IRON AND MANGANESE ORES.

THE CLINTON OR RED ORES OF THE BIRMINGHAM DISTRICT, ALABAMA.

By Ernest F. Burchard.

INTRODUCTION.

Detailed work on the iron ores of the Birmingham district was carried on in the summer of 1906, continuing to the southward the studies of these ores begun in northeast Alabama by E. C. Eckel in the fall of 1905.

By the Birmingham district is meant the area from which the furnaces at Birmingham, Ensley, and Bessemer derive their iron ores. It is comprised within the southeastern part of the Birmingham 30-minute quadrangle, the northwest quarter of the Bessemer quadrangle, and the northeast quarter of the Brookwood quadrangle. As a complete report, with maps, covering the iron ores and iron industry of the Birmingham district, is now in preparation, this paper presents only an outline of the principal facts regarding the red ore that were noted in the course of the survey. The brown ores used in the district come mainly from the vicinity of Woodstock. These ores, together with their geologic relations and extent, have been described in a previous Survey report.[a] The present bulletin contains an article by Charles Butts (pp. 247–255), outlining the distribution and character of the local fluxing materials.

THE TOPOGRAPHY AND ITS RELATIONS TO INDUSTRIAL DEVELOPMENT.

The city of Birmingham and its suburbs are built in the heart of the valley region of Alabama. This valley region lies between the Cahaba coal field on the southeast and the Warrior coal field on the northwest, and its rectilinear ridge and valley type of topography is in

[a] Burchard, E. F., Iron ores in the Brookwood quadrangle, Alabama: Bull. U. S. Geol. Survey No. 260, 1905, pp. 321-334.

strong contrast with the irregular, roughly dissected topography of the coal fields.

The valley topography is characterized by long, narrow, canoe-shaped troughs, in general parallel to each other and separated by well-defined ridges. The trend of the valleys is approximately N. 30° E. Their form is directly dependent on the geologic structure and lithology of the underlying rocks. They are developed mainly on the softest and most soluble rocks, along the axes of anticlines; the most enduring strata on the limbs of the folds forming the rims of the valleys. At distances of 2 to 5 miles apart openings or "gaps," some of which extend to the valley level, are cut at right angles through the ridges and afford convenient passageways between the valleys.

Birmingham Valley, the largest and from an industrial standpoint the most important of these valleys, extends from the vicinity of Springville on the northeast beyond Vance on the southwest, and from the Warrior coal field, or Sand Mountain, on the northwest to the Cahaba coal field, or Shades Mountain, on the southeast. To the southwest the inclosing ridges pass below unconsolidated Cretaceous and Tertiary clays and sands; to the northeast lies Blount Mountain. Birmingham Valley thus has a length of nearly 75 miles, an average width of more than 6 miles, and an area of nearly 500 square miles. This valley is divided into minor valleys by low ridges, such as Red Mountain and West Red Mountain, Flint Ridge, and Cemetery Ridge, all due to folding and faulting of the main anticline; and this complicated structure finds expression in Shades and Roups valleys at the southeast and southwest ends and in Jones and Opossum valleys at the northeast and northwest ends, respectively. This system of valleys varies in the altitude of its lowest levels from about 400 feet at the southwest to 700 feet at the northeast end. These altitudes are higher than the lowest levels cut by streams in the dissected plateau country, and consequently streams do not flow lengthwise through the valleys, but after flowing a short distance break through the bordering ridges and flow out into the lower country beyond. Birmingham Valley, on account of its relatively high altitude, really forms a divide, since its northwestern portion is drained by Warrior River and its southeastern portion by Cahaba River.

Red Mountain, the main minor ridge within Birmingham Valley, furnishes nearly all the red ore smelted in the district, and the Woodstock area, in the southwestern portion of the valley, produces the major part of the brown ore. Coking coal is mined in the Warrior coal field, only a few miles distant from the furnaces. Dolomite and limestone, suitable for fluxing, occur in the valley rocks below and above the red ore. Only in the southern Appalachian iron-ore districts is there grouped this series of deposits, each member of which is more or less dependent on the others, but which taken together form such a matchless combination of raw materials. The simple, regular topographic features of the valley have made accessible the ores and stone at every point where they are of workable character, and enterprising railroad companies have rapidly improved the opportunities for developing the region. The only serious problem involved by the valley topography is that of obtaining a water supply adequate for manufacturing purposes. The relatively high altitude of the valley, as before stated, has diverted the streams that rise within its borders. The supply from large springs is now nearly all utilized as soon as it emerges from the ground, but this is not sufficient to meet the demands. The Birmingham city supply is piped from the distant Cahaba River, and some of this water is used by manufactories, although its cost in large quantities is necessarily almost prohibitive. Two courses are open to the manufacturers—first, that of forming an association and building another large aqueduct from Cahaba River and, second, that of sinking deep wells at the several plants. The first plan involves cooperation and its results are assured. The second plan can be carried out by individual firms, but it would be an expensive experiment.

GEOLOGY.

STRATIGRAPHY.

The rocks underlying Birmingham Valley and constituting its borders may be grouped in the following section:

Section of Paleozoic rocks in Birmingham Valley.

System.	Formation.	Thickness.
		Feet.
Carboniferous	Massive very hard sandstone, somewhat pebbly	100- 600
	Interbedded shale and sandstone	100-2,200
	Bangor limestone	0- 400
	"Oxmoor" sandstone and shale	50- 300
	Fort Payne chert	200- 300
Devonian	Chattanooga shale	0- 20
Silurian	Rockwood (Clinton) shale, sandstone, and iron ore	180- 500
Ordovician	Chickamauga ("Trenton") limestone	200- 800
Cambro-Ordovician	Knox magnesian limestone and chert	2,000-2,700
	Knox dolomite	500- 600
Cambrian	Conasauga shale and limestone	[a] 1,500

[a] Base not exposed.

The base of the Cambrian system is not exposed in this area, and the rocks above the massive sandstone may be considered as belonging to the coal measures and consequently outside of the iron-ore district.

STRUCTURE AND DISTRIBUTION OF FORMATIONS.

A very much generalized section beginning at the Cahaba coal field on the southeast and passing northwestward across the valley at Birmingham would expose the rocks in the order of the above table, reading from the top down, with varying dips on the southeastern flank of a nonsymmetrical anticline having the Conasauga shale and limestone on the axis of the fold. A minor syncline follows, faulted down to the southeast, with the Knox formation held in the basin. The Conasauga again appears to the northwest of the Knox syncline, and bordering the Conasauga, on the northwest side of the valley, is an extensive overthrust fault which brings the Lookout sandstone and coal measures in contact with Cambrian and Ordovician rocks. For a short distance northwest of the fault the rocks show steep reversed or southeasterly dips, so that the only northwesterly dips displayed in the section are in connection with the small syncline of Knox chert and dolomite within the valley.

Here and there along the overthrust fault the throw has not been great enough to engulf the Silurian rocks completely, and at such places the Rockwood formation, dipping steeply, is exposed in a narrow outcrop. The presence of this formation in places on the northwest side of the valley has given to the ridge the name West Red Mountain. In the section outlined above, the Rockwood sandstone forms the crest of Red Mountain, with the Fort Payne chert overlying it and the Chickamauga limestone underlying it, making, respectively, the southeast and northwest slopes of the mountain. All the formations may be considered to extend longitudinally throughout the valley, in practically the relationships already indicated. The minor folding and faulting has duplicated the strata of West Red Mountain in the southern part of the valley, forming McAshan Mountain and a low ridge partly buried by post-Paleozoic sediments, south of Dudley. At the northeast end of the valley the extent of outcrop of the Rockwood and associated strata is increased by the synclinal Blount Mountain with the outlying Cedar Mountains, and by the synclinal structure north of Trussville.

Red ore occurs in practically all the outcrop areas of the Rockwood formation, but only in Red Mountain has it been found of sufficient thickness and purity to be worked on an important scale. The workability of the ore depends largely on the attitude of the inclosing strata. The beds of Red Mountain dip southeastward at moderate angles, which are in the main fairly constant for a mile or more along the strike and for a quarter to half a mile down the dip. Locally there are abrupt "rolls" or changes in the dip due to minor folds parallel to the main axis, and in some places the ore has been so faulted that efforts to find it or to exploit it further have been suspended.

The questions of deepest importance to the district are (1) whether the present quality of the ore will be maintained to great depth, (2) whether the present workable thickness will continue to whatever depth it may be possible to mine the ore, and (3) whether the structure of the rocks underlying Shades Valley—below which the ore beds normally lie—will be favorable for mining the ore. Certain facts have been brought out during this survey which have a bearing on these questions. These will be noted and discussed in the complete paper, but the nature of the present paper precludes more than a reference to the general conclusions.

CHARACTER OF THE ORES.

The ores consist essentially of red hematite, intimately mixed with varying percentages of lime and silica. The hematite occurs in beds interstratified with shale and sandstone, and the strata mostly dip at angles varying from 10° to 50°. In places, more particularly to the north of the Birmingham district, the Clinton ore is oolitic. Throughout its extent some beds are very fossiliferous, and some of the faunas found in the Birmingham district are typical Clinton forms of the New York section. Near Birmingham the ore beds are largely composed of fine to coarse silica pebbles, coated and cemented with ferric oxide. According as the ore is high or low in lime it is termed "hard" or "soft" ore. The distinction between the two varieties is based on differences in their chemical composition rather than on differences in hardness, although the terms "hard" and "soft" as originally applied to the ores probably had reference to their physical condition, since on the outcrop the soft ore is in general rather porous and friable. The unaltered ore is of the hard variety. The soft ore has resulted from the leaching by percolating waters of the soluble lime carbonate contained in the hard ore. This alteration occurs at the outcrop of the ore beds and down the dip to varying distances, depending on the thickness and permeability of the cover. Where the strata dip at fairly high angles and are underlain by impervious shale, the conditions are favorable for the passage of water through the beds to considerable depths. In a few places pockets of soft ore, surrounded by unleached ore, are encountered at relatively long distances from the outcrop. Such an occurrence of soft ore is usually due to the presence of fissures or brecciated rock, through which surface water has reached the ore bed. Where the overlying cover is heavy at the mouth of a slope or tunnel, the soft ore rarely extends more than 50 feet, but here and there the ore has been well leached to a distance of 400 feet from the outcrop. With the removal of the lime carbonate from the original ore the relative percentages of the remaining less soluble constituents, mainly iron oxide and silica, are increased. The following analyses show at the left a typical hard ore and at the right a typical soft ore, with intermediate or semihard grades between them:

Analyses of Clinton iron ores, showing gradation from hard to soft ore.

	1.	2.	3.	4.
Iron, metallic (Fe)	37.00	45.70	50.44	54.70
Silica (SiO_2)	7.14	12.76	12.10	13.70
Alumina (Al_2O_3)	3.81	4.74	6.06	5.66
Lime (CaO)	19.20	8.70	4.65	.50
Manganese (Mn)	.23	.19	.21	.23
Sulphur (S)	.08	.08	.07	.08
Phosphorus (P)	.30	.49	.46	.10

These analyses represent ore samples from a single slope on the same horizon of the Big seam in Red Mountain, near Birmingham, at distances respectively of 540, 480, 420, and 240 feet from the mouth of the slope. Beyond the point at which No. 1 occurs there is no great change in the character of the ore, for, as mined at present, the seam carries an average of 35 per cent metallic iron in this particular mine.

Although the soft ore carries a higher percentage of iron, the hard ore has the advantage of containing almost or, in places, quite enough lime to flux the silica that it contains. In case a hard ore contains more lime than is needed to flux its silica soft ore or brown ore (limonite) may be added to the burden to take up the excess of lime.

RELATIONS AND CHARACTER OF THE ORE BEDS.

The Rockwood formation, in which the ores occur, is extremely variable in thickness and in the details of its stratigraphy, although the presence of beds of hematite somewhere within the formation is a remarkably persistent feature, not only throughout the length of the Appalachians, but in rocks of equivalent age in Wisconsin and New Brunswick. In Alabama the formation is thickest at the north and there contains beds of limestone, which give way to sandstone with the thinning of the formation toward the south; the proportion of shale in the Rockwood is also greatest in the northern part of the State.

DESCRIPTION OF THE ORE-BEARING FORMATION.

BEDS ON RED MOUNTAIN.

Within the district here considered the Rockwood formation shows notable variations in composition from northeast to southwest, as is indicated by the following seven sections on Red Mountain, beginning northeast of Birmingham and continuing at irregular intervals for about 38 miles to the southwest. In each section the observed thickness has been corrected for the dips, which range between 20° and 50°, so that the computed thickness closely represents the actual thickness of the beds.

1. *Section of Rockwood formation in NE. ¼ sec. 23, T. 17 S., R. 2 W., near Irondale.*

		Ft.	in.
Top of formation unexposed.			
Sandstone, yellowish, heavy bedded		40	0
Unexposed		11	9
Sandstone		4	7
Unexposed (probably in large part shale)		19	10
Sandstone, green, flaggy, with yellow shale partings		25	0
Iron ore (*Ida seam*)		5	0
Shale, red			2
Sandstone, ferruginous, laminated		1	8
Iron ore (*Big seam*)	Ore, sandy	1	8
	Ore, lean, filled with small quartz pebbles	5	0
	Ore, minable	7	0
	Ore, fair quality, but not mined at present	6	0
	Ferruginous sandstone, ore, and shale, in layers 1 foot or less thick	20	0
Sandstone, very hard		3	0
"Gouge," calcareous			6
Iron ore (*Irondale seam*)		5	6
Sandstone, brown, thin bedded, with shale		20	0
Unexposed (probably shale)		65	0
Limestone (Chickamauga).			
		241	8

2. *Generalized section of Rockwood formation in SW. ¼ sec. 23, T. 17 S., R. 2 W., just south of Red Gap.*

		Ft.	in.
Chert (Fort Payne).			
Shale (may include a few inches Devonian)		11	0
Sandstone, coarse, ferruginous		25	0
Iron ore, solid (*Ida seam*)		6	0
Sandstone, coarse, ferruginous		25	0
Sandstone, coarse, pebbly; partially a low-grade ore		22	0
Shale			1
Iron ore (*Big seam*)	Upper part, minable	7	0
	Lower part, not yet mined	10	0
Shale		3	
Iron ore (*Irondale seam*)		4	4
Sandstone, red, soft		30	0
Sandstone, brown		35	0
		178	5

3. *Section of Rockwood formation on road across Red Mountain, in NW. ¼ sec. 5, T. 18 S., R. 2 W.*

	Ft.	in.
Chert (Fort Payne).		
Sandstone, heavy bedded	8	0
Unexposed	6	8
Sandstone, medium bedded	6	9
Unexposed	6	8
Shale	5	5

	Ft.	in.
Unexposed	53	0
Iron ore, sandy (*Hickory Nut* (?) *seam*)	3	9
Unexposed	7	6
Sandstone, coarse, very ferruginous, thin bed	2	3
Sandstone, fine grained, very ferruginous, thin bed	3	9
Sandstone, coarse, ferruginous, with beds of ore (*Ida seam*)	10	3
Sandstone, medium bedded, coarse	10	6
Unexposed	6	9
Shale	7	6
Unexposed	3	9
Sandstone, heavy bed	2	5
Iron ore, coarsely siliceous (*Big seam*); top 10 feet minable	16	10
Sandstone	7	8
Iron ore (*Irondale seam*): Ore	1	0
Iron ore (*Irondale seam*): Shale		7
Iron ore (*Irondale seam*): Ore	1	1
Sandstone	1	0
Unexposed, covered by shaly sandstone débris	50	1
Sandstone, massive, with shaly partings	24	1
Sandstone, thin bed	5	7
Unexposed	4	6
Sandstone, thin bed	5	6
Unexposed	4	6
Sandstone, thin bed	3	7
Unexposed	7	6
Sandstone, thin bed	3	7
Unexposed	5	8
Shale, sandy	7	6
Unexposed, covered by red shaly sandstone débris	35	10
Limestone (Chickamauga).		
	331	0

4. *Section of Rockwood formation in Walker Gap, in NE. ¼ sec. 14, T. 18 S., R. 3 W.*

	Ft.	in.
Chert (Fort Payne).		
Shale, clay, and sand (Devonian)	3	10
Sandstone, massive	16	10
Sandstone and shale	13	7
Shale, drab to pink, with thin streaks of sandstone (partly concealed by débris)	85	4
Sandstone and shale, alternating	50	9
Iron ore (*Big seam*), top 8 to 15 feet minable	24	0
Sandstone and shale, with ore seams in upper part	13	7
Débris	50	10
Shale, yellow, red, and olive, with heavy sandstones interbedded	41	0
Sandstone, heavy bedded	3	5
Shale, yellow and red	37	4
Base not exposed, but within distance of 20 feet	20	0
	360	6

5. *Section of Rockwood formation in Tanyard Gap, in SE. ¼ sec. 2, T. 19 S., R. 4 W.*

	Ft.	in.
Chert (Fort Payne).		
Shale (Chattanooga), (less than 1 foot).		
Sandstone, thin bedded	12	2
Unexposed	10	10
Sandstone, dark red, heavy bedded	8	9
Unexposed	11	3
Sandstone, red, heavy bedded	4	8
Unexposed	7	8
Sandstone, red, medium bedded	3	10
Sandstone, very ferruginous, with casts of *Pentamerus* (*Hickory Nut ore seam*)	3	0
Sandstone, red, ferruginous, thin bedded	2	4
Unexposed	16	4
Sandstone, heavy bedded	2	4
Iron ore (*Ida seam*); soft ore, minable	3	0
Sandstone, heavy bedded	3	0
Unexposed	15	4
Sandstone, medium bedded	20	2
Iron ore (*Big seam*): Ore, minable	11	0
Iron ore (*Big seam*): Shale	2	6
Iron ore (*Big seam*): Ore, not minable	4	6
Iron ore (*Big seam*): Shale, sandy, with thin ore seams, not minable	3	0
Sandstone, thin bedded	2	4
Shale	11	3
Sandstone	1	6
Shale	2	8
Unexposed	3	9
Shale, sandy	56	0
Covered by shale débris	12	6
Limestone (Chickamauga).		
	235	8

6. *Section of upper part of Rockwood formation as shown by core from diamond drill, NE. ¼ SW. ¼ sec. 11, T. 19 S., R. 4 W.*

	Ft.	in.
Chert, solidly stratified (Fort Payne).		
Sandstone, red, with coarse grit	5	8
Grit, coarse, soft, with gray sandstone	5	8
Limestone, gray, hard, cherty	6	7
Limestone, ferruginous	31	0
Sandstone, ferruginous	2	7
Sandstone, gray, extremely hard in places	23	6
Sandstone, ferruginous	40	7
Grit, very hard, fine, with reddish sandstone	20	2
Iron ore, limy (*Ida seam* (?))	2	7
Sandstone, gray	7	11
Limestone, "marbleized"	15	0
Sandstone, gray, hard	1	11
Limestone, ferruginous	5	8
Sandstone, ferruginous	22	0

		Ft.	in.
Iron ore (*Big seam*); top 11 feet minable	Ore	14	1
	Sandstone, gray	2	5
	Shale, ferruginous		8
	Ore, limy	2	5
	Sandstone, highly ferruginous	4	8
	Sandstone, mottled, highly ferruginous and fossiliferous	1	3
Calcareous rock, gray, with sandstone and shale interstratified		30	0
Bottom of formation probably within 35 feet.			
		246	4

7. *Section of Rockwood formation as shown by core from diamond drill at Big Spring, in SE. ¼ SE. ¼ sec. 34, T. 21 S., R. 6 W.*

		Ft.	in.
Limestone, decomposed (Fort Payne).			
Limestone, hard		2	1
Sandstone, reddish		35	0
Limestone (?), impure, with shale streak		27	9
Ferruginous rock, red, mottled		2	3
Limestone (?), with mottled red streaks, and shale		25	6
Limestone (?), gray, "marbleized"		1	11
Limestone (?), gray, "marbleized," fossiliferous		8	2
Limestone (?), gray, "marbleized," with liver-colored spots		7	6
Limestone and shale alternating		16	0
Sandstone, dark brown		2	6
Sandstone, laminated, ferruginous		29	0
Shale, gray, sandy		32	10
Ferruginous rock, streaked		26	3
Iron ore (horizon of *Big seam*)	Ore, soft, no core	3	9
	Sand, highly ferruginous, no core	4	10
	Ore, lean, with shale streaks	1	11
Iron ore, fossiliferous		3	7
Limestone (?), gray, impure, streaked with flint		48	8
Sandstone, red streaked		5	0
Limestone, with hard black flint (Chickamauga).			
		284	6

The foregoing sections show, besides the variation in details of the formation, the relations of the several ore beds. Four beds have been recognized and named by the miners. These are all shown in section 3, but in the other sections one or more of them have not been recognized. The following summary shows the salient features of these ore beds, commencing with the uppermost:

DESCRIPTION OF THE ORE SEAMS.

Hickory Nut seam.—This seam comprises 3 to 5 feet of sandy ore or ferruginous sandstone characterized by a great abundance of *Pentamerus oblongus*, fossils which resemble hickory nuts incased in the partly open outer shucks. The ore is of too low grade to be worked at present. The seam is developed principally in the district between Birmingham and Bessemer, and where recognized it lies about 12 to 20 feet above the next lower seam.

Ida seam.—This seam consists of 2 to 6 feet of rather siliceous ore associated with 14 to 16 feet of ferruginous sandstone. Ore at this horizon is more continuous and extensive than at the horizon of the Hickory Nut seam. It has been recognized at many of the workings from Bald Eagle Gap beyond Clear Branch Gap. Where worked the seam is in general from 3 to 5 feet thick and soft ore only has been obtained from it in surface workings. Such ore carries 35 to 44 per cent of metallic iron, with a corresponding range in silica of 45 to 32 per cent. The Ida seam occurs 35 to 50 feet above the top of the Big seam.

Big and Irondale seams.—These two ore beds are considered together since they are very closely associated in space. The ore, however, is somewhat different in quality, and the seams are so sharply separated by thin sandstone or shale that they may be mined independently.

The thickness of the Big seam is variously estimated at 16 to 40 feet. It extends as a traceable unit on Red Mountain practically the whole length of the mining district. Notwithstanding the great thickness there are rarely more than 10 to 12 feet of good ore in a single bench, and at most places only 7 to 10 feet are mined. Probably the maximum thickness is attained between Red Gap (near Irondale) and Bald Eagle, although for a mile southwest of Red Gap the bed remains nearly as thick. From northeast to southwest the total thickness of the ore-bearing sediments gradually decreases, without, however, altering greatly the thickness of the workable portion. About the middle of the district the seam becomes separated into two benches, either by a well-defined parting along the bedding plane or by a shale bed, thin at first, but thickening gradually to the southwest. The middle of the Big seam is the workable part in the northeast end of the district, but the upper bench is of most importance throughout the rest of the area. In the southwest portion of the district the lower bench, which farther northeast is composed of ore that will in later years be mined, becomes a series of thin strata of lean ore and shale, and is consequently of no possible value; and finally the upper bench itself becomes shaly and carries only a very low-grade ore.

The Irondale seam is best developed on Red Mountain between Pilot Knob on the northeast and Lone Pine Gap on the southwest. Southwest of Lone Pine Gap the seam either consists of interbedded low-grade iron ore and shale or else its identity is completely lost. Its soft ore, now nearly all mined out either by surface trenches or slopes, is the best in the district. Its hard ore is also of high grade and hitherto has been for the most part held in reserve, since ore could be produced from the thicker Big seam at a lower cost per unit of iron.

The structure and composition of the Big and Irondale seams is shown in the following series of sections, taken at intervals of 2 to 5 miles apart along Red Mountain, beginning in the northeast portion of the mining district:

Character of Big and Irondale seams 1 mile northeast of Red Gap, near Irondale.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone.		
Big seam:		
Ore, sandy	1 8	Metallic iron, 16-20 per cent; insoluble, 40± per cent; lime, 18± per cent.
Ore, lean, with fine quartz pebbles	5 0	
Ore, massive, cross bedded, mined	7 0	Hard ore, averages metallic iron, 36 per cent; insoluble, 26 per cent; lime, 20 per cent.
Ore, similar in appearance to above, but not mined at present.	6 0	Percentage of iron grades down from 35 at top to less than 20 at bottom; insoluble rises to more than 60 per cent.
Sandstone, ferruginous, lean ore, and shale.	20 0	
Shale	0-6	
Sandstone, very hard	3 0	
"Gouge," calcareous	6	
Irondale seam:		
Ore, mined	5 0	Semihard ore, averages metallic iron, 37 per cent; insoluble, 29 per cent; lime carbonate, 14.25 per cent.
Shale, hard.		

Character of Big and Irondale seams one-half mile south of Red Gap.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, coarse, ferruginous.		
Big seam:		
Ore, containing much silica in coarse grains and fine pebbles.	22 0	Upper half, soft ore: Metallic iron, 22± per cent; insoluble, 64± per cent; lime, trace. Lower half, soft ore: Metallic iron, 32± per cent; insoluble, 47± per cent; lime, trace.
Shale	1	
Ore, mined	7 0	Soft ore: Metallic iron, 36± per cent; insoluble, 45± per cent; lime, trace.
Ore, not mined	10 0	Semihard ore: Metallic iron, 25± per cent; insoluble, 50± per cent; lime carbonate, 8.12 per cent.
Shale, soft	3 0	
Irondale seam:		
Ore, mined	4 4	Soft ore: Metallic iron, 50± per cent; insoluble, 15± per cent; lime, trace.

The two following sections, made within the next 5 miles to the southwest, show that although the total thickness of the iron-bearing strata in this direction grows gradually less, yet the thickness of workable material remains fairly constant.

Character of Big and Irondale seams near Lake View, Birmingham.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, thin bedded.		
Big seam:		
Ore, mined	10 0	Soft ore: Metallic iron, 40± per cent; insoluble, 39± per cent; lime, trace. Hard ore: Metallic iron, 34± per cent; insoluble, 26± per cent; lime, 20± per cent.
Shale	8	
Ore, not mined	7 0	Value decreases regularly downward. Soft ore: Metallic iron, 15 to 25 per cent; insoluble, 50 to 60 per cent.
Shale	2 0	
Irondale seam:		
Ore	2 8	Hard ore: Metallic iron, 38± per cent; insoluble, 16± per cent; lime carbonate, 24± per cent. Soft ore: Metallic iron, 47± per cent; insoluble, 26± per cent. Only hard ore mined at present.
Shale	9	
Ore	2 2	

Character of Big and Irondale seams near Lone Pine Gap.

Strata.	Thickness.	Character.
	Ft. in.	
Shale.		
Big seam:		
Ore, mined	10± 0	Hard ore: Metallic iron, 36± per cent; insoluble, 25± per cent; lime carbonate, 20± per cent. Soft ore: Metallic iron, 44± per cent; insoluble, 35± per cent. Semihard ore mined at present.
Shale	1+	
Ore, not mined	6 6	Deteriorates in value regularly downward, top ore being poorer than the ore mined above.
Shale	2 0	
Irondale seam:		
Ore, not mined	6 0	Low-grade ore interbedded with shale.

The following section illustrates the complete deterioration of the Irondale seam:

Character of Big and Irondale seams at open cut, Greenspring mine, SW. ¼ sec. 11, T. 9 N., R. 3 W.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, coarse, ferruginous.		
Shale, yellow.		
Big seam:		
Ore, massive, cross-bedded and jointed; mined.	8 0	Soft ore: Metallic iron, 42± per cent; insoluble, 31± per cent; lime, 2± per cent. Semihard ore: Metallic iron, 38± per cent; insoluble, 32± per cent; lime, 8± per cent. Mostly semihard ore mined at present.
Parting on bedding plane.		
Ore, rather a ferruginous sandstone or coarse grit; mined in only a few places.	8 0	
Shale	2	
Sandstone, ferruginous and shaly	1 0	
Shale, sandy	6	
Sandstone, ferruginous	1 3	

Character of Big and Irondale seams at open cut, Greenspring mine S W. ¼ sec. 11, T. 9, N., R. 3 W.—Continued.

Strata.	Thickness.	Character.
	Ft. in.	
Shale	2	
Sandstone	4	
Shale	2	
Ore, sandy	5	
Shale	5	
Ore, sandy	3	
Shale	2	
Irondale (?) seam:		
Ore, very sandy	1 6	Not minable.
Shale	2	
Sandstone, fine grained, very ferruginous.	1 4	
Shale	2	
Sandstone, fine grained, very ferruginous.	10	
Shale	1	
Sandstone, very ferruginous	5	
Shale	1	
Sandstone, very ferruginous	10	
Shale.		

At Graces Gap only the Big seam appears to be present. It has a thickness of about 22 feet here, and the upper bench, 10 to 12 feet of ore, is mined. Four miles southwest of the locality of the foregoing section the ore presents the following phase:

Character of Big and Irondale seams at mouth of slope No. 12, Tennessee Coal, Iron and Railroad Company, SE. ¼ sec. 20, T. 18 S., R. 3 W.

Strata.	Thickness.	Character.
	Ft. in.	
Shale and sandstone in thin beds.		
Big seam:		
Ore, mined	8-10 0	Hard ore: Metallic iron, 35± per cent; insoluble, 18± per cent; lime, 16± per cent. Only hard ore mined now.
Shale, thin parting.		
Ore, lean and siliceous, with a few local shale partings.	9 0	Not minable under present conditions.
Ore, oolitic and fossiliferous, in thin bands alternating with streaks of calcite and shale.	2 1	
Ore, shaly	1 3	
Ore	4	
Shale	8	
Irondale (?) seam:		
Ore, siliceous	6	Not minable.
Shale	1	
Ore, siliceous	8	
Shale	3	
Ore, very sandy	1 3	
Shale	1	
Sandstone, ferruginous	7	
Shale, sandy.		

Five miles southwest of slope No. 12 is that part of Red Mountain which lies opposite Bessemer. Here the parting between the upper and lower benches of the Big seam reaches a thickness of 3 feet in places. The upper bench maintains its usual quality and its thickness of 10 to 11 feet, 8 to 10 feet of which are taken in mining. Thin streaks and lenses of shale begin to appear near the top and bottom of this bench. The lower bench of the Big seam has dwindled down to 4 or 5 feet in thickness and is generally composed of alternating thin strata of ore and shale. The Irondale seam evidently has not been recognized here. Three miles farther southwest the seams show the following section:

Character of Big and Irondale (?) seams at mouth of Potter slope No. 1, Tennessee Coal, Iron and Railroad Company, SE. ¼ sec. 21, T. 19 S., R. 4 W.

Strata.	Thickness.	Character.
	Ft. in.	
Shale.		
Big seam:		
Ore, solid, mined	8 0	Soft ore: Metallic iron, 47± per cent; insoluble, 24± per cent; lime, 0.80± per cent. Soft ore mined at present.
Shale	1 6	
Sandstone, shaly, ferruginous	9	Lower bench.
Ore	3	
Shale	1	
Sandstone with shaly partings	1 6	
Shale	3 0	
Horizon of Irondale seam (?):		
Ore, sandy, lean, with shale partings.	1 0	

ORE BEDS ON WEST RED MOUNTAIN.

On West Red Mountain the rocks dip at high angles and appear not to carry valuable seams of iron ore throughout the middle of the district. At the extreme ends of the district, however, the dips are more gentle, and workable seams have been discovered, for instance, at Compton and Dudley. The two following sections of the Rockwood formation, measured by Charles Butts, show the general character of the beds in the northeast half of West Red Mountain. Comparison of these sections with those made on Red Mountain (pp. 136–139) indicates that the formation thickens to the northwest. The measured thicknesses have been corrected for dip, and the figures represent the computed actual thickness of the beds.

Section of Rockwood formation on West Red Mountain, at Cunningham Gap, in SW. ¼ sec. 10, T. 16 S., R. 2 W.

	Ft.	in.
Chert débris (Fort Payne).		
Sandstone, highly ferruginous, exposed in prospect pit	5	0
Unexposed	39	0
Sandstone	7	10
Unexposed	31	6
Sandstone	2	0
Unexposed	15	8
Sandstone, in massive beds	31	6
Unexposed	15	0
Sandstone	4	0
Unexposed	23	9

	Ft.	in.
Sandstone	5	0
Unexposed	7	10
Sandstone	1	0
Unexposed	15	7
Sandstone	2	0
Unexposed	7	9
Sandstone, ferruginous (shown by prospect pit)	2	0
Unexposed	15	8
Sandstone	1	0
Unexposed	7	0
Sandstone, thick bedded	23	8
Unexposed	31	6
Sandstone, thick bedded	27	8
Shale	2	0
Sandstone, thin to very thick beds, with shale partings	102	0
Sandstone, thin bedded	23	8
Unexposed	47	5
Sandstone	4	0
Unexposed	5	0
Limestone, impure and ferruginous (probably top of Chickamauga).		
	507	0

Section of upper part of Rockwood formation in gap of West Red Mountain, near Dale, Ala.

	Ft.	in.
Shale, black (Devonian).		
Sandstone, greenish predominating, grayish and reddish, evenly bedded, with shale partings, most numerous at top	110	0
Shale, yellowish green	5	6
Sandstone, gray, thin bedded	10	6
Iron ore	2	0
Unexposed	6	0
Sandstone, ferruginous, with decomposed ore	6	0
Iron ore, lean, limy, fossiliferous	10	0
Concealed by very red soil and red sandstone débris	210	0
Limestone (Chickamauga).		
	360	0

Workable ore at Compton occurs in but one seam, which shows the following sections:

Sections of ore seam at Compton mine.

1.		2.		3.	
	Inches.		*Inches.*		*Inches.*
Shale.		Shale.		Shale, ferruginous.	
Ore	13	Ore	17	Ore	7
Shale	1-2	Shale	1-3	Shale	1½
Ore	16	Ore	18	Ore	29
Shale.		Shale.			

1. First right entry, near main slope.
2. First left entry, 300 feet from main slope.
3. Outcrop, near top of mountain.

The seam at Compton ranges generally from 30 to 36 inches in thickness, with a thin parting of shale, irregular in position, as shown in the sections. Locally the entire seam is pinched down to a very few inches or entirely cut out by downward bulging of the overlying shale, which at such places has a concretionary or concentric structure. Such structures, which result in the local disappearance of the ore bed, are erroneously termed "faults" by the miners, but there is no dislocation of the beds and the ore is usually picked up again if the workings are driven on in the same plane.

The extreme southwestern part of Birmingham Valley is partly covered by Tuscaloosa clay and Lafayette loam, but in places buried rock ridges have been revealed by stream erosion. Extensive prospecting by drill, test pits, and slopes has been carried on within the last two years in the region between Dudley and Big Sandy Creek, and the Rockwood formation has been shown to contain workable beds of ore. All the evidence heretofore obtained regarding the somewhat obscure geologic relations of this district indicates that the workable beds of ore are in a strip of Rockwood formation corresponding with McAshan Mountain, 17 miles to the northeast. In other words, the outcrop of the formation here has been repeated by folding and faulting. In the region south of Dudley the beds are completely overturned, so that the dips are to the southeast. This locality is in the Brookwood quadrangle and has been more fully discussed in a previous paper.[a]

MINING DEVELOPMENT.

CHARACTER AND EXTENT.

There have been three stages in the development of the mines in the Birmingham district. The first stage consists of trenching the ore beds along the outcrop on the crest or on the northwest slope of Red Mountain, and of mining the ore from open cuts on the southeast slope. The ore obtained in this way is mostly soft. This method of mining has been possible only where the overlying beds are not more than 20 feet thick and can be stripped off profitably. Most of the mines have passed beyond this stage, but at the Helen-Bess and the Green Spring workings this very profitable type of mining may still be seen.

The second stage of development combines the open cut and incline with underground work. A very fortunate relation between the Big and Irondale seams and the topography of Red Mountain exists in many places, particularly in the northern half of the district, wherever the dip of the Rockwood strata is approximately the same as the southeast slope of the mountain. This slope is cut by narrow

[a] Burchard, E. F., Iron ores in the Brookwood quadrangle, Alabama: Bull. U. S. Geol. Survey No. 260, 1905, pp. 321-334.

V-shaped ravines at intervals of one-half to three-fourths of a mile, and on both sides of many of these hollows the two seams are exposed from the crest to the foot of the ridge. Inclined tramways are built on the flanks of the ravine, and when the outcropping ore has been surface worked entries are driven in on the strike of the ore beds from each side of the ravine and the ore is mined from upsets. A cable tramway may be operated by gravity or by power, depending on the side of the mountain on which the ore is to be delivered. At the Sloss-Sheffield Ruffner mine No. 1 the tracks of the railway which transports the ore to the furnaces are on the southeast side of the mountain, making it possible for cars loaded with ore going down the mountain to pull up the empties, but at the Valley View mine of the Birmingham Ore and Mining Company the ore is hauled up over the mountain and loaded into railroad cars on the opposite side. At mines of this type soft, semihard, and hard ores are obtained, depending on the thickness and character of the cover of the seam.

The third stage of mining, the one to which the majority of the workings in the Birmingham district have now attained, involves systematic underground work entirely. The general plan is very simple, comprising a main or central slope, driven on the dip, from which right and left entries are turned off at regular intervals of 60 to 70 feet. The ore, which is mainly hard, is mined from the upper side of the entry, about 30 feet being left between the entries until robbing is begun. Mules haul the trams to the mouths of the entries, whence the ore is moved up the slope by cable to a tipple, below which it is crushed and loaded directly into cars bound for the furnace. A manway is usually provided at one side of the slope for safety. Comparatively little water is encountered even in the deepest workings of this type, so that a 3 to 4 inch pump usually suffices to drain the mine.

A fourth stage, which some of the workings may reach in the near future, will likely be shaft mining in the basin east of Red Mountain. The working face of the ore bed can be reached more directly by a vertical shaft 300 to 500 feet in depth than by a slope five or six times that length.

Mining conditions at present are doubtless at their most favorable stage. The mining companies are making an effort to utilize all the labor available to increase the output of ore. In the summer of 1906 there were no less than 33 mines actively producing red ore in the district, besides seven or eight workings which have been inactive since the soft ore was exhausted from them. Of the 33 mines in operation 30 are on Red Mountain, within a distance of about 25 miles between Pilot Knob on the northeast and Sparks Gap on the southwest. In places in the middle of the district the underground workings are practically continuous for 3 or 4 miles, and the old surface workings on the outcrop of the ore may be traced without break for 15 miles or more.

The Tennessee Coal, Iron and Railroad Company operates 14 slopes and 1 open cut, collectively known to the iron trade as the Red Mountain group; the Republic Iron and Steel Company operates 5 slopes; the Sloss-Sheffield Steel and Iron Company, 2 slopes and 1 combination working; the Woodward Iron Company, 2 slopes; the Alabama Consolidated Coal and Iron Company, 1 slope; the Birmingham Ore and Mining Company, 1 slope and 3 combination workings. All these companies, except the last named, own their ore mines and blast furnaces. The Birmingham Ore and Mining Company leases its several properties and sells ore to the iron-making concerns.

Besides the mines on Red Mountain, just enumerated, there are on West Red Mountain, at the extreme ends of the district, 2 mines that produce red ore. One is at Compton, operated by the Birmingham Ore and Mining Company, and the other is near Dudley, operated by W. P. Pinckard & Co.

BEARING OF DEVELOPMENT ON ORE SUPPLY.

In July, 1906, the deepest slope in Red Mountain was reported to be 2,100 feet long. This slope is about half a mile north of Reeder Gap. Four other slopes have been driven 1,800 feet each, and there were six slopes between 900 and 1,500 feet long. All the slopes 900 feet or more in length are in the strip of mountain below Birmingham. The newer mines at the extremities of the district have slopes ranging between 200 and 500 feet in length. The 2,100-foot slope goes down on beds whose average dip is 28°, so that its present depth is about 650 feet below the level of the valley at a point directly above the bottom of the slope. Projected at the same angle to a point directly below Little Shades Creek the slope would have a length of about 5,000 feet and a depth below the creek of 1,120 feet. It is not known whether the ore extends with an unchanged dip and thickness to this depth. Drill records obtained farther south in Shades Valley indicate that the ore beds with their associated strata flatten out and locally rise toward the surface. The surface rocks in the valley indicate irregularities in the structure, including faulting, which would naturally be shared by the beds below.

No deterioration in either quality or thickness of the hard ore in the direction of dip has yet been disclosed by the deeper slopes—an encouraging fact in so far as it can be used as a measure of the ore ahead of shorter slopes. At one of the larger mines, centrally located, systematic analyses have been made of the ore at intervals of a few feet from the outcrop to the bottom of the slope and throughout the extent of each entry to the right and left of the slope. The composition of the ore has been found to vary appreciably from place to place and the degree of variation is likely to be as great within a few yards as it is between remote parts of the mine, but the average run of the mine is remarkably regular. The facts brought out by this series of analyses show that the content of metallic iron increases about 1 per cent for each 1,000 feet away from the outcrop, that the lime (CaO) decreases about 1 per cent in the same distance, and that the silica content slightly increases.

Studies by members of the Alabama Geological Survey extending over many years have shown that the Rockwood formation tends to thin out and become sandier toward the southeast. There is no reason why this change should not be shared proportionately by the inclosed ore beds, and it is believed that the drill records just referred to indicate that such is the case. However, the complete drill records available from the valley east of Red Mountain are so few that reliable conclusions can be based on them regarding the ore basin only in the southern third of the district. Ore can, perhaps, be expected to underlie the valley southeast of Red Mountain, probably as far as Shades Mountain. The width of Shades Valley is a rough indication of the relative extent of the Red Mountain ore toward the southeast, and the width of the valley is sensibly greater southwest than it is northeast of Reeder Gap.

In reference to the theories heretofore advanced regarding the origin of the Clinton ores it may be stated that all the new facts observed in the course of the work in the Birmingham district are in accordance with the hypothesis that the ore is the result of original deposition of ferruginous sediments. The transition, vertically, between sandstone and ore or between shale and ore, is as sharp as that between coal and its inclosing rocks. The variation in composition of an ore bed from place to place is not unlike the local changes in composition and character of a coal bed. The lenslike form of the beds is common to both coal and ore. Finally, as the lens thins, whether of coal or of ore, it tends to become shaly and siliceous. That the ore is due to the replacement of limestone seems hardly possible when it is considered that instead of a decrease in percentage of iron and an increase in that of lime, with depth, until the bed becomes a limestone, almost the reverse has been noted. The lime in the bed is evidently an accessory deposit, as is the silica. The term "depth" in this connection is subject to misconception, for the sediments were deposited in a horizontal position, or nearly so, and their present attitudes are the result of subsequent foldings. The depth to which the beds now extend is therefore incidental, and in no wise affects their character beyond the soft-ore limit. Indeed, the best criterion for judging the character of the unexploited ore beds in the basin southeast of Red Mountain, is the strike section of the same beds that has been afforded by the mine workings. From northwest to southeast there are likely to occur changes similar to those that are known to take place from northeast to southwest. With all these possibilities kept in mind, the facts in hand still permit a fairly close estimate of the ore reserves in the district, and it is expected that such an estimate will be given in the forthcoming detailed report. It will suffice to state here that this estimate will show probably more ore to be available than has heretofore been supposed by persons not familiar with the district.

Outside of the area of present activity considerable prospecting has been done, especially on the outcrop of the ore-bearing beds. In some places the results have apparently been discouraging, partly because the work has not been thoroughly done, and partly because the outcrop of an ore bed does not tell the whole story. Prospecting with a core drill is expensive, but the information sought in the case of bedded iron ores is of sufficient importance to warrant considerable expenditure. Certain localities may be pointed out as apparently deserving further investigation—for instance, Red Mountain opposite McCalla station and the basin beyond, the strip of the same ridge from Pilot Knob northeastward to the Jefferson County line, and West Red Mountain northeast of Mount Pinson station.

PRODUCTION AND CONSUMPTION OF IRON ORE.

Since 1894 Alabama has held third place among the iron-producing States. In 1905 her total production of iron ore amounted to 3,782,831 long tons, composed of 2,974,413 tons of red hematite, 781,561 tons of brown hematite, and 26,857 tons of magnetite.[a]

The Birmingham district produced in 1905 2,561,264 tons of red hematite, or 86.7 per cent of the total tonnage. The series of mines known as the Red Mountain group are classed among the prominent iron-ore mines of the United States. Together, this group, including the Potter slopes, formerly leased by the same corporation, produced in 1905 1,282,189 long tons, or a little over 50 per cent of the total for the district.

Practically all the ore produced in the district is smelted in the vicinity of Birmingham. The ore is handled by 29 coke furnaces, distributed as follows: In Birmingham city are eight furnaces, four of which belong to the Sloss-Sheffield Steel and Iron Company, two to the Tennessee Coal, Iron and Railroad Company, one to the Atlanta, Birmingham and Atlantic Railroad, and one to the Williamson Iron Company; at Ensley there are six stacks and at Bessemer five stacks of the Tennessee Coal, Iron and Railroad Company; at Thomas, three stacks of the Republic Iron and Steel Company; at Woodward, three stacks of the Woodward Iron Company, and at Oxmoor, two stacks of the Tennessee Coal, Iron and Railroad Company. On the outskirts of the district are the furnace of the Southern Steel Com-

[a] Birkinbine, John, Production of iron ores in 1905: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 56.

pany at Trussville and that of the Central Iron and Coal Company at Holt, near Tuscaloosa.

In general, the furnaces run on a burden of coke, red ore, brown ore, and dolomite or limestone, though certain of them at times use only a self-fluxing red ore. The ores of the district contain too much phosphorus (see analysis, p. 135) to be converted into steel by the Bessemer process, but such pig irons are being very successfully used for basic open-hearth steel making. The open-hearth process is employed by the Tennessee Coal, Iron and Railroad Company at the Ensley rail mill, which consists of ten 50-ton basic Wellman tilting furnaces and one stationary furnace. The entire output of the company's six coke furnaces is transferred as hot metal to the steel mill, where it is made into billets and rails. The use of the open-hearth process as applied to southern ores has passed beyond the experimental stage. The capacity of the Ensley mill is about to be doubled and other steel mills will doubtless soon be built in the district, so that a local market is rapidly arising for southern pig.

THE BROWN IRON ORES OF THE RUSSELLVILLE DISTRICT, ALABAMA.

By Ernest F. Burchard.

LOCATION AND SURFACE FEATURES OF THE DISTRICT.

Russellville, Franklin County, Ala., is in the northwestern part of the State, 25 miles east of the Mississippi State line and 18 miles south of Tennessee River at Sheffield. The Russellville ore district comprises an area of about 25 square miles within a rectangle having dimensions of 8 miles from west to east and about 3 miles from north to south, Russellville being near the middle of its northern edge. The line of the Northern Alabama Railroad from Sheffield to Parrish passes north and south through the area, connecting the ore mines and limestone quarries near Russellville with the blast furnaces at Sheffield. The district lies within the drainage basin of Tennessee River. The northern part of Franklin County immediately surrounding Russellville is a region of comparatively low relief. Russellville has an altitude of about 315 feet above Tennessee River and stands relatively high on the south slope of Little Mountain, the divide between the creeks that flow directly north into Tennessee River and those that make a detour to the west before reaching the main stream. East of Russellville, Payne and Mud creeks, small branches at the headwaters of Cedar Creek, have cut their courses down 100 feet or more below the upland levels, fragments of which remain in the form of flat-topped hills and ridges that show a somewhat even sky line. South of Russellville, toward Sand Mountain, the relief becomes much greater.

GENERAL GEOLOGY.

The rocks exposed from Tennessee River southward to and including the Russellville district are grouped as follows under the formation names employed by the Alabama Geological Survey.[a]

[a] McCalley, Henry, Report on the valley regions of Alabama, pt. 1, Alabama Geol. Survey, 1896, pp. 147 187.

Geologic formations of northwestern Alabama.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary	Lafayette	Loam and gravel	100+
Cretaceous (?)	Tuscaloosa (?)	Clay	Very thin.
Carboniferous (Mississippian) series.	Bangor	Limestone	200+
	Hartselle	Sandstone	350-400
	Tuscumbia	Limestone	125-175
	Lauderdale	Chert	200+

The rocks lie practically flat in some places and in others have been thrown into broad, gentle folds or domes, with dips as great as 10°. Where any systematic structure has been recognized the folds appear to trend northwest-southeast and to have the steeper dips on the northeast limb, the prevailing dips being consequently to the southwest. The oldest rocks outcrop, therefore, at the north, and toward the south each formation passes in turn below the next younger in the series.

The Lauderdale chert shows only along Tennessee River, while the Tuscumbia limestone floors the wide flood plain of the stream. The area of Hartselle sandstone lies along Little Mountain or the divide between the main Tennessee Valley and the Cedar Creek drainage, and on the summit of the divide it is covered by Lafayette loam. South of this divide, in the ore district, the Bangor limestone, overlain by Lafayette, is exposed by the stream at the headwaters of Cedar Creek wherever they have eroded through the Lafayette materials. Only the lower portion of the Bangor limestone is exposed about Russellville, and here it is thin bedded, shaly, rather argillaceous, and at many places contains characteristic Bangor fossils. The full thickness of the formation is not represented near Russellville. The limestone appears to have undergone erosion to such an extent that a very uneven surface existed at the time the Lafayette sediments were spread over it. The Tuscaloosa formation has not been positively recognized in the ore district, but certain mottled clays that occur along the Southern Railway near the Mississippi State line have been referred to the Cretaceous. The Lafayette materials cover the greater part of the area here considered. Where they overlie the Bangor limestone it is to these two formations that the greatest interest is attached, for in such situations conditions seem to have been favorable to the accumulation of iron ore. The Lafayette sediments probably once mantled the whole area as far east as the Franklin-Lawrence county line, but erosion has removed the material along creek beds and very steep hillsides, so that now the thickest and most continuous deposits are found only on the highest parts of the surface.

THE ORE.

Character.—The ore occurs in irregular masses, bowlders, pebbles, sand, and as cementing material in beds of conglomerate. Its color is dark brown and many fragments have a black, varnishlike luster on botryoidal surfaces of masses that show fibrous structure within. This ore has generally been termed limonite, but the pure ore more closely resembles göthite in composition, as is shown by the following two analyses. It is probably a mixture of göthite and limonite, if it contains these minerals at all, in the proportion of about 7 to 1.

Analyses of clean brown ores from surface, 1 mile east of Russellville.[a]

	1.	2.
Ferric oxide	84.696	83.514
Siliceous matter	3.159	2.864
Alumina	.220	1.411
Manganese oxide	.087	.188
Lime	.440	.407
Magnesia	.025	.045
Phosphoric acid	.765	.760
Sulphur	.054	.085
Combined water	10.444	11.849
Moisture	1.648	.833
Total	101.539	100.206
Metallic iron	59.287	58.459
Phosphorus	.334	.332
Specific gravity	3.616	3.800

[a] McCalley, Henry, Valley regions of Alabama, pt. 1, Alabama Geol. Survey, 1896, p. 213.

If the ferric oxide and the combined water of the above analyses be averaged and then estimated on the basis of a pure ore, the result gives a content of 88.36 per cent of ferric oxide and 11.53 per cent of water. The theoretical composition of limonite, according to Dana, is ferric oxide 85.6 per cent, water 14.4 per cent; while that of göthite is ferric oxide 89.88 per cent, water 10.12 per cent.

In the ore as mined the silica and the alumina run much higher than in the above samples, owing to the presence of clay and of chert gravel which washing may fail to remove. Analyses representing the commercial ores of the district are given below.

Analyses of brown ores from Russellville, Ala., and Pinkney, Tenn.

Constituent.	1.	2.	3.	4.	5.	6.	7.	8.
Iron (Fe)	51.00	50.10	51.07	47.80	49.30	44.29	46.60	46.80
Silica (SiO_2)	11.12	11.80	10.60					
Alumina (Al_2O_3)	6.23	6.02	5.01					
Insoluble				17.00	16.90	20.58	16.80	18.00
Manganese (Mn)	.64	.61	.37				.45	.30
Phosphorus (P)	.52	.59	.64	.44			.88	.95

1, 2, 3, Monthly averages of all ores from the Sloss-Sheffield mines; 4, 5, averages of 5 and 7 cars, respectively, from mines of Sheffield Coal and Iron Company; 6, ore from Alabama-Virginia Iron Ore Company; 7, 8, averages of 10 and 4 cars, respectively, from Pinkney, Tenn.

Occurrence and geologic relations.—The irregular masses of ore, as well as the loose deposits, are found in pockets of varying richness, separated by more or less barren material, either directly upon the Bangor limestone or within the overlying Lafayette formation. As has been stated, the surface of the Bangor limestone is irregular, and many of the ore deposits seem to have been segregated at places where this surface is most uneven. Hollows or depressions in the limestone appear to have been favorable places either for the precipitation of the ore or for the collection of ore débris that has been transported to the region by wave or stream action.

According to position the ore may be divided into two types: (A) masses that lie directly on the Bangor limestone or on the clay residual from the limestone, and (B) loose ore that occurs higher up, mixed with the Lafayette loam. The ore of type A is the more limited in extent, but usually the richer of the two, as it contains gravel only in a few cavities or cracks within the mass. In places over this ore and at the base of the loose loam and gravel of the Lafayette there is a very hard, pebbly conglomerate with siliceous iron-oxide cement. The ore is medium to dark brown in color, and may be granular and easily broken or may be hard and composed of large lumps cemented or welded together. Masses of ore commonly cover or surround a "clay horse" or "white horse," which is a thin reef or pinnacle of light-colored residual clay that grades into the argillaceous limestone below. The clay at a few places contains small amounts of fine-grained ore that may have been compressed into it, but care is taken not to mine more of it than is necessary, for when wet the clay is extremely sticky and can not easily be separated from the ore in the washer. At many places in the hollows of the limestone between the "white horses" the ore is found in solid masses locally 10 to 15 feet thick and containing but little foreign matter. Many bowlders and masses of the ore contain cavities that are partly or completely filled with a fine-grained white to yellow clay or powder, the condition of this filling depending on the quantity of moisture present.

Most of the ore of type B consists of pebbles and lumps, but it also occurs in fragments of all sizes, ranging from a coarse sand to bowlders a foot thick. The Lafayette loam in which this ore occurs commonly contains pebbles of fossiliferous chert and of pink quartz, and these in places enter into the recently cemented conglomerate that lies over the ore of class A. In certain places the pebbles of ore have been sorted and concentrated by nature so as to form huge placer deposits.

The relations of the two types of ore suggest that the ore A was accumulated in pre-Lafayette time, and that the ore B was derived from it mechanically in fragmentary form and worked up into the basal conglomerate and loose gravel of the Lafayette formation.

ORE RESERVES.

Although a considerable area of proved iron-ore lands still await development in the Russellville district, landowners and persons concerned in the iron trade display an ever-increasing interest in the possible distribution of brown ores in other parts of the region. As a general guide it may be stated that similar geologic conditions exist throughout the northern portion of Franklin County and the southern and western parts of Colbert County, Ala., and in the eastern part of Tishomingo County, Miss.; also in parts of the Tennessee River Valley in Tennessee and Kentucky. Therefore many deposits of brown ore that are similar in character to those at Russellville may be revealed by prospecting in these localities. In Lawrence, Lewis, and Wayne counties, Tenn., such deposits have been discovered, and ore is being produced from them at Iron City, West Point, Ferro, Pinkney, Riverside, Allen's Creek, and other points. Although surface indications in the Russellville district have usually led to the opening of good ore below, the surface indications above some brown ore deposits, especially those in the Woodstock, Ala., area, rarely afford a true index of the extent or value of the ores below. In northwestern Alabama and in the Tennessee Valley in general there are no doubt local segregations of ore many acres in extent that do not at all appear at the surface. Small test wells 3 to 4 feet in diameter and 20 to 50 feet deep may be easily sunk in the loose loam and gravel without involving the expense entailed by drilling, and such tests yield the information desired. The main points to be borne in mind are that localities worth prospecting for these brown ores must be underlain by limestone beds which are surfaced with 20 to 100 feet of loam and gravel.

INDUSTRIAL DEVELOPMENTS.

Methods of mining and concentrating.—All the workings of the district are open cuts. The scattered deposits of gravelly ores of type B are worked profitably only on a large scale, involving the use of steam shovels to mine the ore and locomotives to haul it to the washers. Some of the richer deposits will pay if worked out by hand and with mule haulage, provided the washer can be built near by. The ore is all concentrated by means of log washers. The ratio in cubic yards of dirt to tons of ore washed varies from about 3 to 1 in the richer deposits to 12 to 1 in the poorer deposits. The washers automatically remove most of the clay from the ore and all the gravel that will pass a 12-mesh screen; but the results are not thoroughly satisfactory, because the washers fail to separate the ore from the coarser gravel and permit the loss of great quantities of ore that is finer than 12-mesh. The larger pebbles of gravel are removed by hand as the ore passes along a belt toward the storage bin. Water for washing is obtained from ponds or reservoirs that are supplied by the small creeks of the district. After being pumped to the washers the residue runs into settling ponds, which eventually yield part of the water for use again. Rough estimates indicate that from 2,000 to 2,500 gallons of water are used for each ton of ore washed, but as a general rule much more ore—perhaps twice as much—might be washed with the same quantity of water, since during the operation ore is delivered irregularly, and often no ore whatever is on the screen, while the water must of necessity be pumped constantly.

Operators.—Three companies—the Sloss-Sheffield Steel and Iron Company, the Sheffield Coal and Iron Company, and the Alabama-Virginia Iron Ore Company—are at present mining in the Russellville district. The first two companies mine ore for smelting in their own furnaces; the latter company mines ore for sale only.

The workings of the Sloss Company are southeast of Russellville and cover the greater part of secs. 27, 28, 29, 31, 32, 33, and 34, T. 6 S., R. 11 W. Four washers handle the output of ore, which ranges from 700 to 900 tons a day, all taken by the company's furnaces at Sheffield. The ore is all mined from open cuts. At the first workings east of the town the ore is mined by steam shovel and hauled by a "dinkey" to washer No. 1. The ore from these cuts is entirely of type B. It lies along an old ridge of limestone, the strata of which have been exposed in places by stripping the ore-bearing loam. This loam varies in depth from a few inches to 30 feet, and 10 to 11 cubic yards of it yield 1 ton of washed ore. The ore worked near washer No. 4 is of type A. It is massive and occurs in association with white to greenish residual clays, which overlie the Bangor limestone. Pots of ore 12 to 15 feet deep and "horses" of limestone and clay are mingled together, but above the general level of the highest clay "horses" a rich deposit of ore extends 10 to 20 feet higher, and this is overlain by an equal thickness of pebbly conglomerate and barren loam. The material worked here yields 1 ton of ore for each $3\frac{1}{2}$ cubic yards of dirt, and the entire output of the property washed 6 to 1 in the summer of 1906.

The mines of the Sheffield Coal and Iron Company lie southwest of Russellville, mainly in sec. 36, T. 6 S., R. 12 W., and sec. 1, T. 7 S., R. 12 W. In August, 1906, one washer was in operation, cleaning up about 250 tons of ore daily, which was supplied from a large open cut two-thirds of a mile to the southeast. Two steam shovels load the dirt into cars singly and in trains. The ore is rather fine grained, especially in the upper beds, which are of loam, and it appears to belong to type B, although richer than most deposits of that kind. The deposit ranges from 12 to 25 feet in thickness and is underlain by flat-lying limestone ledges, which are usually covered by a few inches of residual clay. In the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 35, T. 6 S., R. 12 W., are the old Parrish mines, now being reopened by the Sheffield Coal and Iron Company. The ore here is strictly of a placer type, but the underlying limestone and residual clay have been exposed in the old workings. This company smelts its own ore at Sheffield.

The third system of mines active in 1906 is operated by the Alabama-Virginia Iron Ore Company in the SW. ¼ sec. 3 and the NW. ¼ sec. 10, T. 7 S., R. 12 W. The ore at this point is gravelly and belongs to type B. It occurs in high banks having at their bases irregular masses of weathered limestone and residual clay. Clay lenses and pockets are mixed with the ore. The ore is loose enough to be broken down with a pick, and at some places a face of ore may be worked down by gravity directly into tram cars. One washer is employed here, cleaning up 400 to 500 tons of ore a week, most of which is shipped to the two furnaces at Chattanooga. It is understood that this ore—the only product of the district that is sold on the market—commanded in the summer of 1906 $1.40 per ton at the mines, the rejecting point being a minimum of 44 per cent metallic iron.

Fluxing material.—The Bangor beds in this district contain an abundance of good limestone suitable for smelting purposes. The Sheffield Coal and Iron Company operates a quarry and crusher near the ore washer in sec. 36 The stone is taken from that horizon of the Bangor limestone which commonly underlies the ore deposits and comprises oolitic and fossiliferous strata. The composition of the rock as used in the furnaces at Sheffield is shown in the table below (column I). Limestone for the Sheffield furnaces is also obtained from the extensive Fossick quarries in the W. ½ sec. 10, T. 7 S., R. 12 W., 2¼ miles west of Darlington. Here the rock is a uniformly fine-grained, white, oolitic limestone about 27 feet thick. It lies practically flat in thick beds and is underlain and overlain by cherty strata. This limestone is also quarried largely for building and monumental purposes, blocks weighing 25 tons or more having been cut out by means of channeling machines. From 10 to 12 cars a day of fluxing stone and 3 to 4 cars a week of sawed stone are shipped from this place.

An analysis of the Fossick quarry rock, made at the United States Arsenal, Watertown, Mass.,[a] is shown below in column II.

Analyses of Bangor fluxing stone.

Constituent.	I.	II.
Silica (SiO_2)	2	.50
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	1.40	1.45
Lime (CaO)	54	54.20
Magnesia (MgO)		1.23
Carbon dioxide (CO_2)		42.61

[a] McCalley, Henry, Report on the valley regions of Alabama, Alabama Geol. Survey, 1896, p. 197.

Besides these quarries a new opening and crusher have been established by the Alabama-Tennessee Stone Company about 1,000 feet east of the railroad station at Darlington. The beds exposed here are nearly flat-lying oolitic limestone, and the product, 250 to 300 tons a day, is shipped to the Sloss-Sheffield Steel and Iron Company's furnaces at Sheffield.

Production of brown ore.—As a producer of brown ore Alabama ranks first among the iron-ore producing States. In 1905 there were 781,561 long tons of brown ore mined in Alabama, and of this the Russellville district produced 279,373 long tons, or over 36 per cent. While some of the Russellville ore is smelted at Chattanooga, probably an equivalent quantity from the Iron City-Pinkney district of Tennessee is shipped to Sheffield, so that the production at Russellville fairly represents the tonnage of brown ore locally smelted.

Iron making.—It is a matter of historical interest that probably the first furnace erected in Alabama was built in 1818 on the north bank of Cedar Creek in sec. 10, T. 7 S., R. 12 W., a short distance east of the present Alabama-Virginia Company's workings. Surface ore was fed to this primitive charcoal furnace and was made into cast and malleable iron. The furnace seems to have been abandoned about 1827. Sixty years later, iron making was revived in this region, but in a better location in respect to water supply and transporation routes. In 1887, or shortly afterwards, the three stacks of the Sheffield Coal and Iron Company and the two now controlled by the Sloss-Sheffield Steel and Iron Company were built at Sheffield, and one furnace, inactive in 1906, also controlled by the latter company, was erected at Florence, across the river. All these furnaces use coke for fuel.

The six furnaces mentioned above produce mainly a foundry pig iron that is rather high in phosphorus, but also some mill pig iron. The practice is to run either entirely on local brown ore and limestone, or, if the silica is too high—above 18 per cent, for instance—the burden is usually composed of three-fourths local brown ore and one-fourth Birmingham hard red ore, with the requisite amount of limestone. This combination reduces the phosphorus content of the pig iron, and it is found that the Russellville ores produce a pig with an appreciably lower content of phosphorus than that introduced by the southern Tennessee ores (compare analyses on p. 154). The Tennessee ore, however, carries a slightly lower and more uniform content of manganese than the Russellville ore.

As has been noted heretofore, the Sheffield furnaces must freight their brown ore and limestone 18 to 20 miles and are still less favorably situated in relation to red ore and fuel supply, since they obtain their red ore from Birmingham and the coke consumed comes largely from the Warrior coal field or from points in Tennessee. These disadvantages are partly offset, however, by the fact that the district is closer to the Mississippi Valley markets than are Birmingham and Chattanooga, and also because there is a market for a portion of the pig iron among local manufacturers. One important enterprise that might be cited in this connection is the Sheffield rolling mill, which consists of 12 double puddling furnaces, 6 heating furnaces, and 4 trains of rolls, and has an annual capacity of 30,000 tons, including such products as bars, rods, and cotton ties.

THE GRAY IRON ORES OF TALLADEGA COUNTY, ALA.

By Philip S. Smith.

TOPOGRAPHY AND GEOLOGY.

The gray iron ores of Alabama occur in a narrow belt that is confined almost entirely to Talladega County. The most northern occurrence of gray ore is in the range known as the Talladega Hills. It extends in a general northeast-southwest direction, which changes to a more nearly north-south course in Alpine Mountain. South of Alpine Mountain there is a break of several miles in which faults occur, so that the iron-bearing members are too deeply buried for profitable mining under present conditions. About 4 miles south of the southern end of Alpine Mountain the iron members again appear at the surface in the eastern ridge of the Weewoka Hills, the highest point of which is called Heacock Mountain. The general direction of this range is northeast-southwest.

South of the Weewoka Hills the range is formed by Andeluvia Mountain, an unsymmetrical isolated peak with two spurs, one pointing to the northeast and one to the northwest. Along the southwest face of this mountain the range is abruptly terminated by a fault, so that its connection with the southern continuation of the ridge is somewhat obscured.

South of this gap the iron-bearing ridge continues for 2 or 3 miles with a nearly north-south strike. This portion is cut across by Emauhee and Tallaseehatchee creeks. South of Tallaseehatchee Creek the course of the range abruptly changes from north-south to W. 20° S. and continues thus for about 4 miles to Oden Gap. At this point the range is cut through by a small northward-flowing creek known as Shirtee Creek. From Oden Gap to Fulton Gap the range extends for about 2 miles in a nearly east-west direction. It then continues with a more northwest-southeast direction for 4 miles and forms a high ridge known as the Kahatchee Hills.

As far as Fulton Gap the range is rather narrow, at few places over a mile in width, but is well defined and has a single crest. Beyond, in the region of the Kahatchee Hills, although the highest portion still persists as a single ridge, there are a number of smaller subsidiary ridges, showing great variations in direction, which are formed of the same strata as the main ridge. At the north end of the Kahatchee Hills, beyond the highest point, locally called Flagpole Mountain or Crumplers Peak, there is a cross ridge, with a nearly northeast-southwest trend, which is separated from the main ridge by a fault. This cross range extends within a mile of Childersburg. The western extension of the broken country of the Kahatchee Hills is rather abruptly terminated by a valley occupied by Kahatchee Creek and a creek flowing southward, from near Achates, joining Cedar Creek near Fayetteville. Through this valley, which is a half mile to a mile wide, runs the road from Fayetteville to Childersburg.

Two miles east of the junction of Haye Spring Branch and the Coosa, or about 4 miles N. 60° W. of Fayetteville, another range, known as the Katala Hills, extends for 2 miles in a northerly direction. This range then turns abruptly to the east and then to the south and extends southward along the west side of the valley through which the Fayetteville-Childersburg road runs. About a mile west of Fayetteville this range is cut across by Cedar Creek. The Katala Hills are rather low, with few elevations more than 500 feet above the master stream of the region.

South of the gap in the range, through which Cedar Creek passes, the ridge becomes more disconnected, and although it may still be traced by small knobs, it is at some places only a hundred feet above the surrounding country. These low sags across the range are traversed by railroads and roads. Thus the line from Sylacauga to Talladega Springs and Shelby crosses the ridge at a point about three-fourths of a mile southwest of Fayetteville.

South of the railroad pass the range increases in height and in continuity. The northern part of this southern extension, called Chalybeate Mountain, rises about 500 feet above the surrounding country. South of Chalybeate Mountain, prolonging the general southerly trend, is Sulphur Spring Mountain, which is cut through by Peckerwood Creek at Looney Mill. South of Looney Mill the range extends in a more southwesterly direction, decreases considerably in height, and becomes more broken. About 3 miles south of the mill the range is terminated by a great east-west thrust fault.

Near Columbiana, in Shelby County, west of Talladega County, there is another field in which iron occurs in the same relation to the surrounding rocks as in the range already described. The iron, however, is not of exactly the same character as that in the rest of the field, being more like the red ores of Alabama. The range at this place consists of two ridges, which coalesce toward the north and south forming an elongated ringlike mountain known as Columbiana Mountain. Beeswax Creek cuts entirely across this mountain in its northwest and southeast limbs. The longer axis of the ellipse is northeast-southwest.

Throughout its entire extent the range is tree-covered, and on its gentle lower slopes small, rather poor farms are located. In its upper portions, however, the slopes are steep and are covered with heavy float of coarse conglomeratic sandstone. The summit of the ridge is almost everywhere formed of coarse sandstone that breaks into angular fragments, many of them of large size. The lowland on either side of the range has been eroded on soft rocks, generally limestones or limy shales. The limestones have at many places a very different trend from the ridge-making rocks, so that the contact between these two is generally a fault.

The fact that the ridges stand up above the surrounding country is due chiefly to the protection that has been afforded the weaker underlying rocks by the strong, massive quartzitic sandstones that form the crests of the ridges. In the geological past it is presumable that this whole region was a mountain-built area. By long-continued erosion, however, a nearly continuous plain, practically at sea level, was formed on the hard and soft rocks of which the mountains were made. Later this plain was uplifted and the rivers again began their work of erosion because of the increased slope and velocity given them by the uplift. In this renewed activity it is evident that areas of weak rocks, such as limestones and shales, would be cut down and opened out into larger valleys than areas of harder rocks, such as the sandstones. The ridges therefore do not owe their height to "outbursts" and "upheavals," by which they were elevated higher than the rest of the country, but rather to more orderly, systematic processes of erosion, such as are even now going on, and constantly tending to wear away the softer rocks faster than the harder ones.

In general the structure of the ridge appears to be practically the same throughout the entire region. The typical structure may be well exemplified by a section near Oden Gap. Starting with the dolomitic limestone of the broad valley through which the Central of Georgia Railroad runs, the rocks have a slight southerly dip. As one approaches the ridge the dolomite abruptly gives place to greenish chloritic slates and schists, which also have a southerly dip, at a much higher angle than the dolomite. Higher up the hill and generally nearly at the top of the ridge, there is a heavy quartzitic conglomeratic sandstone with a southerly dip of greater inclination than the slope of the ridge. South of the summit the slope of the surface is not so steep as that of the north side. Here there is a series of slates, schists, and metamorphic sandstones, with occasional seams of iron ore. This series seems to consist of essentially the same members as those that are found in the float on the north slope. Still farther south the slopes become gentler.

In some places the schistose series is succeeded by thinly laminated slightly metamorphosed light-colored shales with thinly banded limestones. In other places the shales and thin-banded limestones are missing and instead rather massive dolomitic limestones with occasional cherty beds are found. As the dips are all in the same direction the structure of the ridge would seem to be monoclinal, but this interpretation is not permissible, for the dolomitic limestones on both flanks are of the same age.

Further facts concerning the structure of the ridge are afforded in the deep cuts or sections across the ridge. These are formed where streams cut across or where low sags occur which have previously been worn by streams that are now diverted, by capture, from their former courses. A nearly continuous rock section several hundred feet below the summit, traversing the entire ridge, is afforded by the railroad cut which follows Shirtee Creek through Oden Gap. At the extreme north end of this section there is a dolomitic limestone which shows a nearly horizontal dip with a little anticlinal fold at the south end. The limestone abruptly terminates against a series of metamorphic schists that have a greenish color and wavy cleavage. In the midst of these schists are bands of quartzite—very hard, close-textured beds, varying from 1 to 3 feet in thickness, not at all like the heavy quartzitic conglomeratic sandstone on top of the ridge. The first quartzite found in the section is folded into a syncline, the bowl of which is well exposed. This quartzite is much metamorphosed and shows the development of secondary chlorite along the planes of shearing. South of the quartzite and relatively below it are more schists, similar to those previously described. These schists are folded into an anticline and then succeeded by another bed of quartzite. Above the quartzite lies a series of schists, the same as the others, with interbedded iron ores which generally occur rather near the quartzite horizons. The dip of the schists is variable, but the lithological character is nearly constant.

MINES AND PROSPECTS.

Although the occurrence of gray ore in Talladega County has long been known, having been reported by Tuomey in 1858, not much attention has been paid to this source of iron. At the present time only one company, the Gray Ore Iron Company, is in active operation in the district. The Gray Ore Iron Company owns approximately 3 miles along the strike of the formation, but has begun operations at only two points, namely, at the Emauhee mine on Emauhee Creek, and at the Mesaba or Tallaseehatchee mine, on Tallaseehatchee Creek.

Within the limits of this property the range changes from a general north-south to an east-west trend. As the strata show the same change in strike, the same geological horizons still continue from the most northern to the most western part of the property.

The Mesaba mine is the only active mine in the district. It is located on the range where it is cut through by Tallaseehatchee Creek in sec. 10, T. 21 S., R. 4 E. The mine is connected with the main line of the Louisville and Nashville Railroad by a spur track one-half a mile long, which runs from Mesaba to the mine. The creek affords sufficient water throughout the year for the demands of mining.

At present the ore is won mainly by open-cut work, although the time is not far distant when deeper work will be necessary. The ore is trammed from the pits on the different levels to gravity inclines where cars are lowered to the weighing shed, run to the crusher, crushed to 4 inches, and without handling dumped into the ore cars on the railroad. The ore is not hand picked or otherwise sorted or washed.

As the present work is entirely on the surface the ore is more or less broken up and disintegrated, so that a large part may be handled by horse scrapers and shovels. As greater depth is attained and stope mining is begun the ore will undoubtedly become more compact and difficult to break down. This will necessitate recourse to blasting on an extensive scale and consequent increase of cost of mining.

The ore occurs in a series of slates and quartzites which have an easterly dip and a north-south strike. The dip varies in different parts of the mine owing to deformation of the crust through folding and faulting. Although the dip is everywhere easterly there is strong reason for believing that the rocks have been folded to such an extent that the folds have been overthrown, and that in some places this overfolding has been so intense that the rocks have actually been broken and pushed on top of strata which geologically lie above them. The slates and quartzites are conformable—that is, the beds of one lie parallel to the beds of the other. Where this relation is not true the discordance is due to faulting.

The distinction between ore and slate is generally based on purely economic grounds, for the two are so intimately mixed that it is impossible to take out one without also removing a large amount of the other. This fact is of considerable importance in estimating the values of the properties, for the usual analyses do not take into consideration the amount of slate that must be removed in winning the ore.

The faults in this region are of two distinct types, normal and reverse or thrust faults. The normal faults—that is, those faults that have the downthrown block on the side toward which the fault plane dips—trend generally at a right angle to the range. The reverse faults extend more nearly parallel with the range and have greater effect upon the topography than the normal faults. Most of the normal faults in this district are of slight displacement, but some of the thrust faults have a throw of a thousand feet or more.

The ore occurs in two forms; the first rather hard, massive, and quartzitic; the second soft, crumbly, and slaty. The soft ore is generally higher in iron and is more easily mined. It undoubtedly has been formed by the replacement of slate by iron. The hard, massive ore breaks into angular blocks bounded by joints. On freshly fractured surfaces the ore is seen in glistening small crystals interspersed with quartz grains. Much of the quartz is of a bluish color but on long exposure becomes white and opaque. The quartz grains are crushed and elongated in the plane of the cleavage. The ore is dark, nearly black, but becomes gray on exposure. This change of color is especially noticeable in the slaty ore.

At the Mesaba mine there are two main veins of ore, which differ but slightly from each other either in character or thickness. The eastern vein varies from 10 to 15 feet in thickness. At two places, however, its thickness has been increased by thrust faulting, which took place before the block faulting occurred. This vein has been uncovered for about 600 feet along the strike. Beyond the point thus exposed the evidence afforded by scattered pits is too incomplete to permit valuable deductions as to the structure which may be encountered in further development.

A vein of ore that has been slightly prospected extends from the mine nearly due south for a quarter of a mile and then swings around toward the southeast. It may be traced for about half a mile, but near the junction of the spur track with the main line of the Louisville and Nashville Railroad it is cut off by the fault along the south and east side of the range which brings the limestone to the surface. This vein has an exposed thickness ranging from 3½ to 5 feet. The ore is of the hard variety, being quartzitic, with numerous flattened and crushed grains of quartz.

The second vein at Tallaseehatchee lies about 75 paces west of the eastern one. Toward the south the western vein diverges slightly, so that the distance between the two veins increases in that direction. In the extreme southern part of the area that has been opened at the mine on this vein about 42 feet of ore is exposed. This unusual thickness is due to the reduplication of beds by thrust faulting. Both the eastern and western veins are cut by normal faults that have east-west strikes, no less than five having been recognized in a distance of only 200 paces.

The entire area that has been opened up at the Mesaba mine is included within a square that measures 200 yards on a side. No depth greater than 20 or 25 feet below the surface has yet been attained, so that the character and continuity of the ore in depth has not yet been determined. It seems, however, that the ore becomes gradually more and more compact with increase in depth.

On account of the slight amount of prospecting that has been done by the company, little is known about the extent and form of the ore bodies. It has been shown, however, that the ore at one or more horizons continues for at least a mile and a half, or to the limits of the company's holdings, south and west of the mine. The amount of float indicates that in at least two places in this distance a great thickness of ore may be expected. Both of these areas occur in sags between hills, but as there are no exposures of underlying rocks at these places the structure could not be determined. It seems probable, however, if the iron series lies below the Weisner formation, as has been supposed, that the apparent thickness is due to the fact that the surface here bevels across the bowls of synclines. This suggestion needs careful and thorough consideration, as its bearing on the economic problems involved is very important.

The other mine of the Gray Ore Iron Company is about three-fourths of a mile north of the Mesaba mine, on the same range, at a point where it is cut through by Emauhee Creek. Operations at the Emauhee have been suspended while work at Mesaba is being pressed. In consequence the pits are filled with water, so that most of the mine could not be visited.

The method of development at Emauhee differs from that used at Mesaba, for the facilities there for stripping are not so good and an incline some 300 feet in length has therefore been driven and drifts have been turned off every 50 feet. The main mining work has been done on the south side of the creek. When the company resumes work the lowest drift will be driven northward at a depth of about 100 feet under the creek and will connect with the surface workings on the other side by an upraise. This connection will afford good ventilation and will block out considerable ground.

The ore at Emauhee is similar to that at Mesaba, but is more dense and quartzitic. This massive character, coupled with the additional expense of underground mining, makes the cost at Emauhee much higher than in the more easily shaken, less massive beds at the Mesaba mine, which for the present, at least, can be handled in open cuts.

There are two veins at Emauhee. The more eastern vein has been most extensively developed and carries the better ore. This vein consists of two benches of hard quartzitic ore separated by a thin parting of iron-impregnated slaty schist, very similar in character to the slates at Mesaba. The thickness of this slate parting varies considerably. In some places it disappears; in others it is several feet thick. The ore also varies in thickness, but near the mine it averages approximately 5 feet 7 inches. This lead has been traced southward and a small amount of development work has been done 1,000 feet south of the main line. In this distance the ore is nearly continuous with apparently but slight interruption by faults.

North of the mine, across the creek, the main vein has been opened for several hundred feet and a good deal of ore has been won by open-pit mining. In the northern part of the open-cut work, about 200 paces from the creek, there is a well-pronounced fault, with a nearly east-west strike, by which the ore is thrown to the west a slight distance. About 100 paces still farther north there is another east-west fault, by which the ore is thrown some distance to the east. Beyond this point the ore, which has previously appeared on the west side of the ridge, is found only on the east side of the ridge. Other openings have been made on this northward extension from Emauhee nearly to Sycamore. The last place where the ore was exposed along this nearly continuous line was just west of the group of houses at Sycamore, southwest of the cotton mill.

These pits had been dug for a long time and had caved, so that the entire thickness of the ore was perhaps not visible in all of them. There were, however, few if any places north of the open cut on the north side of Emauhee Creek where a greater thickness than 4 feet of ore was observed. The ore in these pits was much redder than that exposed in either the Mesaba or Emauhee mines. It seems evident, however, that this lead is the same as the main lead at Emauhee, which is also correlated with the eastern vein at Mesaba.

The second vein at the Emauhee has not been worked at all. It lies west of the main vein and is of much poorer quality. This ore is an impure iron-bearing sandstone. The vein is wider than the first, averaging about 7 feet. This measurement is approximate only, and can not be made exact owing to the lack of development and the poorly defined contact between the ore and the country rock. Near Emauhee this vein seldom runs more than 30 to 34 per cent metallic iron.

In addition to the Mesaba and Emauhee mines there are a number of other places where gray ore has been mined on a small scale in the past. At Columbiana a few hundred tons were shipped a long time ago. At Andeluvia Mountain, according to McCalley,[a] about 100 tons of ore were mined and shipped. In the Weewoka Hills, near Heacock and Riser mountains, also, a small amount of ore has been mined and smelted.

Active prospecting is now in progress only in the Weewoka Hills near Heacock and Riser mountains. The Heacock property has been exploited by numerous pits, so that the general character of the ore and its width, length, and value have been more or less completely

[a] Valley regions of Alabama, pt. 2.

determined. The ore occurs in a series of arenaceous schists and slates which have a nearly northeast-southwest strike. The main openings are on the west side of the easternmost range of the Weewoka Hills opposite the house of Doctor Heacock in sec. 9, T. 20, R. 4 E. The ore bodies are intricately folded and the structure is complicated. The valley between the western range of the Weewoka Hills on Mallory Mountain and the eastern range on Heacock Mountain is occupied by down-faulted limestone which is of either Knox or Aldrich age. The range consists of schists, slates, and sandstones, and in the extreme upper portion of quartzite.

In the slates there are several beds of gray ore, no less than five being exposed between the foot and summit of the hill on the west side. It seems evident, however, that all of these do not represent separate strata, but rather the folded limbs of the same bed. At least three of the five belong to the same bed, and it is a question whether the other two belong together or to the folded vein to which the first three belong. Many important points regarding the details of these ore horizons can not yet be determined, owing to the small number of openings.

The old work done at the Heacock consisted in stripping the easternmost vein, the one nearest the top of the ridge, for nearly a hundred yards. This vein averages about 3 feet in width and consists of good clean hematite ore. About 100 paces southwest of its northern end this bed is folded back on itself so abruptly that it has broken and the southern continuation has slipped past. The vein, therefore, occupies nearly 20 paces less space than it would if the lead were continuous. This feature is mentioned in detail because it must constantly be taken into account in developing these ores. Where the beds have been much faulted and folded, the value of the ore increases, so that the associated difficulties of mining are in some measure compensated for by the higher tenor of the ore.

In the northwestern part of the field this vein lies west of the summit of the ridge, but its strike, somewhat less westerly than the strike of the ridge, soon brings it onto the east side of the range. It has been traced more or less continuously for about 500 paces, though many of the old prospect pits are now filled in, so that no ore is exposed in place.

About 50 paces west of this vein there is another vein, which stands nearly vertical and has a nearly parallel strike. This vein, where exposed in the entrance of an old adit, appears as a 3½-foot bed. Twenty-three paces within this adit in an easterly direction is another vein which has a flatter easterly dip and a more northwesterly strike. On the surface the two veins have approached each other to within about 4 paces. Consequently it seems evident that the two veins in the adit are the same, for the strikes are converging as well as the dips.

The ore body there is in the form of a northward-pitching anticlinal fold.

Between the two leads shown in the adit and the eastern vein on the summit of the hill there is another lead of ore. This seems to connect with the easternmost vein exposed in the adit to form a synclinal fold. These three veins, then, are presumably the same bed, which has been folded and eroded so as to give the appearance of three separate beds. The westernmost bed on Heacock Mountain has been exposed in only four small pits. It lies about 25 paces west of the vein shown in the mouth of the adit. The ore is identical in character with that seen in the other veins, and all the beds may represent only one ore horizon reduplicated by folding.

In connection with Heacock Mountain it is interesting to note that the direction of the mountain is not parallel to the rock structure, but is determined mainly by the direction of faults on the sides of the mountain. The strata run more nearly north and south than the range, which trends northeast-southwest, and therefore the veins, which all appear on the western side of the mountain in the northern part of this property, cross the range and in the more southern portion are on the eastern side.

About a mile south of the Heacock Mountain openings, on the east side of Weewoka Creek, only a couple of hundred paces from the dam at Weewokaville, there is another series of exposures of gray ore. These exposures occur on a small ridge that is separated from Heacock Mountain by faults which bring down the dolomitic limestones so that a valley has been etched on them. This lower ridge because of the early ownership of the property is called Riser Mountain. It has a heavy quartzitic sandstone at the summit and a series of somewhat metamorphic beds on the lower slopes. These beds, however, are not so much metamorphosed as the slates and schists at the Heacock.

The ore at Riser Mountain is rather complexly cut by both normal and reverse faults. These have, however, not materially affected the quality of the ore, which is of somewhat lower grade than that at the Heacock Mountain property. The most marked effect of the faulting has been to increase materially the thickness of the outcrop. Consequently for a distance of 500 feet along the vein it is wide enough to afford good opportunity for stripping. The ore at this place shows rather more intimate connection with the quartzitic sandstone than at most other localities. The sandstone is rather coarse and in a number of places shows well-marked cross-bedding on a small scale. The ore here occurs in two leads, but owing to the slight amount of development it is uncertain whether they are connected or not. From the rapid thickening and thinning of the main lead it is possible that the thick places represent the fold where the two seams coalesce. On the other hand, the fact that the two seams have very different thickness is suggestive that they are really two distinct beds.

Nearly a mile south of Weewokaville, on the east side of Weewoka Creek, there is another group of openings which shows rather good ore. The ore, however, is seldom over 3 feet thick and so would be rather expensive to mine. The structure at this place is complicated. The ore has a more nearly north south strike, with even a slight tendency toward the southeast. The dip is extremely variable. In the western part of the field, where it has been opened up by prospect pits, the dip becomes nearly flat. This flattening is due in part to the creep of the surface but mainly to the actual change in dip which the rocks have undergone. Considering the thinness of the beds, their flat inclination, and the lower tenor of iron, this property does not seem so promising as the Riser or Heacock Mountain fields. This southern field is abruptly terminated toward the north by a fault and the northward continuation of the lead has not yet been successfully located. Throughout the field there are a number of faults of small displacement, most of which seem to be normal faults.

Gray ore float can be traced southward almost continuously to Andeluvia Mountain, though no exploration pits have been put in to uncover the ore. In Andeluvia Mountain at least three veins of ore are exposed. The most valuable occurs on the northwest side, where 6 feet of good clean ore has been exposed in a prospect pit. Near the summit of the mountain there is also some gray ore, but it is of low grade and is merely a ferruginous sandstone with perhaps 25 per cent of metallic iron.

On the summit of Andeluvia Mountain a prospect pit has been sunk and, according to local tradition, about a hundred tons of ore were shipped from it. The ore, however, was so poor that it had no economic value and further work was abandoned. There are at least two kinds of iron ore exposed on Andeluvia Mountain, namely, the gray ore and a variety of specular hematite. The amount of the latter, judging from the float, is rather slight and probably this ore has no economic importance. The specular ore is found in the schists associated with lenses of quartz. At many places some iron carbonate or siderite is associated with the hematite, but it occurs in insignificant amounts.

From Andeluvia Mountain as far south and west as Hickmans Gap, which is about one-half mile east of Herds Gap, the occurrence of the ore has already been described in the paragraphs on the Emauhee and Mesaba mines. From this point westward as far as Fulton Gap there has been more or less desultory prospecting, but the ore so far exposed has generally been in narrow beds much intermixed with slate. Very little systematic exploration has been done in this field, however, and further development work by means of pits and trenches would probably afford interesting results. At least four different beds have been encountered in a single section across the range near Herds Gap, but their interrelation has not been determined.

In the Kahatchee Hills—meaning by this the range west of Fulton Gap as far as the Childersburg-Fayetteville road—practically no development work has been done, owing rather to the roughness of the country than to the absence of ore indications. At a number of places gray ore float is abundant and several outcrops of ore of fair quality have been found. On the surface the outcrops are generally much weathered and many of them appear leaner than they actually are found to be below the soil.

In the cross range near the northern end of the Kahatchee Hills there is an interesting occurrence of ore which possibly throws light on the origin of some of the gray ore. About 1½ miles N. 50° W. of the highest peak of the Kahatchee Hills there is a quartzite striking N. 53° E. This quartzite contains a great abundance of small pyrite crystals, and near the surface, where alteration has affected the rock most, the iron pyrite has decomposed and weathered into a brown ore on which a pit was opened. Apparently on the same strike and not more than a hundred yards to the southwest there is a bed of very lean gray ore, consisting mainly of hematite. This occurrence suggests the possibility that the gray ore here was derived by metamorphism from brown ore, which in turn was apparently derived from iron pyrite through decomposition.

In the Katala Hills, west of the Kahatchee Hills, there is an abundance of iron float near the summit of the ridge. The line of outcrop of the ore can be traced continuously from a point west of Fayetteville throughout the entire length of the ridge. Along the eastern limb of these mountains the ore is sandy and therefore not of very good quality. In the broken western limb north of Haye Spring Branch the ore is of much better quality. This ore, however, is redder than the other gray ores of the district. This field has not been exploited, but promises well.

South of Fayetteville there are few exposures of good ore. The most promising place is on the southeast side of the spur that runs eastward from Sulphur Spring Mountain, where, in an old pit which has now caved considerably, a lead of ore 6 feet across has been exposed. This lead is said to have shown up much thicker when the pit was first opened. It can be traced southward by float from Sulphur Spring Mountain to Looney Mill, a distance of 2 miles. This float is for the most part highly arenaceous and the iron content of this ore is undoubtedly lower than that of the ore in the northern part of the Katala Hills.

As has been previously noted, the iron-bearing member decreases in value south of Looney Mill, becoming more and more arenaceous, until it is only a slightly ferruginous quartzitic sandstone. In this part of the range there have been no openings except a few old pits dug in the hard bluish quartzite that forms the summit of the ridge near the point where it is crossed by a road 1 mile south of Looney Mill.

In Columbiana Mountain, a few miles east of Columbiana, in Shelby County, there is a bed of reddish hematitic iron ore. As its position with respect to the Weisner quartzite is the same as that of the gray ores of Talladega County, mention of its mode of occurrence may be of interest. The structure of the mountain is very complicated. According to Dr. E. A. Smith, the lowland west of Columbiana is formed of Mississippian sandstones and shales. The lowland at the foot of the mountain on the west flank is composed of Knox shales and limestones. Higher up the mountain a fault causes an abrupt transition into a series of sandy shales with some quartzitic beds. The summit of the mountain is formed of heavy quartzitic sandstone, such as characterizes the summits of the range in Talladega County. The form of the mountain is roughly elliptical, the longer axis pointing northeast-southwest. The massive quartzitic sandstone forms the rim of this mountain, except where it is breached by Beeswax Creek in the northwest and southeast. The form of this mountain, with its high elliptical rim and low basinlike central portion, is very peculiar, but is in some respects similar to the canoe-shaped folded mountains of the northern Appalachians. A section along the Columbiana-Mardis ferry road eastward from the summit of the western limb, 1½ miles from Columbiana, is as follows:

Section along Columbiana-Mardis ferry road.

	Paces.
Quartzite, top of ridge	1
Very red soil, all sandstone float	50
Nearly level, practically no float	100
Road descends more abruptly; sandstone with little quartz veins	175
Broken shaly sandstone; dip 38° SE	178
Broken shaly sandstone; dip 72° E	183
Three-foot quartzite ledge, with numerous quartz veins; dip 47° E	204
Slaty sandstone; dip vertical	270
Slaty sandstone; dip 20° E	279
Rather heavy fine-grained sandstone; dip 18° E	304
Light-greenish thinly laminated slates quite arenaceous; dip 22° E	374
One-foot quartzite; dip 22° E	404
Heavy quartzitic sandstone	458
Heavy sandstone float	517
Thinly laminated shales breaking into small pieces; dip E. (?)	538
Two-foot bed of ore forming slight ridge in road	550
Six-inch bed of ore	557
Three-foot bed red iron ore; dip 27° E	560
Greenish shaly slates; dip uncertain	564
? Fault; beyond this the dip is 48° E	584
Greenish shaly slates; dip 30° E	594

	Paces.
Coarse sandstone giving rise to deep iron red soil	617
Beginning of another iron series	623
Eastern wall of iron member. This series is made up of a number of thin beds of hematite ore separated from one another by slate partings. The ore is quite quartzose; dip 45° E	633
Sandy shaly slates; dip conformable with iron series	656
Sandy shales; dip 60° E	666
Heavy fine sandstone rather poorly consolidated; dip 37° E	676
Thinly laminated shaly sandstones	710
Heavier sandstone, fine-grained but rather massive; nonquartzitic	716

In the more eastern limb of Columbiana Mountain the iron series appears on the western slopes. As the dip of the rocks is easterly, the hematite apparently underlies the heavy quartzitic sandstone that caps the summit of the mountain. This shows the same complex relation that has been observed in Talladega County, namely, that in places the dip of the ore would seem to carry it below the quartzitic sandstone, while in other places it appears to be above.

No gray ore has been found in either Alpine Mountain or the Talladega Hills, but as the same series that occur in the productive areas are found also in these hills they may be considered as possible areas. In the Talladega Hills there are numerous brown ore deposits at the horizon in which gray ore occurs farther south. It would appear, therefore, that the horizon of the gray ore is at some places occupied either by lean ferruginous sandstone or by limonite deposits.

The other possibly productive area noted is the western limb of the Weewoka Hills or Mallory Mountain. In this mountain although the rocks appear to belong to the same geological horizon as those of the eastern range of the Weewoka Hills there is no trace of gray ore. Instead, just at the places where gray ore would be expected there are brown ore deposits, a fact that will be further considered in the discussion of the origin of the ore deposits. So far as the present investigation has shown, however, it does not seem probable that any gray ore of economic importance will be discovered in Alpine Mountain, the Talladega Hills, or Mallory Mountain.

CHARACTER OF THE ORE.

Practically all the so-called gray ore in Talladega County is really hematite. An analysis made in the chemical laboratory of the United States Geological Survey (No. 2241) of an average sample of ore from Heacock Mountain, Weewoka Hills, gives 70.04 per cent Fe_2O_3 and 0.74 per cent FeO. If all the ferrous iron in this analysis is derived solely from magnetite the relative percentages of the two minerals would be 97 per cent hematite and 3 per cent magnetite.

In places, however, the relative percentage of magnetite so increases that the ore becomes somewhat magnetic.

When exposed to weathering the ore takes on a rather ashy gray color, and the name gray ore therefore not only describes it, but serves to distinguish it from the red or the brown ores of northern Alabama. As the ore is a variable mixture of magnetite and hematite the simple term gray ore is sufficiently distinctive and yet implies no definite limitation of the iron mineral.

Thin sections of the ore contain, in addition to the iron minerals, a great deal of quartz, which is the main source of the silica content. There is some feldspar, mainly soda-lime feldspar, although there is also some microcline. Mica as a secondary product is represented by scattered blades of muscovite. Biotite is practically absent. Some chlorite, secondary after mica, is found, but it is not abundant.

The main constituents of the ore are quartz and iron. The hematite is in scaly and apparently sheared aggregates, while the magnetite is generally in well-formed, sharp crystals, which have apparently been formed later than the hematite. In a very few thin sections iron sulphide has been recognized. The quartz occurs in two distinct forms—as an original mineral, very much strained and shattered, and as a secondary mineral, showing no optical stress. This secondary quartz includes many crystals of magnetite, the relations of these minerals showing the relative age of crystallization of the magnetite and the later quartz. Mica was apparently contemporaneous with the later quartz. The magnetite, the later quartz, and the mica were probably formed at the close of the period of dynamic metamorphism during which the mountains were built.

The accompanying chemical analyses bring out more clearly the character of the ores of this district. Table I comprises analyses that have already been published. Table II comprises unpublished analyses, most of which have been collected from mining or prospecting companies, and are less complete than those in Table I. Table III also consists of analyses hitherto unpublished, but these were made from material collected by the United States Geological Survey. The analyses in Table III should therefore receive greater weight than those in either of the other two tables, for the samples were taken carefully and the personal equation was eliminated as far as possible. Samples procured by interested parties are generally misleading, for they are not usually taken across the entire width of the vein which is to be mined. It is practically impossible to select one fragment of rock which shall represent the true value of a vein; therefore some method of sampling which shall be entirely impartial must be adopted. The samples from which all the analyses shown in Table III were made were taken by cutting a continuous groove the entire width of the vein and preserving all the chips from the furrow, and it is therefore believed that these analyses accurately represent the character of the ore.

TABLE I.—*Analyses of Alabama gray iron ore.*

	Location.	SiO_2.	Fe.	P.	S.	MnO_2.	CaO.	Al_2O_3.	H_2O.	Ti.
1	Magnetite near Childersburg	24.60	53.90	0.022	0.04	......	0.32	......	12.00	......
2	Do	10.30	60.40	.065	.06	......	.22	......	.08	......
3	Siliceous hematite, near Columbiana	30.03	42.51	Tr.	.90	0.14	1.94	5.88	1.26	......
4	Do	29.06	44.61	.30	......	1.60	......	3.66	......	......
5	Do	23.45	49.08	.34	.11	......	1.58	4.00	......	......
6	Do	16.24	49.27	.61	.60	.26	1.25	3.31	7.45	......
7	Do	20.74	53.81	Tr	......	.51	......	1.55	......	......
8	SW. ¼ sec. 15, T. 22, R. 2 E	40.103	36.272	.330	.037	1.26	.700	13.373	2.078	......
9	NE. ¼ sec. 17, T. 21, R. 4 E	38.10	35.17	.36	Tr.	Tr.	.60	6.06	.40	0.00
10	SE. ¼ sec. 34, T. 20, R. 4 E	7.05	61.23	.16	Tr.	Tr.	.20	5.10	.10	.00
11	½ mile south of Sycamore	7.10	59.47	.16	Tr.	Tr.	.80	4.22	.05	.00
12	Sec. 9, T. 20, R. 4 E., opposite Dr. Heacock's	17.35	51.91	.30	Tr.	.31	.80	4.78	.10	.00
13	Do	12.84	56.01	.11	......	......	.50	......	......	......
14	Do	19.30	49.28	.62	......	......	......	......	......	......
15	Do	11.70	54.47	.195	......	......	......	......	......	......
16	Do	4.40	61.37	.666	......	......	......	......	......	......
17	Do	20.80	47.28	.563	......	......	......	......	......	......
18	SE. ¼ SE. ¼ sec. 16, T. 20, R. 4 E	12.75	60.92	:025	......	......	......	......	......	......
19	Do	11.00	59.03	.091	......	......	......	......	......	......
20	Do	33.40	42.89	.15	......	......	......	......	......	......
21	Columbiana Mountain	31.594	31.746	.20	......	......	......	......	......	......
22	NE. ¼ NE ¼ sec. 17	21.98	46.83	3.00	......	......	......	......	......	......
23	NE. ¼ sec. 34, T. 20, R. 4 E	13.80	58.01	.096	......	......	......	......	......	......
	Average	19.94	50.67	.398	.291	.68	.86	5.19	2.613	.00

Analyses 1-3, 6 by E. A. Smith (Porter, Trans. Am. Inst. Min. Eng., vol. 15); analysis 4 by J. B. Britton (Smith, Rept. Progress Alabama Geol. Survey for 1875); analysis 5 by C. F. Chandler (Smith, Rept. Progress Alabama Geol. Survey for 1875); analysis 7 by F. P. Dewey (Tuomey, Second Bienn. Rept. Alabama Geol. Survey, 1858); analysis 8 by A. F. Brainerd (McCalley, Valley regions of Alabama, pt. 1, 1897); analyses 9-12 by W. B. Phillips (McCalley, ibid.); analyses 13-20, 22, 23 by W. Crafts (McCalley, ibid.); analysis 21 by Henry McCalley.

From Table I it will be seen that the range of silica is from 4.40 to 40.10, the average being 19.94 for the 23 analyses. The metallic iron ranges from 61.37 to 31.74, averaging 50.67. The phosphorus varies from a mere trace to 3.00, its average value being 0.398. The analysis giving 3 per cent phosphorus differs so much from all the others that one is inclined to suspect some error. Inasmuch as the proof reading on the volume from which the analysis was taken was not carefully done it is possible that the decimal point may have been misplaced, so that instead of 3.00 the value should be 0.30. The sulphur has been quantitatively determined for only 6 of the 23 analyses, but for those the average content was 0.291. Manganese also was found in several of the samples, although in most of them it was neglected. The lime is very low, the average being 0.86 per cent. Alumina is the next highest component after iron and silica. Unfortunately this oxide has been determined in only 10 of the analyses; the average, however, is about 5.19 per cent. A striking departure is seen in analysis 8, in which the alumina rises to 13.37 per cent. The water ranges between 12.00 and 0.05, averaging 2.61.

If the iron is Fe_2O_3, the sulphur SO_2, and the phosphorus P_2O_5 the total of average values obtained from all these analyses is 103.16. The excess over 100 is probably due to the incompleteness of many of the analyses and the inclusion in some of them of two or more substances under one head. For instance, in some of the analyses undoubtedly all the insolubles are calculated as SiO_2.

TABLE II.—*Analyses of Alabama gray iron ores.*

	Location.	SiO_2.	Fe.	P.	S.	CaO.	Al_2O_3.	Ti.	Mn.	MgO.	K_2O and Na_2O.	Ign.
1	Mesaba mine	24.10	17.90	0.239	0.46	5.10	3.531	0.72		0.176		
2	Mesaba mine	32.10	39.90	.137			5.53		0.25	.30	1.95	4.15
3	Emauhee mine	42.10	30.60	.418		1.12	5.48		.38	.65	1.57	1.86
4	Emauhee mine	25.60	44.10	.404		2.34	.395		.62	1.14	2.11	2.73
5	Mesaba mine	14.72	52.42	.148				.66				
6	Mesaba mine	18.32	48.90	.364				.88				
7	Mesaba mine	15.42	52.28	.147				.71				
8	Heacock Mountain	15.04	53.55	.219								
9	Heacock Mountain	19.58	50.45	.268								
10	Heacock Mountain	18.94	50.70	.284								
11	Heacock Mountain	15.44	52.74									
12	Heacock Mountain	14.10	53.76									
13	Heacock Mountain	22.20	47.79									
14	Riser Mountain	21.64	45.19									
15	Riser Mountain	20.82	46.66									
16	Riser Mountain	24.40	45.20									
17	Riser Mountain	24.00	44.98									
18	Riser Mountain	25.44	44.52									
19	Heacock Mountain	17.00	50.00	.30								
20	Emauhee mine		42.25									
21	1,000 feet south of Emauhee mine		49.15									
22	Mesaba mine		46.85									
23	200 yards west of Emauhee mine		38.02									
	Average	21.63	45.56	.262	.46	1.32	3.73	.74	.42	.57	1.88	2.91

Analysis 1 by A. S. McCreath; analyses 2–4 by B. Crowell; analyses 5–7 by Hillman (Birmingham Testing Laboratory); analyses 8–10 by P. B. Condit; analyses 11–18 by Seifford (Birmingham Testing Laboratory); analysis 19 by Meissner (Vanderbilt Steel and Iron Co.)

Table II is incomplete, for the main elements that prospecting companies wish to determine are the iron and silica. The first of these elements runs considerably lower than the iron of Table I, being on the average about 45.56 per cent. The silica is higher, having a range between 14.10 and 42.10, the average being 21.63 per cent. The phosphorus is much lower, being 0.262 per cent. If, however, in Table I we omit the excessive phosphorus of analysis 13, the average phosphorus of Table I becomes 0.268, which corresponds very closely with that of Table II. There are not sufficient data to permit a comparison of the sulphur of the two tables.

The average of the analyses of Tables I and II is as follows:

Average of analyses given in Tables I and II.

SiO_2	20.78
Fe_2O_3	68.73
P_2O_5	.75
SO_2	.75
MnO_2	.67
CaO	1.09
Al_2O_3	4.46
TiO_2	.26
H_2O	1.30
MgO	.57
K_2O and Na_2O	.94
	100.30

It is interesting to compare this average with the analyses in Table III, which shows the analyses made for this paper by R. S. Hodges, chemist of the Geological Survey of Alabama.

TABLE III.—*Analyses of gray ore from Tallasechatchee mine, Alabama.*

Location.	SiO_2.	Al_2O_3.	Fe.	Mn.	P.	S.	TiO_2.
1. Middle of east vein	32.71	10.18	35.38	0.24	0.28	0.016	0.53
2. Northwest wall of east vein [a]	47.02		20.36				
3. South end of west vein	49.89		25.97				
4. Northern part of west vein [b]	28.34		43.17				
5. South end of west vein [c]	35.68		35.96				

[a] About 36 feet wide.
[b] Vein at this point 38 feet wide. Hard ore.
[c] Vein at this point 42 feet wide. Many slate partings in the ore.

The most noticeable facts shown by the analyses in Table III are the relatively low iron content and the high silica. The greatest amount of iron occurs in the hard, massive variety of ore (analysis 4). Although Tables I and II represent a much greater number of analyses than Table III, the latter is probably more trustworthy, for the ore was not subjected to any sorting in the sampling. The higher percentage of alumina in the only complete analysis in Table III shows that much more slate was included in the ore than would be inferred from the other analyses. The average iron content of the five samples calculated as Fe_2O_3 is 46.14 per cent as opposed to 68.73 per cent, the average obtained from the analyses of Tables I and II. The silica is also much higher, averaging 38.73 as against 20.78.

Calculating the iron as Fe_2O_3, the sulphur as SO_2, the manganese as MnO_2, and the phosphorus as P_2O_5, the complete analysis of sample 1 of Table III would be—

Complete analysis of sample of gray iron ore from Tallasechatchee mine.

SiO_2	32.71
Al_2O_3	10.18
Fe_2O_3	50.54
P_2O_5	.65
MnO_2	.38
SO_2	.03
TiO_2	.53
	95.02

The difference between this total and 100 per cent is probably mainly H_2O.

ORIGIN OF THE ORE.

The origin of the gray ores of Alabama has been discussed in some of the earlier reports, but misconceptions regarding the precise character of the ore have led to untenable hypotheses. In the earliest work of the Alabama survey it was stated that the "magnetite" or gray ore represented a beach accumulation of black sand, such as occurs at many places along the seashore at the present day. This hypothesis has persisted practically down to the present time. Careful microscopic examination, however, fails to show that the grains had been water rounded. In fact, much of the ore has been carried into its present position since the sedimentary rocks became thoroughly consolidated. This fact is proved by numerous specimens collected and preserved by the United States Geological Survey, which show the ore occurring on joint planes of the quartzite at right angles to the bedding. Then, again, microscopic study shows that many of the grains of iron ore have clean, sharp crystalline outlines, which could only be the case if the ore had been formed where it is now found; otherwise the grains would have been rolled and abraded until little of their crystalline form remained.

Another vital objection to the idea of beach accumulation of magnetite is the fact that by far the larger portion of iron is hematite. According to the analysis of the average sample already noted, hematite formed 97 per cent and magnetite only 3 per cent of the entire iron content of the ore. It is therefore evident that the question of the origin of the ore concerns the origin of hematite rather than magnetite. Beach accumulations of hematite are practically unknown, so that it is necessary to believe either that the hematite was derived subsequently from magnetite or the beach accumulation hypothesis must be discarded. Although instances of alteration of magnetite into hematite are known, they are by no means common under the conditions which must have existed in Talladega County in the geologic past. Besides, it has been proved that the hematite was formed earlier than the magnetite. The idea that these iron ores were originally magnetites which have since been metamorphosed, mainly through deformation and consequent reformation of the different minerals, must therefore be abandoned.

It has also been suggested that the ores were originally deposited in the form of an impure carbonate ore which was subsequently acted upon by great pressure, heat, and moisture. These processes changed the ore into a magnetite and decreased its volume to about one-half its original size. This hypothesis also seems untenable. In the first place the ore is not magnetite. But even neglecting this point and substituting hematite for magnetite—for the theory applies nearly equally well for either—there seems to be no good way of accounting for the almost entire lack of lime either in the ore itself or in the adjacent rocks. If lime were originally present it must have gone somewhere, and must have enriched some region with exactly the same amount of lime that was lost by the iron ores. In Alabama there is no evidence of any such enrichment. Neither is there any evidence of a decided change of volume of the ore bodies such as this hypothesis would entail.

It has also been suggested that these ores may represent very basic intrusions rich in iron. Such a hypothesis, however, is impossible, for the ores show stratification. This stratification is recognized by distinct differences in texture and is not at all to be confused with cleavage. Therefore, as the rocks show stratification it is evident that they can not be igneous.

From a study, in both the field and laboratory, of the conditions under which the ores occur it seems clear that the gray ores, in some stage of their development, have been hydrated iron ores, and that their present form is due to the dehydration of the original limonite by the heat and pressure produced by regional deformation. Where such metamorphism affects a deposit of limonite the first result is to drive off the water, thus forming hematite. If, however, under the conditions of metamorphism the ore body was shut off from a sufficient oxygen supply, so that the iron could not be completely oxidized, or if there were CO or some other deoxidizing agent present, the result, as shown by Van Hise, would be a change of the hematite into magnetite and carbon dioxide. The formula for this change would be $3Fe_2O_3+CO=2Fe_3O_4+CO_2$. If, then, there were present at the time of metamorphism enough oxygen to completely oxidize a large part but not all of the iron, the result would be the formation of a deposit of hematite with smaller amounts of magnetite. The abundance of the magnetite therefore varies inversely with the amount of oxygen.

The belief that the gray ores were at one time in the form of limonite is based mainly upon their field occurrence. In many parts of the field brown ore deposits occur at essentially the same geologic horizon as the gray ores, and in a few places this connection is so close that the gray ore can be traced into brown ore. The composition of the ores, with their high phosphorus and silica content, also strongly suggests their common origin.

While the gray ores have probably been through the limonite stage it is not believed that the limonite was necessarily the original form in which the iron ore was deposited. The ore occurrence on the northwest flanks of the Kahatchee Hills, already described, illustrates this point. At this place a bed of quartzite was found which had been opened for brown iron ore. After a few tons of this had been mined and the pit excavated to a depth of about 5 feet the ore gave place to a disseminated pyrite body. Here the limonite was undoubtedly the residual concentration remaining after the decomposition and oxidation of the pyrite. The most interesting point, however, in connection with this occurrence is the fact that on the strike, not over 100 yards distant, there is a bed of quartzitic gray ore which seems to be a direct prolongation of the bed of pyrite. In this place, at least, it would seem that the gray ore had been derived from pyrite, perhaps having been limonite in an intermediate state. Van Hise, however, in his monograph on metamorphism[a] notes that oftentimes the sulphides may be directly converted into hematite through heat and pressure. It is possible, therefore, that the pyrite may have altered directly into hematite without having passed into the form of limonite. Further evidence along the same line is afforded by the ore itself, which in many places shows areas of limonite that were apparently derived from an iron sulphide.

From the facts just stated it would seem that the iron ores are presumably derived from two sources. The first of these sources is pyrite, which may have been formed through the precipitation of iron solutions by the decomposition of organic matter in the quartzite. The second, and probably by far the most important source, was limonite, which was collected in certain horizons where relatively impervious strata succeeded relatively porous beds and so arrested the free circulation of the descending ore-bearing solutions. These limonite beds were subsequently metamorphosed by the great folding and fault movements that the region suffered during the period of mountain building. Where the metamorphism was moderate and where there was sufficient oxygen the limonite was simply dehydrated into hematite. Where, however, the amount of oxygen was not quite sufficient to oxidize all the iron the limonite changed into hematite with some magnetite, the relative amount of the two minerals depending upon the amount of oxygen present.

Some proof of this hypothesis is afforded by the distribution of the different ores. At Columbiana, where the rocks are but slightly metamorphosed, the ore is a reddish hematite with practically no magnetite. In the range near Mesaba and Emauhee the rocks are more metamorphosed and the magnetite increases perceptibly. In another range in the very highly metamorphosed belt near Chulafinnee, in Cleburne County, an iron ore which seems to occur under nearly the same conditions as the ore in Talladega County is almost entirely magnetite.

ECONOMIC IMPORTANCE OF THE ORES.

In regard to the economic importance of these ores there are four main points which must be considered, namely, cost of mining, value of ore, cost of smelting, and opportunities for marketing product. To determine the cost of mining it is necessary to consider the charges for timber, powder, steel, labor, handling of ore and waste underground and on the surface, and pumping. The cost for

[a] Mon. U. S. Geol. Survey, vol. 47, 1904.

timbering will generally be rather low, for the roof stands well. In the Emauhee mine stulls are used only at distant intervals. Even if poor ground should be encountered the local charges for timber are so low that the cost would be relatively slight. The steel and powder charges become high as soon as the hard quartzitic ores are encountered. In the slaty ore these charges decrease to practically nothing. The cost of labor is low, as is usual throughout the South. This low actual cost is somewhat fictitious, for the labor is inefficient and requires much supervision.

The heaviest charges are those incident to the handling of the ore and slate underground. Owing to the fact that the ore is intimately interlaminated with slate, a large amount of dirt must be mined with it. This is costly to handle and reduces the tenor of the ore. It would probably be desirable to hand pick or wash the ore, but either of these operations would add one more item to the cost of mining. The faulted character of many of the veins necessitates much prospecting and makes the mining less systematic than in more regular deposits. Thus considerable extra dead work is performed and extra tramming and handling charges have to be met. Very few data are available as to the wetness of the mines. It is presumable, however, that the pumping charges would be moderate, for the quartzitic beds seem to be quite impervious.

Concerning the value of the ore mined the three tables of chemical analyses should answer the question effectively. It should be borne in mind, however, that the analyses in Table III are of much greater value than those shown in either of the other two tables. The analyses in Table III, as before noted, were not made from selected samples, but from samples taken across the entire width of the vein, including any slate partings that would necessarily have to be mined and could not readily be hand picked. The character of the ore in other essential particulars is also well shown by these tables. The phosphorus content is too high for Bessemer iron, but as much of the southern iron at the present time is open-hearth iron, this is not much of a drawback. There is also a variable but rather high amount of sulphur, which would make the resulting steel brittle.

There are two ways of economically reducing this ore: (1) Smelting independently and (2) smelting in combination with other ores. In smelting several factors need to be considered, especially flux and fuel. The flux can be easily obtained from the limestones and dolomitic limestones on either flank of the ridge. The relative values of pure limestone and dolomitic limestone as flux are still undetermined. Authorities, however, seem united in believing that if there is a small percentage of alumina in the ore some dolomite is at least no drawback. The flux question is therefore easily settled, for anywhere along the range limestone can be obtained within a distance of at most half a mile from the iron ore.

The fuel supply is not a troublesome question, for coal may be obtained from the Birmingham district at a distance of not over 50 miles from any point in the field. This coal is of good quality and is extensively used throughout the whole Birmingham district. Its sulphur content is about 1 per cent.

With such a siliceous ore the cost for flux and fuel will be high, and it would therefore seem expedient, where possible, to use the ore in combination with other ores which need a siliceous mixture. In Alabama, at the Clinton horizon, there is a great deal of red iron ore which is so rich in lime that it is more than self-fluxing. In the leached zone, above water level, much of the lime has been removed from the red ores. Below water level, however, the lime content becomes so high that it is necessary to add siliceous ore to counteract the excess lime. At the present time the brown ores or limonites with high silica afford a good mixture. In the future, however, the supply of brown ore will probably not be sufficient to meet the demand, and in that case other siliceous ores will become more desirable than they are at the present time. The reduction of the ore that is more than self-fluxing requires practically the same amount of fuel, etc., as that of the ore that is just self-fluxing. It is therefore desirable that the mixture should be nearly self-fluxing. If each ton of more than self-fluxing mixture requires the addition of a quarter of a ton of siliceous ore to make it just self-fluxing, it it evident that the iron of the siliceous ore can be won for practically the same price as the iron of the limy ore alone. It would therefore seem advantageous, where the iron content of the siliceous ores runs about 50 per cent metallic iron, to ship this to some of the furnaces smelting limy ores and there to use the proper mixture of the two.

Not very much of the gray ore has yet been used in furnaces, so the reports regarding its behavior in the furnace are not based on long experience. The earlier reports, however, stated that the gray ore produced an iron that was too brittle to bear its own weight. The chemical composition of the ore, however, does not indicate that this should be the case. Reports of later furnace tests seem to be much more satisfactory. Thus on a furnace run of 200 to 250 tons of gray ore by the Vanderbilt Iron and Steel Company, the report was that "the ore worked well in the furnace, but contains a little too much magnesia for a satisfactory charcoal iron."

In regard to marketing the product, the main thing to consider is the proximity to railroads. This is not at all a serious question here, for no point in the entire field is more than 4 miles from a railroad, and as this distance is almost entirely through open, slightly rolling country, spurs could be run to a mine or smelter at slight expense. Furthermore, three railroads cross Talladega County, so that competition ought to keep the freight rates reasonable.

Regarding the other conditions of marketing the products, the same facts prevail in the gray-ore district as in the other iron regions of Alabama. It therefore may be instructive to compare this district with the well-known and successful Birmingham district, noting wherein the costs in one exceed the costs in the other. The cost of mining gray ore will necessarily be the higher on account of its massive quartzitic character, the interlamination of the ore and slate, and slope rather than open-pit mining. The cost of smelting will be considerably lower in the Birmingham district, owing to the lesser cost of coal haulage. The costs of marketing the product from both fields will be practically the same. It seems evident that, in order to offset the greater cost in mining and smelting, the gray ore must run at least 5 points higher in metallic iron than the Birmingham ores.

MAGNETITE DEPOSITS OF THE CORNWALL TYPE IN BERKS AND LEBANON COUNTIES, PA.

By Arthur C. Spencer.

In the autumn of 1906 the writer began a systematic study of those magnetite ores in eastern Pennsylvania that are associated with intrusive masses of diabase at or near the edges of the belt of Mesozoic rocks which enter the State along Delaware River above Trenton and continue in a general southwesterly direction to the Maryland line. Observations were extended over the eastern portion of this belt in Bucks, Montgomery, Berks, Lebanon, and Lancaster counties, Pa., with the special view of acquiring personal knowledge of the stratigraphy and structure of the Mesozoic sedimentary rocks and their relations to the igneous masses inclosed by them. It was rightly expected that this general study would contribute to a better understanding of the geologic relations of the known ore deposits and that it might reveal data which would show where practical exploration might be undertaken for ore bodies that do not appear at the surface.

To complete the investigation as planned, certain parts of the region already covered must be studied in greater detail, and observations must be carried across western Lancaster, Dauphin, York, and Adams counties, Pa., and thence along the continuation of the Newark belt into Maryland. It is hoped that this work may be done early in the season of 1907.

In this preliminary report no attempt is made to set forth in detail the scientific basis for the conclusions that have been reached concerning the origin of the deposits of magnetite ore, the present object being to present practical suggestions that seem warranted by the investigation in its present state of progress. Though full consideration of the origin of the magnetites may wait until the entire field has been studied, the writer's general conclusions on this point are given, since the manner and conditions of ore formation must form a starting point for all practical suggestions looking to the discovery of deposits as yet unknown.

Magnetite ores of the same general type have been worked on a considerable scale in Berks County at Boyertown; at two localities south of Reading; near Fritztown, about 7 miles southwest of Reading, and near Joanna station, 2½ miles northeast of Morgantown; in Lebanon County at the Cornwall ore banks, and in York County at various points, but especially near Dillsburg. Of these deposits, only one, that at Cornwall, is now worked in a large way, though the several former interests at Boyertown have recently been acquired by the Boyertown Ore Company, and it is expected that these mines at an early date will again soon be in operation. Mining in a small way is in progress at the Wheatfield group near Fritztown, for the purpose of procuring surface ore. The Island and Raudenbusch mines, near Reading, have been abandoned, the former for nearly twenty years and the latter for a longer time. All the deposits named are situated at the northern edge of the Mesozoic Newark belt, and the ore at all places appears to lie in limestones or limy shales that belong to the Paleozoic series rather than in strata of the Mesozoic system itself. The Jones mine, near Joanna station, is situated at the southern edge of the Mesozoic belt and the deposit is in Paleozoic strata capped by Mesozoic beds.

The above statement concerning the stratigraphic position of the deposits is practically in accord with the opinion expressed by Lesley and d'Invilliers in their very clear description of the Cornwall mine.[a] All authorities seem to agree that in York County the ores are contained in Mesozoic strata, and it may be remarked that in at least three places in Berks County minor deposits of magnetite have been noted at the contact of invading masses of diabase with sandstones and shales.

A natural deduction to be drawn from the conclusion that all the known large ore deposits of the Cornwall type are associated with Paleozoic limestones or limy shales is that exploration for other deposits of a similar nature is most likely to be rewarded if confined to localities where similar rocks occur. Though this is a practical point taken by itself, it is so indefinite as to be of no great value to the prospector, for Paleozoic limestones are of wide occurrence both north and south of the Newark belt. Some other criterion is therefore required, and such, it is believed, is found in the fact that intrusive diabase at all places lies close to and at most places in actual contact with ore deposits of the Cornwall type. This fact is brought out by every published description of the magnetite deposits, and the present investigation has served to emphasize both the size of these igneous masses and the importance of their relation to ore deposits.

It is the writer's view that the intrusive masses of diabase have been active agents in segregating the iron contained in the various

[a] Ann. Rept. Second Geol. Survey Pennsylvania, 1885, pp. 491-570.

deposits; or, in other words, that the masses of ore are products of contact metamorphism. Briefly stated, the theory of their origin, which seems to be indicated by all the facts that have been noted concerning their geological relations, is that the magnetite ore bodies of the Cornwall type have been formed by the more or less complete metasomatic replacement of sedimentary rocks, mainly limestones and limy shales, by iron minerals precipitated from percolating heated solutions set into circulation by invading diabase.

Diabase is associated with each of the known ore bodies, but the counter proposition that each mass of diabase should furnish one or more ore deposits is neither warranted by the observed facts nor required by the theory here proposed. As a matter of observation, it is to be noted that in Lebanon, Lancaster, Berks, and Montgomery counties no industrially important magnetite deposits have been discovered within the Mesozoic area. Such properties as the Esterly mine, situated 4 miles northwest of Birdsboro; the Wren mine, 1 mile southwest of Boyertown; and certain prospects near the northwest fork of Perkiomen Creek, about 5 miles northeast of Boyertown, exhibit relatively small masses of magnetite, more or less mixed with pyrite, segregated at the contact between greatly baked shales and intrusive diabase. At two of these places the dip of the contact is greater than 45°, while at the third place—the locality northwest of Boyertown—the dip of the contact may be as low as 20°, and the deposit here is smaller than the deposits at the other places. Here it is notable that the diabase mass next to which the ore occurs is one of the larger masses of the region and one around which there is more than the usual amount of alteration in the invaded sandstones.

On comparing these unimportant deposits with those in the more or less extensively productive mines where Paleozoic strata are involved, it must be concluded that the sandstones, conglomerates, and shales of the Mesozoic system have been very much less susceptible to replacement by iron-bearing solutions than the calcareous strata, mainly limestones and limy shales, of the older formations. The unequal effects of intrusive masses in causing the metamorphism of siliceous and calcareous rocks invaded by them, and especially the greater frequency of metalliferous segregations of contact origin in limestones than in shales and sandstones, are facts of common observation in many fields. Large ore bodies composed of magnetite, pyrite, and chalcopyrite that were evidently formed by the replacement of limestone at or near igneous contacts are worked at several places in California, British Columbia, and Alaska for the copper which they contain, and throughout this region the presence of limestone seems to be essential for the existence of a valuable ore deposit, contacts of intrusive rocks with other sediments being far less favorable for the occurrence of ore bodies.

Diabase intrusions are characteristic of the Mesozoic Newark system throughout practically its whole extent, from Nova Scotia to Richmond, Va., and occur at but few places outside of this Mesozoic belt. Where they do so occur they are found mainly at no great distance from the edge of the Mesozoic belt, and few of them are masses of considerable size.

At most places within the Mesozoic area the diabase occurs as extensive and relatively thin sills between strata of sandstone and shale. Local cross-cutting may be observed, and in certain places the invading rock, though following a group of strata, cuts back and forth across the beds of the group. It is believed that when masses of essentially like size are compared intrusions of this sort offer conditions that are distinctly less favorable to intense metamorphism than those presented by extensively cross-cutting bodies. A deep-seated source for the molten rock must be admitted, and in order to reach the position it now occupies the diabase must have cut through the rocks that form the basement of the Mesozoic system and across the lower strata of the latter as well. Lateral spreading of the invading magma could have occurred only at relatively shallow depths, where the weight of overlying strata would be not too great to be lifted by the pressure acting upon the molten rock. Masses of molten rock injected between the strata to considerable distances, especially if the strata lie at low angles, become isolated from the main source of intrusion. It is evident, therefore, that the degree of alteration of the inclosing rocks depends wholly on the amount of energy residing in the heated mass at the time of its injection. This would of necessity be a limited source of metamorphism. On the other hand, the more steeply inclined fissures through which the sills are supposed to have been fed would afford direct connection with the original source of energy, so that transfer of heat and the movement of mineralizing waters would here be continued through a much longer period.

Undoubtedly different masses of diabase within the same general field may have differed greatly in respect to efficiency in producing metamorphism, but, other things being equal, the amount of variation in the directness of their paths from the original reservoir must have been a very important factor in determining the relative amount of alteration which different masses could have produced. The foregoing considerations indicate certain practical suggestions to searchers for iron ores in this field:

(1) Ore bodies should be sought only at or near the walls of masses of diabase.

(2) Large masses of diabase are more favorable for ore deposits than smaller masses.

(3) Cross-cutting intrusions and highly inclined sills are more favorable than sills of low inclination.

(4) Limestones and limy shales are far more likely to be replaced by ore than clay shales or sandstones.

(5) Particularly favorable locations for ore are found in masses of limestone that lie between masses of diabase and beds of strata that are in a marked degree less susceptible to the metamorphosing influence of the igneous rocks.

(6) The most promising situations will be found at places where the largest number of the above favorable conditions occur in combination.

Many or all of the more favorable conditions enumerated existed at places where the larger ore deposits of the Cornwall type were formed, and as several of these conditions may be fairly inferred to exist at a few other localities, still other deposits of iron ore may yet be found in the same general field. With a view to pointing out these supposedly favorable situations descriptions of the geologic conditions in several districts along the borders of the Newark belt have been prepared and will be presented in the forthcoming report.

THE HARTVILLE IRON-ORE RANGE, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

In the summer of 1906 the writer spent three months in studying the geology and the iron-ore deposits of the Hartville, Wyo., iron range. The following preliminary description of the results of the work will be followed in the near future by a more extended article, accompanied by adequate maps. Some of the conclusions here stated may be modified by a more detailed study of collections and notes. The writer wishes gratefully to acknowledge his indebtedness to Supt. Louis B. Weed, Engineer George C. Botsford, and Capt. Thomas Tucker, of the Colorado Fuel and Iron Company; to Mr. C. A. Guernsey, of Guernsey, and to Messrs. Lauck & Stein, of Frederick.

The literature concerning the iron of the Hartville range is summarized in the following bibliography:

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1888, Cheyenne, Wyo., pp. 64–68. Briefly describes the geology and mentions the presence of large bodies of iron ore near Sunrise.

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1890, Cheyenne, Wyo., pp. 51–61. Briefly describes the geology and reports upon the ore deposits in considerable detail, dividing them into three classes: (1) Lenticular masses between walls in crystalline slates, (2) stratified deposits at the base of the cap rock (Guernsey formation), and (3) residual deposits. He describes in detail the development of the Sunrise mine and the presence of ore in a number of other claims in the near vicinity, and from its trend infers that the ore of the Chicago claim is an extension of the Sunrise deposit. He gives a number of analyses of iron ore, all of which are notably high in iron and low in phosphorus and silica.

Knight, Wilbur C., Bull. 14, Wyoming Experiment Station, University of Wyoming, Laramie, Wyo., Oct., 1893, pp. 176–177.

Snow, E. P., Eng. and Min. Jour., vol. 60, pp. 320–321, 1895. General description. Mentions mining by the Indians. Estimates ore in sight at 10,000,000 tons.

Chance, H. M., The iron mines of Hartville, Wyoming: Trans. Am. Inst. Min. Eng., vol. 30, pp. 987–1003. In this excellent report Mr. Chance describes the original pre-Cambrian lenses of ore, as well as the deposits at the base of the Guernsey, and in addition placer and residual deposits. He gives a number of analyses of the ores. Mr. Chance's work is of great value, since he records the conditions in many shafts now inaccessible. This paper is accompanied by a map showing the location of the principal mines and prospects.

SMITH, W. S. T., and DARTON, N. H., Description of the Hartville quadrangle, folio 91, U. S. Geol. Survey, 1903. Describes the general geology, geological history, and economic geology of the Hartville quadrangle. The iron ore is briefly described.

BEELER, HENRY C., Wyoming mines and minerals in brief, Cheyenne, Wyoming, 1904, p. 6.

BEELER, HENRY C., Report of the State Geologist of Wyoming, Cheyenne, Wyoming, 1904, p. 37.

BROOKS, BRYANT B., The State of Wyoming, 1905, Sheridan, Wyoming, pp. 94–95.

GEOGRAPHY AND HISTORY.

The Hartville iron range, lying north and east of North Platte River, is situated in Laramie County, in east-central Wyoming. It forms a portion of the Hartville uplift, a broad and low domal mountain mass similar in many respects to the Black Hills in South Dakota. The maximum height of the uplift is about 6,000 feet above sea level, and the region is one of comparatively little relief. Near the iron mines erosion has detached many hills from the Carboniferous plateau. These are sharp granite peaks or flat-topped buttes capped by horizontal Carboniferous rocks. The area is dissected by intermittent streams, some with narrow gulches and others with broad, wide valleys. The climate is semiarid, and in consequence timber is confined to the higher peaks. Lower elevations are covered sparsely by bunch grass, cactus, and low desert shrubbery.

The iron range extends from Guernsey to Frederick, a distance of 8 miles. The iron-bearing rocks reach a maximum exposed width of 3 miles. The productive area is, however, considerably smaller and extends from Sunrise northeastward 2 miles and from the same point southeastward 1 mile. The towns of the iron range are Sunrise, Hartville, Ironton, and Guernsey. The principal mine of the range and the local offices of the Colorado Fuel and Iron Company are at Sunrise, a village having a population of 1,500. Hartville, a town of 150 people, is supported by the miners of Sunrise. Ironton is the mining camp of the Chicago mine. Guernsey is an ore-shipping town of 150 people. The Hartville iron range has two railroads; the Colorado and Wyoming Railroad extends from the Colorado and Southern Railroad at Hartville Junction to Sunrise and is the line by which the Sunrise ore is shipped; the Chicago, Burlington and Quincy Railroad has built a branch from its present terminus at Guernsey to the Chicago mine.

The history of the Hartville iron range may be divided into four periods: (1) That during which the Indians mined soft ore for war paint; (2) a period stretching from 1880 to 1887, during which the range was a copper-mining district; (3) an iron-prospecting period extending from 1888 to 1897, and, lastly, the period of productive mining, from 1898 to the present day.

The value of the iron deposits of the Hartville iron range was proved while copper was being mined at Sunrise. With the exhaus-

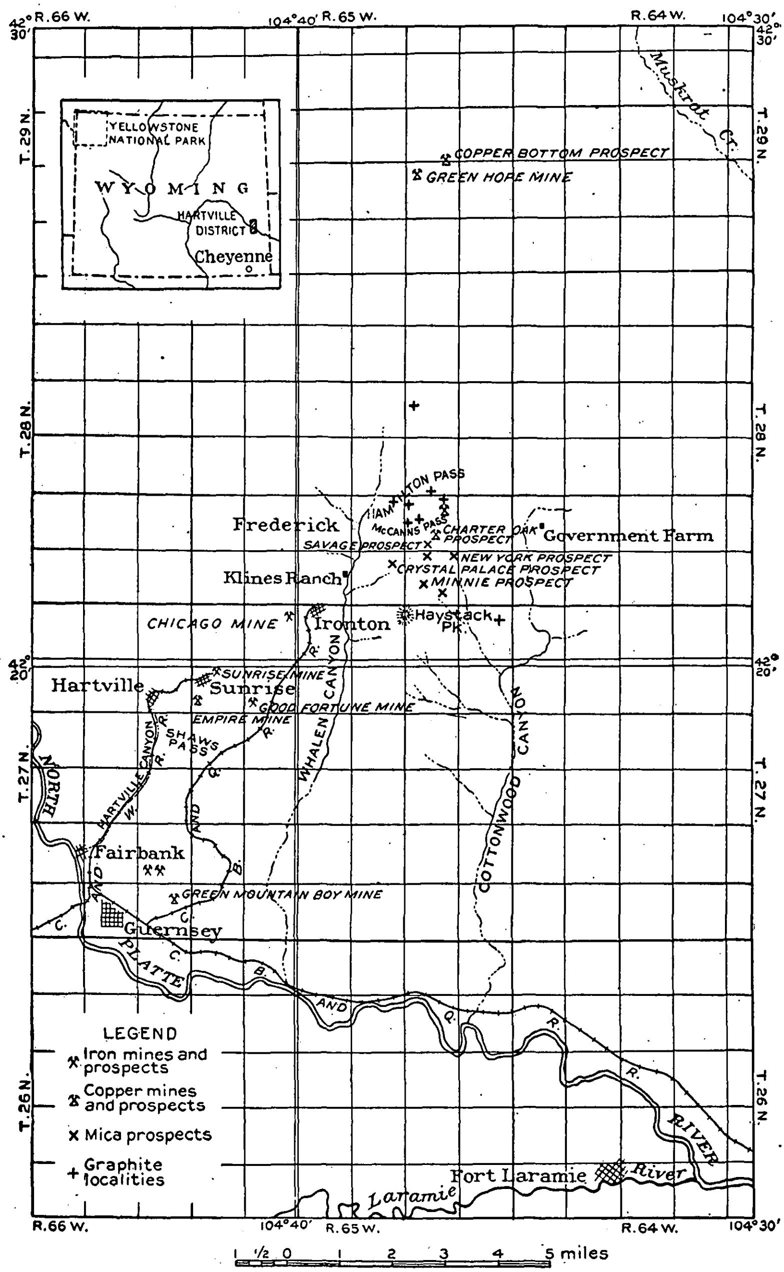

FIG. 5.—Economic map of the Hartville uplift, Laramie County, Wyo.

tion of the copper deposits, Messrs. I. S. Bartlett and C. A. Guernsey began to prospect for iron ore, and in 1900 Mr. Guernsey, having segregated most of the larger deposits, sold his group of claims to the

Colorado Fuel and Iron Company. Since that time this company has been adding to its holdings and now controls most of the more valuable claims. It is rapidly developing two mines, the Sunrise and Chicago, which now furnish the greater portion of the ore used at its smelters at Pueblo, Colo.

PRODUCTION.

The production of the Hartville iron range is tabulated below:

Production of Hartville iron range, 1898–1906.

Year.	Mine.	Quantity.
		Long tons.
1898–99	Good Fortune mine	30,000
1900	Sunrise mine	73,663
1901	.....do	134,161
1902	.....do	209,272
1903	.....do	214,880
1904	.....do	135,167
1905	Sunrise and Chicago	474,545
1906	.....do	....

In 1905 the Sunrise mine was in point of production the twentieth iron mine in the United States, but two mines outside of the Lake Superior region exceeding it in output. The product of the range shows an encouraging increase, which will presumably become greater from year to year.

GEOLOGY.

STRATIGRAPHY.

The rocks of the Hartville iron range fall naturally into three groups: (1) The steeply dipping pre-Cambrian rocks, (2) the flat-lying or gently dipping Carboniferous and Mesozoic rocks, and (3) the rocks of Tertiary and Recent age encircling the older rocks and filling depressions of erosion extending up into them.

The pre-Cambrian rocks consist of metamorphosed sedimentary rocks and of igneous rocks and their mashed equivalents. The oldest rocks are an interbedded series of siliceous limestones, probably dolomitic, and muscovitic and biotitic schists. In all there appear to be about fifteen beds of limestone and schist, which alternate with one another. The beds vary in thickness from 20 to 500 or more feet. The schist also occurs as lenses in the limestone, these lenses grading both parallel to and across their longest direction into rocks that are intermediate in composition between schist and limestone. The limestone is typically a fine-grained rock of pinkish or grayish color and has a conchoidal fracture. Lenses and beds of cream-colored flint lie parallel to the original planes of stratification and to a minor extent cut these. The schists vary in color from silvery to very dark gray. They are typically fine grained and pass from biotitic to muscovitic varieties both along and across the bedding. Slaty schists and siliceous schists also occur. Interbedded with this old series are thin beds and lenses of gray quartzose rock and dark-brown or black jaspers.

In the broad schist area east of Sunrise a second sedimentary series lies unconformably upon the uppermost bed of the series just described. The unconformable character of this series is indicated by its location in synclinal troughs upon the uppermost beds of the older rock series, which is folded into a syncline, by a conglomerate that is present in some places at its base, by the fact that it slightly cuts across the beds of the older formation, and by its sharp contacts with and lithological differences from the older formation. This second series of sedimentary rocks is composed of gray, thoroughly crystalline quartzose rocks, which are at some places conglomeratic and at others nonconglomeratic. Associated with these altered sandstones are beds of jasper, which vary in color from gray through browns and reds into black. The banding of the jaspers is at some places close. Although most of the exposures are too poor to determine the younger age of the quartzose rocks and jaspers of all the areas, there is no doubt that two sedimentary series occur in the pre-Cambrian of this district and that many of the areas of siliceous rocks are younger than the schist-limestone series.

The next youngest pre-Cambrian rocks are gabbros, diorites, and allied porphyries and the same rocks mashed into hornblende and chloritic schist. These rocks grade into one another. At most places these igneous rocks are intrusive in the older pre-Cambrian sedimentary series. It is possible, however, that some of the chloritic and hornblende schists may represent later basic lava flows. The age relation of the rocks of the third to those of the second pre-Cambrian series is unknown, since at no place were the two observed in contact, although it is believed from differences in the amounts of folding suffered by the two formations that the sedimentary is the older series. The intrusion of the gabbros and the diorite was followed by that of a coarse-grained pink biotite granite, which at many places contains large feldspar crystals. It occurs in rounded, intrusive masses characterized by but few offshoots and in isolated dikes. Aplites and pegmatites allied in composition to the granite followed its intrusion. The last of the pre-Cambrian series is a diabase which occurs in dikes that are sparsely distributed throughout a wide area.

The Carboniferous series alone of the Paleozoic and Mesozoic rocks occurs in the immediate vicinity of the ore deposits. The Carboniferous consists of a basal member, the Guernsey, and an upper member, the Hartville formation. The Guernsey is normally 150 feet thick and comprises at its base either a conglomeratic quartzite, a quartzite, or a limestone containing sand grains. The upper part of the formation is composed of massive beds of gray limestone. Prior to the deposition of the Guernsey formation the pre-Carboniferous land surface was reduced to a peneplain. The contact between the pre-Cambrian and Carboniferous rocks is therefore a flat surface that has been locally warped by post-Carboniferous folding. When the Carboniferous rocks are in contact with the pre-Cambrian schist the contact plane is level, while the Carboniferous extends down into the pre-Cambrian limestone in many ramifying rounded bodies. Evidently where the pre-Carboniferous peneplain was underlain by limestone, solution formed caves with attendant cave galleries, sink holes, and irregular solution joint cavities. Unconformably upon the Guernsey lies the Hartville formation, which is at most places 650 feet thick. Its basal member is a deep red sandstone and above this is white or gray limestone. Some distance northwest of the iron range Messrs. Smith and Darton [a] found a number of Jurassic-Triassic and Cretaceous sedimentary formations.

The older rocks prior to late Tertiary times were deeply eroded, and the resulting older gulches, canyons, and valleys have been filled by the Tertiary sandstone, which in the folio already mentioned is called the Arikaree. The Pleistocene formations consist of terrace gravels, alluvium, and wash.

STRUCTURE.

The pre-Cambrian sedimentary rocks have been folded into a complexly folded trough or synclinorium with east and west axis. The axis of the synclinorium passes through Sunrise. The beds of the north arm near Sunrise course north of east. To the northeast they bend farther northward and at Frederick course east of north. North of Frederick the direction of the axis is north-south, its direction being determined by the contiguous granite mass. Between Sunrise and Guernsey the strike of the beds is practically east-west, although in the isolated hills south of Haystack Peak, across Whalen Canyon, the strike is again north-south. Presumably, therefore, beneath Whalen Canyon, east of Guernsey, the beds strike southeastward. In the main schist area east of Sunrise the folding is probably close, since it is known that the schist is repeated by folding at least four times. Minor folds in the synclinorium are of two kinds—(1) those formed contemporaneously with the main folding of the series, and (2) those due to buckling caused by the intrusion of the granite.

Faults, particularly those cutting the extension of the beds of the synclinorium at right angles, are common in the pre-Cambrian complex. The greatest fault in the area, however, extends eastward from a point one-half mile north of Guernsey. Here the pre-Cambrian and

[a] Description of the Hartville quadrangle: Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

Guernsey formations are in fault contact, the amount of displacement being over 200 feet, with the downthrown side on the south. Brecciation has accompanied both faulting and folding, and the main ore deposits are intimately associated with it. There is evidence also that in some places the schist was opened along its planes of schistosity during the folding.

The Carboniferous formations occur usually as flat-lying remnants capping the pre-Cambrian hill. On the borders of the uplift, however, the Carboniferous formations at many places dip rather steeply beneath younger formations.

ORE BODIES.

FORM AND PLACE OF THE ORES.

The most important iron-ore deposits of the Hartville iron range are lenses that occur in schist on a limestone foot wall. The ore largely replaces the schist, although it partially fills cavities in the schist which are due to jointing, faulting, and brecciation. Detrital ores of secondary derivation from these deposits are situated (1) at the base of the Guernsey formation, (2) at the base of the Hartville formation, and (3) in the Tertiary lake and Pleistocene and Recent stream deposits. The pre-Cambrian jaspers, an amphibolitized phase of the schist, and the matrix of some of the conglomeratic facies of the second pre-Cambrian series, also locally contain considerable iron.

The most important ore deposits next to the lenses above the contact of the pre-Cambrian schist and limestone are situated along the fault already mentioned, north of Guernsey, between the pre-Cambrian series and the Guernsey formation. Although but little developed, these deposits will perhaps repay careful prospecting. Masses of hematite and limonite in the Haystack Mountains are evidently the iron hats or gossans of sulphide deposits and are economically important.

LENSES OF IRON ORE IN SCHIST UPON A LIMESTONE FOOT WALL.

GENERAL CHARACTER.

The principal bodies are irregular lenses, elongated parallel to the strike of the metamorphic sedimentary rocks in which they occur. Their range in width is from a few to 100 feet or more, and some of them are over 1,000 feet long. It is reported that one ore body in the district has been proved to a depth of 900 feet. The principal deposits of this type include those of the Sunrise mine and its practical extension—the Lone Jack—and the Chicago and the Good Fortune mines. Similar ore masses occur at a number of points between these ore bodies.

ORE AND GANGUE MINERALS.

The chief ore of these deposits is hydrated hematite. It is either (1) a hard gray ore filled with numerous cavities, which are lined with finely crystalline specular hematite, or (2) a soft greasy ore of brownish-red color. Fibrous varieties of hematite, including mammillary ore, grape ore, and stalactitic ore, occur less frequently. Minor quantities of siderite and limonite are associated with the hematite. The limonite is in some places compact and finely granular; at others it is mammillary, and at still others it is a soft yellow ocher. Magnetite is not present in masses large enough to attract the eye, although slight local magnetic variations noted at some places in the vicinity of the ore deposits may indicate its presence. Pyrite and marcasite were not observed and probably do not occur in the ore bodies.

The gangue minerals are calcite, quartz, gypsum, chalcedony, barite, and a kaolinlike mineral, and the copper minerals are chrysocolla, malachite, chalcocite, azurite, and native copper. Calcite occurs in colorless or slightly yellow crystals. The most important development of quartz, like that of calcite, is clearly later than the ore. It also occurs as brecciated fragments in the ore and is then older than the hematite, while to a less extent it is contemporaneous with the ore. At the Chicago mine the quartz sometimes is of a beautiful amethystine tint. The copper minerals[a] occur in fractures in the hematite and associated rocks and are the younger.

Irregular masses of iron-stained schist, "soapstone," and to a less extent iron-stained limestone and iron-stained siliceous rocks occur as vein material in the ore bodies. Schist and soapstone occur as irregular horses throughout the ore body. The "soapstone" is an unctuous substance of pale green color.

PARAGENESIS.

The hard and soft ores grade into schist and it is evident that each was formed through the replacement of the schist by hematite. The soft ore is thus in part derived directly from the schist, but a considerable portion of it is derived secondarily from the hard ore. Pseudomorphous replacements of hard ore by soft ore are common. Perhaps the best evidence of this change is seen in the pebbles of soft ore of beautifully rounded form that occur in the detrital deposits at the base of the Guernsey formation. Pebbles of this formation are usually of the dense hard gray ore, and it is absolutely impossible that a substance offering as little resistance to attrition as the soft ore could form such well-rounded pebbles. The secondary character of much of the soft ore is further indicated by the fact that on

[a] See this volume, pp. 93-107.

the surface at the Sunrise mine the soft ore equals the hard ore in bulk, while on the lowest levels hard ore greatly predominates. In the Lone Jack tunnel, which after entering the hill gains considerable depth beneath the surface, the soft ore gradually decreases in amount from the entry of the tunnel to the breast, and at the latter point is practically absent. Alteration of the hard ore into the soft by percolating waters is well exemplified by the presence of soft ore along channels of maximum water circulation. There is also reason to believe that soft ore originates from the hard through shearing, since it occurs along many fault planes in the ore bodies.

The mammillary, grape, and stalactitic forms of hematite are clearly younger than the hard ore and in most places are younger than the soft ore. The mammillary ore occurs in fractures cutting the hard and soft hematite, while the grape and stalactitic ores cover cavities in the older varieties. Some of the mammillary ore was undoubtedly formed after the deposition of the detrital ore at the base of the Guernsey (Carboniferous) formation.

Limonite is a product of the surface alteration of the other iron-ore minerals. It occurs as pseudomorphs after both hematite and siderite. Great rounded bodies of limonite associated with an iron-stained flint are found in the Lone Jack and Sunrise open pits immediately beneath the Carboniferous rocks. The limonite and flint grade, on the one hand, into schist and, on the other, into hematite and are evidently a product of the surface alteration of the schist. Siderite occurs in cavities in the hematite and is clearly younger than it. After the deposition of the siderite came that of quartz in small crystals. Quartz is in turn at places coated with calcite. Of earlier origin than either the quartz or the calcite are the copper ores. These copper ores were, in the main, deposited after the Guernsey formation had been laid down, and in consequence the quartz and calcite were evidently formed in Carboniferous or post-Carboniferous times.

GRADE OF ORE.

The ore of the Hartville iron range is a high-grade hematite, some masses of which contain over 68 per cent of iron, although the ore as a whole will probably not average over 60 per cent. The iron content, where the contact of the ore and country rock is a fault, usually holds its grade up to the fault plane. The iron content in the Sunrise mine increases perceptibly with depth, indicating, perhaps, a considerable redeposition of iron at depths through secondary processes. The ore of the Hartville iron range examined by early writers was very low in phosphorus, many samples showing only a trace. At the present time much of the ore shipped is of a non-Bessemer grade. The earlier analyses are believed by the officers of the Colorado Fuel and Iron Company to have been made from picked samples, since their analyses from the same points show a higher content of phosphorus. Some of the ore is high in silica, its only other detrimental constituent. Sulphur, so far as known, is absent, while the copper minerals occupy such restricted areas that their presence is not troublesome in the sorting of the ores. The ore is rather heavy, occupying approximately 10 cubic feet per ton.

DISTRIBUTION.

The iron ore lenses all occupy similar positions in relation to the inclosing rocks. They lie in schist immediately above the uppermost limestone of the older pre-Cambrian series. This limestone swings from the Good Fortune mine east to Whalen Canyon, where it is covered by alluvium. Since limestone does not outcrop on the east side of Whalen Canyon south of this point the contact is perhaps situated near the center of the valley. In the other direction the contact courses from the Good Fortune mine north of west to a point where it passes beneath horizontal Carboniferous rocks. The contact between the schist and limestone in this direction is again exposed in the Republic shaft at the tail of the railroad Y in Sunrise. From here it courses to a point beneath the Colorado Supply Store, from which it goes north and then northeast, forming the foot wall of the Sunrise ore body. Thence it bows out to the northward, passing north of the Biwabik shaft beneath the Carboniferous, and appearing at the surface again 100 feet north of the Chicago open pit. The contact here is hidden in a valley, but appears again on the hill west of the Colorado Supply Store at Ironton. After passing beneath the alluvium of Whalen Canyon this contact next appears in a hill south of the house at Kline's ranch. From this point it courses practically due north to Frederick, where it lies slightly east of the ranch house. Along this contact, then, all of the larger iron deposits of the Hartville iron range occur.

The presence of large ore bodies is determined apparently by the minor structural peculiarities of this contact. For instance, in the Sunrise mine the two richest bodies of ore lie in minor synclines superimposed upon the main syncline. At the Good Fortune mine the ore is closely associated with a sharp minor fold accompanied by considerable brecciation. At the Sunrise mine the hanging wall and the foot wall are both schist, although on the foot wall the schist between the ore and the underlying limestone is thin. At the Chicago mine the ore on the north side is directly against the limestone or its iron-stained alteration products. At the Good Fortune mine a thin shell of siliceous iron-stained schist separates the ore from the underlying limestone. The contact between the ore body and the country rock is in some places sharp and in others gradational. On the whole, gradational contacts are probably more common, and it is evident that the ore is but a replacement of the schist, since no hard-and-fast line can be drawn between unaltered schist, iron-stained schist, siliceous ore, and good ore. Where the contact between the country rock and the ore is sharp, considerable differential movement has taken place, and most of such contacts are lines of recognized faulting.

ORIGIN OF THE ORES.

The ore lenses in the pre-Cambrian rocks are of secondary origin. This is proved by the close relationship between them and secondary structures, such as folding, jointing, faulting, and brecciation. Further, the ore was deposited by descending water. This is indicated by the position of the ore along a contact which is a maximum zone of downward water circulation and by the presence of lenses and veins of iron ore at a distance from the main ore bodies along joints and faults, natural sites of maximum water circulation. Further, the ore is associated with calcite, quartz, and limonite, minerals known to be deposited by water. Circulating waters naturally flow in some pervious stratum above an impervious bed, or follow more or less open channels along zones of maximum rock crushing. That the limestone is relatively impervious and the schist relatively pervious is indicated by a number of the characteristics of these rocks. Thus the pre-Cambrian diabase dikes in limestone are comparatively fresh, while those in schist are greatly altered. Likewise veins of pegmatitic quartz, presumably deposited by very dilute aqueous solutions, are much more abundant in schist than in limestone. Further, the limestone, when folded, appears to have escaped important brecciation, while the more siliceous bands of the schist were intensely fractured. The limestones naturally confined the circulation of the water to the more pervious rock that overlay it. The main circulation, then, was in schist down the dip slope of limestone. The faults crossing the pre-Cambrian formations would furnish outlets by which the descending water could reach the surface. From the depth of the deposits it is inferred that the topography, when the ores were deposited, was of a rugged character.

The possible sources of the iron ore are (1) magnetite, hematite, and pyrite in schist; (2) pyrite in quartzose beds; (3) iron carbonate in the limestone; and (4) hematite in the pegmatite veins.

Pyrite and magnetite are very common minerals in much of the schist of the Hartville iron range. Pyrite in diamond-drill cores of biotitic schist occurs usually along the planes of schistosity in very small flakes. In the muscovite schists, particularly in those near the ore bodies, are many tiny cavities which are heavily iron-stained. Some of these represent hematite and magnetite crystals; others are, without much question, the casts of small crystals of pyrite, which, to judge from their even distribution throughout large masses of the schist, were original to the recrystallization of the schist. Pyrite also appears to be present as an original constituent in some of the quartzose beds interbedded with the schist member. The chemical composition of the schist shows that it had a low iron content prior to its alteration.

Locally there are probably small amounts of iron carbonate, ferruginous dolomite, or ferruginous calcite in the limestone. The unstained character of much of its weathered surface, however, indicates that the quantities of such minerals in the limestone are so small as to be absolutely inadequate to supply material for the concentration of large iron-ore bodies. Further, this iron carbonate of the limestone lies below the main course of circulating waters. In the schist and limestone there are a few quartz veins, probably of pegmatitic origin, and a small amount of hematite forms a constituent of these veins. The rôle of the pegmatite as an original source of the ore may, however, be neglected.

It is believed, then, that the iron ores were concentrated by surface waters from magnetite and iron pyrite of the schist lying above the limestone foot wall. During pre-Cambrian erosion large bodies of this schist were carried away, and carbonated surface waters probably broke down the iron minerals into iron carbonate or other soluble iron salts. This material was carried downward in solution along the impervious limestone foot wall, where it was precipitated by oxygen-bearing waters descending more directly from the surface through cross faults or other passages of free water circulation

AGE OF DEPOSITS.

These lenses of ore were evidently formed after the pre-Cambrian rocks had been subjected to the synclinal folding, which has already been described. This is shown by the fact that the position of the ore deposits depends closely upon rock structure. As to the relative age of the granite intrusion and the ore deposition certain evidence is lacking, although it is believed that the ore was deposited after the granite was intruded. This much, at least, is certain that in the ore deposits there are zones of brecciated quartz, which were probably once pegmatitic veins cutting schist that is now replaced by ore. It is also certain that in the main the ore was formed prior to the deposition of the Guernsey formation, since this Carboniferous terrane locally contains at its base pebbles of hard ore similar to that of the Sunrise deposit. To provide water circulation adequate for the deposition of bodies of iron ore that lay so deep the topography at the time of their formation must have had sufficient relief to cause deep circulation of surface waters. In consequence it is probable that the ore was deposited long before the production of the peneplain, which preceded the deposition of the Guernsey formation. After the iron ore was deposited, surface waters modified the deposit, forming considerable bodies of soft ore along planes of maximum circulation, a like effect being produced by movement along shear zones. Further, limonite has been formed along some of the water channels of the past and the present day.

RULES FOR PROSPECTING AND GROUND FAVORABLE FOR PROSPECTING.

The restriction of the important ore bodies of the Hartville iron range to a single contact has already been mentioned and the extension of this contact has been described. In prospecting it the diamond-drill holes should be located in the schist area at a distance of from 400 to 600 feet from the foot wall of limestone. Where the contact is covered by alluvium, as it is from Ironton to Kline's ranch, it will be necessary by churn or diamond drill to more accurately locate this contact. Drill data indicating the presence of minor folds should be carefully sought, for ore will probably be found in minor synclines. Whether this portion of the contact will prove as rich as that which has already been prospected may be questioned, but ore bodies probably exist within this new prospecting ground. The proximity of the detrital Carboniferous ore bodies, later to be described, is a further help in prospecting, since they are apparently confined to the immediate vicinity of iron-ore lenses in the pre-Cambrian rocks. The dial compass and dip needle are valueless for use in this iron-ore range, since considerable bodies of the iron ore are nonmagnetic, while some of the noniron-bearing formations, such as the gabbro, affect the needles appreciably.

The conditions that determine the presence of iron ore along the contact already described appear to be (1) the folding to which the rocks have been subjected and (2) the presence of a thick body of schist—to serve as a source of the ore—superimposed upon an impervious body of limestone. The schist-limestone contacts throughout the range are similar to this one as regards the folding. In most places, however, the schist above the limestone is too thin to be the source of large ore bodies. The only probable exception to this statement is the contact between the schist and limestone in the west half of sec. 26 and the east half of sec. 27, T. 27 N., R. 66 W. Along this contact north of the furnace at Fairbank there is a hill of pre-Cambrian limestone. North of this hill is a wide valley, beyond which pre-Cambrian muscovitic schist is exposed. This schist is very thick, and beneath it the limestone dips northward at an angle of 70°. It is believed that this contact, which is hidden in the valley, is worth careful prospecting. Farther north of east, in sec. 26, hornblendic schists cut out the muscovitic schist. The large body of detrital ore at the base of the Guernsey formation, 1,850 feet south and 525 feet west of the northeast corner of sec. 26, may have been derived from some pre-Cambrian ore lens along this contact.

DETRITAL ORES AT THE BASE OF THE GUERNSEY FORMATION.

The basal bed of the Guernsey formation, which is at many places iron stained, is a quartzite or a limestone containing clastic grains. When conglomeratic the pebbles ordinarily consist of quartz, but locally of iron ore. The iron-ore pebbles are usually confined to the immedate vicinity of known deposits of pre-Cambrian iron ore. The pebbles are well rounded, many of them being beautifully polished, and reach a maximum diameter of 1 foot. The ore is typically the hard gray ore, which in some places has been altered to soft ore. Where such iron-ore pebbles with the associated iron-stained quartzite lie in the irregular sink holes and cave galleries that extend into the pre-Cambrian limestone (see p. 195), the ore has in many places been considerably recrystallized. Each sink hole, when partially cut away by erosion, has acted as an impervious trough, in which iron has been concentrated by downward circulating waters. In consequence the quartzite is wholly or partially replaced by red hematite, which is often of excellent grade. In places the detrital iron-ore pebbles are intact; in others they have been completely destroyed by recrystallization. Calcite, quartz, chalcedony, siderite, and copper ore are at many places closely associated with this hematite and ordinarily fill fractures in it. So far as known, none of these deposits are of large size, and as a rule the ore is too siliceous to be of economic value.

DEPOSITS AT THE BASE OF THE HARTVILLE.

The base of the Hartville formation is an iron-stained sandstone which at a few places contains small pebbles of iron ore. The material of these pebbles was directly or indirectly derived from pre-Cambrian ore bodies through the breaking up of the detrital pebbles of the Guernsey formation. North and west of Hartville the base of the Hartville formation at a number of places is an iron-stained shale, upon which lies the typical Hartville sandstone. Where this shale has been folded into gentle synclines the iron of the sandstone has been redeposited upon the shale, and in consequence blanket beds of low-grade hematite mark this horizon. Ore bodies of this class will probably never be of economic importance.

RESIDUAL AND PLACER ORE.

In the early days of mining at Sunrise the surface was covered by bowlders of iron ore which were derived from the breaking down of the pre-Cambrian iron-ore body at that point. Although large amounts of this ore have been shipped, iron-ore float even now occurs throughout the productive portions of the iron range.

Pebbles of iron ore are found in the bed of Platte River some distance below the town of Guernsey. At Guernsey they are 1 inch or less in diameter and increase gradually in size upstream. The pebbles do not occur in the Platte above the mouth of Hartville Canyon, but are found in the canyon as far up as Sunrise.

IRON IN OTHER PRE-CAMBRIAN ROCKS.

The jasper of the second pre-Cambrian series contains at many places some hematite and limonite. Veins of hematite occurring in fractures cut it and irregular masses of hematite cement its brecciated fragments. The jasper itself is also more or less replaced by hematite and limonite, but no considerable body of ore has yet been discovered in it, and most of the ore found in it is probably too siliceous to be of value. South of Shaws Pass a peculiar metamorphosed type of the pre-Cambrian schist, containing a large amount of amphibole, is heavily iron stained. The matrix of the conglomeratic phase of the second pre-Cambrian series contains at many places considerable iron, but none of the prospects in such rocks have yet proved valuable.

DEPOSITS ALONG THE FAULT CONTACT OF THE PRE-CAMBRIAN AND THE GUERNSEY LIMESTONE.

Along a line beginning approximately one-half mile north of Guernsey and extending eastward across low hills to Whalen Canyon, the Guernsey formation and the pre-Cambrian rocks are in fault contact. The downthrown side of this fault is to the south and appears to have been dropped more than 200 feet. The fault plane is everywhere iron stained and a number of prospects are situated along it. Three shafts in the south-central portion of sec. 25, T. 27 N., R. 66 W., owned by Mr. C. A. Guernsey, are within 100 feet of one another. The northern or hanging wall of the ore body is smooth, and the contact between the ore and the pre-Cambrian limestone is sharp. Farther south the ore passes gradually into iron-stained Guernsey limestone. The iron ore lens, consisting of good soft and hard grades, is from 2 to 6 feet wide upon the surface, and widens somewhat toward the west. At the bottom of the shafts, which range in depth from 24 to 60 feet, the lens is somewhat wider and apparently increases in thickness with depth. One-quarter of a mile west of this locality several shafts and tunnels develop other ore bodies in breccia zones within the pre-Cambrian limestone, parallel to this fault. The ore here is a black pulverulent hematite containing considerable calcite and siderite. The appearance of the ore indicates that it contains manganese. Not enough development work has been done upon the ore bodies of this fault plane to determine satisfactorily either their commercial possibilities or their mode of origin. It is certain that prospect work should be confined to the fault contact between the two formations. These iron-ore lenses were deposited by water which circulated along the fault plane. It is unknown whether the water which formed the iron ore ascended or descended along this plane, although the close resemblance of the ore to much of that of the pre-Cambrian type indicates that the lenses were deposited by descending waters. In this connection, however, the apparent thickening of the ore bodies in depth should be borne in mind.

GOSSAN DEPOSITS.

In the Haystack Mountains, particularly in McCanns Pass, comparatively large areas are covered by a low-grade hematite, with which is associated some limonite. These minerals cement irregular fragments of schist. Here and there small amounts of iron pyrites occur and the deposit is in every way similar to the surface croppings of some of the copper deposits of the district. There is little doubt that this deposit is the gossan or iron hat of a sulphide vein. The mechanical impurities in the ore are so finely divided that its quality can not be bettered by hand picking, and sulphur is present as a chemical detriment.

TITANIFEROUS IRON ORE OF IRON MOUNTAIN, WYOMING.[a]

By Sydney H. Ball.

INTRODUCTION.

In the fall of 1906 the writer visited Iron Mountain, Wyoming. Since the economic possibilities of the deposits there are awakening wide interest and since the descriptions already published are out of print or are difficult of access, a short description of this region may be of value. The following bibliography includes the principal articles relating to Iron Mountain:

Stansbury, Howard, Captain, Corps Topographical Engineers, U. S. Army. Exploration and survey of the valley of the Great Salt Lake of Utah, etc. Philadelphia, 1852, p. 266.

Hayden, F. V. First, Second, and Third Ann. Repts. U. S. Geol. and Geog. Survey Terr. (1867–1869), 1873, pp. 80–81.

——— Preliminary Rept. U. S. Geol. Survey of Wyoming and portions of contigu ous territories (1870), 1871, p. 14.

King, Clarence. U. S. Geol. Explor. Fortieth Par., vol. 1, p. 27.

Hague, Arnold. Ibid., vol. 2, pp. 14–16.

Zirkel, F. Ibid., vol. 6, p. 107.

Knight, Wilbur C. Bull. 14, Exper. station, Laramie, Wyo., Univ. Wyoming, Oct., 1893, p. 177.

Kemp, J. F. Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 420.

Lindgren, Waldemar. Science, new series, vol. 16, 1902, pp. 984–985.

Kemp, J. F. School of Mines Quarterly, vol. 20, 1900, pp. 352–355.

Hill, B. F. School of Mines Quarterly, vol. 20, 1900, p. 364.

The conclusions herein expressed are in all essential particulars in accord with those set forth by Mr. Lindgren and by Professor Kemp.

GEOGRAPHY AND HISTORY.

Iron Mountain is in southeastern Wyoming in the east-central part of Albany County. It lies 8 miles west of Iron Mountain station, on the Colorado and Southern Railroad, and approximately 40 miles northwest of Cheyenne, Wyo. The deposit, which is in the Laramie

[a] After this note had been partly written in the field an article by Prof. J. F. Kemp in the Zeitschrift für praktische Geologie (vol. 13, pp. 71-80) came to the writer's attention. Professor Kemp, in addition to describing Iron Mountain, mentions the occurrence of similar iron ore in dikes at the Shanton ranch 4 miles southwest of Iron Mountain.

foothills 1 mile from the eastern border of the pre-Cambrian complex, in secs. 22, 23, 26, and 27, T. 19 N., R. 71 W., is reached from Iron Mountain station by a wagon road. Chugwater Creek passes in a gorge through the iron ore body.

Beside this main body of the magnetic iron minor masses occur in the pre-Cambrian rocks in a belt which is reported to extend from Horse Creek to Sibylee Creek, a distance of 20 miles. This belt, which courses a little east of north and west of south, is in places 5 miles wide.

Iron Mountain, a rugged ridge from 300 to 600 feet wide and 1¼ miles long, rises sharply from the anorthosite hills to the east and the rolling pre-Cambrian uplands to the west. Its ragged top presents a marked contrast to the regular hogbacks of the foothill sedimentary rocks.

The iron was first noticed by Capt. Howard Stansbury, U. S. Army, on September 30, 1850, when he was in camp on the banks of Chugwater Creek, on his way to Great Salt Lake. He found along the banks of the stream and in the adjacent hills "immense numbers of rounded black nodules of magnetic iron ore, which seemed of unusual richness." [a] In 1866 F. V. Hayden visited the mountain itself. The greater portion of the main deposit passed into the hands of the Union Pacific Railroad as a part of the land granted to it in 1862. In 1872 a wagon road was built to the deposit, prospectors rushed in, and the whole countryside was staked. In the following year a post-office, Iron Mountain, was established at the base of the iron ridge, but was abandoned in 1874. Eight or ten years ago the Colorado Fuel and Iron Company employed 15 teams for several months in hauling ore from the mountains to the railroad, whence it was shipped to their smelters at Pueblo. The work was suddenly abandoned, however, although the same company is reported to have made a small shipment four years ago. In 1905 and 1906 the main ore body was visited by a number of surveying corps, and the Colorado Land and Iron Company is said to have located claims between Chugwater and Sibylee creeks.

GEOLOGY.

The pre-Cambrian complex near the large dike of iron ore at Iron Mountain consists of three granular igneous rocks—an anorthosite,[b] the iron ore, and a granite. The anorthosite is the oldest of these and is cut by dikes and lenticular masses of iron ore and granite. The relative ages of the iron ore and granite was not certainly determined, since exposures are poor where the two rocks are close together. All the available evidence, however, indicates that the iron ore is older than the granite.

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[a] Stansbury, Howard, Exploration and survey of the valley of the Great Salt Lake of Utah, Washington, D. C., March, 1851.

[b] Anorthosite is a granular, wholly crystalline igneous rock, composed essentially of striated lime-soda feldspar, usually labradorite.

The anorthosite is a bluish to medium-gray holocrystalline rock of medium to coarse grain. It is composed almost wholly of gray feldspar, which in some places shows a feeble play of blue colors. Large flat crystals (phenocrysts) of gray feldspar, from 2 to 3 inches long and one-quarter to one-half inch thick, occur in some portions of the rock. Irregular masses of the rock are made up wholly of a granular aggregate of these large crystals. Immediately east of the iron ore dike, for a distance of 6 feet from the ore, the anorthosite contains crystals of magnetite (probably titaniferous) from one-eighth to 3 inches in diameter. In other parts of the mass, also, magnetite is abundant. Biotite and greenish black pyroxene are likewise visible to the naked eye in some portions of the anorthosite. As seen under the microscope the anorthosite is a fine to coarse-grained evenly granular igneous rock, composed predominantly of labradorite (plagioclase feldspar). Biotite is everywhere present, while titaniferous iron ore, olivine, a monoclinic pyroxene, occur in some specimens, and a single thin section contains apatite and a little quartz. The secondary minerals include chlorite, serpentine, calcite, and sericite.

The mass of iron ore is an igneous dike 1¼ miles long and 40 feet to 300 feet wide, the greatest observed width being at the point where Chugwater Creek cuts through the mass. The dike trends east of north; most of it lies north of the creek. It widens and contracts rather abruptly throughout its course. Toward the north it gradually narrows and finally disappears while 300 feet south of Chugwater Creek it narrows slightly and then abruptly ends. At several places it is almost cut in two by wedgelike masses of granite, but throughout practically its whole length it is bordered by anorthosite. The contact between the anorthosite and the ore, where exposed, is sharp, neither rock having undergone important gradational changes. A second dike of iron ore is exposed 300 feet downstream (east), on the south side of Chugwater Creek. This dike varies in width from 6 to 20 feet and is clearly intrusive in the anorthosite, with which it has sharp contacts. About one-eighth of a mile southeast of the south end of the main mass is a third dike of iron ore in anorthosite. The trend of this dike, which is 300 feet long and from 10 to 30 feet wide, is approximately parallel to that of the main mass. Several small magnetite dikes that are from 10 to 50 feet long and have maximum widths of 3 feet lie east of this mass, in parallel alignment.

The iron ore is a black, granular, holocrystalline igneous rock, with constituent grains varying from one-eighth to one-half inch in diameter. It has a metallic or submetallic luster. Changes in granularity occur in irregular masses or along well-defined parallel planes. In consequence of this distribution the rock has at some places an original gneissic structure. The greater portion of the iron is free from mechanical impurities, but biotite, olivine, and feldspar are sporadically distributed throughout its mass. Olivine is particularly abundant in portions of the small dike 300 feet east of the main mass. The iron ore is cut by rather closely spaced joints and by slickensided fracture planes. In consequence, the outcrop is angular, and its surface is littered with square blocks broken from the ore in place.

Weathering has broken down the iron ore mechanically and produced some chemical changes. Many weathered surfaces are pitted by reason of the complete removal of olivine and feldspar grains and the partial removal of biotite. On joint surfaces and along other fractures, limonite and less frequently hematite has been formed from the magnetite by percolating waters.

As seen under the microscope the ore in some specimens consists principally of titaniferous iron with a little spinel. Other thin sections show considerable olivine, while biotite and labradorite are present in many specimens and in a single section a crystal of what appears to be brown hornblende was noted.

Analyses of the iron ore are given in the following table:

Analyses of iron ore from Iron Mountain, Wyoming.

	A.	B.	C.	D.	E.	F.[a]	G.
Fe_2O_3	......	45.03	......	48.97	......	47.21	83.43
FeO	......	17.96	......	24.55	......	25.80	......
SiO_2	......	.76	......	[b] 2.15	......	1.21	1.64
TiO_2	[c] 20.68	23.49	23.32	23.18	49.47	22.43	14.06
Al_2O_3	......	3.98	......	......	......	......	......
Cr_2O_3	.16	2.45	......	......	......	......	......
Cr	.11	......	......	......	......	......	......
MnO_2	......	1.53	......	......	......	......	1.14
CaO	......	1.11	......	......	......	......	.22
ZnO	......	.47	......	......	......	......	......
MgO	......	1.56	......	......	......	......	......
S	.04	1.44	......	.03	......	1.14	.03
P	[d] .011	Trace.	......	......	......	......	.036
Total	......	99.78	......	98.88	......	......	100.556
Metallic iron	49.66	45.49	50.83	53.33	34.29	......	58.40

[a] Other constituents not tried for. [b] Insoluble residue in acid. [c] Ti 12.42. [d] P_2O_5 .026.

A. Average sample across width of dike on north side of Chugwater Creek. Analysis by Dr. Eugene C. Sullivan.
B. Analysis by J. P. Carson, Fourth Ann. Rept. U. S. Geol. Survey Terr., Hayden, Washington, D. C., 1871, p. 14.
C. Analysis by Prof. O. D. Allen, U. S. Geol. Explor. 40th Par., vol. 2, p. 14.
D. Analysis by Professor Richards, Mass. Inst. Technology, ibid, p. 15.
E. Analysis by Prof. R. W. Woodward, ibid, p. 14.
F. Analysis by W. C. Knight, Univ. Wyoming, Bull. Wyoming Experimental Station, No. 14, p. 177, 1893.
G. Sample of Iron Mountain ore smelted at Portland Exposition, loaned by Dr. D. T. Day. Analysis by Columbia Engineering Works, Portland, Oreg.

The iron content is fairly high, averaging perhaps 50 per cent, and the most notable feature of the ore is its high titanium content. Of the injurious constituents besides titanium, the sulphur in three analyses is low and in two others high, while phosphorus in the three analyses in which it was determined is below the Bessemer limit.

The iron ore is younger than the anorthosite, but since each is massive no orogenic movements of importance separated the two intrusions. The writer considers the iron ore and the anorthosite differentiation products of a common magma, the iron ore having been intruded into the anorthosite after that rock had completely solidified. The relationship of the two rocks is shown not only by their close association, but also by the presence in each of similar minerals, the two differing in the proportion rather than in the kind of minerals composing them. Iron ore is locally abundant in the anorthosite near the iron-ore lens, while feldspar occurs sparingly in the iron ore, and biotite and olivine are present in each. Chemically the monoclinic pyroxene of the anorthosite and the monoclinic hornblende of the iron ore probably approximately balance one another. Apatite, present in the anorthosite, was not observed in the iron ore, although the phosphorus determined in two analyses of the ore probably indicates its presence. The spinel of the ore is, then, the only mineral not common to both rocks. Spinel has, however, been found in rocks rather similar to the anorthosite in composition from other regions.

The loose masses of iron ore broken off from the main mass have already been mentioned. Chugwater Creek has carried these downstream and rounded them, and it was these rounded-ore pebbles that first attracted the notice of the early explorers. Where the Colorado and Southern Railroad crosses the creek, 10 miles from the iron-ore body, the pebbles are 1 inch in diameter and beautifully rounded. Much larger pebbles of iron ore, some 6 inches in diameter, occur in the Pleistocene terrace deposits that characterize this portion of the front of the Rocky Mountains. The difference in the size of the bowlders in the two stream deposits rudely indicates the differences between the transporting power of the stream depositing them.

Apparently the youngest of the pre-Cambrian rocks is a granite. This certainly occurs in dikes in the anorthosite and probably cuts the iron ore as well. It is a pinkish-gray, medium-grained biotite granite, some specimens of which contain pink porphyritic feldspars one-half inch long. It grades into and is cut by a biotite pegmatite. Magnetite is at some places present in the pegmatite, and at such places the magnetite, which distinctly belongs to the pegmatite period of intrusion, impregnates the immediately surrounding granite. Under the microscope the granite is seen to be an even granular rock rich in microcline and, for a granite, rather poor in quartz.

The presence of an iron ore as a visible constituent of the three igneous rocks of this area and as the dominant constituent of one of them is worthy of note. This, then, may be considered a pre-Cambrian metallographic province,[a] characterized by abundant magnetite.

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[a] Spurr, J. E., Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 276.

COMMERCIAL POSSIBILITIES OF THE ORE.

The immense ore body at Iron Mountain, extending 1¼ miles with an average width of perhaps 175 feet, is, like granite, an igneous rock and is likely to hold its width for a great depth from the surface or even, perhaps, to thicken somewhat with increasing depths. Chugwater Creek has cut a deep channel through the ore, and in consequence conditions are favorable for open-pit mining. A narrow-gage railroad could be built from the Colorado and Southern Railroad at Iron Mountain to the deposit or, at considerably greater expense, a broad-gage road could be constructed. The cost of fuel in this portion of Wyoming is surprisingly high in view of the proximity of coal mines. Chugwater Creek is too small a stream to produce cheap electric power, which, however, might be obtained from some of the Colorado power companies.

In the present day smelter practice iron ores with such high titanium content are practically valueless, but progress is being made in the treatment of these ores, and at some future time the deposit at Iron Mountain will doubtless be of great commercial importance.

Titanium is very undesirable in iron ores because of its refractory character, its ores being practically unreducible at the temperature of blast or open-hearth furnaces. As a constituent of iron and steel, however, titanium increases toughness and tensile strength. In consequence the production of high-grade iron from titaniferous ores is under some conditions profitable. Titaniferous iron ores have been successfully smelted in Sweden, England, and the United States, but even in Sweden the cost was so great that the annual output has gradually diminished, until, in 1892, the Taberg mine produced but 40 tons of pig as against 9,204 tons in 1875.[a] Mr. A. J. Rossi[b] in the early nineties successfully smelted ores with 20 per cent TiO_2 in smelters of 3-ton daily capacity. Thirteen years after the publication of his article, however, no attempt has been made to verify his results on a commercial scale.

Some attempts to separate the nontitaniferous from the titaniferous ores by magnetic processes have been partially successful. The waste of iron, however, since titaniferous iron itself carries considerable iron, is so great that the process is commercially a failure. This process requires fine crushing, and hence, subsequently, briquetting.

[a] Hulst, N. P., Proc. Lake Superior Mining Institute, vol. 10, p. 40.
[b] Trans. Am. Inst. Min. Eng., vol. 21, pp. 832-867, 1893.

The most promising method of treating titaniferous iron ores is reduction in the electric furnace. Experimentally the process is successful, and its commercial application is wholly a question of cost. Concerning this F. W. Harbord [a] states:

Pig iron can be produced on a commercial scale at a price to compete with the blast furnace only when electric energy is very cheap and fuel very dear. On the basis taken in this report with electric energy at $10 per estimated horsepower year and coke at $7 per ton, the cost of production is approximately the same as the cost of producing pig iron in a modern blast furnace.

Under ordinary conditions where blast furnaces are an established industry, electric smelting can not compete, but in special cases where ample water power is available, and blast-furnace coke is not readily obtainable, electric smelting may be commercially successful.

These conclusions apply to nontitaniferous ores, although Dr. Eugene Haanel [b] says:

The experiment made with a titaniferous iron ore containing 17.82 per cent of titanic acid permits the conclusion that titaniferous iron ores up to perhaps 5 per cent titanic acid can be successfully treated by the electric process.

In 1905–6 experiments in smelting magnetic iron ores electrically were carried on under the direction of Dr. David T. Day of the U. S. Geological Survey, at Portland, Oreg. In the course of the experiments cast iron of good quality was obtained from the titaniferous ores of Iron Mountain, Wyoming. An analysis of the impurities in this iron is given below:

Impurities in iron produced from titaniferous ores of Iron Mountain, Wyoming.

Silicon	0.93
Manganese	None.
Phosphorus	.074
Sulphur	.005
Total carbon	4.3
Titanium	.53
Chromium	.09

Doctor Day states that 3,760 kilowatt hours were used on the average in smelting a ton of 2,000 pounds of pig iron produced, the total charge averaging approximately two of the Wyoming iron to one of briquettes made of Pacific coast magnetite sands. During a run of 2,583 pounds of iron, 205 pounds of graphite electrode were consumed.

[a] Rept. of Commission appointed to investigate the different electro-thermic processes for the smelting of iron ores and the making of steel in operation in Europe: Dept. of the Interior, Ottawa, 1900, pp. 115–116.

[b] Prel. rept. on experiments made at Sault Ste. Marie, Ontario, under government auspices, in the smelting of Canadian iron ores by the electric-thermic process, Dept. of Interior, Ottawa, 1906, p. 23.

SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey or by members of its staff are listed below:

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CLEMENTS, J. M., SMYTH, H. L., BAYLEY, W. S., and VAN HISE, C. R. The Crystal Falls iron-bearing district of Michigan. Monograph XXXVI. 512 pp. 1899.

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HAYES, C. W., and ECKEL, E. C. Iron ores of the Cartersville district, Georgia. In Bulletin No. 213, pp. 233–242. 1903.

HOLDEN, R. J. The brown ores of the New River-Cripple Creek district, Virginia. In Bulletin No. 285, pp. 190–193. 1906.

IRVING, R. D., and VAN HISE, C. R. The Penokee iron-bearing series of Michigan and Wisconsin. Monograph XIX. 534 pp. 1892.

KEITH, A. Iron-ore deposits of the Cranberry district, North Carolina-Tennessee. In Bulletin No. 213, pp. 243–246. 1903.

KEMP, J. F. The titaniferous iron ores of the Adirondacks [New York]. In Nineteenth Ann. Rept., pt. 3, pp. 377–422. 1899.

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——— Geologic work in the Lake Superior iron district during 1902. In Bulletin No. 213, pp. 247–250. 1903.

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YALE, C. G. Iron on the Pacific coast. In Mineral Resources U. S. for 1883–84, pp. 286–290. 1885.

In addition to the papers listed above, iron deposits of more or less importance have been described in the following geologic folios (for location and further details see pp. 8–13): Nos. 2, 4, 5, 6, 8, 10, 11, 12, 14, 18, 19, 20, 21, 22, 24, 25, 28, 32, 33, 35, 36, 37, 40, 43, 44, 55, 56, 59, 61, 62, 64, 70, 72, 78, 82, 83, 84, 115, 116, 118, 120, 124, 125, 126, 129.