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The Mayari Iron-Ore Deposits, Cuba

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(New York Meeting, February, 1915)

Introduction

THE *Bulletin* of the Institute for March, 1911, is chiefly devoted to papers upon the iron ores of northeastern Cuba. At that time information about the new developments in the peculiar brown hematites of the region was becoming widely circulated and interest was especially keen. For some years exploration had been conducted with pits and trenches and so great an area had been shown to contain ore in the Mayari, Moa, and Cubitas or San Felipe districts, that the reserves conveniently situated for the consumption of American furnaces were estimated as quite two billions of tons. In the subjoined footnote will be found a list of the principal papers of special interest which have already been published.¹ The further remark may, however, be made that the

¹ C. W. Hayes, T. W. Vaughan, and A. C. Spencer: Report on a Geological Reconnaissance of Cuba, under the Direction of Gen. Leonard Wood, Military Governor. The work in the Mayari, Moa, and Cubitas areas seems to have been chiefly done by Mr. Spencer, pp. 28, 83, 84 (1901).

Anon: The Mayari Iron-Ore District of Cuba. *The Iron Age*, vol. lxxx, pp. 421 to 426 (Aug. 15, 1907).

Anon: Iron Mining in Cuba. *The Iron Age*, vol. lxxxi, pp. 1149 to 1157 (Apr. 9, 1908).

A. C. Spencer: Three Deposits of Iron-Ore in Cuba. *Bulletin No. 340, U. S. Geological Survey*, pp. 318 to 329 (1908).

C. M. Weld: The Residual Brown Iron-Ores of Cuba. *Trans.*, xl, 299 to 312 (1909).

J. S. Cox, Jr.: Iron-Ores of the Moa District, Oriente Province, Island of Cuba. *Trans.*, xlii, 79 to 90 (1911).

W. L. Cumings and B. L. Miller: Characteristics and Origin of the Brown Iron-Ores of Camaguey and Moa, Cuba. *Trans.*, xlii, 116 to 137 (1911).

C. W. Hayes: The Mayari and Moa Iron-Ore Deposits of Cuba. *Trans.*, xlii, 109 to 115 (1911).

C. K. Leith and W. J. Mead: Origin of the Iron-Ores of Central and Northeastern Cuba. *Trans.*, xlii, 90 to 102 (1911).

J. E. Little: The Mayari Iron-Mines, Oriente Province, Island of Cuba, as Developed by the Spanish-American Iron Co. *Trans.*, xlii, 152 to 169 (1911).

A. C. Spencer: Occurrence, Origin and Characters of the Surficial Iron-Ores of Camaguey and Oriente Provinces, Cuba. *Trans.*, xlii, 103 to 109 (1911).

D. E. Woodbridge: Exploration of Cuban Iron-Ore Deposits. *Trans.*, xlii, 138 to 152 (1911).

nature of the ore has been the subject of an interesting litigation, because under the peculiar property rights inherited by the Cuban government from the previous Spanish authorities, a distinction is made between pigments and iron ores. The necessity therefore arose for deciding that these deposits were iron ore rather than raw materials for paint. The decisions of the Cuban courts have now interpreted them to be actually iron ores. The testimony of a number of geologists, specially qualified to speak authoritatively on this question, was sought for the judicial hearings and thus some of the earlier special studies, as printed in the *Bulletin* and *Transactions*, were made.

In summary, the published descriptions already impart to all readers the location of one great district near the town of Mayari, southeast of Nipe Bay, in northeastern Cuba; of a second, 40 miles and more farther east, called the Moa district; and of a third, about 160 miles to the northwest of Mayari, called the Cubitas in the papers of Cox and Spencer, but the San Felipe by Cumings and Miller. Still other areas of the red ferruginous soil are apparent in portions of western Cuba, but in most, if not in all, cases, they are so far from the sea, or so valuable for agriculture, as not to have attracted attention as a source of iron. Goodly percentages of iron are of course primarily necessary, coupled with absence of objectionable components, and so situated as to give transportation to American smelting centers at low freights. The chief interest at present is therefore attached to the Mayari district, as it is the only one as yet in active operation. In the Mayari district the ore is 15 miles from salt water, but when reached it forms a continuous area. In the Moa district, the ore-bearing ground even runs down to the sea-coast in places, but as a whole it is more dissected by erosion, so that the productive area is cut up into separate blocks. The San Felipe (or Cubitas) is farther from a deep harbor than either of the others. In all the three districts the ore mantles the tops of relatively elevated areas. In the Mayari it covers a plateau ranging about 1,800 ft. above tide. In the Moa district the ore near the coast is on the tops of hills of moderate altitude but rises to the south. In the San Felipe it covers a plateau at 450 to 500 ft. above the sea.

History

Crusts and concretionary masses of brown iron ore were early noted in northeastern Cuba. J. S. Cox, Jr., writing in 1911 (see citation, p. 79), states that claims were located upon them in the Moa district more than 20 years earlier. A. C. Spencer remarked them in 1901 as appearing in red clay, but no one seems to have realized until three or four years later that the entire mass was high enough in iron to be an ore. Under J. S. Cox, Jr., explorations were begun in the Mayari district in 1904 upon the crusts or "plancha," and then analyses revealed the fact that

not only the upper, dull-red portion of the-so-called clay was valuable, but also the lower yellow parts as well. The construction of the Mayari plant of the Spanish-American Iron Co. was begun in 1907 and was completed in December, 1909. Shipments have been active ever since. The plant and mines were well described with maps and views by J. E. Little in 1911, as cited above. The chief changes since then have been the greater extent of the pits on the plateau at Woodfred, and the improvements in the village of Felton, the shipping port on Nipe Bay. The ore is principally treated at Sparrows Point, Md., and Steelton, Pa. It is shipped both in the crude state and as so-called "nodulized ore," or the product of kilns similar to modern cement kilns, in which the water, both absorbed and combined, is driven off and the fine ore is half fused or fretted into nodules. Mushiness in the stack is thereby prevented and the rather heavy percentage of water (25 per cent. absorbed and 14 per cent. combined) is driven off, to the diminution of freight charges. There or four per cent. of water is again absorbed in the cooling vats into which the kilns discharge. Analyses of the raw ore are customarily made on samples dried at or above 100°C . They have averaged by the year: Fe, 48 to 49; Ni, 1; SiO_2 , about 3; Cr, 1 to 2; Al_2O_3 , 11 to 11.5; combined H_2O , 13 to 13.5. The nodulized ore runs: Fe, 55 to 56; Ni, 1 to 1.2; SiO_2 , 4 to 4.4; Cr_2O_3 , slightly more than the raw ore; Al_2O_3 , 13 to 14; absorbed water, 3 to 3.5. In both, sulphur and phosphorus are negligible. In time, the great purity of these ores, combined with their percentages in nickel, and their convenient shipment from deep-water docks, should win a European as well as an American market.

Previous Work on the Geology

To the report of Messrs. Hayes, Vaughan, and Spencer, made in 1901 to Gen. Leonard Wood, at that time the Military Governor of Cuba, during the American occupation, we owe the only available systematic description of the island. As Messrs. Vaughan and Spencer were on the island but 12 weeks and Mr. Hayes but five, the report contains an extraordinary amount of detail when one recalls that the climate is tropical. The three geologists were chiefly busied with the mineral resources, but they give much information regarding general formations and made a careful summary of such previous literature as existed. Nevertheless, the report only whets our appetites for a full and accurate geological map and description of the island. Were it possible for the U. S. Geological Survey or some of our Academies of Sciences to make a co-operative survey with the Cuban government, as is now being done in Porto Rico in co-operation with the Porto Rican government, by the New York Academy of Sciences and affiliated New York City institutions, a great service would be rendered Cuba, as well as general science. Messrs.

Hayes and Spencer made a trip of eight days with a pack train from Santiago to Mayari and return. They crossed the tract of the Mayari mines and have drawn a geological section, which is here reproduced from their Plate XVIII, Section 6, in so far as it relates to the Sierra Nipe, on which the ore lies (Fig. 1).

The following quotations are taken from the report:

P. 28. "Along the line of the trail which crosses the Sierra Nipe leading from San Luis to Mayari, near the line of the section presented in Plate XVIII, Fig. 6, there is a belt of metamorphic and dense igneous rocks, between the Oligocene limestone and the serpentine which forms the axis of the Sierra. This series is very poorly exposed, but is probably older than the serpentine. Indications of a similar series were observed near the edge of the serpentine on the south side of the Sierra Cristal in the vicinity of Mayari Arriba.

"The main mass of the Sierra Nipe is composed of serpentine, which is shown by the microscope to have originated through the alteration of a rock originally composed largely of bronzite, fragments of which mineral are still frequently to be observed in the otherwise completely altered mass. Since this chemical alteration occurred, the serpentine has been intruded by dense diabase. These last-named rocks occur in



1, Metamorphic rocks; 2, Serpentine with diabase and gabbro intrusions; 7, Massive limestone (Oligocene?); 8, Coastal soborruco and Oligocene marls.

FIG. 1.—REPRODUCTION OF NORTHERN PART OF GEOLOGICAL SECTION, PLATE XVIII, FIG. 6, OF REPORT BY HAYES AND SPENCER.

such abundance that it is impossible to find any large area of the serpentine which is not cut at least by small dikes of the later rock, and frequently it is found in very large masses.

"On the northern side of the Sierra Nipe the Oligocene limestone reaches an elevation of about 900 ft., dipping northward toward the sea. In the higher exposures the dips are between 10° and 15° , but become less as the coast is approached."

On pp. 83 to 84 the following remarks appear with reference to the shot-like masses and crusts of limonite now called *plancha*:

"Occupying the general region between Nipe Bay and Moa Bay, and somewhat back from the northern coast, there is a region reaching a general elevation of from 1,500 to 2,000 ft., and occupied by serpentine and other igneous rocks. Upon the top of this sierra there are many large areas which are practically level, and these are always covered by a thick mantle of red clay, which contains a large proportion of iron ore in the form of spherical pellets. Locally this material entirely replaces the clay, and the separate particles are cemented together by ferruginous materials, making a spongy mass of brown iron ore. Similar occurrences of shot and massive ore were noted upon the tops of certain hills lying to the north of the city of Puerto Principe, and following the general trend of the Sierra Cubitas. The rock in this vicinity is also serpentine, and the ores have identical characteristics with those of the region mentioned above. Analyses were made of these residual ores collected near Rio Seco along the trail between Mayari and San Luis."

The following two analyses are given with two others from localities of no interest in this connection:

	1 Per Cent.	2 Per Cent.
Moisture.....	....	0.56
Iron.....	52.00	54.69
Manganese.....	0.364	0.594
Phosphorus.....	0.0368	0.0189
Silica.....	2.62	2.51
Chromium.....	tr.	present
Titanium.....	0.25	....

1. Iron ore from Sierra Nipe near trail crossing the Rio Naranjo, about 10 miles from Mayari, Santiago Province (now Oriente Province).

2. Iron ore from Sierra Nipe near Rio Seco, Santiago Province (now Oriente Province).

"These residual ores are locally known as 'tierra de perdigones' or 'moco de herrero,' signifying shot-soil and blacksmith's waste, either of which terms is a very apt designation. Rodriguez Ferrer is authority for the statement that hydrated oxide of iron in the form of pellets in the soil occurs at various points in the Island. The following localities are mentioned: Province of Pinar del Rio, between Consolacion del Sur and Candelaria; Matanzas Province, in the Sierra Morena, between Cardenas and Sagua la Grande; Loma Iman near the city of Puerto Principe, and Monte Libano north of Guantanamo, Santiago Province. The amount of these ores in various parts of the island is certainly very large and it seems not improbable that they may eventually find a market in the United States in cases where they are situated near a sufficient supply of running water for washing them free from the clay with which they are mixed."

That the mantle of surface materials was due to the alteration or weathering of serpentine was recognized by Hayes and Spencer, and some notes on the mother rock of the serpentine were made, based on microscopic study. They also noted the later dikes described as diabase, presumably observed in ascending and descending the plateau, since on the top everything was then concealed. So far as the ore is concerned it only remained for Mr. Cox and his engineers to discover that the "clay" was also iron ore.

All the other observers corroborate the derivation of the ore by the weathering of serpentine, and Mr. Spencer in his paper of 1908 goes more at length into this subject, and notes the parallels with the ores formerly dug on Staten Island, N. Y., and with the deposits known to exist at Clealum, Wash. C. M. Weld in 1909 takes up the process of tropical weathering much more fully and acutely recognizes the similarity of the ore to the laterites of India. Mr. Weld also gives four fairly complete analyses from Mayari, Moa, Taco, and Navas, which he had evidently recast into their possible minerals because he states, p. 302: "Within the clay-ore are found disseminated nodules and pellets of brown ore ranging apparently through all the hydrated forms from limonite to turgite; hematite also is present and at times magnetite." Mr. Weld

obviously recognized that the combined water was too small to satisfy the alumina for bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) and the iron for limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). The same point is emphasized by C. K. Leith and W. J. Mead and will be more fully discussed later on. Mr. Weld gives the first published analysis of the serpentine, placing by its side a reconstructed complete analysis of the ore. The serpentine came from Moa Bay. It is of special interest to compare these analyses with a similar analysis from Mayari later given. In quoting Mr. Weld's analyses, the components have been rearranged to correspond with the order now almost universal in rock analyses.

	Serpentine, Moa Bay	Iron Ore, Moa
SiO_2	37.29	1.71
TiO_2	See note	0.14
Al_2O_3	1.33	11.60
Fe_2O_3.....	.....	66.90
Cr_2O_3	See note	2.65
FeO	8.55	....
MnO	tr.	0.80
NiO	See note	0.60
MgO	36.53	See note
CaO	0.29	See note
K_2O	tr.	See note
Na_2O	0.39	See note
H_2O	15.27	13.15
P_2O_5	0.07	0.07
	99.72	97.62

NOTE.—Under the first analysis, 0.28, the balance to 100 per cent., is assigned to TiO_2 , Cr_2O_3 , and NiO . Under the second analysis, 2.38, the balance to 100 per cent., is ascribed to MgO , CaO , K_2O , and Na_2O .

W. L. Cumings and B. L. Miller specially studied the field north of Camaguey, which their predecessors had apparently named the Cubitas, but which, because of its separated position from the Cubitas Mountains proper, they prefer to call San Felipe. They also add interesting and important details on the Moa field. The San Felipe ores contain in their lower portions impressive amounts of chert, which fails in the other districts. They note large, recognizable crystals of pyroxene in the serpentine, and remark the relations of the serpentine with massive Triassic limestone (p. 119 of their paper) along the Jigüey River. Hayes, Vaughan, and Spencer do not mention Triassic rocks in their stratigraphic column (p. 33 of their report to General Wood) and it would be of great interest to record the evidence. Messrs. Cumings and Miller were well aware that all the iron in the ore was not hydrated, and mention both magnetite and hematite (p. 128) as components. Small pellets of hematite and some magnetite were detected in microscopic slides of serpen-

tine (p. 135), so that these minerals are regarded as survivors from the serpentine.

C. K. Leith and W. J. Mead visited all three of the large districts but gave special attention to the Mayari. They emphasize the presence of bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) and gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) in the ore. Eleven samples were taken in a 10-m. section of the ore and were analyzed, as was also the bedrock serpentine, so as to trace out the changes. The

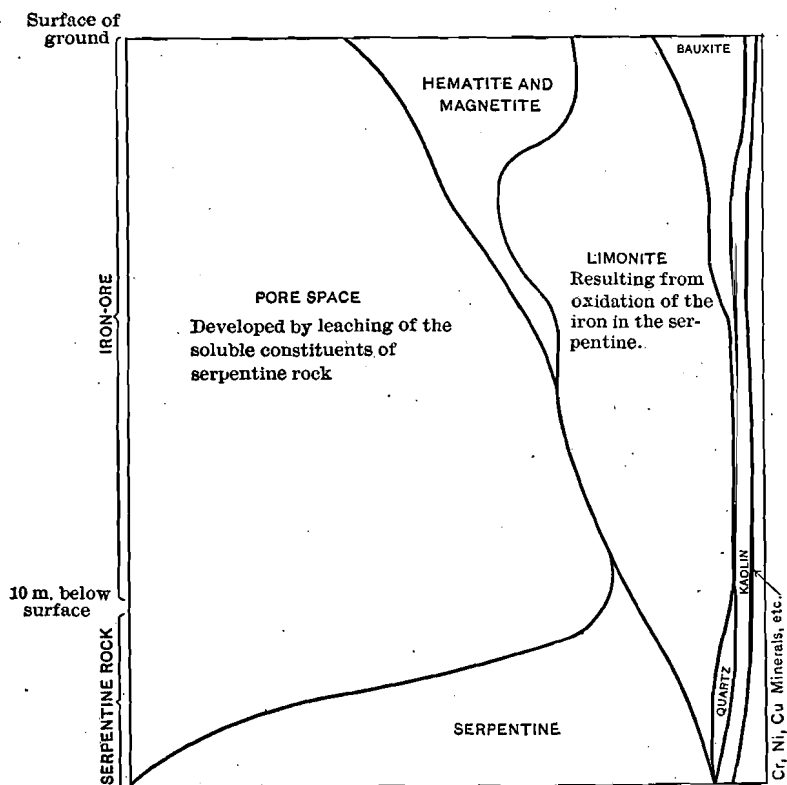


FIG. 2.—DIAGRAM BY C. K. LEITH AND W. J. MEAD ILLUSTRATING THE PHYSICAL AND MINERALOGICAL CHANGES OF THE SERPENTINE IN ITS PASSAGE TO IRON ORE. REPRODUCED FROM P. 93 OF VOL. XLII OF THE *Transactions*.

analyses are not published, but a chart, plotted so as to show the pore space, progressively left by the lost components, and the relative volumes occupied by the residual minerals, is given and is here reproduced (Fig. 2). In order to run some comparisons with the mineralogy of the ore as determined by recasting some new analyses, the writer has scaled off in fiftieths of an inch the cross-section of the chart, first at the top, next in the middle of the ore, and lastly at the bottom of the ore. After leaving out the pore space the other proportionate measurements have

been multiplied by the respective specific gravities of the minerals involved, and the products have been recalculated to percentages with a total of 100, so as to express the percentages of the minerals by weight. These will be used in comparison later on. The general chemistry and physical changes in the passage from serpentine to ore are carefully reviewed by the two authors. On the geology the following sentences are significant:

"Geologists are substantially agreed that the ores of the Moa and Mayari fields are residual or mantle deposits resulting from surface alterations in place, of serpentine rock, which in turn probably represents the alteration of some other rock like a peridotite not yet disclosed by underground explorations. With the serpentine there are present very minor quantities of intrusive dike rocks, high in alumina, which by the surface alterations yield clay, not iron ore."

This summarized review will afford, the writer hopes, a serviceable idea of what has been already recorded. Some further notes on the general geology and some petrographic details of the serpentine will be next given and then the actual and so far as possible the proportionate mineralogy of the ore will be further discussed.

Geology

At the coast and along the low bluff arising from the water, a marly clay with lumps of limestone intermingled forms the surface. The same general formation extends for some miles back, and appears as thin, flat beds of tender limestone in thicker beds of clay or marl. Twelve miles from the coast, quite solid, white limestone appears in flat beds and is quarried as shown in Fig. 3. No fossils were found after careful search, nor could the writer learn of any from the men at work. Presumably the same formation extends to the plateau and appears as far up as the head of the lower incline. It could also be seen across a valley, as shown in Fig. 4, a photograph taken from the head of the lower incline looking westward. The point of view was at 680 ft. elevation above the sea. Above this point serpentine soon appears and, with the associated dikes of diorite as later described, constitutes the plateau so far as known. Undoubtedly more detailed exploration of the valleys, and of the lower contact of igneous rocks on limestones would bring to light additional facts of much interest. There must be a vertical thickness of exposed serpentine of at least 1,200 ft.

The cuts of the upper incline give an excellent section of the serpentine, since they have been sunk as much as 40 ft. below the surface. Good, fresh rock has thus been afforded for study. Other cuts along the railway between the head of the incline and the station at Woodfred give good exposures, and a third cut made in the bedrock near the southwest workings, known as the Three-Hill mine, has opened up excel-



FIG. 3.—LIMESTONE QUARRY AT ARROYO SEBORUCO, 12 MILES FROM FELTON.



FIG. 4.—VIEW OF LIMESTONE FOOT HILL OF SERPENTINE PLATEAU, LOOKING WEST FROM HEAD OF LOWER INCLINE.



FIG. 5.—LOWER TWO-THIRDS, BASTITE (HIGH RELIEF) AND SERPENTINE (LOW RELIEF) FROM PYROXENE; UPPER THIRD, OLIVINE CHANGING TO SERPENTINE. ACTUAL FIELD, 0.1 IN.; WHITE LIGHT.



FIG. 6.—THE SAME AS FIG. 5, BUT TAKEN WITH CROSSED NICOLS.

lent material for microscopic study. A very fresh and surprisingly unaltered boulder of rock was met in the mines at the Y, where the spur to the northeast branched from the main line, in 1914.

The serpentine is derived from a peridotite which consisted of olivine, and pyroxene, apparently an orthorhombic variety which is now thoroughly changed to bastite and fibrous serpentine. The original rock probably also contained monoclinic pyroxene, since in the slides some extinctions not parallel with the cleavage would suggest it. The chemical change has been so thorough as to destroy most of the optical properties of the original. The bastite has feeble double refraction, giving



FIG. 7.—BASTITE PRESERVING CLEAVAGES OF A PYROXENE CRYSTAL IN RIGHT CENTER. ABOVE IT A DARK PICOTITE. GENERAL MASS SERPENTINE FROM OLIVINE. ACTUAL FIELD, 0.1 IN.; WHITE LIGHT.

pale grays. It still displays prismatic cleavage which has parallel extinction. It passes into fibrous serpentine, as is illustrated in the lower two-thirds of Fig. 5. The serpentine fibers maintain parallelism with the prismatic cleavage of the original pyroxene. The fibers are curved slightly in Fig. 5, suggesting some pressure effects. In the change to serpentine some highly refracting mineral has developed in the cracks, which behaves like quartz, but extinguishes at various angles across the elongation. It is shown in Fig. 6, which is the same field as Fig. 5. In Fig. 7 is a pyroxene crystal with its prismatic cleavages well shown and in addition pronounced partings parallel with the vertical pinacoids.

The dark, angular grain just above the pyroxene crystal is a brown, isotropic mineral of high index and is probably the chrome spinel, picotite. It is quite frequently seen in the slides and is believed to be picotite because the dark brown mineral becomes transparent too readily to be chromite. The slides show occasional opaque metallic grains, which are doubtless magnetite and chromite. The serpentine develops in the olivine in cross fibers, along cracks, and is well illustrated in Fig. 8. A further stage, from which the olivine has almost all disappeared and serpentine with the so-called mesh structure has taken its place, is illustrated in Fig. 9. Numerous black specks of secondary iron ore are shown.



FIG. 8.—SHOWING GENERAL DERIVATION OF SERPENTINE FROM OLIVINE. ACTUAL FIELD, 0.1 IN.; WHITE LIGHT.

Finally, in Fig. 10, we have only serpentine left, with the mesh structure emphasized by taking the photograph with crossed nicols.

In the cuts in the serpentine along the upper incline rather poorly defined streaks of dense black or dark-gray rock can be frequently detected. So much movement or crushing has taken place, either from dynamic disturbance or from the swelling and adjustment incident to the change from peridotite to serpentine, that their regularity is greatly obscured. Doubtless they were once dikes, but now on the edges they shade into the schistose serpentine and probably have themselves altered to it in part. Under the microscope they are all diorites with strong suggestions of original diabasic texture. The long banded rods in Fig.



FIG. 9.—SHOWING ALMOST COMPLETE CHANGE OF SILICATES TO SERPENTINE. ACTUAL FIELD, 0.1 IN.; WHITE LIGHT.

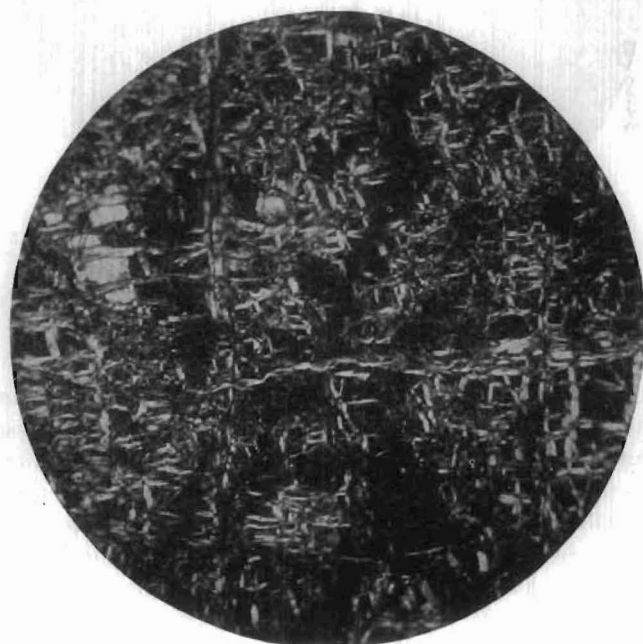


FIG. 10.—SIMILAR VIEW TO FIG. 9, BUT TAKEN WITH CROSSED NICOLS TO BRING OUT THE MESH STRUCTURE OF THE SERPENTINE.

11 are the plagioclase. The other minerals of uniform gray to black tints are hornblende. Magnetite in small grains can also be detected in the slides. In other dikes the hornblende becomes more abundant and the plagioclase less. In Fig. 12, taken in white light, the darker mineral making up three-quarters of the field is all hornblende. The lighter areas are plagioclase. Some dead-black magnetite is also shown. The boulder mentioned above as found near the Y of the mine railway is a coarser diorite, rich in feldspar, which even shows micropegmatitic structure. Although appearing as a loose boulder, this rock proved to be surprisingly unaltered in the thin section, all the minerals being clear



FIG. 11.—DIORITE WITH DIABASIC TEXTURE. THE DARK AND LIGHT Banded MINERAL IS PLAGIOCLASE; THE DARK MINERAL IS HORNBLENDE. Crossed NICOLS. ACTUAL FIELD, 0.1 IN.

and fresh. It must indicate a dioritic dike in the serpentine. Mr. Spencer has reported diabase dikes to be numerous and widespread in the serpentine, and, as he crossed this area years before mining was begun, he must have observed them along the steep sides of the plateau, since practically no outcrops appear on top. One cannot but suspect from the textures of the dikes here illustrated that the hornblende is secondary after augite, and the slides justify this surmise. A few cases of unchanged augite have been observed in the midst of the hornblende, whose leek-green color would almost of itself be demonstrative of a secondary variety. In slides made from several dikes gathered on the

incline the feldspar has passed to an aggregate of not strongly bi-refracting rods, which are probably some zeolite. Doubtless this is the first stage in the alteration, which in the long run yields laterite. Although no chemical analyses have been made, all these diorites will run much higher in alumina than the serpentine. They will certainly yield from 15 to 18 per cent., and are doubtless responsible for some of the alumina in the ore and its local exceptional abundance.

An analysis of the fresh serpentine from the Three Hill mine cut, from which Figs. 5, 6, and 7 were taken, has been kindly made by T. C. Kraemer, chemist of the Spanish-American Iron Co. at Felton. By its side is placed the analysis given by C. M. Weld, as earlier noted:

	I Serpentine, Woodfred	II Serpentine, Moa
SiO ₂	37.28	37.29
Al ₂ O ₃	2.45	1.33
Fe ₂ O ₃	5.14	....
Cr ₂ O ₃	1.68	....
FeO.....	5.14	8.55
MnO.....	....	tr.
NiO.....	0.30	....
MgO.....	34.59	36.53
CaO.....	none	0.29
K ₂ O.....	....	tr.
Na ₂ O.....	....	0.39
H ₂ O (combined).....	12.80	15.27
H ₂ O (absorbed).....	0.91	....
P ₂ O ₅	0.013	0.07
	100.303	99.72

In analysis II, Mr. Weld assigns to the difference between the total and 100, TiO₂, Cr₂O₃, and NiO, amounting to 0.28 per cent.

Much interest attaches to the recasting of these analyses into the percentage composition of the component minerals of the rocks. At first sight the presence of so much Fe₂O₃ in the analysis of the Woodfred sample strikes one as unusual, since in general in serpentine the iron oxide is chiefly in the state of protoxide. If, however, in recasting we assume it to be ferrous, we have far too little silica to satisfy the serpentine molecule 3(MgO.FeO), 2H₂O, 2SiO₂. The ferric oxide has therefore been arbitrarily distributed between limonite and magnetite, the governing motive being the exhaustion of the silica. As checked by study of thin sections, we are thus not very far from the true components of the rock nor their relative amounts. The chief variation lies in the undoubted presence of some unaltered olivine. Bastite is generally credited with the same composition as serpentine. Mr. Weld's analysis is stated to be the average of a number of samples. When one attempts to recast it, assigning the magnesia and the ferrous iron to the serpentine molecule, there is lack of silica, and the difficulties are increased by assuming any

probable silicate for the soda and lime. Any one of the averaged individual analyses would be better for recasting than the average of them all.

Fully realizing, therefore, that the percentages given by the recasting of the Woodfred sample are approximations rather than mathematically correct expressions, we have some idea of the minerals or compounds whose alteration has produced the ore. Sharper definition is thus given to our conceptions of the necessary changes than if we only had the analysis before us. The total does not exactly check with the analysis, from small rejections of decimals, here and there.



FIG. 12.—MORE BASIC DIORITE WITH PREDOMINATING HORNBLLENDE. ACTUAL FIELD, 0.1 IN.; WHITE LIGHT.

	Serpentine, Woodfred		Total serpentine
Magnesia serpentine.....	79.33	}	85.986
Iron serpentine.....	6.174		
Nickel serpentine.....	0.482		
Kaolinite.....	1.548		
Bauxite.....	2.346		
Limonite.....	4.114		
Magnetite.....	2.320		
Chromite.....	2.472		
Unassigned water.....	0.396		
Absorbed water.....	0.910		
P ₂ O ₅	0.013		
	100.105		

The change to ore obviously involves the entire disappearance of the magnesia; the nearly total removal of the silica; the probable change of the nickel-serpentine to one or more of the other hydrated silicates such as have been named from various nickel mines—genthite, connarite, garnierite, etc., and of which F. W. Clarke² states: "These silicates are rarely if ever found as definite mineral species, although they have been described as such." One called nepouite has, however, the same formula as nickel-serpentine, $3(\text{NiMg})\text{O}$, $2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, or $(\text{NiMg})_3\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ as cited by Dr. Clarke. In the passage to ore, whose composition is later shown, some nickel surely migrates downward, because it is not increased in percentage in the same ratio as the alumina, and the serpentine below the ore is much richer in nickel than the sample above analyzed. Instead of 0.3 per cent. we may find 2 per cent. and over of NiO . The kaolinite breaks up in large degree to bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) or some other aluminum hydrate such as gibbsite (called also hydrargillite), $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. There seems to be no good reason why there should not be also present $2\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, corresponding with limonite, but no such mineral has yet been named. Even bauxite itself may be interpreted as an intimate mixture of diasporite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and gibbsite, as Dr. F. W. Clarke remarks (p. 472), since the last two are known in a crystallized condition while bauxite is not. The chromite and magnetite survive with little change, both being very resistant minerals. Hematite may also be a mineral in the serpentine, as considered by Cumings and Miller, even though not calculated as such in the above recasting. It may survive in the residual product. The iron passes into some form of hydrated oxide, as will be later shown. Limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, probably is in excess over goethite, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and turgite, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. Some iron doubtless has also escaped. All these changes are facilitated by the situation of the serpentine on a high plateau, whose top is 1,500 to 1,900 ft. above the surrounding lower country, and which has extremely steep sides. Underground discharge for the percolating rain water has been extremely free, since serpentine is pre-eminent among rocks for checks, slips, and cracks. The great increase in volume incident to the combination of so much water with the anhydrous silicates of the peridotite makes readjustments on a grand scale inevitable.

The Ore

In the faces of the pits as now extensively exposed, the observer can readily note that there are three distinct layers: An upper, of crimson-brown hue; a middle one, yellowish brown, and a bottom layer of a lighter shade of yellowish brown. In one face, called the Three-Hill cut, the

² F. W. Clarke: Data of Geochemistry, *Bulletin No. 491, U. S. Geological Survey*, p. 664 (1911).

upper was noted at 5 to 6 ft.; the middle at 6 to 12 ft.; and the lower at 4 to 6 ft. The two upper layers are illustrated in Fig. 13. Analyses of each layer, but from another station, will be subsequently given. As distinct from these varieties the engineers in charge have noted that in the occasional and rather rare spots in the residual mantle where the iron percentage is too low for mining there appears at the surface a peculiar purple color, quite easily recognized and an indication of high alumina in the samples. The color appears to be due to the relatively rich admixture of normally white bauxite with the darker-hued brown iron ore. The explanation of the higher alumina is to be found in local changes in the original rock, as later set forth.

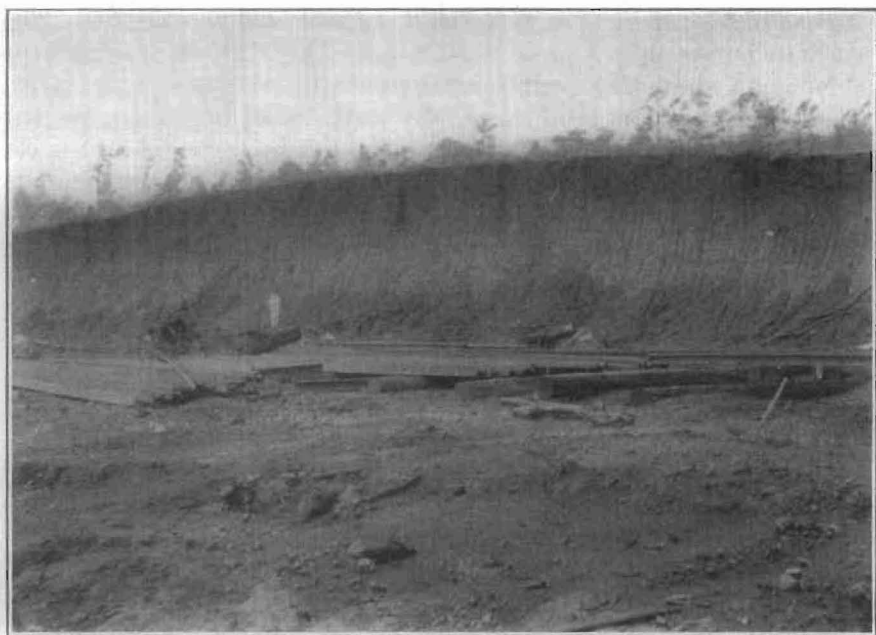


FIG. 13.—FACE LEFT BY STEAM SHOVELS IN THREE-HILL MINE, AND SHOWING TOP, DARK LAYER, AND MIDDLE, LIGHTER LAYER. THE TOP DARK LAYER HAS CAVED DOWN ON THE BASE, CONCEALING BOTTOM LAYER.

In some places, at the surface or a few feet below it, slabs and even continuous sheets of solid iron hydrate appear and afford the cellular varieties of brown ore, very similar to the crusts and lumps long familiar in the mines of the Appalachian belt. As earlier stated, the solid ore is called *plancha*. In the residual mantle shots and larger lumps of solid brown ore are at times intermingled, chiefly in the upper, darker layer. The general run of the ore is, however, earthy, and reminiscent in the strongest degree, alike in color and texture, of the Mesabi ores. The higher con-

tent of absorbed water, the higher alumina, and the lower silica of the Mayari ores give them perhaps a somewhat more spongy aspect than one notes on the Mesabi range; on the other hand, at Woodfred there is no overburden whatsoever, and the ore is obtained from grassroots to bedrock.

The recently mined ore has a peculiar mealy character, reminding one of nothing so much as dampened meal, but as it dries out this character disappears. No doubt the colloid nature of the hydrates of alumina and iron is the cause of the peculiarity.

The following analyses made by T. C. Kraemer, chemist of the Spanish-American Iron Co., were based upon samples gathered by the writer to illustrate the three contrasted layers. The samples were taken as nearly as practicable in a vertical section.

	I Surface Ore. Sta. 11,35,10. Crimson-brown.	II Middle Layer. Sta. 11,35,10+15 Yellow	III Bottom Layer. Sta. 11,35,11 Yellow
SiO ₂	2.26	2.70	7.54
Al ₂ O ₃	14.90	7.13	4.97
Fe ₂ O ₃	68.75	71.89	64.81
Cr ₂ O ₃	1.89	3.17	3.66
FeO.....	0.77	1.29	1.49
NiO.....	0.74	1.60	2.75
MgO.....	....	....	1.50
H ₂ O combined....	11.15	12.90	12.75
Total.....	100.46	100.68	99.47
Metallic iron....	48.65	51.32	46.52
Metallic nickel....	0.59	1.20	2.10
H ₂ O absorbed*....	4.62	9.72	27.00

* Determinations of absorbed water based on original sample. Other determinations on dried sample at 110° C.

From these analyses we draw the following conclusions:

Silica progressively increases from above downward. It is relatively high in III because of bits of included serpentine and probably because of the descent of the silica in solution and loss in largest proportion from the uppermost layer, which has been longest exposed to alteration.

Alumina decreases downward because it is the least soluble of all the components and therefore reaches a maximum in the most weathered portion.

Ferric oxide, as we pass downward, increases and then declines. In III the silica and magnesia of the bits of serpentine relatively reduce it. Doubtless, in the long run descending rain waters dissolve some iron from the upper layer and re-deposit it in part in the yellow middle layer. Some probably runs off altogether.

Chromic oxide progressively increases downward, a relation at first causing surprise. Since chromite is an extremely resistant mineral,

one would naturally expect it to become concentrated near the top. It must either work its way downward because of its relatively high specific gravity or else it must appreciably yield to waters in the long run. The former supposition is more probable.

Ferrous oxide impresses one at first sight as being sympathetic with chromic oxide, although a little below the requirements of chromite. The difference could be explained by small percentages of magnesia or even of nickel oxide in the chromite. Tests with the magnet, however, prove the presence of appreciable quantities of magnetite. It therefore seems more reasonable to assign the FeO to magnetite; and to infer from the insoluble nature of chromite that its FeO was finally determined as Fe_2O_3 . In recasting the analysis all the FeO has been used for magnetite, and enough Fe_2O_3 to furnish the necessary FeO for chromite has been taken for this purpose.

Nickel oxide progressively increases downward. It may be in very small part in the chromite. It is undoubtedly present as some hydrated nickel silicate. It is probably affected by the rain waters and has been removed by them to a relatively great degree from the upper layers. Concentration in the bedrock and in the bottom layers of ore is quite certainly shown by analyses, additional to the three cited.

Magnesia practically disappears with the general breaking down of the serpentine.

Combined water shows a slight increase, because surviving serpentine in the bottom layer accounts for some, and increased percentages of iron, presumably in the molecule, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, in the middle layer for the rest. There is reason to infer the increased percentage of magnetite and perhaps hematite in the top-layer. Leith and Mead plot these two as forming more than half the solids by volume, and this would involve an even greater percentage by weight, because the minerals bauxite and kaolinite of low specific gravity enter in an important way into the residue. The writer's tests with the magnet and by microscopic study of the samples gathered for the analysis here published showed that the shots of ore were magnetic to an appreciable degree, perhaps 5 to 10 per cent. of them, but the fine ore was practically inert. The shots were all discolored with brown ore and when crushed showed a goodly portion of limonite in the powder.

If we seek to combine the iron and all the water of I into the common limonite molecule, there is too little water; in II there is a slight excess of water; and in III there is a large excess. But the alumina in each calls for some water, and it is therefore clear that all the iron is not in the limonite molecule, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, but there must also be present some iron hydrate calling for less water. From microscopic study, we are certain that there is a little magnetite, and this helps to solve the difficulty, but there must also be present large proportions of goethite, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and

there may be some turgite, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. The absorbed water is exceptionally low in I and II, and the small percentage is undoubtedly due to evaporation during a period of slight rainfall.

Much interest attaches to the recasting of these analyses in the endeavor to bring out the actual or probable proportions in which the constituent minerals enter and the identity of the minerals themselves. The low percentage of silica makes clear that kaolinite, $2\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, one of the first minerals to be considered, can be present in only small amounts. The presence of chromic oxide makes justifiable and indeed unavoidable the conclusion that chromite, $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, is also present. Recasting shows that there is from a little to a good deal too much Cr_2O_3 in the analyses for the reported FeO. As stated above, we infer from this, since chromite is a very insoluble mineral, that the reported FeO is in magnetite. On this assumption the magnetite has been calculated, assigning to it all the reported FeO, and then taking from the Fe_2O_3 enough to correspond to the FeO required for chromite. The resulting percentages are so close to the general indications of microscopic study as to be worthy of much confidence. We infer that the greater part of the nickel is combined with silica and water as some form of hydrated silicate. The normal nickel-serpentine molecule has been used. Leaving one side the nickel as one of the minor components, we recognize the fact that the iron hydrates and the alumina hydrates are the large components.

As a further preliminary to the results of attempted recasting, a brief summary may be given of a careful microscopic examination made by Dr. Charles P. Berkey for the Spanish-American Iron Co., in order to determine the condition of the iron minerals and their relations to other components. The ore proved to be in largest part an extremely intimate mixture of some iron hydrate, assumed to be limonite; and some alumina hydrate, assumed to be bauxite; with minor proportions of recognizable chromite and admixtures in minute particles of quartz, epidote, hornblende, and possibly feldspar. By fractional treatment with hydrochloric acid, and study of residues, the above conclusions were reached. The sample was different from the ones used in the three analyses here published, but the results give us a definite and interesting point of view. Chamosite and thuringite, the hydrated silicates of iron, familiar in the minette ores of Luxemburg and Lorraine, were considered, but no reason appeared for inferring their presence.

In the tables of recast results, different assumptions are made and tabulated for iron and alumina hydrates in the endeavor to work out combinations of the water, which is too small in amount for limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, and bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, alone. The methods employed are those now widely used for rock analyses.³

³ Kemp: *Handbook of Rocks*, pp. 161 to 179. Cross and others: *The Quantitative System for the Classification of Igneous Rocks* (Chicago, 1903). Finlay, G. I.: *Igneous Rocks* (New York, 1913).

	I Top Layer, Recast			II Middle Layer	III Bottom Layer
	Ia	Ib	Ic		
Limonite.....	39.66	21.32	.....	59.09	69.96
Hematite.....	31.68	.....	.....	.....	.....
Turgite.....	.....	50.02	30.76	.....	.....
Goethite.....	.....	.....	40.58	18.87	.....
Magnetite.....	2.55	2.55	2.55	4.18	4.87
Chromite.....	2.79	2.79	2.79	4.85	5.58
Bauxite.....	17.98	17.98	17.98	7.45	1.34
Kaolinite.....	4.05	4.05	4.05	3.78	9.80
Ni-serpentine.....	1.30	1.30	1.30	2.69	4.70
Mg-serpentine.....	.....	.....	.....	.....	3.45
Excess water.....	.....	.....	.....	.....	0.04
	100.01	100.01	100.01	100.91	99.74

In recasting analysis I, the relatively small amount of water has compelled three assumptions. In the first, after providing for bauxite, kaolinite, and nickel-serpentine, all the water is assigned to the limonite molecule and the excess of ferric iron is calculated as hematite. So much hematite is, however, contradicted by microscopic study of the sample. The magnetite and chromite account for approximately as much as one actually observes of the iron minerals which do not afford on crushing a yellow or brown powder. Therefore, a second recasting was carried out by allotting the water to limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, and turgite, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. By this assumption yellow-brown hydrates of iron alone are used. The third recasting was made also to use only iron hydrates; but assuming turgite, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and goethite, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, one sees that hematite is not a necessity in any great quantity. In the diagram given by Professors Leith and Mead, if we select sections at the top, middle, and near the bottom of the ore, scale off a proportionate part for each mineral by its specific gravity, and then reduce the products to percentages, we will turn the diagram into percentages by weight. In doing this the following specific gravities have been used: Magnetite and hematite, 5; limonite, 4; bauxite, 2.4 (as given by J. C. Branner, *Journal of Geology*, vol. v, p. 270, 1897); kaolinite, 2.5; chromium, nickel, and copper minerals, 4.5 (a value probably high); serpentine, 2.6.

	I Top	II Middle	III Bottom
Hematite and magnetite....	64.8	15.0	.....
Limonite.....	19.2	72.4	75.4
Bauxite.....	12.7	2.4	.....
Kaolinite.....	1.6	3.0	8.4
Chromite, etc.....	1.7	7.2	9.0
Serpentine.....	.....	.....	7.2
	100.0	100.0	100.0

In the smaller components, kaolinite, chromite, and serpentine, the results are generally reasonably parallel with those obtained by recasting the three analyses given above. The bauxite is not beyond the allowable differences of samples. The chief contrasts are in the distribution of the iron oxides among the several iron minerals in the top layer. The samples used in the present paper indicate less hematite and magnetite.

Samples were also collected at station 21.02.16 of the lean so-called ore, of purple color, and too low in iron for mining. A second sample of a cellular decomposed mass, supposed at the time to be bedrock, was taken from the base of the exposed section. Both were kindly analyzed by T. C. Kraemer. Apparently the samples were derived from the weathering of the peridotite, where penetrated by diorite dikes.

	I Upper Portion	II Lower Portion
SiO ₂	6.88	2.28
Al ₂ O ₃	23.44	39.80
Fe ₂ O ₃	54.46	34.44
Cr ₂ O ₃	1.89	0.27
FeO.....	.....	.....
NiO.....	0.25	0.09
H ₂ O combined.....	13.84	24.01
	<hr/> 100.76	<hr/> 100.89
H ₂ O absorbed.....	4.72	1.86
	<hr/>	<hr/>
	I Upper Portion	II Lower Portion
Limonite.....	38.17	40.06
Hematite.....	20.80	.....
Bauxite.....	24.02	19.05
Gibbsite.....	.....	36.19
Kaolinite.....	14.49	4.90
Ni-serpentine.....	0.41	.....
Chromite.....	2.85	0.43
NiO not used.....	.....	0.09
	<hr/> 100.74	<hr/> 100.72

In No. I we are forced to use hematite, or appeal again to goethite and turgite, which latter step in this case has not been taken. In No. II the water is so high as to necessitate the presence of gibbsite, Al₂O₃.3H₂O, along with bauxite. The gibbsite molecule is important in the laterites. Undoubtedly in all these processes of weathering colloids are formed, since, with the exception of chromite, hematite, and in the previous analyses magnetite, practically all the molecules employed appear in amorphous and structureless forms, which are most reasonably explained by assuming an original colloid. At the International Geological Congress, held in Toronto, in August, 1913, Prof. Paul Krusch, of Berlin, emphasized the importance of this form of matter both in the results of surface weath-

ering and in a few possible situations placed deeper within the earth.⁴ The hydrated nickel silicates received special mention and were interpreted as colloidal precipitates.

Recently Described Areas of Laterite Ores

In the earlier papers cited on the Mayari and related districts mention is made of similar ores at Staten Island, N. Y.,⁵ and Clealum, Wash., and of others in the Mediterranean region. Besides these two, additional instances have recently been described to which reference may be made in conclusion. Prof. Alfred Lacroix, of Paris, has been for over 15 years carrying on extended studies of the tropical alteration of rocks in French Guinea in latitude 10 N.⁶ Professor Lacroix defines laterites (p. 259) as "The products of the decomposition of all rocks containing silicates of alumina, and which, from the chemical point of view, are characterized by the predominance of the hydroxides of alumina and iron generally with the oxide of titanium, after the elimination more or less complete of the other elements of the fresh rock: alkalis, lime, magnesia, and silica." While the original peridotite of the Mayari iron ore is one of the poorest of all igneous rocks in alumina, yet there was enough in it so that the residual products of its decay became relatively high in this oxide. Professor Lacroix gives (p. 296) the accompanying analyses, which range from much less altered peridotite than we have yet obtained at Mayari to iron ore apparently like the crusts of Cuban plancha.

Analysis (d) is analogous to the Mayari ore and therefore much interest attaches to the following comment of Professor Lacroix, p. 297:

"As for analysis (d) it reveals a complete disappearance of the silica. The interpretation of the constituents of the hydrates is uncertain. The red coloration, of variable shades, in the specimens studied leaves no doubt about variations in the hydration of the iron. If we assume that the hydrate of alumina is the one with three molecules of H₂O, the remainder of the water, which is combined in the hydroxide of iron, makes necessary for the latter a composition less hydrated than that of goethite. If on the contrary, we assume a hydrate of alumina with one molecule of water, then the hydroxide of iron would have the composition of goethite; but any such hypothesis ought to be rejected, since this mineral certainly does not exist in this laterite. Microscopic examination only proves the presence of a mixture of hematite and limonite."

⁴ Paul Krusch: Primaäre und sekundaere Erze unter besondere Beruecksichtigung der "Gel" und der "schwermetallreichen" Erze (Primary and Secondary Ores with Especial Consideration of the Colloid Ores and of the Ores Rich in the Heavy metals), *Compte Rendu de la XII Congrès Internationale Géologique*, pp. 275 to 286.

⁵ A recent paper by C. R. Fetteke, Limonite Deposits of Staten Island, N. Y. (*School of Mines Quarterly*, vol. xxxiii, pp. 1 to 10, July, 1912), interprets the ores in accord with the most recent views.

⁶ Les Laterites de la Guinée, *Nouvelles Archives du Museum National d'Histoire Naturelle*, vol. v, pp. 255 to 356 (1913).

	Peridotite: a	Peridotite b	Laterite c	Iron Capping d	Iron Ore e
SiO ₂	40.01	38.32	12.67	.....	2.8
Al ₂ O ₃	2.54	2.66	12.59	4.80	8.7
Cr ₂ O ₃	0.16	0.16	.....	0.20	tr.
Fe ₂ O ₃	1.00	4.35	46.84	83.50	77.2
FeO.....	11.70	11.78	.....	.....	.....
MgO.....	39.90	36.22	1.26	.....	.....
CaO.....	1.68	2.74	0.04	.....	.....
Na ₂ O.....	1.07	0.16	.....	.....	.....
K ₂ O.....	0.52	0.06	.....	.....	.....
TiO ₂.....	.....	0.28	0.55	.....	.....
H ₂ O combined.....	1.10	3.38	15.32	10.18	11.4
Insoluble.....	.....	.....	10.73 ^a	1.70 ^a	.....
	99.68	100.11	100.00	100.48	99.6

^a The insoluble matter contains the chromic oxide in picotite.

In the Mayari ore, scales or needles which would correspond to the typical forms of goethite have not been observed, but as goethite is also believed to be at times massive or apparently amorphous the writer did not feel sure of its absence in the earthy and indefinitely flocculent mixtures to be seen in the ore when puddled with water under the microscope. Calculations based on this molecule therefore did not seem beyond the range of possibility. Professor Lacroix uses the special name of stilpnosiderite (an old term for a variety of limonite) for the colloid having the composition of limonite. Turgite, however, he concludes is a mixture of hematite and stilpnosiderite, such that the formula $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ is obtained. If a mixture corresponding to four hematite molecules and one limonite chanced to be analyzed, the formula of turgite would result. In French Guinea the same darkening of color is noted in the surface layer, and it is explained by Professor Lacroix as due to the dehydration of the limonite (stilpnosiderite) by the sun. The only two demonstrated hydrates of alumina in nature are believed by Professor Lacroix to be diasporé, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and gibbsite (or hydrargillite), $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. Both are known crystallized; but both appear to form colloids as well. Bauxite is not believed to be of definite composition, but to be a mixture of these two. So far as study of the Mayari ore has gone, no crystallized diasporé or gibbsite has been seen. We therefore appear to be dealing with a mixture of colloids and no inaccuracy of serious moment was involved in using the bauxite formula, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, which is practically a combination of one diasporé and one gibbsite. With superabundant combined water, an excess of gibbsite would be inferred, as in analysis II of the lean ore above. An extended literature has developed in recent years regarding the aluminum hydrates, but such new contribution to general knowl-

edge as it contains is chiefly based on the conceptions of colloids. The papers are, however, hardly germane for further citation here.

A very recently discovered body of ore, similar in all respects to the Mayari deposits, has been reported from the northern portion of the island of Mindanao in the Philippines. Its nature seems to have been first recognized by H. F. Cameron¹ of the Government Engineers' staff, who had had earlier experience in the Mayari district in Cuba. The ore is a surface mantle produced by the tropical weathering of basic, igneous rocks in latitude 9 N. Reserves of 800,000,000 tons are estimated and the following analysis is given:

SiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	NiO	H ₂ O	S	P	Total
1.20	12.20	1.28 ^a	77.71 ^b	none	7.63	tr.	tr.	100.02

^a 1.28 Cr₂O₃ = 0.88 Cr.

^b 77.7 Fe₂O₃ = 54.4 Fe.

This one sample is richer than the run of the Mayari ores by the year (48 to 49 Fe), but one would need to be assured by extensive boring and sampling that so high a yield as 54.4 could be maintained for long periods.

The thanks of the writer are due in full measure to Charles F. Rand, President of the Spanish-American Iron Co., for every facility to study the ores. Acknowledgments should also be made to the officers of the company at Felton and Woodfred for many courtesies.

¹ Personal letter to the writer.