northeast Birmingham district. 1/

Basic factors:

Feed	28% Fe
Concentrate	50% Fe

85% recovery $\frac{50}{.85X28}$ = 2.1 tons ore/ton of concentrate

Costs:

Mining (all costs to mill)	$7.36
Crushing and grinding	.30
Flotation (labor, power, materials)	.40
Filtration	.12
Agglomeration	.65
Tailing disposal	.01
Maintenance and labor	.15
Taxes	.10
Amortization	.05
Laboratory, Insurance and Social Security	.21
Cost per ton of ore treated	$9.35
Times 2.1, tons of crude ore to make 1 ton of concentrate	$19.64

1/ Clemmons, B. H., The Future of Birmingham Red Iron Ore, Jefferson County, Ala., Part II: Bureau of Mines Report of Investigations 4988, 1953, 71 pp.

turned to brown ores, imported ores, and scrap.

New blast furnaces would have to amortize the high construction costs and should therefore be no better able to compete than existing ones.

Several direct reduction processes, such as the recently developed R-N process, probably could be used to smelt the hard red ores. These have the advantage of lower capital investment and do not depend on top-quality coking coals for fuel, but the operating economies would still not make new local steel centers competitive with established sources.

Summary of competitive position.--The hard red ores of the region outside the Birmingham district are at a distinct disadvantage, as compared with present ore sources, for the following reasons:

1) The ore beds are thin, averaging at best only a few feet thick, whereas Birmingham mines work a seam averaging 8 feet of good ore. Mining costs alone would equal or exceed the average value of $6.53 per ton reported in 1958 for Alabama direct-shipping hematite ore.

2) The grade averages perhaps 28 to 30 percent iron, as compared to a 40 percent minimum specified for purchased ores at Birmingham (although the companies may use lower grade material from their own mines if it is self-fluxing). Most ore would have to be upgraded.

3) Probable costs of concentrates would be $15 to $20 per ton plus freight to Birmingham, as compared with a valuation of about $8.00 per ton for concentrates produced in the Birmingham district and used in nearby steel mills.

4) Imported ores, now increasingly used at Birmingham, are considerably higher grade (perhaps averaging 60 percent iron) and are correspondingly higher priced than local ores, but the price per unit of iron

contained in them is believed to be roughly equivalent to that of local ores. Furthermore, smelting economies achieved through the lowered flux and fuel costs probably more than offset any price differential. By contrast, the low-grade hard red ores would have higher flux and fuel requirements.

The establishment of local industries would not overcome these competitive disadvantages, for finished products could be brought in more cheaply than they could be manufactured on the spot with indigenous raw materials.

Conclusions

The present study has led to the following conclusions, which except in detail confirm the results of previous studies and explain the general lack of activity by private mining interests in the area.

1) The hard red Silurian iron ores constitute by far the greatest part of the iron ore resources of the Southeast.

2) Potential resources of red ore outside the Birmingham area are estimated, in round figures, at about 5 billion tons that may average close to 30 percent iron, contained in one or more beds that could be extracted as a unit and total at least 30 inches of ore.

3) Very little of this material is of present commercial interest because it cannot compete with ores from other sources, nor could steel be produced from it for costs equal to or lower than prices for steel from other places.

4) If access to other ores should be cut off, or should prices so increase for any reason that the red ores of northern Alabama, Georgia,

and Tennessee became economically attractive, they could furnish large quantities of ore for many years. However, conditions under which this situation would arise are not envisioned as likely in the foreseeable future because large reserves of better ore are readily available.

5) The foregoing does not deny the possibility that special conditions may permit relatively small operations to be undertaken profitably from time to time, but there is no likelihood that any such developments would have national or even regional significance.

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