SOME CONSTITUENTS OF METEORITE RUSTS

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I have stated elsewhere that the mineral composition of meteorite rusts is still unknown but that the magnetism suggests magnetite.[1] The presence of magnetite is further indicated by the observation of Krantz of octahedral and dodecahedral crystals in druzy pits in the oxide of Xiquipilco (Toluca), Mexico. He regarded these as magnetite.[2] I have myself observed similar crystals on the oxide coating of an iron of uncertain origin, but which is very probably a member of the same fall. Meunier treated the rust of this meteorite (Toluca) with bichloride of mercury and hydrochloric acid and analyzed the residue. This contained (Fe,Ni)O and Fe_2O_3 in almost the exact proportions for magnetite.[3] It is thus almost certain that this meteorite rust contains magnetite, or perhaps a mixture of magnetite and trevorite, the only objection being that the specific gravity of 4.89 is somewhat low for magnetite which averages about 5.17. This, of course, does not prove that magnetite is always present in such oxides, but it does show that it can occur if FeO is present. Even if FeO is absent, trevorite could probably be formed from the NiO which is present.

I have to report a new analysis of the oxide of the Xiquipilco meteorite made by G. D. Van Arsdale, assayer in Pasadena, California. In a sample of about two grams he reported:

Fe_2O_3	74.98%
FeO	9.00
(Ni+Co)O	5.15
P	0.13
S	trace
Loss at 110°C.	0.48
Ignition loss	4.68
Insoluble	0.88
	95.30

This analysis refers to the nonmetallic portion. The oxide as a whole contained 20.10% of metallic particles. The remaining 4.70% in the reported analysis is presumably undetermined minor constituents. There is one other analysis of this oxide by Pugh,[4] but all the iron is reported as

[1] *Popular Astronomy*, **47**, 93–97 (1939).

[2] *Pogg. Ann.*, **101**, 152–153 (1857).

[3] *Ann. chim Phys.*, 4th ser. **17**, 49–51 (1869). Incidentally, I have seen an analysis of terrestrial, nickeliferous magnetite with an almost identical composition.

[4] *Ann. d. Chem. u. Pharm.*, **98**, 385–386 (1856); Abstract in *Am. Jour. Sci.*, **24**, 295 (1857).

Fe_2O_3 and NiO is not reported at all. The agreement of the above with Pugh's analysis is not very close. Pugh found 25.04% of metal which was very rich in nickel (Fe:Ni=4.97), as compared with his analysis of the metallic core of the piece from which he obtained the rust (Fe:Ni=11.8). This is probably due to an enrichment in taenite as this is more resistant to oxidation than kamacite. The 20.10% of metallic particles reported by Van Arsdale contained a little oxide and was probably mostly metal as it appeared to be malleable instead of brittle as schreibersite would be. Pugh reported only 0.66% of this mineral, although it has been repeatedly reported in this as well as many other oxides. It has also been observed by the writer.

I have already reported on the frequent occurrence of zaratite as a green stain on meteorite rusts. In every case that I have examined, this stain has had the properties of zaratite, rather than nickel oxide or hydroxide as it is sometimes called. It would be natural to assume that it is derived from the metallic nickel in the meteorite. Some may have this origin, but while examining flakes of oxide from Xiquipilco I found evidence that it may possibly be derived from the $NiCl_2$ component of lawrencite. I observed globules like those formed by the exudation of lawrencite but instead of being brown or greenish, they were bright emerald green. Under the microscope they were isotropic like zaratite, but contained minute anisotropic specks. These could be unaltered lawrencite as $NiCl_2 \cdot 6H_2O$ is monoclinic. Microchemical tests showed the presence of chlorine and nickel, and acids produced an effervescence suggesting a carbonate. The action of moisture and carbon dioxide from the air on $NiCl_2$ might produce zaratite as follows:

$$3NiCl_2 + 9\ H_2O + CO_2 \rightleftarrows NiCO_3 \cdot 2Ni(OH)_2 \cdot 4H_2O + 6HCl.$$

Even if the equilibrium in a closed system should strongly favor the left side of the equation, the reaction could go to completion under natural conditions due to the volatility of the HCl.

It is certain that nickel is lost from the oxide in some form.[1] Whether or not this has any relation to the formation of zaratite is uncertain. The Toluca oxide, like most others, has lost some nickel. The NiO in Van Arsdale's analysis is equivalent to 4.04% metallic nickel. Most of the oxide used for this analysis was derived from the mass of uncertain origin already mentioned. This mass contained 7.29% Ni, which is typical of Xiquipilco.[5] Therefore, this oxide has lost about 3.25% Ni. The specific gravity of a large solid piece of this rust was 3.81.

A third constituent of meteorite rust is vivianite. I have never observed this myself, but it has been reported in the oxides of Santa Catha-

[5] *Popular Astronomy*, **45**, 103–106 (1937).

rina, Brazil[6], and Magura (Arva), Hungary.[7] As this mineral occurs naturally with such iron oxides as bog ore, where it is probably derived from phosphates in the soil, it is not clear whether its occurrence with meteorite oxides is another instance of this kind, or whether it is derived from the oxidation of schreibersite. Since schreibersite is very resistant and is found unaltered in the oxides of both Santa Catharina and Magura, I am inclined to doubt that it is an oxidation product. If it were, it should be more common as schreibersite is abundant in some oxides but as far as I can determine, vivianite has been reported only twice.

Since the oxidation of troilite forms sulphuric acid and iron oxide, it seems odd that no iron or nickel sulphates have been definitely reported. Since Lawrencite is retained in meteorites, soluble sulphates should be retained also. Nininger, digested one of his meteorodes[8] with tap water and the extract was found to contain the sulphate radical,[9] but unfortunately this radical might also have been present in the tap water. The only other possible sulphate containing mineral to be reported, so far as I am aware, is a basic nickel sulphate supposed to be analogous to copiapite. This was reported by Meunier in the oxide of Mezquital, Durango, Mexico.[10]

Since analyses of meteorite rusts almost always show more Fe_2O_3 than would be needed to form magnetite and trevorite from the FeO and NiO, and as the ignition loss must be mostly combined water, it seems inescapable that one of the hydrated oxides such as FeO(OH), is present. Hematite is also a possibility. Calcium carbonate has been reported but is undoubtedly derived from the soil.

[6] Daubrée, *Compt. rend.*, **85,** 1620 (1877).
[7] Clark, *Am. Jour. Sci.*, **15,** 16 (1853).
[8] *Trans. Kansas Acad. Sci.*, **32,** 63–67 (1929).
[9] *Am. Mineral.*, **23,** 536–537 (1938).
[10] *Compt. rend.*, **108,** 1028–1029 (1889).