On the possible existence of a nickel-iron constituent (Fe_5Ni_3) in both the meteoric iron of Youndegin and the meteoric stone of Zomba.

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[Read June 16, 1908.]

IN a paper read before the Mineralogical Society on April 10, 1894,[1] describing the details of the analysis of a meteoric stone which had been found at Makariwa in New Zealand, attention was called by the present author to the fact that the operation of extracting the nickel-iron by mercuric solution from the material separated from the powdered stone by the magnet was scarcely a terminable one; for even the twelfth extraction by means of a solution of mercuric ammonium chloride evidently contained an appreciable amount of colouring matter, while the colour of the extract indicated an increase in the proportion of the nickel. 'It was clear that one or other constituent of the attracted material was being only slowly dissolved, and that it was practically useless to push the operation farther. It was inferred from subsequent observations that the continued extraction was due to the presence of particles of nickel-iron and metallic nickel partially protected from the mercuric solution by adherent rust' (p. 293).

As the meteoric stone of Makariwa had been long buried in the earth and was evidently 'weathered', there was no doubt about the fact of the rusting. It was inferred that the iron had been more affected than the nickel during the weathering, and that the metallic iron was more quickly brought into solution than the metallic nickel by the mercuric liquid, the later extracts thus being richer than the earlier ones in the latter constituent (p. 319).

The same fact was observed, some years later, during the extraction of the nickel-iron from a meteoric stone which had fallen at Zomba, British Central Africa, and the observation was recorded in a paper

[1] Min. Mag., 1894, vol. x, p. 287.

read before the Society in the year 1900.[1] There was again no doubt that, as the extraction proceeded, the extract became richer in nickel, and that complete extraction would require too numerous a set of solvent operations to be practicable in the course of a quantitative analysis. But in this case the meteoric stone was a fresh one, not having been rusted through exposure to the weather.

The ten extracts obtained by means of the mercuric solution were collected into two sets.

1. The first set consisted of the seven extracts made before the attracted material had been heated to redness in a current of hydrogen; it gave the following numbers (p. 35):—

Nickel-iron. gram	Fe. gram	Ni(Co). gram	Percentage of Ni(Co).
0·3908	0·3423	0·0485	12·41

2. The second set consisted of three additional extracts obtained from the material which remained after the preceding seven extractions, the material being in each case first heated to redness in a current of hydrogen; this set gave (p. 35):—

Nickel-iron. gram	Fe. gram	Ni(Co). gram	Percentage of Ni(Co).
0·0442	0·0307	0·0135	30·54

The residue from these ten treatments was submitted to the action of hydrochloric acid and completely analysed; the numerical results were found to correspond to a large amount, namely 0·2529 gram, of silicates, admixed with a small amount, namely 0·0187 gram, of nickel-iron, the latter having the following composition (p. 35):—

Nickel-iron. gram	Fe. gram	Ni(Co). gram	Percentage of Ni(Co).
0·0187	0·0115	0·0072	38·50

The total amount of nickel-iron from the two sets and the residue was thus:—

Nickel-iron. gram	Fe. gram	Ni(Co). gram	Percentage of Ni(Co).
0·4537	0·3845	0·0692	15·25

The most simple and obvious interpretation of the above numbers is that the nickel-iron of the Zomba meteorite contains a constituent having 38·50 per cent. of nickel, and that the said constituent is less easily affected than the rest of the nickel-iron by the mercuric solvent.

[1] Min. Mag., 1901, vol. xiii, p. 1.

But the same kind of result having been regarded as due to slow rusting in the case of Makariwa, and it being conceivable in the case of Zomba that many of the particles of nickel-iron (some no doubt of so small a size that they become immediately oxidized on coming into contact with the air), might have quickly rusted during the filtrations, notwithstanding all the care that had been taken, the explanation given in the case of Makariwa was extended to that of Zomba, and it was pointed out (p. 35) that :—

'The variation of the percentage of Ni(Co) from 12·41 to 38·50, as the extraction proceeds, does not necessarily imply the existence of different alloys of nickel-iron in the material; it is probably a mere result of the easier oxidation of the iron than the nickel during exposure of the alloy to the atmosphere in the course of the operations.'

Having occasion lately to read through the paper once more, the author perceived that the explanation there suggested by him is untenable. It is true that some of the particles of nickel-iron are of so small a size that they must become oxidized, when magnetically separated from the powdered stone and exposed to atmospheric action. The explanation thus introduces a *vera causa*, and one which accounts both for the increase of the percentage of nickel during the first set of seven extractions, and for the increase of the extracted nickel-iron which follows the heating in a current of hydrogen; but the cause is not quantitatively sufficient to account for all the facts observed. For the iron rusted through atmospheric exposure of the nickel-iron particles after magnetic separation from the powder, or after being subjected to the mercuric solvent, must all have gone to the increase of the iron in the second set of extracts and in the final residue. The latter, therefore, should each have yielded smaller percentages of nickel than 15·25, the amount calculated to be present in the unrusted nickel-iron; on the contrary, they actually yielded larger percentages, namely 30·54 and 38·50 respectively.

The published explanation thus being untenable, the author is compelled to infer that the analytical operations had been more successful than he had thought possible at the time; that the rusting during the operations, instead of being appreciable, was really small in amount; that in the unrusted nickel-iron particles of the Zomba meteorite there is actually a constituent containing about 38·50 per cent. of nickel; and that this particular constituent is only slowly acted upon by the mercuric solution. In the original paper (p. 12) mention was made of the presence of bright metallic spangles among the grains of the silicate residue after the ten mercuric treatments; and it was suggested that they might be schreibersite, but merely because they were in small proportion and had remained undissolved by the mercuric solution; they were more probably thin plates of the hypothetical nickel-rich constituent.

And in a paper on the Youndegin (Western Australia) meteoric iron[1] read in 1899, only a few months before, the author had given an account of an apparently homogeneous constituent having almost precisely this percentage composition. From 97·25 grams of that meteoric iron there was obtained 0·087 gram of a constituent which was not easily soluble in very dilute hydrochloric acid; on analysis of 0·0621 gram it was found to contain 38·13 per cent. of nickel. The substance corresponded in mode of occurrence and chemical composition to the constituent of meteoric iron known as taenite, for which various percentages of nickel (from 13·02 to 48·61) had already been assigned. The compound Fe_5Ni_3 would contain 38·61 per cent. of nickel; having regard to the small amounts of metallic material analysed, namely, 0·0621 gram in the case of Youndegin and 0·0187 gram in the case of Zomba, the numbers 38·13 and 38·50, obtained for the Youndegin and Zomba constituent respectively, are remarkably close to the number 38·61 required by the above formula.

Recently Dr. S. W. J. Smith, of the Imperial College of Science and Technology, has brought to a conclusion a long series of investigations of the thermo-magnetic characters of the Sacramento meteoric iron[2]; and can only interpret his results by imagining the Sacramento meteoric iron to consist of plates of a nickel-poor constituent, kamacite (containing 6 or 7 per cent. of nickel), interrupted by plates of a nickel-rich constituent, taenite, containing about 27 per cent. of that metal.

But he infers from his thermo-magnetic observations that the taenite of the Sacramento iron is itself composite, and that it consists of kamacite admixed with a nickel-iron constituent containing not less than 37 per cent. of nickel; and he calls attention to the fact that, according to the analyses already published, taenite mechanically extracted from meteorites contains from 25 to 30, or approximately 27 per cent., of nickel, while taenite chemically extracted always contains a higher percentage, and in the case of Youndegin as much as 38·13 per cent. In only a single instance, that of Beaconsfield, the per-

[1] Min. Mag., 1899, vol. xii, p. 171.

[2] Philosophical Transactions, 1908, ser. A, vol. ccviii, p. 21.

centage of nickel in the corresponding thin plates has been found to be above 38 (in fact, 48·61). Further, Dr. Smith suggests that taenite as it exists in meteorites in general has an approximately constant composition, not because it is a definite compound, but because it is really a eutectic substance, and that it is an intimate mechanical mixture, in fixed proportion, of thin plates of a nickel-poor constituent (kamacite) and thin plates of a nickel-rich constituent (containing not less than 37 per cent. of nickel). Hitherto Mr. F. Osmond and others have regarded the plessite, not the taenite, of meteoric iron as being of eutectic character.

In the description of the small, thin plates extracted by the author from the meteoric iron of Youndegin, he stated as follows (p. 173):—

'It may be mentioned that during the determination [of the specific gravity of the taenite which had become oxidized during the eleven years which had passed since its isolation] great difficulty was experienced in removing all the interpenetrant air; the plates were composite, and the air was only slowly removed from the intervening spaces by an oft-repeated use of the air-pump.'

It may thus be a fact that the dilute hydrochloric acid, used for the extraction of this material from the meteoric iron, had at the same time removed plates or patches of kamacite of microscopic thinness which had been present between, or within, the thin plates of nickel-rich constituent, and that the composite plates, as present in the meteorite, were not merely a mixture but, as suggested by Dr. S. W. J. Smith, a eutectic mixture.

The percentage composition assigned to kamacite (6 or 7 per cent. of nickel) corresponds to the formula $Fe_{15}Ni$ (which requires 6·53 per cent. of nickel); hence, if the results obtained for Youndegin and Zomba are true for meteorites in general, the nickel-poor constituent (kamacite) and the nickel-rich constituent of meteoric iron would be respectively $Fe_{15}Ni$ and $Fe_{15}Ni_9$; if Fe_5 be denoted by A, and Ni by B, the formulae are symmetrical, namely, A_3B and AB_3.

If taenite is really a mixture of these two constituents and contains about 27 per cent. of nickel, 4 parts by weight of kamacite (containing 6·53 per cent.) must be mixed with 7 parts by weight of the nickel-rich constituent (containing 38·61 per cent.); for the percentage of nickel for such a mixture would be 26·94.

The results obtained for the meteoric iron of Youndegin and the nickel-iron extracted from the meteoric stone of Zomba are in such remarkably close agreement both with each other and with the formula

Fe_5Ni_3, and the observation relative to the structure of the thin plates extracted from the Youndegin meteorite is in such close agreement with Dr. S. W. J. Smith's interpretation of the compositeness of taenite in general, that it seems worth while to direct special attention to them; still, it must be remembered that the material analysed was very small in quantity and that the taenite of one mass (Beaconsfield) has been found to contain a much higher percentage (48·61) of nickel. As the Beaconsfield and Cranbourne masses belong almost certainly to the same fall, and the taenite of Cranbourne has been found to be normal in chemical composition, confirmation of the Beaconsfield determination is desirable; the iron was in that case determined only by difference, and it is possible that the taenite had been to some extent rusted, for it was obtained from rusted fragments of the mass.