IRON AND MANGANESE.

During the past year special attention has been attracted to the American iron industry, both by its remarkably prosperous condition and also by the publicity which has been given to attempts to effect a merger of important southern iron interests. Another feature worthy of note has been the commencement of active exploration work on western iron deposits. In both these fields the Survey has taken up detailed work during 1905, and preliminary reports on the results of some of this work are presented in the following papers:

THE CLINTON OR RED ORES OF NORTHERN ALABAMA.

By Edwin C. Eckel.

Introduction.—During the fall of 1905 detailed work was commenced on the iron ores of Alabama. The Clinton or red ores were examined in the district along the flanks of Lookout Mountain, from the Georgia line to Attalla and Gadsden; and the brown ores of the Anniston and Talladega districts were also surveyed. The present preliminary report contains notes on the developments in the red-ore districts covered.

In view of the practical importance of the subjects, descriptions of the ores of this district will be prefaced by brief notes on the origin and character of the red ores in general.

ORIGIN AND CHARACTER OF THE CLINTON ORES.

THEORIES OF ORIGIN.

For many years the origin of the oolitic and fossil ores which occur in rocks of "Clinton" age has been a much discussed subject. Minor points of difference being disregarded, it may be said that the various theories which have been advanced to account for the origin of these ores can be reduced to two. These two opposing theories are, briefly stated, as follows:

(1) *Original deposition.*—The ores were formed at the same time as the rocks which inclose them, having been deposited in a sea or basin along with the sandstones and shales which now accompany them.

(2) *Replacement.*—The ores are of much later origin than their inclosing rocks, having been formed by the replacement of original beds of limestone by iron brought in by percolating waters.

PRACTICAL IMPORTANCE OF THE QUESTION.

In addition to the questions of purely geologic interest which are connected with the differences of opinion as to the origin of the Clinton ores, the matter has a very distinct practical bearing on the working of the ores. This phase of the subject may be stated as follows:

If the ore deposits are due to the replacement of a limestone we can expect them to rapidly decrease in value with depth, becoming lower in iron and higher in lime, until at no great depth the bed will consist entirely of unaltered limestone.

If, on the contrary, the ore deposits are original, no such regular decrease in richness is to be expected as the mines are driven deeper. Patches of low-grade ore may be struck, but these will be due to original differences in the richness of the ore, and a slope might pass downward through such a patch of lean ore into another zone of high-grade ore.

PROBABLE METHOD OF ORIGIN.

In the present report no attempt will be made to discuss the arguments that have been advanced on both sides of this question, though such a discussion will be given in the final report on the district. For this paper, however, it will be sufficient to say that in the writer's opinion the ores unquestionably originated at the same time as their inclosing sediments, and that, except immediately at the surface, they have been subjected to no later alterations or enrichments. As pointed out above, this theory of origin implies that the ore bodies are practically continuous in depth and that they could be followed down the dip, in a syncline or basin, until the dips changed and the workings reached the surface on the other side of the fold. The practical importance of this is obvious, for it implies that the ore bodies can be traced and measured as exactly as if they were coal seams or limestone beds. The amount of Clinton ore in any area can probably be determined by a geologist within 5 or 10 per cent, and estimates of red-ore reserves can be made by competent men with a degree of accuracy impossible in dealing with the magnetite, hematite or brown ores of other districts.

"HARD" AND "SOFT" ORES.

The terms "hard" and "soft," as applied to the two principal varieties of Clinton ores, are hardly expressive of the facts, for the distinction between the two varieties in question is based on differences in their chemical composition rather than on differences in hardness.

The red ore of Alabama is, in its typical or "hard" variety, a highly limey ore. The ore beds are usually underlain by comparatively impervious shales and in most places dip at fairly high angles. These conditions favor the penetration of the ore, near the surface, at least, by percolating water. The result is that near the outcrop and for some distance down the slope the lime carbonate of the original ore is largely or entirely leached out. This removal of one constituent of course increases the relative percentages of the remaining less soluble constituents, while it renders the ore more porous and friable. The resulting "soft ore" is therefore very low in lime and correspondingly high in iron oxide. A secondary effect of the change, shown best when the cover is heavy and the dip low, is that the overlying shales settle down slightly as the bulk of the ore is reduced, so that on the outcrops the ore bed often appears to be less than its true underground thickness.

RED ORES OF NORTHERN ALABAMA.

GEOLOGY OF THE DISTRICT.

The geologic section found in this district is as follows, from above downward:

Geologic section in northern Alabama.

Formation.	Age.	Thickness.
		Feet.
Bangor limestone	Carboniferous	500-800
Fort Payne chert		100-250
Chattanooga shale	Devonian	20-30
Rockwood ("Clinton") shale	Silurian	400-800
Chickamauga ("Trenton") limestone		600-1,800
Knox limestone	Ordovician	2,000-4,000

Along the western side of Lookout Mountain, in Little Wills Valley, the rocks dip at low angles (10° to 30°) toward the mountain; on the eastern side the rocks dip steeply toward the mountain and are often almost vertical. The crest of Lookout Mountain is composed of the Coal Measures, and the Bangor limestone outcrops on the flanks of the mountain and underlies Little Wills Valley. The ridge northwest of this valley—the "Red Mountain"—shows the Fort Payne chert along its southeastern face, while the Rockwood beds, including the ore seams, form its crest and northwestern flank.

ORE DEVELOPMENTS OF THE DISTRICT.

The Clinton ores have been carefully traced throughout this district by Dr. C. W. Hayes and the writer, and in the final report large-scale maps will be included, showing the exact location of the ore-bearing formation. Since such maps can not be presented here, attention will be confined to a description of the developed ore deposits of the region. These will be described in geographical order, from Battelle south to Attalla, after which the chief facts concerning the Gadsden and Gaylesville deposits will be briefly noted.

Battelle.—The mines of the Ragon Mining Company, which supply the furnace of the Lookout Mountain Iron Company at Battelle, are located about one-fourth mile west of the furnace, on the northwest side of Red Mountain. Four ore beds are shown in the section here, with following dips and thicknesses and approximate distances apart:

Section showing ore beds near Battelle, Ala.

	Dip (southeast).	Thickness.
	°	*Feet.*
Bed 1 (top)	23–45	4½
Shale		40
Bed 2	25–45	2
Shales		300
Bed 3	85	3
Shales		200
Bed 4	85	3½

Of these beds, however, the second is too sandy to be workable and the third seems to be a very local development which can not be traced many feet from its outcrop. The first or top bed is worked by three slopes, each of which is now down about 200 feet; the fourth bed has two small and almost vertical openings.

The soft ore has been practically worked out, and the mines are now entirely in a hard, very limy ore. The following analyses, by Mr. I. P. Todd, chemist of the Lookout Mountain Iron Company, will serve to show the range in composition of the ore from the different beds and slopes:

Analyses of ores from mines near Battelle, Ala.

	Silica (SiO_2) and alumina (Al_2O_3).	Metallic iron (Fe).	Lime (CaO).	Magnesia (MgO).
Upper bed, slope 1	11.80	27.50	22.08	2.50
	9.40	29.30	22.87	n. d.
	10.60	29.40	22.40	n. d.
Upper bed, slope 2	7.20	31.18	22.54	n. d.
	8.40	31.30	23.04	n. d.
Upper bed, slope 3	15.60	24.15	23.45	n. d.
	12.60	24.80	24.20	n. d.
	12.90	23.25	26.05	n. d.
	15.00	25.30	22.90	n. d.
Bottom bed, slope 4	9.80	32.57	20.04	n. d.
Bottom bed, slope 5	10.10	31.77	20.54	n. d.

The difference in the ore from the different slopes on the upper bed is rather marked, for slope 2 averages 31.24 per cent of metallic iron, while slopes 1 and 3 average only about 27 per cent. This is accounted for by the fact that the ore from slopes 1 and 3 passes through a crusher, while that from slope 2 is hand picked and sledged over bars. The ore from the bottom bed, as will be seen, is somewhat better than even the best ore from the upper bed.

Mr. Todd furnished the following average analysis of all the hard ore, as fed to the furnace:

Average analysis of hard ore from mines near Battelle, Ala.

Silica (SiO_2)	9.20
Alumina (Al_2O_3)	3.68
Metallic iron (Fe)	27.00
Manganese (Mn)	.13
Lime (CaO)	22.54
Magnesia (MgO)	1.22
Phosphorus (P)	.376

Fort Payne.—McCalley [a] quotes the section shown by a well driven at Fort Payne furnace, probably about 1890. Rearranged slightly, this section is as follows:

Section of well at Fort Payne furnace, Alabama.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	25	0–25
Fort Payne chert	190	25–215
Devonian black shale	12	215–227
"Clinton" green and gray shales	340	227–567
"Clinton" shales and ore	18	567–585
"Clinton" shales, sands, and ore	50	585–635
"Clinton" shales and sandstone	180	635–815
"Clinton" ferruginous sandstone	50	815–865
"Clinton" shales and sandstone	40	865–905
Chickamauga limestone	....	905–

The well section given above can be compared directly with the following section, measured in 1905 by Mr. L. N. Christensen and the writer through the gap back of Fort Payne furnace.

Section through gap back of Fort Payne furnace, Alabama.

	Feet.
Fort Payne chert.	
Chattanooga shale	24½
Sandstone and shale	306
Ore	2–2½
Shale parting	1½–2½
Ore	2½–3
Shale	270
Covered interval, probably mostly limestone	246
Chickamauga limestone.	

Readings taken at a number of points in this gap gave a very uniform dip—varying only from 13½° to 15° to the southeast.

[a] Report on the Valley Regions of Alabama, pt. 2, p. 154.

The mines formerly worked to supply the Fort Payne furnace are located about half a mile northwest of the furnace, in the gap above mentioned. The original report on this property gave the following analyses for the ore from the mines:

Analyses of ores from mines near Fort Payne, Ala.

	Soft ore.	Hard ore.
Silica (SiO_2)	10.37	4.11
Metallic iron (Fe)	55.34	25.39
Lime (CaO)	1.07	30.13
Phosphorus (P)	.46	.34

While these analyses are quoted from a prospectus and the name of the analyst is unknown, the analysis of the hard ore at least seems to contain internal evidence as to its accuracy, for no prospectus writer would imagine a 25 per cent ore.

Analyses by J. L. Beeson [a] of samples from old surface cuts near the Fort Payne mines gave the following results:

Analyses of ore from surface cuts near Fort Payne, Ala.

	Soft ore.	Hard ore.
Silica (SiO_2)	7.93	3.97
Metallic iron (Fe)	56.02	26.41
Lime (CaO)	n. d.	29.80
Phosphoric anhydride (P_2O')	.52	.86

It will be seen that these check closely with the reported analyses of the Fort Payne furnace ores.

Portersville.—The Portersville mines of the Southern Steel Company are located about three-fourths of a mile northwest of Portersville station, near the northwestern flank of Red Mountain. A switch track from the mines to the Alabama Great Southern Railroad passes on a very easy grade through a convenient gap in the red ridge.

The principal openings at present are on the north side of this gap, though extensive stripping is now in progress on the south. The main slope shows a section about as follows:

Section in main slope of mine near Portersville, Ala.

	Inches.
Shales.	
Ore	24
Shale	12–18
Ore	24

This slope is now down 400 feet on the dip of the ore, which is 15° SE.; and below cover the ore beds thicken slightly in places to give a total thickness of 4½ feet. Owing to the heavy shale parting between the seams the stripped ore is hardly as clean as that of the Crudup mines.

On the south side of the gap 5 to 30 feet of stripping (soft greenish shale) is being removed so as to get back to a point where the roof is firm enough to permit underground mining.

[a] McCalley, Report on the Valley Regions of Alabama, pt. 2, p. 153.

Measurements of the ore here gave the following results:

Sections on south side of gap near Portersville, Ala.

	1.	2.
	Inches.	*Inches.*
Ore	20	23
Shale	14	8
Ore	17	20

About 50 feet vertically below this main ore bed a thin seam of ore, perhaps averaging 1 foot in thickness, shows in the road. This is not worked, and no other ore seams have been found.

The following analyses by M. C. Shannon cover the results on a large number of carloads of the Portersville hard ore:

Analyses of Portersville hard ore.

	1.	2.	3.	4.	5.	6.	7.	8.	Average.
Silica (SiO_2) } Alumina (Al_2O_3) }	5.56	4.94	5.60	9.18	6.42	7.86	5.80	5.02	6.29
Metallic iron (Fe)	33.05	33.72	25.52	38.00	30.35	31.20	31.95	32.00	31.98
Lime (CaO)	25.20	22.90	30.82	19.04	25.88	23.71	26.62	24.22	24.80
Phosphorus (P)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	....

Crudup.—The Lacey-Buek Iron Company operates mines on an exceptionally heavy ore bed at Crudup, the ore being mostly shipped to the furnaces at Trussville, Ala. The ore bed is from 5 to 7 feet thick, without any shale parting. At the mine the bed dips 26° SE. The mines were formerly worked as open cuts, but now practically all the ore comes from a single slope. No analyses of ore from these mines are at present available, but McCalley quotes the following as an average of the ore from a group of old workings near Crudup:

Average analysis of ore from old workings near Crudup, Ala.

Silica	10.51
Metallic iron	42.45
Phosphorus anhydride	1.017

Attalla.—In the immediate vicinity of Attalla two mining companies are now operating on the red ore, the mines being located west and northwest of the town, on and near Moragne Mountain.

The mines of the Alabama Consolidated Coal and Iron Company are located near a gap at the northeast end of Moragne Mountain, about half a mile north of Attalla. The ore here is from 3 to 4 feet thick, dips 30° to 35°, and has been worked down on the slope for almost a thousand feet without marked change in character. This fact is worth noting, for the surface developments at this mine caused Russell to consider the Clinton ore to be merely a surface deposit. This early error has been followed by most text-book writers on economic geology, despite the fact that even a casual personal acquaintance with the district in its present condition would suffice to prove that it is an error.

Soft ores from surface workings near this gap gave McCalley the following results:

Analysis of soft ores near Attalla, Ala.

Silica	8.39
Metallic iron	53.92
Phosphorus anhydride	1.55

The hard ore from the Alabama Consolidated mines is still of very high grade for this district.

The Northern Alabama Mining Company has several surface cuts and one slope located on Moragne Mountain. The ore here varies from 34 to 40 inches in thickness, without parting, and dips at an angle of 23° to 26°. At some points soft ore has been found as far down as 300 feet, measured on the slope, equivalent to a vertical depth of 75 feet below the ground surface. The larger part of the ore now shipped is, however, hard ore.

The following analyses of hard and soft ores from the Moragne Mountain mines of the Northern Alabama Mining Company are by chemists of the Woodstock Iron Company:

Analyses of ores from mines at Moragne Mountain, Alabama.

	Soft ores.				Hard ores.	
Silica (SiO_2)	10.74	7.16	8.40	8.76	9.26	8.40
Alumina (Al_2O_3)	2.00	n. d.	n. d.	n. d.	n. d.	n. d.
Metallic iron (Fe)	51.02	52.56	51.90	52.75	43.88	38.05
Lime (CaO)	n. d.	n. d.	n. d.	n. d.	17.86	27.00

Red ore has been exposed by a prospecting pit on the Rhea place, about 2 miles west of Attalla. The ore at the outcrop is 27 inches thick, but much of it seems to be very sandy. The ore bed at this point strikes N. 10° E. and dips 80°–88° W.

Gadsden (Shinbone Ridge).—Several small mines were formerly worked at Gadsden, but the workings now in operation are located respectively 2 and 3 miles northeast of the town, on the southeast flank of Shinbone Ridge. The mine nearer town shows an ore bed 3½ to 4 feet thick, on which workings have been carried down about 200 feet. The farther mine (Etowah No. 2) shows an ore bed 2½ to 3½ feet thick, dipping 80° NE. and striking N. 42° E. This slope is now down about 200 feet. Both mines ship their product to the furnace of the Alabama Consolidated Coal and Iron Company at Gadsden.

Southeast of Gadsden red ores have been worked in earlier days on the ridges north and south of Rock Springs station. The beds here are usually 14 to 18 inches thick, though one opening is said to have shown a 3-foot ore seam. The ore lies above the heavy sandstone which caps these ridges.

Gaylesville (Dirtseller Ridge).—Extensive work is being carried on by the Southern Steel Company along the southeast flank of Dirtseller or Tuckers Ridge about 2 miles north of Gaylesville. Working slopes and prospect pits have developed the ore for a distance of 2 miles or so along the strike and give an excellent opportunity for its examination.

The northernmost slope—the Skeen slope—is at present the principal working. This slope is driven in the direction S. 40° E. and is run in on the dip of the ore, which is here 20°. The section exposed was as follows:

Section in Skeen slope, near Gaylesville, Ala.

	Inches.
Good solid ore	20
Mixed (shaly) ore	7

At the southernmost series of openings the dip is still 20° SE., but the ore bed is split by a heavy shale parting into two seams. Sections measured here are as follows:

Sections at southernmost openings near Gaylesville, Ala.

	1.	2.
	Inches.	*Inches.*
Ore	4	4
Shale	8	10
Ore	19	18

The three sections above noted are, it is believed, fairly representative of the conditions existing in this portion of Dirtseller Ridge. In places the ore thickens locally to 3 or even 5 feet, but on the other hand local thinning occurs at other points on the outcrops. It is probably safe to assume that the average thickness over the whole outcrop is between 20 and 24 inches.

As this particular area had never been worked to supply ore for the old charcoal furnaces, the Southern Steel Company has been able to secure a very large amount of soft ore of good grade from this property. Analyses of representative shipments of this soft ore by M. C. Shannon follow:

Analyses of soft ore from Dirtseller Ridge, Alabama.

	1.	2.
Silica (SiO_2)	13.70	15.87
Alumina (Al_2O_3)	5.86	5.87
Metallic iron (Fe)	49.70	49.55
Lime (CaO)	2.35	2.61
Phosphorus (P)	.44	n. d.

Most of the workings have now been driven deep enough to have passed through the soft ore into the hard, of which no analyses are available. Northeast of the Southern Steel Company's holdings red ore has been mined near Dewey post-office and at other points across the Georgia line.

THE IRON ORES OF BATH COUNTY, KY.[a]

By E. M. Kindle.

Introduction.—Bath County is located in the northeastern portion of the State just outside the blue-grass region. The topography of the southeastern portion is of the bold, hilly type characteristic of the Kentucky mountain districts. Rugged, steep-sided hills and ridges left by the dissection of the Lower Carboniferous sandstones are the dominant features of this section. These command a broad sweep of hilly but somewhat less elevated country which comprises the northwestern two-thirds of the county. The deeply incised and widely meandering channel of Licking River receives the drainage of the county and forms its northeastern boundary. Within the limits of this county occur all the main divisions of the geologic column which are developed in the State of Kentucky. The oldest rocks are the Ordovician, which outcrop in the northwestern part of the county. These are carried downward by a moderate southeasterly dip, resulting in a series of deeply scalloped belts of successively younger beds which cross the county in a northeasterly-southwesterly direction. The Coal Measures, which are the youngest rocks in the area, cap some of the hills near the southeastern boundary.

Geologic relations and character of the ores.—Iron ores occur at three distinct geologic horizons in Bath County. The Lower Carboniferous beds contain the highest or youngest of these ores. These Carboniferous ores lie in very thin beds, sometimes seven or eight in number, occurring usually as scattered kidney-shaped masses of iron carbonate in the shales. They have generally a thickness of only a few inches, but occasionally reach 1 or 2 feet. These ores are carbonates of low grade.

The expense of mining ores of this character, which, unlike the other ores of this county, can not be stripped, together with their rather high sulphur and phosphorus content, will probably make profitable mining of them impossible for some time to come.

The ores which were mined for many years at the Preston ore banks lie in a Devonian horizon,[b] holding a position between the Black shale and the Silurian beds. Iron ore is reported to occur locally at this horizon in small amounts to the southwest of Bath County in Montgomery, Boyle, Lincoln, and Casey counties. In Ohio, about 50 miles northeast of Bath County, the writer has observed iron ore which was formerly mined occurring at the same horizon southeast of Peebles. The belt of occasional ore deposits to which the Preston ore banks belong has therefore an extent of about 150 miles along the southeast flank of the Cincinnati geanticline. The Preston ore is an exceptional development of the thin lenticular and usually worthless ore masses occurring occasionally at this horizon. This ore was reported by Mr. Linney[c] to have a thickness of from 7 to 15 feet. It is a limonite and carries from 52 to 80 per cent of oxide of iron, according to Doctor Peters's analysis.[d]

The third and lowest ore horizon occurs in the Clinton shales. This ore bed seldom exceeds 4 feet and is frequently less than 2 feet in thickness. Several thousand acres to the east and southeast of Owingsville are probably underlain by the ore bed. Considerable

[a] The author is indebted to Mr. W. C. Phalen for the use of notes on the mines of the Rose Run Company.
[b] Report on Bath and Fleming counties, Kentucky Geol. Survey, 1886, p. 25.
[c] Report on the Geology of Bath and Fleming counties, Kentucky Geol. Survey, 1886, p. 28.
[d] Rept. Kentucky Geol. Survey, old series, vol. 4, p. 62.

areas occur where the land is sufficiently flat and the iron near enough to the surface to permit mining by stripping the overlying shales and shaly sandstone. This ore is a hematite of oolitic structure, the particles composing it being quite small and lenticular or flattened in shape. It does not anywhere appear to be a "fossil ore," the few fossils occurring in it being generally minute forms. A chemical analysis of the specimens of the Clinton ores made by Doctor Peters's [a] showed the following results:

Analyses of Clinton iron ores, Kentucky.

	1.	2.	3.
Iron peroxide	47.630	51.430	58.570
Alumina	5.468	5.132	3.720
Lime carbonate	16.560	13.080	15.160
Magnesia carbonate	9.974	9.444	4.528
Phosphoric acid (P_2O_5)	1.202	1.138	1.010
Silica	7.160	7.800	6.960
Moisture expelled at 212° F	1.143	.693	1.607
Undetermined carbonic acid, water, organic matter, etc	10.865	11.283	8.444
	100.000	100.000	100.000
Percentage of iron	33.341	36.001	40.999

The iron which this ore produces is described as a "soft fluid foundry iron, somewhat cold short."

Development.—The Bath County ores are of some historic as well as economic interest. As early as 1791 an iron furnace was in operation on Slate Creek, 2 miles south of Owingsville. Here charcoal iron was produced for nearly half a century and shipped down Licking River to various trade centers of the Mississippi Valley long before railways had become factors in the commerce of the Central West. The iron produced here, owing to the high percentage of phosphorus in the ore, was a hard but not very tenacious metal. Cannon balls which were made from Bath County iron for the war of 1812 may still be seen in some of the curio collections of Owingsville. On the expiration of a lease this furnace went out of blast and was never reopened. The old furnace is still standing—a monument to the part played by Kentucky in the early development of the iron industry.

At a later period the Preston ore banks, which supplied this furnace, were reopened by the Slate Creek Iron Company, which shipped the ore for smelting until the supply was exhausted. In 1838 a furnace was erected on Caney Creek. Iron was made here from the Lower Carboniferous ores for some years, charcoal being used as a fuel. The venture does not appear to have been a profitable one, and no attempt has been made to utilize these ores in recent years.

At the time of the survey of this county by the Kentucky Geological Survey in 1885 the Clinton ores had not been developed. These ores have since been extensively mined and are at present the only ores worked in Bath County. The Rose Run Iron Company is engaged in mining them. The mines are located about 3½ miles east of Owingsville, and are connected by switch with the Chesapeake and Ohio Railway at Olympia. The ore is stripped, a part of the stripping being done by a steam shovel. Formerly the ore was smelted at the mine, at present it is shipped for reduction. The ores are transferred from the mine breast to the tipple by a small locomotive and cars. Fifty men are employed, and an average of about 125 tons of ore per day are produced. The ore is used for pig iron, and is shipped to various points for reduction. Some of the furnaces which are using it or have used it are located at Ashland, Ky.; Ironton, Ohio; Lowmoor, Va., and Big Stone Gap, Va.

[a] Report on Bath and Fleming counties, Kentucky Geol. Survey, 1884, p. 19.

Approximately 25,000 tons of ore were produced during the year 1905. The mine section as exposed at one point shows the following beds:

Section at mine of Rose Run Iron Company near Owingsville, Ky.

	Feet.
Yellow surface clay	2
Thin-bedded sandstone and shale	5
Blue clay shale	6
Iron ore	4

The ore varies in thickness from 1½ to 5 feet, 2 feet being perhaps an average. About 5 inches of green ore generally overlie the red ore. This 5-inch band carries a percentage of sulphur, which necessitates roasting before it can be used. It was formerly roasted at the mines, but at present it is thrown out. The high percentage of lime in the ore makes it unnecessary to add lime for fluxing. A series of 5 analyses, made by different parties, show the lime content to run from 8.86 to 11.91 per cent, and the silica from 4.19 to 8.73 per cent. The same analyses show the iron to run from 35.7 to 38.6 per cent; magnesia, 4.08 to 5.84 per cent; alumina, 3.54 to 6.80 per cent, and phosphorus, 0.43 to 0.61 per cent.

About 15 acres of the ore have been worked out. The yield of ore per acre is estimated at about 3,000 tons per foot of thickness. The Clinton ore which has been mined may therefore be estimated at approximately 125,000 tons. There are probably several thousand acres of the Clinton ore of about the same grade and thickness as that which has been mined. Only a small percentage of this can be mined by stripping, however.

With the rapid exhaustion of the supply of high-grade ores and the consequent increase in the demand for ore of this grade which may be expected in the future, much of the Clinton ore which can not now be profitably mined may eventually be utilized.

THE ORISKANY AND CLINTON IRON ORES OF VIRGINIA.

By EDWIN C. ECKEL.

INTRODUCTION.

During the year 1905 work was carried on by the United States and Virginia Geological Surveys, acting in cooperation, on the iron ores of Virginia. This work was placed in charge of the writer, who also did most of the actual field work on the Oriskany and Clinton ores, while Mr. R. J. Holden, of the Virginia Survey, did all the work on the New River-Cripple Creek brown ores and spent some time in the Oriskany district. Mr. J. S. Grasty carried out areal mapping in the Oriskany district, covering a few small areas left unmapped by Prof. H. D. Campbell, who in previous years, and largely at his own expense, had made detailed maps of most of this region. Professor Campbell kindly placed these earlier results at my disposal, and exercised general supervision over Mr. Grasty's field work.

Detailed reports on the work above mentioned are now in preparation and bulletins on the iron ores of Virginia will be issued independently by the Federal and State Geological Surveys as the field work in the different districts is completed. In the following pages brief notes are given on the work so far accomplished in certain important districts. The relations of these various pieces of field work to one another can be best understood if the reports are prefaced by an introductory statement as to the ore districts of Virginia.

IRON ORES OF VIRGINIA.

Considered from either an industrial or geologic view point, the iron ores of Virginia fall into 6 groups:

I. Magnetites and specular hematites of the Blue Ridge and Piedmont districts.

II. Red hematites (Clinton ores, "fossil ores," "oolitic ores") of the foothills of the Allegheny Mountains.

III. Brown hematites (Oriskany ores) of the Goshen-Longdale-Lowmoor-Oriskany district, mostly in Augusta, Bath, Botetourt, Alleghany, and Craig counties.

IV. Brown hematites of the New River-Cripple Creek district, mostly in Wythe and Pulaski counties.

V. Brown hematites of the Roanoke, Shenandoah, and Page valleys.

VI. Brown hematites ("gossan ores") of Carroll and Floyd counties.

During last season detailed field work was done on the ores of classes III and IV, the ores of class II were examined in less detail at several localities, while on those of classes I, V, and VI no field work was done. It is planned to complete the work during 1906 by examination of the ore deposits not visited during 1905.

ORE RESERVES AND IRON PRODUCTION.

The most striking fact brought out by the work of last year is the small amount of workable ore now in sight. Few of the furnaces are in an entirely satisfactory position as regards ore reserves, while several have only a few years' supply available. Most of the brown-ore districts worked ten years ago are now within measurable distance of exhaustion and new deposits are not being developed rapidly enough to offset the drain on the older beds. Several rich deposits of the Oriskany brown ore have been opened within the last year or two, but elsewhere little of promise has been uncovered.

In the face of such conditions as to brown-ore supply, it would seem wise to commence active and careful exploration of the other two classes of ore known to exist, in workable quantities, in the State. These are (1) the Clinton red or fossil ores of western Virginia, and (2) the magnetites of the Blue Ridge and Piedmont districts. Neither of these classes of ore has as yet been given proper consideration.

At present from 100,000 to 200,000 tons of ore are shipped into Virginia furnaces from Tennessee, North Carolina, and the Lake Superior districts, a fact which must be borne in mind when comparing the iron-ore and pig-iron statistics given later. Lake Superior ores cost from 8 to 10 cents per ton per unit of iron when they reach the Virginia furnaces, as compared with 3 to 5 cents per ton per unit for the native brown ores.

The following data in cost of iron production in various States have been calculated from figures given in the reports of the Twelfth Census (1900). The total costs as here given include raw materials (ore, fuel, flux, etc.), wages, salaries, and repairs.

Cost of production of coke iron, per ton, 1900.

Alabama	$8.12
Tennessee	9.97
Illinois	10.12
Pennsylvania	11.23
Virginia	12.12

The Alabama and Virginia costs above given have been checked with a number of detailed cost sheets kindly furnished by several companies in those States, and it is believed that the averages given can be accepted as correct enough for present purposes. They may, at any rate, be profitably compared with the estimates to be found in prospectuses.

The iron-ore and pig-iron production of Virginia are summarized for the years 1899 to 1905, inclusive, in the following table:

Iron-ore and pig-iron production of Virginia and West Virginia.

Year.	Brown ore.	Red hematite.	Magnetite.	Total iron ore.	Total pig iron.
1899	968,143	17,173	1,160	986,476	365,491
1900	918,157	3,664	....	921,821	490,617
1901	910,214	13,156	2,024	925,394	448,662
1902	953,128	31,677	3,153	987,958	537,216
1903	764,948	31,069	4,604	801,161	544,034
1904	528,853	17,952	3,448	550,253	310,526
1905	[a] 702,000	[a] 45,000	[a] 3,000	[a] 750,000	510,210

[a] Estimated. All other figures are exact.

ORISKANY BROWN ORES.

In the counties of Alleghany, Augusta, Rockbridge, Bath, Botetourt, and Craig, and, to a less extent, in other areas of central-western Virginia, large deposits of brown iron ore are associated with certain beds of the Silurian rocks. The deposits are frequently overlain by the Oriskany sandstone, and most observers have considered the ores to be original deposits in that formation, so that the term "Oriskany ores" has come into common use. Careful examination, however, shows that the ores are replacements, mainly of the "Helderberg" or Lewistown limestone, but also of the adjacent beds of the Oriskany. As a matter of convenience the term "Oriskany ores" may well be retained, even though it is somewhat misleading.

Early in the field season of 1905 the writer commenced work on the ores of this district, studying their occurrence, character, and origin. After the completion of this general work, Mr. R. J. Holden, of the Virginia Geological Survey, was detailed to map certain of the more important ore deposits on a large scale, while Mr. J. S. Grasty took up general geologic mapping of several adjoining areas. Prof. H. D. Campbell, of Lexington, Va., kindly gave the use of his geologic maps of the district, and in addition exercised general supervision over the areal work of Mr. Grasty.

General geology of the district.—The rocks exposed in this district are of Devonian and Silurian age, the ores being associated with the uppermost Silurian and basal Devonian formations. The formations are as follows:

Geologic formations in Oriskany district.

	Thickness in feet.
Devonian black shales	1,000-2,000
Oriskany sandstone and siliceous limestone	50- 250
Lewistown ("Helderberg") limestone	300- 800
Rockwood (" Clinton") shale and sandstone	300- 600
Clinch ("Medina") quartzite	50- 150

The above generalized section will cover the variations in thickness shown in different parts of the district. It may profitably be compared with a carefully measured section shown at a point near the middle of the ore-bearing area.

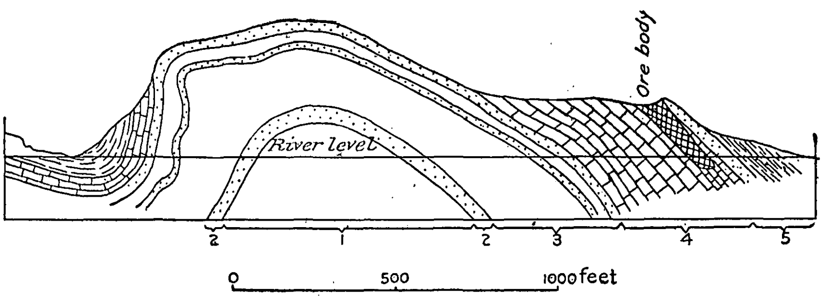

FIG. 8.—Generalized section at Iron Gate, Va.

The following section was measured in 1905 by E. O. Ulrich at Iron Gate, Va.:

Section at Iron Gate, Va.

			Thickness in feet.
Devonian black shales			(?)
Oriskany	a. Calcareous sandstone	50	209
	b. Siliceous limestone, with many beds of chert	54	
	c. Bluish-gray limestone, with sandy beds in upper part	65	
	d. Quartzitic sandstone, with two shaly beds	40	
Lewistown ("Helderberg")	Thin-bedded shaly limestone shales		322
Rockwood ("Clinton")	a. Heavy sandstone	42	452
	b. Alternating sandstone and shale	125	
	c. Sandstones and shales, overlying a red and white mottled shale; with a heavy ferruginous sandstone ("block ore") near base	115	
	d. Shales, with fossil ore bed near top	170	
Clinch ("Medina")	Hard, massive white sandstone		50

Structure of the district.—In the Oriskany district the rocks above described have been thrown into a series of parallel folds, trending about N. 35° E. These folds are not symmetrical, for they show low dips (5° to 25°) toward the southwest, while the northeastward dips are steep—from 60° to vertical, and sometimes even overturned slightly. After this folding erosion removed the less resistant beds from the more exposed portions, so that now the crests of the ridges are made up of the hard "Clinton" and "Medina" quartzites and sandstones, while the "Helderberg" and Oriskany beds outcrop on the slopes and in the valleys are covered by the Devonian shale. These structural conditions, as will be seen later, exercised a very marked influence on the localization of the ore bodies.

Occurrence of the ores.—The iron ores of this district are brown ores, occurring in bed-shaped deposits, continuous in length on the outcrop for considerable distances.

The ore bodies usually outcrop on the southeast flanks of the ridges, from 200 to 400 feet above the valley bottoms. Near the outcrop they are overlain either by sandstones of Oriskany age or else directly by the Devonian black shale. They are immediately underlain in most cases by a bed of cherty clay, which in turn rests upon "Clinton" sandstone or shale. As the ore bodies are followed deeper it is found that they thin somewhat and that limestone appears in one or both walls of the deeper workings. It is to be expected that finally the ores will entirely disappear in depth, their place being taken by continuous beds of limestone.

When for any reason the Lewistown ("Helderberg") limestones appear in several parallel outcrops, the ore bodies are likely to be similarly duplicated.

At the lower or southwest end of the Dolly Ann property northeast of Covington, for example, the ore beds are seen to occur in three parallel synclinal basins, thus giving six distinct lines of outcrop of the ore. Farther northeast only the easternmost of these basins persists, the other two dying out owing to cross folding. Similarly, to the southwest the easterly basin is cut off by limestone near Jackson River, but occurs again south of the river, while the two westerly basins are cut off some distance north of the river and do not reappear. The ore in this area varies from 3 to 32 feet in thickness, probably averaging about 12 feet over the entire property. It lies on a foot wall of loose chert or cherty clay, which is usually about 1 foot thick, but in places 5 to 6 feet. In most of the openings the ore is capped by 10 to 20 feet of yellow sandstone, which is in turn overlain by the black Devonian shale.

Opposite the company store the remains of the old Dolly Ann furnace stand on an ore bank which shows the following section:

Section at ore bank near Covington, Va.

	Feet.
Pebbles, gravels, etc	6
Bluish to black shale	4
Yellow-brown crumbling sandstone	18
Brown ore	10 +

Origin of the ores.—The Oriskany ores have been usually described as being original deposits or as having originated through the weathering and hydration of carbonates which were deposited with the limestones and sandstones that now inclose the brown ores.

In the final report on these ores the question of origin will be taken up in some detail and the reasons for the writer's conclusions will be stated more fully. Here it is possible only to state the main results briefly.

The workable ores are undoubtedly of much later origin than the rocks which now inclose them; and the ore deposits occupy spaces formerly filled by Lewistown and Oriskany limestones and sandstones.

There seems to be little reason to believe that much of the ore has originated by the replacement of limestone by iron carbonates and the subsequent hydration of this carbonate. It is true that iron carbonate has been found at several points in the deeper portions of the Longdale mines and it may be found in other mines of the district. But in general it seems certain that the ore was deposited directly as brown hematite. The deposition was in part simply a filling of cavities in the limestone, but most of the deposition probably followed the solution of the limestone so closely as to amount practically to a replacement process.

Character of the ores.—The ores usually range from 32 to 36 per cent of metallic iron and are commonly very high in silica.

An analysis of the Dolly Ann ore, by H. L. Morris, follows. It is typical of the material shipped to Lowmoor furnace, and is fairly representative of the Oriskany ores in general.

Analysis of ore from Dolly Ann property, near Covington, Va.

Silica (SiO_2)	33.26
Alumina (Al_2O_3)	5.26
Iron oxide (Fe_2O_3)	52.86
Manganese oxide (MnO)	.61
Lime (CaO)	.28
Sulphur (S)	.014
Phosphorus anhydride (P_2O_5)	1.312
Carbon dioxide (CO_2)	.21
Water (H_2O)	1.90

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THE CLINTON, RED, OR FOSSIL ORES.

The Clinton ores of Virginia are not particularly well developed, as regards either quality or thickness, and so far have attracted little attention. But the gradual exhaustion of the supply of good brown ores is operating to create interest in the Clinton ores at present.

The Clinton ores have recently been opened by the Lowmoor Iron Company along the southeastern face of Horse Mountain, about 3 miles southwest of Lowmoor station. The ores here outcrop near the crest of the ridge and dip about 10° into it. When visited by the writer in June, 1905, several slopes had been run in, the workings having progressed for 100 to 130 feet in each slope. Sections of the ore and associated rocks were carefully measured at the entries of two of these slopes, with the following results:

Section on slope 1, near Lowmoor, Va.

	Ft.	In.
White quartzite	35	
Shale		2
Sandstone		3
Shale		½
Sandstone		3
Shales and thin sandstone		10
Fossil ore, brown and porous		7
Fossil ore, red and fairly hard		14
Ochery clay		6
Shales	2	

The brownish fossil ore in this section was said to average about 40 per cent and the red ore about 56 per cent without washing. Another slope gave the following section:

Section on slope 2, near Lowmoor, Va.

	Ft.	In.
White quartzite	30	
Shales		2
Red fossil ore	1	4
Ochery shales and thin sandstones	1	
Shales and sandstones	2	

The ore is hand picked at the mines to clear it of slate, and then run down an incline to the cars below. An analysis of the red ore from these mines, by H. L. Morris, chemist of the Lowmoor Iron Company, is as follows:

Analysis of red ore from mines near Lowmoor, Va.

Metallic iron (Fe)	57.00
Manganese (Mn)	.15
Silica (SiO_2)	7.12
Aluminum (Al_2O_3)	6.31
Lime (CaO)	1.46
Magnesia (MgO)	.08
Phosphorus anhydride (P_2O_5)	1.54
Carbon dioxide (CO_2)	1.23
Water (H_2O)	1.18

From this analysis it can be seen that the ore so far handled is a thoroughly leached ore—a "soft ore," to use the Alabama term. Its lime carbonate has been almost entirely removed and in consequence its iron percentage is relatively high. Farther under cover the ore will become hard and probably fall to 35 per cent or less of metallic iron.

The Clinton ore has been mined in the river gap at Iron Gate, but the beds are very thin and irregular and the unleached ("hard") ore is of very low grade. The following analyses have been furnished by the Longdale Iron Company:

Analyses of Clinton ore from Iron Gate, Va.

Metallic iron	46.5	46.0
Insoluble	19.90	20.24
Phosphorus	.49	.48

The beds examined here are rarely over 8 to 12 inches thick, and as practically all the soft or leached ore has been used, the deposits can hardly be regarded as of commercial value.

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THE BROWN ORES OF THE NEW RIVER-CRIPPLE CREEK DISTRICT, VIRGINIA.[a]

By R. J. HOLDEN.

Location.—The New River-Cripple Creek area includes most of the limonites of the valley region. The area in which ores are now mined lies chiefly in the southwestern part of Pulaski County and the southern part of Wythe County. It is a narrow strip of territory about 3 miles wide and 55 miles long and lies on the southeastern side of the Great Valley near the foot of the mountains.

Geology.—The rocks with which most of these ores are associated are of Cambrian and Ordovician age. The chief rock is the Cambro-Ordovician limestone, which is here dolomitic through many of its phases and which contains considerable interbedded red shales. While in a major way this formation conforms to the structure described later, in a minor way it is complexly folded and somewhat faulted, so that its thickness is difficult to determine. Its southeastern border is only a few hundred feet thick, while toward the center of the valley it attains a great thickness. This formation furnishes the chief surface rock of the valley, which is here from 6 to 12 miles wide. Underlying the limestone is a Cambrian quartzite and under this in turn a shale. These latter formations are probably to be correlated, respectively, with the Erwin quartzite and the Hampton shale of the Cranberry folio. They form the main portion of the mountains to the southeast and appear in the valley in a few places as anticlinal ridges.

Structure.—Structurally the region is characterized by thrust faults, with the fault planes dipping to the southeast. These faults are apparently not very closely spaced, yet are sufficiently so to give to the strata their prevailing southeastward dip. The most conspicuous faults are those at the margins of the valley. On the southeast side the quartzite is locally faulted over onto the limestone. On the northwest side the limestone is thrust over onto the Devonian and Lower Carboniferous sediments. While faulting has been the dominant type of deformation, folding has not been unimportant. The Cambrian shows a number of anticlines. The mountain to the southeast is in the main anticlinal, as is also Lick Mountain, a valley ridge. There are a number of anticlinal ridges which extend into the valley as spurs of the main mountain. However, these anticlines show a tendency toward faulting on their northern sides.

Relief.—The region in which the ore territory lies is one of considerable relief. The crests of the ridges are from 500 to 1,500 feet above the valley floor and New River and its branches have cut down 200 to 300 feet below the general level of the valley. The topography is controlled by the rock structure, the southeastward dips having produced northeast-southwest ridges and valleys. The exception to this is the modifying influence of New River, which is an antecedent stream, cutting directly across the trend of the mountains. In the valley, while the streams have cut down several hundred feet, erosion has cut back from the stream courses in the softer strata, making the valley surface a series of oval domes.

[a] This report is the result of cooperative work carried on in 1905 by the Virginia and United States Geological Surveys, and is here presented by permission of Mr. T. F. Watson, State geologist of Virginia. The relations of this particular area and report to the general problem are discussed on pp. 183-184 E. C. E.

Occurrence and character of the ores.—The residue from the decay of the limestone shows considerable variation in depth. In places it is so thin that the limestone is exposed every few feet, while in other places mining has shown it to have a depth of 80 feet. Where the residue is protected by overlying strata from the weight of other material, it can frequently be traced, stratum for stratum, into the limestone. It is perfectly certain that this material has its origin in the limestone. Solution of the limestone takes place very irregularly, and in consequence the surface of the unaltered rock is very uneven. Commonly these irregularities take the form of pinnacles or domes, varying from those which are small and closely spaced to larger ones 20 feet in diameter and 50 feet in height. The residue lies between these limestone "horses" and forms a cover over them from 5 to 20 feet thick.

In this iron-ore region the residue contains a large percentage of iron oxide. Most of this is in the form of fine particles, which give to the residue its deep-red color. Where the iron oxide takes the form of granules of such size that they will not pass a screen which has 12 meshes to the inch and the particles are present in an appreciable quantity, it becomes an iron ore. The individual pieces of ore may vary from the minimum size up to lumps several feet in diameter. Much of the ore consists of angular fragments which have been broken and moved from the position in which they were deposited from solution. A smaller portion of the pieces of ore have the form and position which they assumed when they were precipitated. The form of the pieces varies with the environment in which the precipitation occurred. The clay derived from the limestone is relatively pervious. Ores deposited in this material assume irregular shapes and, where the aggregates are of sufficient size, are generally cellular; frequently inclosing clay in the cavities. In a few instances the ore has been precipitated on the surface of the limestone itself. In such cases the ore laminæ are one-half inch or less in thickness and sometimes form closed spaces, including rectangular blocks of limestone an inch or so on a side. The residue from shale is relatively impervious. Iron oxide precipitated in or above this material, instead of having cavernous or honeycomb structure, is apt to occur in sheets of compact material 2 inches or less in thickness or in irregular, compact masses of greater size. Not only do these ores have a different physical appearance, but the impurities which they hold give them a somewhat different chemical composition. The ores occurring in the limestone residue are locally known as "limonites;" the shale and sandstone ores as "mountain" ores. There are a few mines whose ores have characteristics intermediate between these two classes and such ores are known as "semilimonites." Analyses furnished by the companies[a] operating these ores show the following content:

Analyses of iron ores from New River-Cripple Creek district, Virginia.

	Limonites.[a]	Semi-limonites.[b]	Mountain ores.[c]
Metallic iron	43.76	40.72	37.86
Silica	13.52	20.12	18.60
Alumina	1.79	1.81	2.32
Phosphorus	.17	.31	.40
Manganese	.58	.83	1.49

[a] Average of 56 analyses from 12 mines.
[b] Average of 15 analyses from 5 mines.
[c] Average of 17 analyses from 4 mines.

The "limonites" are relatively high in iron and low in silica, phosphorus, and manganese. The three first named are fairly constant from mine to mine, while the manganese varies between 1 and 0.1 per cent. The alumina values are bases on few determinations. These values will vary according to the thoroughness with which these ores are washed. In the "mountain" ores there are lower values in the iron content, while the silica, phosphorus, and manganese are higher. The manganese here varies between wider limits than in the

[a] Virginia Iron, Coal and Coke Company; Pulaski Iron Company; New River Mineral Company.

"limonites." The "limonites" are throughout the more desirable ores. The ratio of the amount of ore to the total material of the bank varies widely. In some of the "mountain" ore mines the ore constitutes the larger portion of the material. In the "limonite" mines the ore content of the bank varies from 20 to 4 per cent. In other words, it is necessary to handle from 5 to 25 yards of bank to get 1 yard of ore. Samples taken by the writer from 20 mines show an average content of iron, computed to ferric oxide, of 44.59 per cent, with a variation between 63 and 23 per cent.[a] These samples were washed by hand and the fine material, which was removed in suspension, showed an average of 30 per cent ferric oxide.[a]

Origin of the ores.—It seems probable that these ores are concentrations of the iron which was originally disseminated in the Cambro-Ordovician limestone. It has been previously recognized[b] that the ores are associated with the lower measures of this limestone. In order to determine the possibility of the limestone being the source of the iron, it was sampled in the immediate vicinity of a producing mine, 190 samples being taken through a vertical thickness of 600 feet of the lower measures of the limestone. The average of the analyses[c] of these gave the following results for the more insoluble constituents of the rock: Silica, 1.74 per cent; metallic iron, 0.66 per cent; alumina, 0.50 per cent.

The following table shows a comparison between these analyses and that of the residue in the mine, including the ore. The percentages of the limestone analyses are reduced to the basis of 100.

Comparative analyses of limestone and residue from New River-Cripple Creek mines, Virginia.

	Insoluble matter in 600 feet of limestone.	Residue.
Ferric oxide	30	34
Silica	54	46
Alumina	16	....

The above comparison shows that, with the per cent of iron in the limestone as indicated by these analyses, a thickness of 600 feet of the limestone will contain a quantity of iron equal to that in the mine, the latter being estimated from the above analyses of the residue and from its thickness. As in this case several times 600 feet of limestone has been weathered, it is unnecessary to look farther for the source of the iron. Systematic sampling of the limestone has not been done over the region, but scattered analyses indicate similar conditions in regard to the iron content. In order to make a comparison with a region not iron-bearing samples were taken through about 300 feet of limestone at Staunton, Va. The analysis of this material shows that ferric oxide here constitutes 7 per cent of the insoluble portion of the limestone. This corresponds to the 30 per cent given for the Foster Falls region, which is iron bearing. The average content in ferric iron of twelve "limonite" mines is found to be 39 per cent. This is somewhat higher than at Foster Falls.

It is evident that there has been concentration of the iron in the residue by at least two methods. The first is essentially chemical. The body of the residue has a deep-red color, while the upper two feet are usually dark colored, but not red. This difference in color is believed to be due to the loss of iron by the upper portion. The reducing action of plant roots changed the ferric oxide to the ferrous condition and rendered it soluble. Percolating waters carried this down a few feet to a point where it was oxidized and precipitated. Erosion removed the leached portion until the ferric oxide was again within reach of the influence of vegetation. The process was repeated many times. Where iron was especially

[a] Analyses by J. H. Gibboney.
[b] McCreath, A. S., and d'Invilliers, E. V., The New River-Cripple Creek Mineral Region; a report to the president of the Norfolk and Western Railway, 1887.
[c] Analyses by J. H. Gibboney.

abundant or on steep slopes where erosion was particularly rapid, reduction and solution could not keep pace with the erosion and the red residue appeared at the surface. The process outlined above resulted in a concentration of the iron, which was removed from the sphere of surface erosion, while the other insoluble substances were exposed to it.

The other method of concentration in the residue was mainly mechanical. It is recognized by some of the leading mining men of the district that areas where limestone sinks are abundant are favorable for deep ore deposits. When the roof of a cavern in the limestone falls in the residue follows and a funnel-shaped depression is created. Into this the surface waters pour and remove in suspension the fine material and leave the lump ore. Abundant waterworn pebbles of a recrystallized quartzite occur normally at the surface of the residue. These are found at the bottom of the deepest mines. Apparently in some cases limestone sinks have been an important means of concentration of the ore.

If it is conceded that the "limonite" ores have their origin in the limestone, it is not necessary to go beyond this source for the origin of the ores which are now associated with the shales and sandstones. In this case all traces of the limestone except the ores have been removed and the ores let down upon the underlying rocks.

There are other ores in this region. On both margins of the limestone small deposits occur along the faults. The faults furnished a little better channel for water circulation, and the fault planes became the locus of a deposit, but these ores need not be distinguished in origin from the other ores with which they are associated.

At Radford Furnace, near the southeastern edge of this area, there is a deposit of limonite ore which, at one place at least, is associated with an iron carbonate. This ore may be the oxidized outcrop of a bedded carbonate. The mines have not been worked for some time, and the present limited showing prevents definite statements in regard to this point.

In Draper Mountain, on the northwestern border of this area, five mines are now in operation. This mountain is made up largely of Devonian and Lower Carboniferous sediments, chiefly sandstones and shales. Some of these ores are different in form, mode of occurrence, and chemical composition from the other ores. The Lower Carboniferous contains coal measures and considerable disseminated iron. This may be looked to as the source of the iron ore. The iron was carried in solution and deposited in favorable situations, which varied in their nature in the individual cases.

Near Abingdon are scattered deposits of ferruginous limestone, hematite, and magnetite which have been mined in a small way. The limestone as mined carried about 30 per cent of metallic iron. The deposits occur at the top of the Cambro-Ordovician limestone. Athens shales [a] lie in synclines of the limestone. The ores occur at the outcrop of the contact. Iron leached from the shale has been precipitated in the limestone as hematite and magnetite. At one place the limestone has been much brecciated, and here the iron has been irregularly deposited in the limestone both as ferrous and as ferric iron. The ferrous iron is clearly a replacement of the limestone.

Summary.—The iron ores of the valley region of southwestern Virginia, with one exception, are limonite. They occur in the residual clay and usually constitute about 7 per cent of this material.

Classified according to their probable origin, there are four classes of ores. Named in order of their importance they are as follows:

1. The limonite ores of the valley, associated with the limestone. Iron originally disseminated in the limestone.
2. The limonite ores of Draper Mountain. Iron leached from the Lower Carboniferous sediments.
3. The limonite ore at Radford Furnace. Oxidation in situ of carbonate of iron.
4. Hematite, magnetite, and ferruginous limestone near Abingdon. Iron leached from Athens shale.

Classes 1 and 2 are mined at present, and the average monthly production for the last half of 1905 was 20,000 tons [b] for the New River-Cripple Creek area.

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[a] Campbell, M. R., Geologic Atlas U. S., folio 59, U. S. Geol. Survey, 1899.
[b] This figure is based on records of ore shipments kindly furnished by the Norfolk and Western Railway.

IRON ORES OF THE WESTERN UNITED STATES AND BRITISH COLUMBIA.

By C. K. Leith.

INTRODUCTION.

An insignificant part of the iron-ore production of the United States has come from west of Mississippi River—in recent years about 2 per cent. Nevertheless, in that vast region there are many ore deposits known and doubtless more to be discovered. Present economic conditions demand that the nature, extent, and availability of the ores of this region should be generally known. The present writer has given attention primarily to the geological relations and origin of the ores as affording a basis of comparison with present producing districts of the United States rather than to estimates of tonnage and study of present commercial conditions, although some incidental attention has necessarily been paid to these matters. In the fall of 1903 the iron ores of Iron County, southern Utah, were examined and a brief report published in the Economic Bulletin for that year.[a] The work of the past two field seasons, including detailed mapping of the Utah deposits, is summarized below.

GENERAL RECONNAISSANCE.

HARTVILLE, WYOMING.

In 1904 the deposits at Sunrise, in the Hartville district of Wyoming, were looked over. The facts observed correspond with the description by W. S. Tangier Smith in the folio on this district.[b] The ores occur in the Whalen group of limestone, quartzite, and quartzose schist, extending along the west side of Whalen Canyon, south and west of Fredericks, to Sunrise and Hartville. Ore is mined at present only at Sunrise. Here an open pit, with terraces rising toward the north, exposes the ore and its associated rocks. The foot wall on the west consists of banded calcareous and siliceous schists and cherts. Smith describes these as schistose quartzites. The writer's examination, both in the field and with the microscope, disclosed no positive evidence of their sedimentary origin, though he has no reason to doubt that Smith's conclusion is correct. These grade up into the ore through phases which in the Lake Superior country would be called ferruginous cherts. The hanging wall is of much the same nature. The structure of both the foot and hanging walls, whether it be bedding or schistosity, dips steeply to the east. Immediately to the east of the deposit, near the power house, and also to the southwest, are limestones of the Whalen series. Resting unconformably upon the ores and associated rocks are Carboniferous limestones and sandstones, forming an amphitheater, opening to the southwest, about the ores and associated Whalen rocks. The lateral extent of the ore to the northwest is hidden by the capping of Carboniferous sandstones and limestones. Drilling is said to have shown the extension of the ore beneath these rocks to a considerable distance. Here it will have to be won by underground methods.

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[a] Bull. U. S. Geol. Survey No. 225, 1903, pp. 229-237.
[b] Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

The ores are soft and hard hematite somewhat similar to those of the Chandler mine, in the Vermilion district of Minnesota. There is present also a considerable amount of massive blue ore like that of the Soudan mine, in Minnesota. An abundance of botryoidal quartz, stringers of malachite and azurite, yellowish chert phases, and ferrous aluminum-silicate rocks appear as minor constituents of the ore. The iron content grades from 45 to 65 per cent. According to Mr. Ahbe, superintendent, there is some difficulty in close grading of the ores for shipment. The phosphorus is for the most part near the Bessemer limit. Some of it will run above 0.1 per cent.

Smith describes the ores as in the form of lenses in the Whalen beds. Several phases of the ore and rock possess striking similarity to altered carbonates in exhibiting irregular and spotted areas of limonite. These facts, together with the nature of the foot wall and hanging wall observed at the mine, and the presence of ferruginous cherts, suggest that the ore has developed by either the replacement or alteration of lenses of a carbonate formation within the Whalen beds. In this connection Smith says that the limestone of the belt to the southwest contains a considerable amount of ferrous iron. Detailed studies should be made of the relations of the ore to the limestones and so-called schistose quartzites and the true nature and structure of the series determined. For purposes of folio mapping Smith was obliged to treat the Whalen beds as essentially a structural unit, though its petrographic phases were described and their approximate distribution outlined.

This deposit is the only one the writer has seen in the West which suggests possible similarity in lithology, origin, and relations of adjacent rocks to certain of the Lake Superior ores.

WASHINGTON.

Visits were made in 1904 to ore deposits in Stevens County, northeastern Washington. Southeast of Northport, near Deep Creek Lake, both northeast and southwest of the lake, yellow porous limonite occurs associated with limestone, resting on the flank of the mountains. The ore is exposed in a considerable number of pits and drifts. On the way to the area the cores of the mountains were observed to be granite flanked by limestone. No igneous rock was observed near the ore, but presumably, from the general structure of the region and analogy with other districts, it occurs not far away.

About 14 miles west of Valley is a shaft 75 feet deep from which have been thrown out fine dense hematite, coarse amphibolitic martite ore, and gradations between the two; also green schistose rocks whose relations to the ore were not determined. To the east sericitic slates may be seen dipping under the shaft and to the west are limestones, presumably forming the hanging wall.

To the southwest, on the Rogers's claim, several drifts were observed penetrating limestone with a small amount of hematite near the surface, suggesting a surface replacement of the limestone. Higher up the hill ferruginous slate and magnetitic slate, locally called jasper and indeed somewhat resembling jasper, are exposed. The relations to the limestone are unknown. Diorite was observed along the road in such relations as to indicate its lower stratigraphic position. From what the writer observed and from discussion with local prospectors, there is apparently in this region more or less ferruginous alteration of the limestone near its base, where it rests on slate. The occurrence of diorite intrusives in the vicinity suggests a possible genetic relation.

About 6 miles east of Valley limonite occurs between andesite forming the core of the large hill and limestone resting upon its flank. The ore is in general soft, hydrated hematite and limonite of red and brown colors, and very porous. Locally the ore seems to dip toward and under the andesite, which is spoken of as the hanging wall. There is evidence here also of some brecciation, faulting, and folding, some of it later than the formation of the ore. Near the contact with the ore both the andesite and the limestone are much altered and are represented by clay showing the texture and structure of the original rock. Stringers of the ore run both into the limestone and into the andesite. For the most part the contacts are very sharp. The extent and shape of the deposit has not been determined. A thickness of 20 feet was observed in one place and less in others.

VANCOUVER AND TEXADA ISLANDS, BRITISH COLUMBIA.

The best-known sources of iron ore for the northwestern United States are Texada Island and the west side of Vancouver Island, British Columbia, especially near Barclay Sound. The furnace at Port Townsend, Wash., has drawn its ore from the first of these localities and in plans for the use of this ore American capital has largely figured. Each of these localities was visited in 1904.

Without going into detailed descriptions, it may be reported that these ores are largely magnetite, carrying usually considerable amounts of iron and copper sulphides, apatite, amphibole, and garnet. At the surface is an oxidized zone, usually a few inches thick, of limonite and white sulphate. The metallic-iron content averages from 35 to 60 per cent and above in different deposits, the Texada ores and a part of those on Barclay Sound having the higher percentages. The sulphur content is for the most part high, requiring that the ores be roasted. The copper content is also high, particularly in the Texada ores (2 per cent). The phosphorus in the higher grade ores is mainly below the Bessemer limit.

The ores occur at or near the contact of acid igneous rocks with limestone and are obviously replacements of limestone. In some instances the ore may be seen entirely surrounded by igneous rock, evidently a replacement of limestone intruded by and caught up in igneous rock near the contact. The contacts of the igneous rock with the ore are characteristically sharp and present no gradation features that would accord with the view that the ore represents segregations from igneous rocks. The abundant occurrence of lime garnet, however, both in the ore and in the crystalline limestone adjacent to the igneous contact, suggests the concentration of the deposit under the influence of igneous intrusion. The shape, size, and vertical extent of the deposits have for the most part not been determined, but it is obvious that a large tonnage of iron ore is here to be obtained. In the Barclay Sound area several pits and tunnels have penetrated ore from a few feet to a maximum of 110 feet horizontally and approximately the same amount vertically. In Texada Island belts have a maximum thickness of about 100 feet and in one place a belt has been cut by a tunnel 300 feet below the surface. Here the ore is as wide and apparently of as good a grade as at the surface.

COLORADO.

In company with C. R. Van Hise a reconnaissance was made in 1905 of the iron ores south of Ashcroft, in Pitkin and Gunnison counties, near White Pine, Gunnison County; and in the Cebolla district, also in Gunnison County.

About 6 miles south of Ashcroft iron ores appear on both sides of the Elk Mountains divide, near its junction with the Saguache Range, in Pitkin and Gunnison counties. At "Cooper's," on the northwest side of the divide, at an elevation of between 11,000 and 12,000 feet, the iron lies on the steep face of the ridge. It is apparently underlain and overlain by limestone, and stringers of it may be seen extending into the limestone. The dip of the iron belt seems to be down the slope. Eight tunnels have been driven into the iron, the longest one 122 feet and the shortest 40 feet in iron. The vertical distance between the highest and lowest tunnels is between 75 and 100 feet. The greatest distance between the tunnels along the slope is 300 feet. The iron may be seen to extend along the slope for about 500 feet. These figures are not exact. Specimens taken at random showed a metallic-iron content varying from 30 to 64 per cent, phosphorus 0.007 to 0.069 per cent, and sulphur 0.077 to 0.970 per cent. The bulk of the ore is high in iron and sulphur and low in phosphorus. The iron at the surface is magnetite, with cavities filled with secondary limonite and quartz. Back in the tunnels the ore becomes harder and contains unaltered sulphides, garnet, epidote, and feldspar, suggesting original concentration under the influence of igneous rocks, which appear on the adjacent ridges.

On the southeast side of the divide the iron ores, supposedly continuous with those of the northwest side, extend in a belt along the east side of Taylors Peak and reappear on Crystal Peak and Mount Tilton. They were examined at Taylors Peak, the principal occurrence, where they lie both parallel and transverse, mainly the former, to the bedding of Carboniferous and Silurian limestones and shales dipping westward into the mountain. These rocks are underlain by a thin layer of Cambrian quartzite and this in turn by the "Sawatch" granite, which appears on the lower parts of the steep erosion slopes of the mountain. The overlying rocks are fine-grained diorites of recent age. The ore probably occurs in more than one layer, but how many the explorations do not show. At Taylors Peak a vertical pit 40 feet deep has been sunk in the ore. The dip of the ore while probably westward, was not determined at the pit, so that the thickness of the belt can not be estimated. The ore is here mainly a magnetite containing iron sulphide and chlorite. At the surface it is oxidized to limonite, which appears abundantly on the lower slopes. A single specimen collected here to show the nature of the ore carries 48.36 per cent of iron, 0.007 per cent phosphorus, and 5.88 per cent sulphur, but the average of the hole is said to show better-grade ore. A tunnel is now being driven into the underlying blue limestone in search for silver and lead.

Like the ore on the northwest side of the divide, the concentration of this ore under the influence of igneous rocks is apparent. It is said to be continuous with the ore on the northwest side; indeed, ore can be seen extending to the divide on each side. This would give the belt an approximate length of a mile, with a maximum width of 122 feet, as shown in one of the tunnels on the northwest side of the divide, but with an average width probably much less. The depth is unknown.

A visit was made to the iron-ore deposit about three-fourths of a mile northeast of the village of White Pine, Gunnison County. It occurs on the east slope of the valley, on a spur of the Saguache Mountains. The ridge has a granite core and carries on its slope Cambro-Silurian quartzite and limestone, dipping westward down the slope. The ore is at the contact of the limestone and quartzite, apparently replacing both. The dip of the ore seems to be parallel to the slope, although locally it dips into the hill, perhaps as a result of creep. Six tunnels crossing the ore were examined. One tunnel showed two seams 14 and 75 feet in width. The ore was not followed along the strike for any great distance, but it is said to extend to Marshall Pass, several miles away. The ore is crystalline magnetite and hematite containing epidote, garnet, and some iron sulphide, but not in large amount. At the surface it is altered to limonite, hematite, and clay. In some of it fragmental quartz grains may be seen. A sample analyzed by Chauvenet averaged 58.75 per cent in iron and 0.04 per cent in phosphorus. An average analysis of ten samples published by Birkinbine gives 59.32 per cent in iron, 0.036 per cent in phosphorus, and 7.9 per cent in silica.

Iron ores were examined along the north side of Cebolla Creek, about 15 miles south of Iola station, on the Denver and Rio Grande Railroad. Here there is an amphitheater of granite opening out to the southeast diagonally across the creek, partly inclosing quartzite and above this limestone, iron carbonate, and iron ore. On the northwest trachyte flows cap both the granite and the sedimentary rocks. The limestone, iron carbonate, and iron ores appear principally in three small east-west hills arranged en échelon north of the creek. The limestone may be seen to grade up into iron carbonate or ferriferous limestone or dolomite, which constitutes most of the central hill, the west end of the western hill, and an unknown part of the eastern hill. This iron carbonate varies from fine to coarse grained and is intimately interbanded with magnetite and hematite, suggesting contemporaneous origin. Whether the iron carbonate and its associated iron oxide consists of an original sedimentary formation conformable with the limestone below or is a result of subsequent alteration aided by igneous agencies was not determined. In favor of the former is its fine grain in places and apparent conformability with the limestone. In favor of the latter is its local coarsely crystallized character and the occurrence of this coarser carbonate in distinct veins. At the surface the carbonate is altered to limonite and clay, with the development and introduction of chlorite, chalcedony, and manganese oxide. One specimen here taken runs 45.92 per cent in manganese. This alteration is confined principally to the localities adjacent to the overlying trachyte capping, especially near the east ends of the western and central hills. Solution cavities here are almost certain evidence that waters heated by the trachyte, similar to those now coming from it on the south side of the gulch and in one spring depositing limonite, were the agents of the alteration.

The limonite and other alteration products of the iron carbonate, together with the residual magnetite and hematite which were originally associated with it, constitute the ores of this area. The principal showing of ore is on the east end of the western hill. Here several drifts have been run into the hill. The ore may be seen to extend along the hill for 500 or more feet, and into the hill horizontally for 50 feet. The ore consists of nodules and irregular masses of limonite, magnetite, and hematite lying in an iron-stained matrix of clay and carrying abundant secondary chlorite or talc. It is much broken and contorted. Beneath the surface the harder nodules disappear and the ore is principally soft limonite or hematite, with clay and some magnetite. The best of the ore is said to run 55 or 60 per cent metallic iron, but the average published by Birkinbine is 35 per cent. Several published analyses show phosphorus below the Bessemer limit, but much of the ore is said to run higher. Sulphur is low in both the main body of the ore and the oxidized portion.

On the central iron-carbonate hill several tunnels have been driven into the hill to a distance of 100 or more feet. The oxidation of the iron carbonate may be seen to extend but a few feet into the hill.

In two localities titaniferous magnetite was observed. One is to the northeast of the central hill, between this hill and the trachyte, where it is shown in a pit associated with an altered greenish rock now represented only by large mica plates and some feldspar in a clayey matrix. The other locality is across the creek from the springs just east of the bridge, where there is a belt fully 50 feet wide apparently running up the slope for 100 feet or more. This has been opened at one place. One specimen taken here showed 42.71 per cent iron, 0.002 per cent phosphorus, 0.009 per cent sulphur, and 4.15 per cent titanic acid. No associated rocks are visible, but the magnetite contains narrow bands of greenish amphibole, partly altered to asbestos. It may be that the associated rock is the basic granite to be seen in the creek bottom beneath the bridge.

CALIFORNIA.

A visit was made to the Cave Canyon iron area, about one-fourth of a mile north of Scott station, on the San Pedro Railroad (Cave Canyon mines). It lies on the south side of the hills, between a complex of acid and intermediate rocks on the north and coarsely crystalline marble on the south, dipping southward at about 30°. The iron is mainly along the contact, but apparently projects into the igneous complex below and into the marble above. Little patches of marble were seen in what was taken to be iron ore. The exposure is much broken and covered by desert varnish, with the result that the surface distribution is not at once obvious. While the iron-ore débris covers the slope, in several places the igneous rocks appear through it. The ore occurs in two belts, one along the trend of the other, but separated by an erosion valley. The western belt is about 2,000 feet long and the eastern 1,700 feet long. The width of outcrop reaches a maximum of 450 feet. Its average width for the western belt may be 300 feet and for the eastern belt 100 feet. The true thickness of the ore body, assuming that it follows approximately the contact of the limestone, is probably less than half the width of outcrop because of the southward dip of the formation and the fact that the erosion slope follows the dip. Four tunnels are reported on the property. Two were seen in ore, the longer one 30 feet in length. The ore is mainly red hematite and limonite, soft and broken, showing limestone bedding. In one of the western tunnels green iron silicates were observed in the ore. The ore was not sampled. Commercial analyses from two sources show a percentage of iron above 60 per cent and phosphorus within the Bessemer limit.

DETAILED MAPPING IN UTAH.

During the summer of 1905 detailed mapping of the iron ores of Iron County, Utah, was begun by C. K. Leith, with the assistance of E. C. Harder and F. J. Katz, who continued the work independently during the fall. The iron ores, extending in narrow and discontinuous belts for a distance of about 18 miles northeast and southwest, were mapped with plane table on the scale of 250 feet to the inch, all pits and exposures (numbering 700 to 800) being shown. The total area so mapped was 5½ square miles. Pits and tunnels were measured and an attempt made to estimate tonnage. On the completion of the topographic base, the geology of a somewhat wider area will be mapped during the present winter and the report and maps will be submitted at an early date thereafter.

The ores appear on the erosion surface at or near the contact of intrusive andesite laccolites with limestone and sandstone and in one instance conglomerate; also in veins in the andesite itself. The ore is clearly a replacement of the limestone or an infiltration in veins in the other rocks. Evidences of two and perhaps three periods of concentration were observed. Under the influence of intrusion of the andesite laccolites iron carbonate, iron sulphide, and magnetite developed locally along contacts. During the subsequent erosion there seems to have been a further concentration, consisting in alteration of the carbonate and sulphide to hydrated oxide and perhaps further replacement of limestone by the hydrated oxide. These two concentrations have not yet been certainly separated and there is a possibility that they are really but one. The last and most conspicuous concentration occurred under the influence of later lavas which were poured out upon the eroded edges of the series, resulting in the coarse recrystalization of the ores, the development of magnetite and siderite, and the deposition of apatite and quartz, leaving the ores substantially as we now find them, though in the subsequent weathering they had been broken down and covered with desert varnish.

The ore at the surface is thus, because of the last concentration, predominantly magnetite and hematite containing chalcedonic quartz and a considerable amount of apatite in crystals sometimes reaching a length of 2 or 3 inches. Beneath the surface the ore becomes a soft blue and red hematite with subordinate quantities of magnetite. The average percentage of iron varies widely from 45 to 66. A large tonnage will average above 50 per cent. The phosphorus, for the most part, averages above 0.1 per cent.

The depth to which the ores extend along the inclined (30°) contact of the andesite and limestone is not yet known. Pits have shown it to extend for 150 feet in depth. Along the strike the ores pinch out in lens fashion. The longest lens in the district reaches 2,000 feet.

The relations of the ores to the adjacent rocks are complicated by faulting of block type, characteristic of the basin region. The main directions of the fault planes are a little west of north and north of east. The planes are vertical. The district lies about 15 miles west of the great Hurricane fault, marking off the high plateau region from the basin region to the west, where the displacement is down on the west side.

CONCLUSION.

The ores of the Hartville district of Wyoming seem to have certain features in common with Lake Superior ores, but much work remains to be done on them before their origin can be definitely stated. With this exception the iron ores of the western United States seen by the writer and other deposits of which he has seen reports occur along or near the contact of limestones with intrusive igneous masses, both acid and basic, often laccolitic in form, and are frequently associated also with surface eruptives. The ores are clearly replacements of limestone and to a minor extent vein fillings in the limestone or igneous rock. Their association with igneous rocks and frequent content of metamorphic minerals point clearly to their development and concentration under the influence of igneous rocks and in some cases to more than one concentration. The precise nature of the influence of the igneous rocks can not now be stated. They may have contributed hot waters bearing the iron ore; they may have contributed hot waters which have leached the ore from the intruded limestones; they may have contributed only heat necessary to make meteoric waters highly effective in concentration; or probably there was some combination of these factors.

The ores are predominantly magnetic, particularly in their upper portions. Locally, as in Utah, they grade down into hematite. The magnetite sometimes shows a thin surface alteration to limonite. In places the ore is largely limonite. The iron content locally runs up to 65 or 66 per cent, but the average is lower. A considerable proportion of the ores may average above 50 per cent. The phosphorus content is variable but usually high. The phosphorus often occurs in apatite in large crystals, making it possible to effect a rude separation of high phosphorus ores by hand sorting. A considerable proportion of the ores contain iron or copper sulphides or both to such an extent as to require roasting, though to this there are important exceptions.

The exposures are such that the horizontal dimensions of the ores may be ascertained. The vertical extent down the usually inclined contact surfaces has for the most part not been determined. Depths of more than 300 feet are known, and the geological structure makes greater depths probable. Neither is it known how rapidly the deposits narrow below. Until these facts are known, satisfactory estimates of tonnage can not be made. While no single western district has yet been shown to be comparable both in quantity and quality of ores with any one of the Lake Superior districts, it is still certain, from the facts now known, that the West will in the aggregate furnish a large supply of iron ore and that the expenditure of money for exploration and exploitation is warranted. This does not mean that all of the western iron ores may become immediately available, for the grade and quality of the ores, together with their distance from consuming centers, may make it necessary to hold them for many years.

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