

# THE OXIDATION OF METEORIC IRONS WITH COMPARATIVE DESCRIPTIONS OF TWO NEW EXAMPLES OF MAGNETIC IRON OXIDES FROM TERRESTRIAL SOURCES

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## INTRODUCTION

Meteorities are divided into three major subdivisions, briefly the irons, the stony irons, and the stones. These differ from each other in degree rather than in kind and all contain more or less iron in the form of a crystalline metallic alloy with an average content of nickel not far from 10 per cent. The nickel is accompanied by only minor amounts of other elements, which include cobalt, copper, phosphorus, and platinum, usually in amount in the order named. Many such have been seen to fall, and from the number and weight of those known to have reached the earth in historic times it is certain that the total number which has fallen throughout geologic ages is enormous. However, like a lump of ordinary manufactured iron or steel exposed to atmospheric agencies, the metal of meteorites is subject to rapid alteration and their forms and identities are soon lost by mechanical and chemical disintegration. The meteorities are even more prone to chemical alteration, under the influence of the weather, because of the fact that they almost invariably contain some ferrous chloride, which hastens the change, as has been pointed out repeatedly. Of those iron meteorites which have fallen during geologically recent times the very latest have almost invariably a very thin oxide scale or crust. Those of intermediate age may consist of oxide masses inclosing cores of unaltered metal, while the older are entirely oxidized and hydrated and their provenance is only established by the presence of minor constituents or an inherited structure.

The earliest published reference to the nature of the oxidation products arising from the alteration of meteoric iron appears to have been

the statement by Merrill<sup>1</sup> that, in the oxidation of the Admire pallasite "the first product of the oxidation of the iron is not limonite, but a highly lustrous—on polished surfaces, blue—material which crushes down readily to a fine brown magnetic powder." While this was an original observation of some importance, Doctor Merrill overgenerously credited priority to J. Lawrence Smith, while the paper by Smith cited deals not with the natural products of oxidation but with the properties of the oxide prepared from the metal of meteoric irons in the laboratory. The attention of the present writer has from time to time been directed to the subject of the oxidation products of meteorites through work under Doctor Merrill's direction and received impetus through examination of the Coldwater, Kans., material described below and considered by him to be in all probability a completely oxidized meteoric iron. This shortly preceded the appearance of a paper by Sosman and Posnjak<sup>2</sup> on "ferromagnetic ferric oxide, artificial and natural." Almost simultaneously with the appearance of the latter paper there was received at the United States National Museum a very striking example of magnetic ferric oxide, the polarized iron ocher from Durant, Okla., as described in detail below. In previous descriptions of oxidized meteorites it has been assumed that the iron oxidized first to magnetite which gradually went over to limonite on further oxidation and hydration despite the very low content of ferrous oxide shown by analysis. In describing the "shale balls" of the Canon Diablo locality Farrington assumed to account for this the presence of magnetites into which the nickel, cobalt, and copper occupied the place of the bivalent iron of ordinary magnetite. The emphasis placed by Sosman and Posnjak on the fact that magnetite might readily oxidize to an anhydrous ferric oxide retaining the magnetic properties of the magnetite suggested the propriety of a further investigation into the nature of the material formed from meteoric iron. There are accordingly considered in detail below the Canon Diablo shale balls; the Coldwater oxidized iron and the scale from the York, Greenland, iron. In comparison there are described the Durant, Okla., ocher and a martite iron ore typical of the great deposits of Durango, Mexico.

#### PURPOSE OF THE INVESTIGATION

The problems presented for solution were briefly:

First. Does meteoric iron oxidize to fine-grained magnetite as the first product of atmospheric weathering?

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<sup>1</sup> George P. Merrill. A newly found meteorite from Admire, Lyon County, Kans. Proc. U. S. Nat. Mus., vol. 24, p. 910, 1902.

<sup>2</sup> R. B. Sosman and Eugene Posnjak. Journ. Wash. Acad. Sci., vol. 15, pp. 329-342, August, 1925.

Second. Does such magnetite, if formed, further oxidize to anhydrous ferric oxide of ferromagnetic character?

Third. Were there formed any nickel or other analogues of magnetite of the type of trevorite ( $\text{NiO} \cdot \text{Fe}_2\text{O}_3$ ) in the process of oxidation?

Fourth. Could a second ferromagnetic ferric oxide similar in atomic grouping or space lattice to metallic iron be formed without the intermediate formation of magnetite through the oxidation of crystalline metallic iron?

Fifth. Could intermediate stages of ferrous chloride (lawrencite) or of ferric chloride (molysite) influence the space lattice or the magnetic properties of the oxide formed?

Sixth. Do terrestrial examples, as known, compare with iron meteorites in the nature of their oxidation products?

#### SUMMARY OF CONCLUSIONS

The results attained and the conclusions deduced therefrom may, in brief, be tabulated as answers to the above queries:

First. Magnetite forms only in relatively small amounts as a transitory and unstable stage in the oxidation.

Second. The magnetite and the iron itself rapidly change to limonite or ferric hydrate without the intervention of appreciable amounts of ferromagnetic ferric oxide.

Third. The formation of trevorite ( $\text{NiO} \cdot \text{Fe}_2\text{O}_3$ ) and of analogous compounds of cobalt and copper—persistent ferrites—seems to be established and that these are strongly ferromagnetic and account for the magnetic properties of the whole.

Fourth. There is no evidence in support of the assumption that any ferromagnetic oxide of any kind is formed except the ferrites of bivalent oxides above mentioned.

Fifth. Owing to the lack of evidence and the unstable nature and deliquescent character of the chlorides it is doubtful that they have any action other than to promote the formation of amorphous hydrated ferric oxide from the iron.

Sixth. The terrestrial occurrences of ferromagnetic ferric oxide are different in composition and origin and present no analogies to the oxidation of meteorites.

#### ACKNOWLEDGMENTS

The writer is indebted to Doctor Merrill for the free use of material and data and for the time and opportunity to prosecute the present investigation. To Dr. Eugene Posnjak he is indebted for free discussion and advice regarding the points involved and to Mr. Forrest A. Gonyer for much valuable assistance in the preparation and analysis of the samples studied.



## CANON DIABLO SHALE BALLS

Among the most widely known and thoroughly studied examples of oxides derived from the alteration of meteoric iron are the so-called "iron shale" masses which are common around the rim of the meteoric crater of Coon Butte near Canon Diablo, Ariz. These masses of iron oxide are scattered concentrically around the crater for a distance of several miles from the rim.<sup>3</sup> The origin of the smaller masses of the "shale" is inferred from the fact that they all contain nickel and cobalt and have similar form and occurrence to larger masses which either include cores of unoxidized meteoric iron or scattered plates of the nickel-iron phosphide schreibersite or show on polished surface, even when completely oxidized, ghostlike outlines of the widmanstätten structure of octahedral meteoric iron.

The oxides from this source have been described by Farrington,<sup>4</sup> who gives the following analysis, made by H. W. Nichols:

*Analysis of "iron shale"*

Fe <sub>2</sub> O <sub>3</sub> .....	74.63
FeO.....	3.91
NiO.....	9.79
CoO.....	.49
CuO.....	-----
CaO.....	1.27
Al <sub>2</sub> O <sub>3</sub> .....	.05
SiO <sub>2</sub> .....	1.09
CO <sub>2</sub> .....	.35
P.....	.10
C.....	.15
Cl.....	.08
H <sub>2</sub> O.....	8.02
	99.93

In the interpretation of the above results, Farrington assigns all of the nickel and cobalt oxides to form "magnetite" along with the ferrous iron, arriving at the following composition:

Limonite.....	52.99
Magnetite.....	42.39
Schreibersite.....	.64
Graphite.....	.15
Lawrencite.....	.14
Aragonite.....	.80
Andradite.....	2.45
Quartz.....	.21
	99.77

<sup>3</sup> See George P. Merrill. The meteor crater of Canyon Diablo, Ariz., its history, origin, and associated meteoric irons, Smithsonian Misc. Coll., vol. 50, pp. 461-498, particularly pp. 484-487, 1908.

<sup>4</sup> O. C. Farrington. Analysis of "iron shale" from Coon Mountain, Ariz. Amer. Journ. Sci., vol. 22, pp. 303-309, 1906.

Assuming 42.39 per cent of iron, nickel, and cobalt ferrites, all strongly magnetic, in fine distribution through the stone, Farrington explains the magnetic character of the material as assignable to this cause.

Barringer and Tilghman<sup>5</sup> had previously described these shale balls and had, without giving analyses, concluded that the central cores of unoxidized metallic iron were surrounded by a crust of magnetic iron oxide which they presumed to be magnetite, surrounded by an outer scaly and peeling crust of hydrated oxide or limonite. Many of the masses are described by these authors as containing green nickel hydroxide scattered through their mass. No such green nickel compound was observed in the material examined by Farrington.

Barringer and Tilghman concluded that the magnetic oxide or magnetite crust was formed while the meteorites were passing through the atmosphere and that this magnetic oxide was later decomposed to limonite by atmospheric weathering. Farrington dissents from this opinion and assigns all of the oxides to long weathering of the metal. The latter seems the more reasonable view in consideration of the thinness of the crust visible on all meteorites known to have fallen within historic times.

Wirt Tassin<sup>6</sup> analyzed and described examples of the iron shale, his first analysis being from the crust of a shale ball having a metal core, while the second is of a platy mass of iron oxide having a structure thought to be due to schreibersite. These analyses gave the following results:

*Analyses of shale balls by Tassin*

	1.	2.
Fe <sub>2</sub> O <sub>3</sub> .....	78.82	81.07
FeO .....	.65	.00
NiO .....	8.85	4.66
CoO .....	.39	.00
MgO .....	.02	1.00
SiO <sub>2</sub> .....	.76	1.47
S .....	.01	.00
P .....	.20	.09
Cl .....	.03	----
C .....	.10	----
H <sub>2</sub> O .....	10.00	12.81
	<u>99.83</u>	<u>100.10</u>

These results differ from those of Farrington, above, and of the writer, below, in the very low ferrous iron content of the one and the

<sup>5</sup> D. M. Barringer and B. C. Tilghman. Proc. Phila. Acad. Nat. Sci., vol. 57, pp. 861-914, 1925. Amer. Journ. Sci., June, 1906, p. 402.

<sup>6</sup> Wirt Tassin: See George P. Merrill and Wirt Tassin. Contributions to the study of the Canyon Diablo meteorites. Smith. Misc. Coll. (quarterly issue), vol. 50, pt. 2, pp. 213-214, 1907.

absence of this constituent in the latter. If we interpret Tassin's results in mineralogic terms, the following results are obtained:

	1.	2.
Limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ )-----	69.27	88.73
Magnetite ( $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ )-----	2.69	None.
Trevorite ( $\text{NiO} \cdot \text{Fe}_2\text{O}_3$ )-----	27.53	14.50
Cobalt trevorite ( $\text{CoO} \cdot \text{Fe}_2\text{O}_3$ )-----	1.26	----
Schreibersite ( $\text{Fe}_2\text{NiP}$ )-----	1.30	.58

There is no excess of  $\text{Fe}_2\text{O}_3$  in the above interpretation. In fact there is not quite enough shown by either analysis to use up all of the water as a limonite with the formula above used for this mineral. Limonite is an amorphous material having the composition  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , usually with approximately the additional amount of water necessary to approximate the formula above used. This mineralogic interpretation is of interest in comparison with Tassin's discussion of his results. He disagrees thoroughly with Farrington's interpretation and regards the shale as made up essentially of limonite and some turgite, saying that this opinion is based upon the physical characters of the shale in preference to data derived by the arbitrary combining of the bivalent bases to form ferrites. Tassin says positively that, in the portions analyzed by him, the magnetic character of the samples was certainly due to the relatively large amount of unaltered schreibersite present and which was plainly visible in many sections of the iron shale. The inconsistency of this reasoning is patent from his analytical figures. His results for phosphorus are equivalent to only 1.30 per cent of schreibersite in the first sample and 0.58 per cent in the second. To these small amounts certainly can not be credited the strong magnetism of the samples.

The specimen supplied for examination to the writer by Doctor Merrill is a nodule of blackish-brown color and brecciated appearance. Its main mass is composed of hard lustrous brownish to blue-black homogeneous-appearing material of submetallic luster. The cracks and interstices are filled with a little yellow ocher and pinkish material of clayey appearance which contains some carbonate. When crushed to pass 80 mesh the powder is near Mars brown, Ridgway (13'*m*) and is entirely picked up with an ordinary horse-shoe hand magnet. The material is not polarized. Fairly large chunks of the unground material are easily lifted by the magnet. The partial analysis was made by the following procedure. One-half gram of the sample was dissolved in boiling 1:3 sulphuric acid in an iron reduction flask through which a current of  $\text{CO}_2$  was passed. After titration for ferrous iron, the whole solution was reduced by hydrogen sulphide, the hydrogen sulphide expelled with carbon di-



oxide and again titrated for total iron. The insoluble was filtered out, ignited and weighed, after which citric acid was added to the solution and the nickel determined with dimethylglyoxime. Water was determined as loss on ignition of a separate portion and corrected for oxidation of the ferrous iron. The results were as follows:

Insoluble .....	0.36
Fe <sub>2</sub> O <sub>3</sub> .....	79.50
FeO .....	3.68
NiO .....	6.44
H <sub>2</sub> O .....	8.19
Undetermined .....	1.83
	100.00

Mineralogically combined, following the same assumptions as used in the interpretation of Tassin's analyses above, the figures give the following:

Limonite (2Fe <sub>2</sub> O <sub>3</sub> .3H <sub>2</sub> O) .....	56.73
Magnetite (FeO. Fe <sub>2</sub> O <sub>3</sub> ) .....	11.86
Trevorite (NiO.Fe <sub>2</sub> O <sub>3</sub> ) .....	20.03
Fe <sub>2</sub> O <sub>3</sub> (excess) .....	8.36
Insoluble (SiO <sub>2</sub> etc.) .....	.36
	97.34

In the absence of appreciable amounts of schreibersite and of any residual unoxidized metallic iron, the magnetism exhibited by the material must be attributed to the oxides themselves. The 8.36 per cent of free Fe<sub>2</sub>O<sub>3</sub> indicated above is very probably not present as such, but is in the limonite, the variability of that mineral in water content making water a very unsatisfactory index to the amount of hydroxide present. The ferrous oxide, equivalent to only 11.86 per cent of ordinary magnetite, is not sufficient to account for the degree of magnetic susceptibility. If the nickel oxide be combined as ferrite, it adds 20.03 per cent of trevorite, giving a total of 31.89 per cent of magnetic ferrites. The excess of Fe<sub>2</sub>O<sub>3</sub> may or may not be the ferromagnetic form of this compound, but its amount is small enough to be disregarded, especially as it is quite probably limonite, as stated above. If, however, the existence of magnetic nickel ferrite is not admitted, it is necessary to assume the presence of ferromagnetic Fe<sub>2</sub>O<sub>3</sub> to account for the properties of the material.

There is considerable evidence in support of the assumption of the existence of nickel ferrite in this material. J. Lawrence Smith<sup>7</sup> as long ago as 1875 pointed out certain magnetic peculiarities of ferric

<sup>7</sup>J. Lawrence Smith. Singular anomaly of the sesquioxide of iron as prepared from meteoric iron. Amer. Chemist, vol. 5, 1875, pp. 356-358; Chem. News, vol. 31, 1875, pp. 210-212; Compt. Rend., vol. 53, 1875, pp. 301-304.

oxide prepared by the precipitation of the iron of solutions of meteoric iron. These results were summarized as follows:

1. The artificial hydroxide of iron, prepared from pure iron and dried at low temperatures, is attracted feebly by the hand magnet, but loses this property at and below red heat.

2. Ferric oxide, prepared in the ordinary manner, from solutions of meteoric iron and dried at a low temperature, acts similarly to the ordinary oxide, but becomes decidedly magnetic on being heated from 400° C. to a red heat.

3. The ferric oxide from ordinary iron, mixed with nickel or cobalt or both, from whatever source, exhibits magnetic properties identical with that from meteoric iron.

4. Ferric oxide from meteoric iron, freed entirely from traces of nickel and cobalt, corresponds to the ordinary ferric oxide in its behavior to the magnet.

5. Ferric oxide made from iron mixed with copper resembles that from meteoric iron.

6. Ferric oxide made from iron mixed with manganese, gold, platinum, zinc, or calcium differs in no way from the pure ferric oxide in its behavior to the magnet.

By reducing the oxides in hydrogen and analyzing the resultant metal, Smith found 2 or 3 per cent of cobalt, nickel, or copper in the magnetic oxides, and he expresses the opinion that these in some manner act to reduce a small part of the ferric iron to magnetic oxide. Only in a footnote does he mention that it has been suggested to him by Prof. F. C. Chandler that the nickel, cobalt, and copper oxides present may form, with ferric oxide, a magnetic oxide as  $\text{NiO.Fe}_2\text{O}_3$ , analogous to  $\text{FeO.Fe}_3\text{O}_2$ .

It is clear that the magnetic character of the ignited oxides is due to the formation of ferrites. In the analysis of meteoric irons it is very difficult to quantitatively separate the nickel and cobalt by precipitation of the iron with ammonia even when the precipitation is repeated several times. With a single precipitation the nickel is largely held by the precipitate, and it is not uncommon to find more nickel in the second ammoniacal filtrate than in the first.

Artificially prepared ferrites of copper, nickel, and cobalt have been found to be strongly ferromagnetic<sup>8</sup> while the analogous ferrites of  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{Cu}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{BaO}$ ,  $\text{MgO}$ ,  $\text{ZnO}$ , and  $\text{PbO}$  were nonmagnetic.

Natural and relatively pure nickel ferrite of terrestrial origin from South Africa has been recently described by Crosse<sup>9</sup> and

<sup>8</sup> S. Hilpert and P. Beyer. *Über eisenoxyduloxyside und eisenoxyde*. Ber. Deut. Chem. Ges., vol. 42, pt. 4, 1909, pp. 4893-4895.

<sup>9</sup> A. F. Crosse. A rich nickel ore. Journ. Chem. Met. and Mining Society of South Africa, vol. 21, p. 126, 1921.



Walker,<sup>10</sup> who makes it a distinct species, a nickel equivalent of magnetite with the formula  $\text{NiFe}_2\text{O}_4$  or  $\text{NiO}\cdot\text{Fe}_2\text{O}_3$ . The mineral is black, very strongly magnetic, and has a metallic luster, hardness about 5 and specific gravity 5.165.

These ferrites of nickel, copper, and cobalt are also referred to by Frebold and Hesemann,<sup>11</sup> in their paper on the iron oxides which is further referred to below.

The natural trevorite yielded the following results upon analysis:

$\text{Fe}_2\text{O}_3$ -----	66.24
$\text{FeO}$ -----	1.96
$\text{NiO}$ -----	29.71
$\text{MgO}$ -----	.24
$\text{SiO}_2$ -----	1.40
$\text{H}_2\text{O}$ -----	.36
	99.91

RESIDUAL MASS OF IRON OXIDES, PRESUMABLY METEORIC, FROM  
COLDWATER, COMANCHE COUNTY, KANS.<sup>12</sup>

The mass, upon which the following discussion and description are based, was submitted for examination to Dr. George P. Merrill by Prof. H. H. Nininger, of McPherson College, Kansas. If meteoric it was obviously of an old fall regarding which no historical data were to be had. The severed mass, weighing 18.545 kilos, had the appearance of a somewhat flattened septarian nodule, the surface of which had been checked by weathering and oxidation. Tests showed the presence of nickel, but a sawing of the mass through the middle showed it to be composed essentially of iron oxides, compact externally but more porous within with no structure indicating meteoric origin, although there were revealed a few specks of minute size of a material of tin white color and high metallic luster. Further slicing, however, revealed other surfaces traversed by platy areas of softer and more porous nature than the surrounding material which were arranged in lines giving triangular intersections reminiscent of the medium coarse octahedral structure of meteoric irons. Since the evidence seemed to suggest a meteoric origin for the mass of iron oxides of which the individual was composed it was submitted for analysis to Dr. J. Edward Whitfield. Doctor Whitfield's analysis gave the following results:

<sup>10</sup>Thos. L. Walker. Trevorite a distinct mineral species. Contrib. to Canadian Mineralogy. Univ. Toronto Geol. Ser. No. 16, pp. 53-54, 1923.

<sup>11</sup>G. Frebold and J. Hesemann. Über magnetischen und nichtmagnetischen eisenglanz, etc. Centralbl. Min. Abt. A. No. 10, pp. 314-321, 1926.

<sup>12</sup>The writer is indebted to Doctor Merrill for the notes on the present material and for the analysis by Doctor Whitfield.

*Analysis of Coldwater Meteorite*

By J. E. WHITFIELD

Insoluble	3.361
SiO <sub>2</sub>	2.910
Al <sub>2</sub> O <sub>3</sub>	1.610
Fe <sub>2</sub> O <sub>3</sub>	81.595
P <sub>2</sub> O <sub>5</sub>	.621
CuO	.038
NiO	1.999
CoO	.113
MgO	.331
SO <sub>3</sub>	.219
H <sub>2</sub> O	7.205
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	100.002

Disregarding the minor constituents and calculating the oxides on a combined basis this analysis gives:

Limonite (2Fe <sub>2</sub> O <sub>3</sub> .3H <sub>2</sub> O)	49.89
Magnetite (FeO.Fe <sub>2</sub> O <sub>3</sub> )	None.
Trevorite (NiO.Fe <sub>2</sub> O <sub>3</sub> )	6.22
Co trevorite (CuO.Fe <sub>2</sub> O <sub>3</sub> )	.35
Cu trevorite (CuO.Fe <sub>2</sub> O <sub>3</sub> )	.12
Hematite (Fe <sub>2</sub> O <sub>3</sub> )	34.36
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	90.94

Since the above analysis showed no value for ferrous iron it was not known whether the state of oxidation had been directly determined or whether the whole of the iron had been presumed to be in the ferric state. Another portion of the specimen was accorded partial chemical examination in the United States National Museum laboratory. This material was blackish-brown in color, compact, and with a somewhat metallic luster, especially on polished surfaces. Fairly large pieces are easily lifted by a hand magnet. The result of this partial analysis was as follows:

Insoluble	5.02
Fe <sub>2</sub> O <sub>3</sub>	75.12
FeO	1.77
NiO	4.32
H <sub>2</sub> O	12.38
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	98.61

The last analysis, interpreted in mineralogic terms gives the following:

Magnetite (FeO.Fe <sub>2</sub> O <sub>3</sub> )	5.70
Trevorite (NiO.Fe <sub>2</sub> O <sub>3</sub> )	13.44
Limonite (2Fe <sub>2</sub> O <sub>3</sub> .3H <sub>2</sub> O)	85.86
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	105.00

It will be seen from the last total that there is not sufficient ferric iron to form limonite with all of the water if the formula  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$  is assumed for the latter. Limonite is variable in water content, however, it being the amorphous equivalent of goethite with the formula  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O} \cdot n\text{H}_2\text{O}$ . The difference in the water content of this and Whitfield's results suggest that he dried his sample at or near  $100^\circ$  before analysis. It is obvious that enough water is present in the last sample to form limonite with all of the ferric oxide so that the magnetic susceptibility of this portion at least must be credited to the 19.14 per cent of trevorite and magnetite shown by the last tabulation.

The powder obtained by grinding the Coldwater material to pass an 80 mesh sieve was between cinnamon brown (XV-15'-*k*) and Prout's brown (XV-15'-*m*) Ridgway in color. By working over it with a hand magnet it was found to be attracted 88.3 per cent, unattracted 11.7 per cent. The attracted and unattracted portions were identical in color and appearance.

#### OXIDIZED OUTER CRUST OR SCALE FROM THE YORK METEORITE

For comparison with the foregoing a sample of the scale from the York, Greenland, meteoric iron consisting of flat brown flakes was examined. The flakes were up to 3 centimeters broad by 1 to 3 millimeters thick and, although consisting principally of oxides, they showed metallic particles upon grinding. The metal was removed in large part by screening out the flattened particles from the agate mortar, and only a small part of the metal passed through an 80-mesh sieve. The powder which passed 80 mesh was separated into magnetic and nonmagnetic portions with a horseshoe magnet. Both these powders were about Mars brown (13'*m*) Ridgway, in color. The proportions of the rough separation were as follows:

	Per cent
Metal.....	11.4
Magnetic.....	85.0
Nonmagnetic.....	3.6
	100.0

Only the magnetic oxide was further examined, and this, partially analyzed by the method of procedure above, gave the following results:

	Per cent
Insoluble.....	1.86
$\text{Fe}_2\text{O}_3$ .....	65.97
FeO.....	9.52
NiO.....	6.78
$\text{H}_2\text{O}$ .....	12.44
	96.57



These figures are less satisfactory for mineralogical interpretation as there was unquestionably some metallic iron in the material analyzed, increasing the ferrous iron content by its amount as well as by the hydrogen generated by its solution in acid. The results interpreted in combination are, however:

	Per cent
Magnetite ( $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ )-----	30.68
Trevorite ( $\text{NiO} \cdot \text{Fe}_2\text{O}_3$ )-----	21.09
$\text{Fe}_2\text{O}_3$ -----	30.50
$\text{H}_2\text{O}$ -----	12.44
Insol-----	1.86
	96.57

Since there is much too little remaining  $\text{Fe}_2\text{O}_3$  to form the compound  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$  with all of the water, these constituents are stated separately above. Calculation shows the  $\text{Fe}_2\text{O}_3$ :water ratio to be 1:3.82. There can thus be represented in this meteorite scale no anhydrous  $\text{Fe}_2\text{O}_3$  either magnetic or nonmagnetic. The magnetic content indicated above, even were it corrected for the effect of metal in the powder, is much higher than in the two preceding examples, a condition which may depend to a considerable degree to the peculiarities of weathering under the climate of Greenland as compared with the climates of Arizona and Kansas. The magnetite and the trevorite, together amounting to over 50 per cent are ample to explain the magnetic properties of the material.

#### FERROMAGNETIC POLARIZED ANHYDROUS IRON OCHER FROM OKLAHOMA

In a lot of materials received for examination from Mr. O. C. Duncan of Durant, Okla., was a specimen of impure oxide of iron which proved to be of unusual interest. The sample was accompanied by a number of other materials, chiefly bentonitic clays, and was said to have come from near Durant, but no additional information regarding the occurrence has been received.

At first observation the material has the appearance of an ordinary compact red-brown ocher. Its color, both in mass and finely ground, is cinnamon rufous (11 $\frac{1}{2}$ ) Ridgway and the mineral is entirely dull and lusterless. It forms small rounded masses up to 1 centimeter across which are frangible enough to be broken with the fingers and are easily crushed in an agate mortar by only moderate pressure of the pestle. Ordinarily this would have been reported as a common ocher but it was observed that the grains had a strong tendency to cohere and the finer powder attached itself to larger grains in mossy aggregates after the manner of lodestone. The material was not only highly ferromagnetic but it was also strongly polarized. Micro-

scopic examination showed the sample prepared for analysis to contain a considerable amount of finely granular quartz as the only notable impurity. The partial analysis made in the museum laboratory gave the following results:

*Analysis of ferromagnetic ocher*

Insoluble (quartz) -----	17.80
Fe <sub>2</sub> O <sub>3</sub> -----	72.20
FeO-----	1.64
Al <sub>2</sub> O <sub>3</sub> -----	3.12
CaO-----	Trace.
NiO-----	None.
H <sub>2</sub> O above 110°C-----	2.80
H <sub>2</sub> O below 110°C-----	1.10
Undetermined-----	1.34
	100.00

Mineralogically interpreted as in the above, this analysis gives:

Quartz-----	17.80
Fe <sub>2</sub> O <sub>3</sub> -----	46.07
Limonite (2Fe <sub>2</sub> O <sub>3</sub> .3H <sub>2</sub> O)-----	26.38
Magnetite (FeO.Fe <sub>2</sub> O <sub>3</sub> )-----	5.29
Al <sub>2</sub> O <sub>3</sub> -----	3.12
Loss-----	1.34
	100.00

This interpretation indicates that not more than 5.29 per cent of magnetite can be present so that the strongly magnetic and polarized character of the material can not be attributed to this constituent either as mechanically admixed magnetite or as magnetite present in solid solution in hematite.

This appears to be a rather good example of ferromagnetic ferric oxide of natural origin. The 3.90 per cent of water tabulated in the analysis actually represents loss on ignition and may include some carbon dioxide or other volatile material. Although this amount of water is equivalent to 26.38 per cent of limonite of an assumed composition of 2Fe<sub>2</sub>O<sub>3</sub>.3H<sub>2</sub>O, it is doubtful that any such amount of limonite is present. Any material of such fine grained structure is bound to hold some hygroscopic water and the alumina indicated in the analysis is probably present as a clay which may be highly hydrous.

Although no information as to the occurrence or origin of this material could be obtained it seems unquestionably native and not produced by the heating or other treatment of any of the other forms of iron oxide. The subject of ferromagnetic ferric oxide has been thoroughly discussed by Sosman and Posnjak,<sup>13</sup> their studies being

<sup>13</sup> Robert B. Sosman and E. Posnjak. Ferromagnetic ferric oxide, artificial and natural. Journ. Wash. Acad. Sci., vol. 15, No. 14, pp. 329-342, Aug. 19, 1925.

based largely upon the artificially prepared material, although they describe one natural example. The materials of their experiments were obtained by shaking precipitated magnetite with oxidizing agents at ordinary temperatures. They found that heating destroys the magnetic character of ferromagnetic ferric oxide and that hematite can not be converted into the magnetic modification of the compound. It was also found that dehydration of goethite and limonite would yield only nonmagnetic  $\text{Fe}_2\text{O}_3$ , although lepidocrocite, when dehydrated, did yield the magnetic  $\text{Fe}_2\text{O}_3$ .

The example of natural magnetic ferric oxide described by Sosman and Posnjak was also polarized. It was in the form of a light chocolate-brown powder containing yellowish brown specks and came from a gossan deposit at Iron Mountain in the Shasta County copper district, Calif., where it was collected by Drs. L. C. Graton and B. S. Butler. This material upon analysis gave the following:

Insoluble.....	1.80
$\text{Fe}_2\text{O}_3$ .....	85.30
FeO.....	2.40
CaO.....	Trace.
$\text{H}_2\text{O}$ to red heat.....	3.10
Other volatile matter.....	2.50
	95.10

No discussion of the probable origin of this material is given by these authors beyond the statement that it is in a gossan and contains some pyrite. They suggest the advisability of giving the material a new mineral name but consider it desirable, before so doing, to have a type specimen less contaminated with impurities.

#### MARTITE FROM CERRO MERCADO, DURANGO

In connection with his studies of the iron ores of the Cerro Mercado, near the city of Durango, Durango, Mexico, Dr. W. F. Foshag found material, evidently martite since it showed the crystal form of magnetite yet revealed little magnetite on polished surface. This had a magnetic susceptibility in excess of that which could be explained by the visible magnetite inclusions. For comparison with the ferromagnetic ocher from Oklahoma and the oxidized meteoric irons, a sample was briefly examined.

The specimen, from "Penasco de la Industria" is a heavy cellular mass of reddish black color and metallic luster. The cavities are lined with lustrous and brilliant octahedral crystals which are thinly coated with small amounts of various later minerals. When ground to pass 80 mesh the color of the powder is chocolate (7''-m) Ridgway. Upon being worked over with a hand magnet 78 per cent was separated as attracted while the remaining 22 per cent was



unattracted. No color difference could be detected between the attracted and the unattracted portions.

The attracted portion was analyzed partially with the following results:

*Martite ore, Durango*

Insoluble.....	10.84
Fe <sub>2</sub> O <sub>3</sub> .....	80.72
FeO.....	2.58
H <sub>2</sub> O.....	1.36
Undetermined.....	4.50
	100.00

These figures, combined as previously, gave:

Quartz, etc.....	10.84
Magnetite.....	8.31
Limonite.....	9.42
Hematite.....	66.93
Undetermined.....	4.50
	100.00

The amount of magnetite indicated in this table is just about what can be observed in polished surfaces under the reflecting microscope so that this constituent is present in mechanical admixture and not in solid solution. This is not enough to explain the magnetic attraction exhibited by the whole material and it seems certain that a considerable portion of the ferric oxide above tabulated as hematite must be the ferromagnetic form. The martites have been carefully studied by Sosman and Hostetter<sup>14</sup> who found a number of martites which consisted of granular or fibrous aggregates of homogeneous material apparently contained ferrous iron in solid solution.

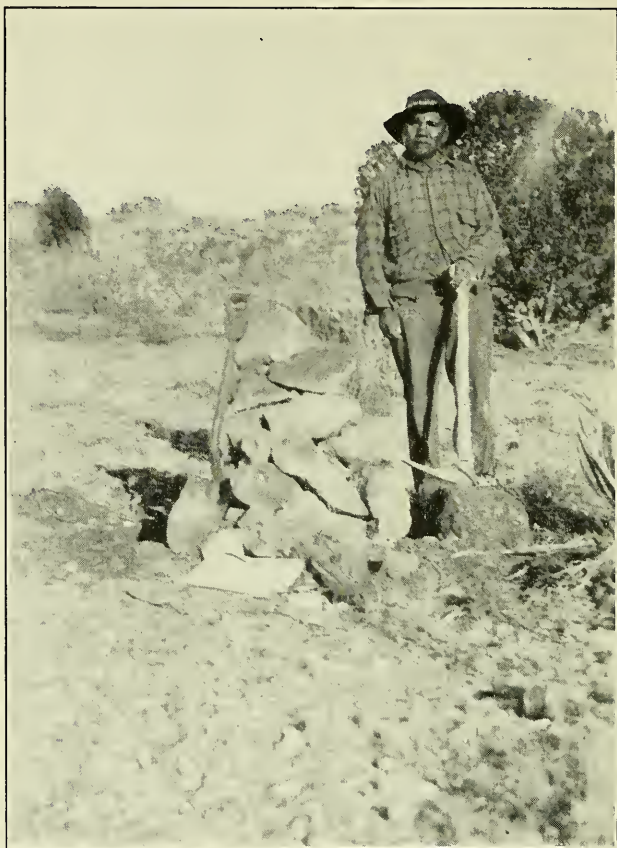
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<sup>14</sup>R. B. Sosman and J. C. Hostetter. The ferrous iron content and magnetic susceptibility of some artificial and natural oxides of iron. Bull. Amer. Inst. Min. Eng., No. 126, June, 1927.









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WALLAPAI METEORIC IRONS