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A method for the quick determination of the approximate amount and composition of the nickeliferous iron in Meteorites; and its application to seventeen meteoric stones.[1]

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In the classification proposed by the author in a previous paper[2] meteorites are divided into five groups according to the ratio of iron to nickel in the nickeliferous iron they contain. In the case of the meteoric irons such a classification, as shown by Farrington's list of analyses,[3] is a natural one, since the structure of the irons, as revealed by etching, varies with the amount of nickel they contain. Thus Group 1, in which the metal is poor in nickel, with a ratio of Fe to Ni of 13 upwards, includes nickel-poor ataxites, hexahedrites, and coarsest and coarse octahedrites; Group 2, in which Fe : Ni = 8–13, the rest of the

[1] Communicated by permission of the Trustees of the British Museum.

[2] G. T. Prior, Mineralogical Magazine, 1916, vol. xviii, p. 42.

[3] O. C. Farrington, 'Analyses of Iron Meteorites Compiled and Classified.' Field Museum of Natural History, Chicago, 1907, Publication 120, Geol. Series, vol. iii, No. 5.

octahedrites from medium to finest; Group 3, in which Fe : Ni = 5–8, nickel-rich ataxites; Group 4, in which Fe : Ni = 2–5, ataxites still richer in nickel; while Group 5 may include the doubtful Oktibbeha meteorite in which the ratio of iron to nickel is even less than one.

The extension of this classification to the chondrites and achondrites is not arbitrary, but is justified by the fact that in their case also the grouping is a natural one; for the author's analyses, together with those of Fletcher, Penfield, Hillebrand, Borgström, Mingaye, and others, indicate that in these stony meteorites the amount of ferrous oxide in the magnesium silicates varies directly with the percentage of nickel in the nickeliferous iron. Thus the chondrites of Daniel's Kuil (Hvittis) type and the achondrites of bustite type, of Group 1, which contain nickel-iron poor in nickel like that of the hexahedrites and coarse octahedrites, have magnesium silicates almost free from oxide of iron; while the chondrites and achondrites, containing metal of composition similar to that of the meteoric irons of Groups 2–5, have magnesium silicates richer and richer in ferrous oxide.

The explanation of these facts offered by the author was that the meteorites, both irons and stones, in these different groups differed by the degree of oxidation the magma which produced them had suffered, those of Group 1, *to which the sulphur minerals oldhamite and daubreelite are practically confined*, being the poorest in oxygen. Support to this view was afforded by the fact that in the majority of meteorites the less the amount of nickeliferous iron the richer it is in nickel; for by increasing oxidation the amount of nickel-iron would diminish, the oxidized iron passing into the composition of the magnesium silicates while the residual metal became richer and richer in nickel, since the latter would suffer no very appreciable oxidation so long as any iron remained in the metallic state. The idea that the nickel-content of the nickel-iron in meteorites varied inversely with the amount of nickel-iron had been enunciated by Flight[1] nearly forty years ago, but had hitherto met with no general acceptance. The author, in a previous paper, has brought forward evidence from his own and other analyses to prove that it is substantially true for meteorites generally, although a few exceptions occur, notably amongst the achondrites in the case of the bustites and ureilites. The analyses given in the present paper, with two exceptions, serve to confirm the general accuracy of the idea in the case of chondritic stones.

If meteorites are to be classified by the factor which is seen to

[1] W. Flight, Proc. R. Soc. London, 1881-2, p. 34; 'A chapter in the history of meteorites,' 1887, p. 222.

determine many of their other characters, i. e. by the amount of nickel in their metallic constituent, a fairly quick method for the determination of the approximate amount and composition of the nickel-iron is desirable.

The method adopted by the author is based on that described in a previous paper.[1] A 10–20 gram fragment of the meteorite is crushed until all the material except the larger particles of metallic iron passes through a sieve of about 80 meshes to the linear inch (about 0·20 mm. diameter of aperture). The fine sieved material, in small portions at a time, is then separated into unattracted (weight in grams $= w$) and attracted portions by repeated combing with a magnetic comb, the attracted parts being added to the coarse metallic particles. The attracted material (weight W), consisting of metal together with a certain amount of unattractive material entangled with it, is digested with dilute (two of water to one of concentrated acid) aqua regia until all the metal is dissolved. The insoluble residue consisting mainly of pyroxene is allowed to settle, as much as possible of the perfectly clear solution is decanted off, and the insoluble is then washed mainly by decantation. It is then digested for a short time with strong sodium carbonate solution to remove any silica derived from the soluble silicate, and after being again washed is dried at 100° C. and weighed (weight $= i$). The solution of the iron is evaporated to dryness and the rest of the silica from the soluble silicate is separated and weighed. The weight (s) of the soluble silicate is given fairly approximately by multiplying the silica total by 2·6, since the ratio of olivine to its silica in most meteorites varies only from 2·5 to 2·7. After the separation of silica, the solution of the iron is collected in a measured flask, and the nickel (weight $= n$) is determined by precipitation with dimethylglyoxime in an aliquot portion. In other portions of the solution sulphur and phosphorus may be estimated, though the latter in most cases is in negligible amount. From the weight of sulphur the weight (t) of troilite in the attracted material is calculated. The actual weight of nickel-iron in the attracted material is approximately $W - i - s - t = f$, and the ratio of iron (with a little cobalt) to nickel is then $\frac{f-n}{n}$; and the percentage amount of nickel-iron in the meteorite is $\frac{100\,f}{W+w}$.

This simple and fairly expeditious method gives perfectly reliable results as regards the amount of nickel, for there is no uncertainty in its determination, as is the case when the iron and nickel are separated by

[1] G. T. Prior, Mineralogical Magazine, 1913, vol. xvii, p. 24.

ammonia or even by sodium acetate when proper precautions[1] are not observed.

The following meteorites, to the analysis of which the method has been applied, include many of those, enumerated in a list given in the previous paper,[2] of which the results of the older analyses were most at variance with the author's views.

The results of the analyses of the attracted material are as follows :—

	Adare.	Gnaden-frei.	Shel-burne.	Chanda-kapur.	New Concord.
Insoluble silicate (*i*)	22·85	20·76	14·70	11·86	18·50
Soluble silicate (*s*)	16·64	12·14	13·17	11·01	14·98
FeS (*t*)	1·93	1·14	2·52	trace	2·53
Ni (*n*)	4·93	4·87	6·45	7·89	6·99
Fe (+Co) by diff.	(54·15)	(61·09)	(63·16)	(69·74)	(57·00)
	100·00	100·00	100·00	100·00	100·00
Weight of Attracted (*W*) ...	2·7384	2·6743	1·6049	1·1390	2·6748
,, Unattracted (*w*)	6·1524	5·4790	9·1931	9·9377	5·4790

	Henderson-ville.	Felix.	Eli Elwah.	Lunds-gård.	Château Renard.	Shytal.
Insoluble silicate ...	7·00	6·83	8·98	7·24	6·87	11·65
Soluble silicate ...	7·77	13·39	6·55	5·30	5·14	9·00
FeS	trace	trace	trace	trace	trace	trace
Ni	9·39	8·59	10·09	11·10	11·49	10·79
Fe (+Co) by diff. ...	(75·84)	(71·19)	(74·38)	(76·36)	(76·50)	(68·56)
	100·00	100·00	100·00	100·00	100·00	100·00
Weight of Attracted	0·2006	0·1033	0·5939	1·0161	0·8708	1·1728
,, Unattracted	6·3418	5·4451	7·3865	9·5105	8·3196	11·5634

	Bluff.	Kakowa.	Cyn-thiana.	Ensisheim.	Dhurm-sala.	Lodran.
Insoluble silicate ...	7·77	13·31	11·21	7·51	15·12	2·73
Soluble silicate ...	8·55	8·53	13·39	8·08	14·99	4·91
FeS	trace	trace	trace	trace	trace	trace
Ni	11·09	11·14	10·67	18·26	15·41	7·36
Fe (+Co) by diff. ...	(72·59)	(67·02)	(64·73)	(66·15)	(54·48)	(85·00)
	100·00	100·00	100·00	100·00	100·00	100·00
Weight of Attracted	0·5932	0·8343	0·7886	0·4955	0·5343	1·0756
,, Unattracted	9·4175	7·3248	9·2866	11·9291	9·4795	2·2594

The percentage amounts, in whole numbers, of the nickeliferous iron in these meteorites, and the ratios of iron (+ cobalt) to nickel in it, as calculated from the above analyses, are given in the following table under (1) as compared with the results of the older analyses given under (2)[3] :—

[1] e.g. The addition of sufficient acetic acid, after the neutralization of the solution with sodium carbonate and the addition of sodium acetate.

[2] G. T. Prior, Mineralogical Magazine, 1916, vol. xviii, p. 33.

[3] The numbers calculated from the older analyses are taken from the previous paper (loc. cit., pp. 31–35).

	Percentage of Nickel-iron.		Ratio of Fe (+ Co) to Ni.		Group.
	(1)	(2)	(1)	(2)	
Cronstad (type)	18½	—	11	—	C 2
Adare	18	19	11	6	C 2
Gnadenfrei	21½	26	12½	5½	C 2
Shelburne	10½	8	10	10	C 2
Chandakapur	8	6	9	10	C 2 3
New Concord	10	10½	8	7	C 2–3
Hendersonville	2½	2½	8	11	C 2–3
Felix	1½	3	8	7	C 2–3
Baroti (type)	9	—	6½	—	C 3
Eli Elwâh	6½	—	7½	—	C 3
Lundsgård	8½	12	7	5	C 3
Château Renard	8½	8½	6½	4	C 3
Shytal	7½	10	6½	6	C 3
Bluff	5	5½	6½	5	C 3
Kakowa...	8	8	6	6	C 3
Cynthiana	6	6	6	11	C 3
Soko-Banja (type)...	4	—	3	—	C 4
Ensisheim	3½	9	3½	7	C 4
Dhurmsala	3½	8	3½	4	C 4
Lodran	30	—	11½	7	A 2

The analysis of Lodran was undertaken because the older analysis gave a ratio of iron to nickel of 7, which was anomalous considering the high ratios of MgO to FeO in the pyroxene and olivine. The above result brings Lodran into conformity with most of the other stony-irons.

The results of the analyses, with two exceptions, support the idea that in most chondritic stones the proportion of nickel in the nickel-iron varies inversely as the amount of nickel-iron. This is very evident in the case of such extremes as Adare and Gnadenfrei on the one hand and Ensisheim and Dhurmsala on the other, but in the intermediate cases belonging to Group 3 the interrelation is not rigidly exact for the comparatively small samples used in the analyses, and Hendersonville and Felix are certainly exceptions. The new analyses of the metallic constituents of the two latter stones do not differ very materially from the previous ones. They show that both meteorites contain nickel-iron, in small amount, but not correspondingly very rich in nickel. According to the previous analyses, however, the magnesium silicates of Hendersonville and the insoluble silicate of Felix are poor in oxide of iron and thus agree with the composition of the nickel-iron in placing both meteorites in Group C 2–3.