On the remarkable similarity in chemical and mineral composition of chondritic meteoric stones.[1]

By G. T. Prior, M.A., D.Sc., F.R.S.

Keeper of Minerals in the British Museum.

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THE observation of the striking similarity both in chemical and mineral composition of the Baroti, Wittekrantz, and St. Michel meteorites (see the preceding paper) suggested the idea of testing how far such a close relationship applied to other chondritic meteoric stones.

The practical identity in chemical composition of different meteoric stones has been often pointed out. For example, A. E. Nordenskiöld[2] showed in the case of the stones of Erxleben, Lixna, Blansko, Ohaba, Pillistfer, Dundrum, Hessle, Orvinio, and Ställdalen that the percentage chemical compositions differed very slightly if the proportions of the metals, silicon, &c., were considered instead of the oxides. The general resemblance of chondritic stones is also very obvious in thin-sections examined under the microscope; for the most part only some of the so-called crystalline chondrites,[3] such as Hvittis, Pillistfer, Daniel's Kuil, Clégućrec, and Khairpur, distinguishing themselves at all markedly from the rest. It is this close resemblance which has rendered the possible recognition of any periodicity of falls of similar meteorites difficult.[4]

It is the object of the present note to bring into prominence these imilarities, since they appears to have been rather obscured than otherwise by the somewhat too elaborate schemes of classification which have been devised. The Tschermak-Brezina classification, which has

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

[2] A. E. Nordenskiöld, Geol. Fören. Förh. Stockholm, 1878, vol. iv, p. 56; abstract in Neues Jahrb. Min., 1879, p. 77.

[3] 'Ck' of Brezina's Classification.

[4] See G. Tschermak, Sitz.-Ber. Akad. Wien, 1907, vol. cxvi, p. 1430, and L. Fletcher, 'An Introduction to the Study of Meteorites,' 10th edit., 1908, p. 46.

been generally adopted, is based in the case of chondritic stones almost solely upon physical and structural variations, some of which are of a quite trivial character. A classification of terrestrial rocks upon similar lines would not bear contemplation, when the present embarrassing superfluity of specific rock-names is considered. Even when a terrestrial rock classification is applied to meteorites we find that its effect is to some extent to disguise rather than to emphasize similarities. This is the case with the interesting attempt which O. C. Farrington[1] has made to classify meteoric stones on the same principles as those used for the quantitative classification of igneous terrestrial rocks.[2] The difficulties, however, involved in the chemical analysis of meteoric stones, especially in respect to the apportioning of the total iron between the metallic iron, the troilite, the silicates, &c., are so great, and the methods generally employed of separating the metallic iron by means of copper chloride, mercuric chloride, or iodine are so tedious, that only in the hands of expert and very patient analysts can fairly accurate results be expected. A critical examination of the analyses quoted by Farrington shows in fact that the variations, apart from those of the nickel-iron, by which according to the quantitative system the chondritic stones are divided into groups, are in many cases simply due to errors of analysis involved in the determination of the iron according to its different conditions as to oxidation, &c. Where the percentage of ferrous oxide is higher than the average it will often be found that the iron is low and vice versa. That the amount of metallic iron has been underestimated in the case of the meteoric stones of Ergheo, Mauerkirchen, Long Island, Stavropol, and Zavid is rendered highly probable by merely a cursory examination of the specimens of these meteorites in the British Museum Collection, for they all show quite normally fair amounts of metallic iron upon polished surfaces, whereas the percentages recorded in the analyses are so small as to be either insufficient or very little more than sufficient to form troilite with the sulphur. For such reasons it appears much more probable that where, as is sometimes the case, different analyses of the same stone bring it into different groups, this result is due rather to analytical vagaries than to actual variations in different parts of the stone. What material, for example, could be more homogeneous in appearance than that of the Alfianello stone, yet in the

[1] O. C. Farrington, 'Analyses of Stone Meteorites,' Field Mus. of Natural History, Chicago, 1911, Publication 151, Geol. Ser., vol. iii, No. 9, pp. 195–229.

[2] W. Cross and others, 'Quantitative Classification of Igneous Rocks,' Chicago, 1903.

quantitative classification it falls into two different groups, and could be placed in two more according to the data of two other analyses which have been published.[1]

Objection has been made to the quantitative classification of terrestrial rocks that in some cases it tends to separate far apart rocks which are mineralogically very similar. That it has the same tendency to disguise similarities in the case of meteorites, however, appears to be due not so much to faults in this system as to imperfections in the analytical material to which it has been applied.

Instead of considering the individual percentages of the bulk analyses as is done in the quantitative classification, I have sought to compare the mineral composition of a number of meteoric stones for which this has been determined by analyses of the soluble and insoluble silicates. The results obtained in the case of forty-one chondritic stones are given in the accompanying table (pp. 36, 37).

The table shows the remarkable similarity, if not specific identity, as regards chemical and mineral composition of these particular stones. In the case of these meteorites, when allowance is made for some variation in the amount of nickel-iron, not only are the amounts of the soluble and insoluble silicates remarkably constant, but their actual chemical composition varies very slightly, the proportion of magnesium to iron atoms in the olivine being generally about 3 : 1, and in the bronzite 4 : 1.

In two columns of the table are given the symbols and names of the stones in the Brezina and quantitative classifications respectively as quoted from Farrington's paper. From these it is evident that the structural and physical variations on which the Brezina classification is based have little or no connexion with changes in the chemical and mineral composition; and that in the quantitative classification the groups Estacadose, Parnallose, Pultuskose, Farmingtonose, Castaliose, and Kernouvose are practically identical. Into these groups, changes in the chemical composition relating mainly to the relative amounts of iron and ferrous oxide would bring most of the members of the Traviose and Wacondose groups, including Ergheo and the other stones referred to on p. 34, in the analyses of which too little iron is recorded. These groups account for most of the chondritic meteoric stones of which we have what have been regarded as accurate analyses.

These considerations, therefore, lead to the conclusion that almost all of the chondritic meteoric stones at present known are, apart from some

[1] See C. Friedheim, Sitz.-Ber. Berlin. Akad., 1888, p. 345.

CHEMICAL AND MINERAL COMPOSITION

No.	Name of Meteorite.	Date of Fall.	Specific Gravity.	Percentage of Nickel-iron.	Ratio of Fe to Ni in Nickel-iron.	Percentage of Troilite.	Percentage of Olivine.	Ratio of Mg to Fe Atoms in Olivine.	Percentage of Insoluble Silicates (Bronzite and Felspar).	Ratio of Mg to Fe Atoms in Bronzite.	Percentage of Felspar (when determined).
1	Ausson	Dec. 9, 1858	3·54	10	9	4	45	3	37	4	8
2	Bachmut	Feb. 15, 1814	3·56	6	4	6	43	2	41	4	10
3	Baldohn	April 10, 1890	3·79	18	—	6	37	3	38	4	—
4	Baroti	Sept. 15, 1910	3·54	9	11	7	42	3	40	4	10
5	Beaver Creek	May 26, 1893	—	17	10	5	37	3½	40	5	—
6	Cape Girardeau	Aug. 14, 1846	3·67	18	11	6	35	3	41	5	—
7	Carcote	(Known since 1888)	3·47	10	10	6	40	2½	41	4	—
8	Chantonnay	Aug. 5, 1812	—	8	6	6	42	3	41	4	—
9	Cléguérec (Kernouvé)	May 22, 1869	3·75	20	12	6	35	3	40	4	—
10	Dhurmsala	July 14, 1860	3·40	8	4½	6	48	4	34	4	—
11	Estacado	(Found in 1902)	3·63	14	9	4	41	2	42	4	—
12	Farmington	June 25, 1890	—	8	7	5	46	3	41	3	—
13	Hessle	Jan. 1, 1869	3·74	19	8	5	42	3	33	4	10
14	Honolulu	Sept. 27, 1825	—	4	2	6	48	2	38	4½	7
15	Khetri	Jan. 19, 1867	3·68	18	—	5	35	3	42	4	—
16	Lesves	April 13, 1896	3·57	8	8	6	46	2½	38	3	—
17	Linn County	Feb. 25, 1847	—	10½	9	6	42	3	41	3	—
18	Lixna	July 12, 1820	3·73	15	8	6	39	2½	38	5	6
19	Lundsgård	April 3, 1889	3·61	12	5	6	41	3	39	4	—
20	Makariwa	(Found in 1879)	—	5	4	6	49	3	39	3	—
21	Meuselbach	May 19, 1897	3·47	8	7	8	39	2½	38	4	—
22	Mezö-Madaras	Sept. 4, 1852	—	10	5	6	42	3	40	3	—
23	Modoc	Sept. 2, 1905	3·54	5	10	4	46	3	44	4	14
24	Muddoor	Sept. 21, 1865	—	9	7	4	44	3	41	3	—
25	Nerft	April 12, 1864	—	6	4	5½	46	2½	39	4	10
26	Rakovka	Nov. 20, 1878	3·58	7	4	6	44	3	41	4	—
27	Richmond	June 4, 1828	3·37	8	7	4	46	4	42	3	—
28	St. Christophe	Nov. 5, 1841	—	9	4	7	43	3	40	4	8
29	St. Denis-Westrem	June 7, 1855	—	8	6	5	46	2½	39	4	13
30	St. Michel	July 12, 1910	3·56	9	11	6	43	3	41	4	15
31	Searsmont	May 21, 1871	3·70	15	10	3	43	3	39	3	—
32	Sevrukovo	May 11, 1874	3·50	16	8	5	48	4	31	4	—
33	Shelburne	Aug. 13, 1904	3·50	8	10	5	45	3	41	4	13
34	Tennasilm	June 28, 1872	3·53	7	5	6	44	2	42	4	—
35	Tjabé	Sept. 19, 1869	—	14	10	6	40	3	40	5	—
36	Tourinnes-la-Grosse	Dec. 7, 1863	3·61	12	5	6	41	3	39	4	—
37	Utah	(Found in 1869)	3·66	17	11	5	40	3	36	5	—
38	Utrecht	June 2, 1843	3·61	9	—	5	43	3	42	3	—
39	Winnebago County	May 2, 1890	3·80	19	14	6	36	4	38	4½	—
40	Wittekrantz	Dec. 9, 1880	3·49	8½	10	3½	47	3	39	4	12
41	Zomba	June 25, 1899	3·54	8½	7	5	42	3	44	4	9

OF CHONDRITIC METEORIC STONES.

No.	Symbol in Brezina's Classification.	Name in Quantitative Classification.	Analyst.	Reference.
1	Cc	Pultuskose	A. A. Damour	C. R. Acad. Sci. Paris, 1859, **49**, 31
2	Cw	Castaliose	A. Kuhlberg	Archiv Naturk. Dorpat, 1867, **4**, 18
3	Cc	—	E. Johanson	Neues Jahrb. Min., 1892, i, 104
4	Cw or Ro	—	G. T. Prior	Mineral. Mag., 1913, **17**, 22
5	Cck	Pultuskose	W. F. Hillebrand	Amer. Journ. Sci., 1894, **47**, 430
6	Cc	Farmingtonose	S. L. Penfield	Amer. Journ. Sci., 1886, **32**, 230
7	Ck	Parnallose	W. Will	Neues Jahrb. Min., 1889, ii, 177
8	Cgb	—	C. Rammelsberg	Zeits. Deutsch. Geol. Ges., 1870, **22**, 889
9	Cka	Kernouvose	F. Pisani	C. R. Acad. Sci. Paris, 1869, **68**, 1489
10	Ci	Pultuskose	S. Haughton	Proc. Roy. Soc. London, 1866, **15**, 214
11	Ckb	Estacadose	J. M. Davison	Amer. Journ. Sci., 1906, **22**, 59
12	Csa	Farmingtonose	L. G. Eakins	Amer. Journ. Sci., 1892, **43**, 66
13	Cc	Pultuskose	G. Lindström	K. Svenska Vet. Akad. Handl., 1870, **8**, No. 9
14	Cwa	—	A. Kuhlberg	Archiv Naturk. Dorpat, 1867, **4**, 1
15	Cgb	Pultuskose	D. Waldie	Journ. Asiatic Soc. Bengal, 1869, **38**, 2, 252
16	Cw	Parnallose	A. F. Renard	Bull. Acad. Roy. Belg., 1896, **31**, 654
17	Cwa	—	C. Rammelsberg	Monatsber. Akad. Berlin, 1870, **70**, 457
18	Cga	Pultuskose	A. Kuhlberg	Archiv Naturk. Dorpat, 1867, **4**, 1
19	Cw	Parnallose	O. Nordenskjöld	Geol. Fören. Förh., 1891, **13**, 470
20	Cgb	—	L. Fletcher	Mineral. Mag., 1894, **10**, 287
21	Ccka	Estacadose	G. Linck	Ann. Naturhist. Mus. Wien, 1899, **13**, 103
22	Cgb	Estacadose	C. Rammelsberg	Zeits. Deutsch. Geol. Ges., 1871, **23**, 734
23	Cwa	Castaliose	W. Tassin	Amer. Journ. Sci., 1906, **21**, 359
24	Cc	—	F. Crook	Inaug.-Diss., Göttingen, 1868, 33
25	Cia	Estacadose	A. Kuhlberg	Ann. Phys. Chem. (Pogg.), 1869, **136**, 448
26	Ci	Parnallose	P. Grigoriew	Zeits. Deutsch. Geol. Ges., 1880, **32**, 417
27	Cck	Pultuskose	C. Rammelsberg	Monatsber. Akad. Berlin, 1870, **70**, 440
28	Cg	Pultuskose	A. Lacroix	Bull. Soc. Sci. Nat. Ouest France, 1906, **6**, 81
29	Cca	Pultuskose	C. Klement	Bull. Mus. Hist. Nat. Belg., 1886, **4**, 280
30	Cw or Ro	Estacadose	L. H. Borgström	Bull. Comm. Géol. Finl., 1912, No. 34
31	Cc	Pultuskose	J. L. Smith	Amer. Journ. Sci., 1871, **2**, 200
32	Cs	—	A. Eberhard	Archiv Naturk. Dorpat, 1882, **9**, 115
33	Cg	Pultuskose	L. H. Borgström	Trans. Roy. Astron. Soc. Canada, 1904
34	Cca	—	G. Schilling	Archiv Naturk. Dorpat, 1882, **9**, 95
35	Ck	—	E. H. Baumhauer	Archiv. Néerl., 1871, **6**, 305
36	Cw	Parnallose	F. Pisani	C. R. Acad. Sci. Paris, 1864, **58**, 169
37	Cgb	Pultuskose	S. L. Penfield	Amer. Journ. Sci., 1886, **32**, 228
38	Cca	Farmingtonose	E. H. Baumhauer	Ann. Phys. Chem. (Pogg.), 1845, **66**, 465
39	Ccb	—	L. G. Eakins	Amer. Journ. Sci., 1890, **40**, 319
40	Ci	—	G. T. Prior	Mineral. Mag., 1913, **17**, 28
41	—	—	L. Fletcher	Mineral. Mag., 1901, **13**, 1

variation in the amount of nickel-iron, practically identical in chemical and mineral composition, the identity extending in the main even to the chemical composition of the olivine and pyroxene.

The type to which most chondritic meteoric stones approximate has in round numbers the following percentage mineral composition :—

Nickeliferous Iron (in which Fe : Ni is about 10) ...	9
Troilite	6
Olivine (in which Mg : Fe = 3)	44
Bronzite (in which Mg : Fe = 4)	30
Felspar (Oligoclase)	10
Chromite, &c.	1
	100

How far this may be too wide a generalization can only be definitely shown by analyses of chondritic stones not hitherto examined and by new accurate analyses to replace many of the older ones; and for this purpose analyses made with all care by the simple time-saving method described in a previous paper (p. 24) might suffice.