On the structure and composition of the Strathmore meteorite.[1]

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THE fall of this meteorite, which took place at 1.15 p.m. on December 3, 1917, was witnessed by many people over a large area. The circumstances were investigated immediately by Mr. Henry Coates who has given in a paper[2] already published full and accurate details of the appearance of the meteorite as it described its path, the direction in which it travelled, and the noise caused by its explosion. Fragments were recovered at four different localities lying on a line running from South Corston in Forfarshire north-westwards for about six miles to Easter Essendy in Perthshire, and the following table gives the particulars of the weights and localities of the various pieces:

Locality.	Number of Pieces.	Weight in Grams.
South Corston, 2 miles S.E. of Coupar Angus, Forfarshire	1	1,066
South Lodge, Keithick, $1\frac{1}{4}$ miles S.W. of Coupar Angus, Perthshire	1	1,172
Carsie, $2\frac{1}{2}$ miles S. of Blairgowrie, Perthshire	1	1,085
Easter Essendy, 2 miles S.W. of Blairgowrie, Perthshire	2	9,911 21
Total weight		13,255 grams.

Of the above fragments, the Corston piece is deposited in the Perth Museum, the Keithick piece is in the possession of Miss Brodie Wood of Keithick Lodge, the Carsie piece is in the British Museum, and the

[1] Published by permission of the Director, H.M. Geological Survey, and of the Government Chemist.

[2] Henry Coates, History of the Strathmore meteoric fall of 3rd December, 1917. Trans. Perth. Soc. Nat. Sci., 1920, vol. 7, pp. 80–89, 11 pls. [Min. Abstr., vol. 1, p. 400].

Essendy piece is in the Royal Scottish Museum, Edinburgh. The present investigation has been carried out largely on the smaller of the Essendy pieces, obviously a chip from the corner of the larger piece, but a certain small amount of the Carsie piece has been used for the petrographical part of the work. We take this opportunity of expressing our indebtedness to Mr. A. O. Curle, Director of the Royal Scottish Museum, Edinburgh, for kindly placing the material at our disposal.

Physical Characters.

Full descriptions, with plates, of the appearance of the stones, with their shapes and dimensions have been given by Mr. Coates. They show the typical crust, 'thumb-marks', pittings, and striae characteristic of aerolites, and most probably were derived from the disruption of one parent meteorite. On a fractured surface grains and small nodules of troilite and nickel-iron are clearly visible embedded in a greyish-white, stony matrix throughout which are small, brownish patches. On a polished face small chondrules are occasionally visible with a lens; they are not easy to distinguish and do not separate readily from the matrix.

Thin sections under the microscope show grains of nickel-iron and troilite in a granular matrix consisting principally of olivine and bronzite with a few chondrules consisting mainly of these two minerals. The bronzite shows good cleavage, a fairly large optic axial angle, and negative sign with the zone of elongation positive. Olivine occurs sometimes as crystals showing moderately sharp outlines and distinct cleavage but more often as irregularly-shaped fragments with rough, broken boundaries. The spaces between the larger fragments and crystals are filled with an aggregate of small, rounded grains of olivine and pyroxene. In addition to these two minerals, which constitute the bulk of the stony part of the meteorite, felspar is also present as small, colourless grains and crystals. In most cases it shows distinct birefringence and in a few instances well-marked twin-lamellation; its refractive index is very near that of Canada balsam, and a determination by the immersion method gave the mean value of 1·538. These characters indicate an acid plagioclase.

Sporadic patches of a clear, colourless mineral with exceedingly low birefringence and high relief are also present. These patches have, usually, irregular, angular outlines and are crossed occasionally by cleavage-lines intersecting at approximately 60°; more often they show

a series of irregular, curving cracks. Their refractive index is well above that of the felspar and Canada balsam but below that of bronzite and olivine. Although repeated trials have been made, it has been found impossible to determine accurately the optical characters as, with convergent light, none of the fragments yields a satisfactory interference-figure. Microchemical tests made on an uncovered section indicated the presence of phosphate in the mineral, which in general appearance bears some resemblance to apatite.

There can be little doubt that this mineral is the one described by G. P. Merrill [1] from the meteorites of Alfianello and Rich Mountain and previously noted by Tschermak [2] who compared it to monticellite. The mineral has since been named merrillite by Wherry.[3] Merrill, as the result of microchemical tests, concludes that it is a phosphate of lime and compares it with francolite. Both he and Tschermak describe the mineral as biaxial and Merrill gives its sign as doubtfully positive.

So far we have been unable to confirm these optical determinations, but chemically the mineral is undoubtedly a phosphate and in general appearance bears some resemblance to apatite, which, it is to be noted, sometimes shows optical anomalies. Further, sufficient chlorine has been detected in the course of the analysis to account for the phosphate being present as chlor-apatite, and it seems fairly certain that the mineral in question resembles that species closely. Until more of the material is available it is impossible to give precise specific characters, but it is of interest to note that a similar mineral is present in slides of the Launton and Warbreccan meteorites, kindly placed at our disposal by Dr. Prior; both of these stones contain appreciable quantities of phosphate.[4]

The chondrules consist principally of olivine and bronzite. They vary considerably in type. Monosomatic chondrules of olivine, circular in outline and with sharp boundaries against the matrix, have been noted. The interior of these chondrules consists of one crystal of olivine, sometimes riddled with black or dark-brown inclusions; they are bounded by a circular layer of olivine, which, under crossed nicols, may or may not extinguish simultaneously with the centre. In one such chondrule the

[1] G. P. Merrill, Proc. Nat. Acad. Sci. U.S.A., 1915, vol. 1, p. 302; Amer. Journ. Sci., 1917, vol. 43, p. 322 [Min. Abstr, vol. 1, p. 41].

[2] G. Tschermak, 'Die mikroskop. Beschaff. d. Meteoriten,' 1885, p. 11, and pl. XIV.

[3] E. T. Wherry, Amer. Min., 1917, vol. 2, p. 119 [Min. Abstr., vol. 1, p. 41].

[4] G. T. Prior, Min. Mag., 1916, vol. 18, pp. 5 and 9.

olivine in the centre has a rod-like structure, the spaces between the rods being occupied by dark inclusions and a finely granular aggregate of bronzite and olivine, with occasional patches of felspar and the phosphate mineral described above.

Polysomatic chondrules of fibrous bronzite are also present. They are usually circular in outline and the fibres of which they are composed may radiate from a common centre, or the chondrule, under crossed nicols, breaks up into a series of sectors composed of fibres radiating from different centres. The boundary of these chondrules may be sharply defined and marked by a margin of black grains; on the other hand, the chondrule may merge into the matrix.

One example of a porphyritic chondrule has been noted. It is circular in outline but does not possess a sharp boundary; the interior is composed of crystals of olivine and bronzite, none of which shows sharp crystal outlines. The spaces between these fragments are filled with a finely granular aggregate of bronzite and olivine and the whole chondrule is riddled with black inclusions.

The above characters show that the Strathmore meteorite belongs to the intermediate chondrite group, *Ci*.

Chemical Analysis.

The scheme of analysis of the meteorite, though differing in some of the methods of chemical separation, was similar to that described by Dr. G. T. Prior.[1] A fragment weighing about 15½ grams was crushed, and separated by means of a weakly magnetic comb into attracted and unattracted portions, weighing 2·0521 grams and 13·2563 grams respectively. These were analysed as follows:

Attracted Portion.—The whole of the material obtained in the magnetic separation was heated on the water-bath with dilute aqua regia (1 part acid to 2 parts water), and the gases evolved were passed through absorption bulbs containing concentrated nitric acid, to trap any hydrogen sulphide not oxidized by the dilute aqua regia. This precaution was necessary as the attracted material contained appreciable amounts of troilite; any loss of sulphur affects not only the percentage of troilite but also that of the nickel-iron, and gives a low summation for the analysis. Extraction was repeated several times with fresh portions of dilute acid, until all the soluble iron was removed. The combined extracts were filtered, and the residue washed with water, digested with 10 per cent. sodium carbonate solution to dissolve gela-

[1] G. T. Prior, Min. Mag., vol. 18, et seq.

tinous silica, and again washed with water. The insoluble portion was dried at 105° C., weighed, and mixed with the unattracted portion.

Silica was determined by separate evaporation of the acid and acidified alkaline extracts. The filtrate from the silica was collected in a weighed 500 c.c. flask and made up to the mark. Aliquot portions by weight were taken for the determination of sulphur, phosphorus, and the metals. The sulphur absorbed by the concentrated nitric acid was also determined, and added to that found in the main solution. For the determination of the metals two portions were used in the following way:

First Portion.—The iron was separated by two precipitations as basic acetate and one as hydroxide. The final precipitate, after ignition and weighing, was fused with potassium pyrosulphate and the iron titrated with potassium permanganate. Traces of nickel not completely separated were determined in the titrated solution, by precipitation with dimethyl-glyoxime in the presence of tartaric acid. In the main filtrate from the separation of the iron, the nickel, cobalt, &c., were precipitated as sulphides, dissolved in aqua regia, and the nickel determined by dimethyl-glyoxime. The lime and magnesia were determined in the filtrate from the sulphide precipitation.

Second Portion.—This was treated similarly, but the solution of the nickel and cobalt sulphides in aqua regia was, in this case, made up to a known bulk and divided into two parts. In one of these cobalt was determined by precipitation with nitroso-beta-naphthol, and, in the other, tests were made for copper, manganese, zinc, &c.

As a further check on the iron determination, the hydroxides, separated by ammonia from the portion taken for the estimation of sulphur, were dissolved in sulphuric acid and titrated.

Nickel was also directly determined in a fresh portion of the main solution by precipitation with dimethyl-glyoxime in the presence of tartaric acid.

The amount of ferrous oxide present as silicate in the attracted material was found by determining, in a portion of the unattracted material, the ratio of ferrous oxide to magnesium oxide in the silicate soluble in dilute aqua regia.

Unattracted Portion.—The analysis of this portion was made by the usual methods of rock analysis. Only a small amount of nickel was found; this being calculated to nickel-iron, from the ratio of iron to nickel obtained by analysis of the attracted material. Vanadium, barium, and lithium were not found.

	Attracted.	Unattracted.	Bulk-analysis.
Fe	52.60	0.29	7.31
Ni	9.05	0.05	1.26
Co	0.36	—	0.05
Fe	1.36	4.29	4.00
S	0.78	2.46	2.29
SiO_2	6.34	44.34	40.32
TiO_2	—	0.16	0.14
Al_2O_3	—	2.89	2.57
Cr_2O_3	—	0.50	0.44
Fe_2O_3	—	0.39	0.35
FeO	3.64	14.05	12.99
MnO	nt. fd.	0.33	0.29
CaO	trace	2.07	1.84
MgO	6.68	27.03	24.96
K_2O	—	0.12	0.11
Na_2O	—	1.01	0.90
H_2O	—	0.19	0.17
P_2O_5	0.08	0.25	0.23
Cl	—	0.03	0.03
Insoluble	18.97	—	—
	99.86	100.45	100.25

Analysis of the solution obtained by extracting 1 gram. of the unattracted material with 1 in 3 aqua regia gave 9·61 per cent. of ferrous oxide and 17·66 per cent. of magnesia in the soluble ferro-magnesian silicate. The composition of the olivine deduced from these figures is expressed by the formula 3·27 Mg_2SiO_4 . Fe_2SiO_4.

The following is the mineral composition of the meteorite, calculated from the bulk-analysis, and the above composition of the olivine :

$KAlSi_3O_8$	0.65		
$NaAlSi_3O_8$	7.64	10.93	Felspar.
$CaAl_2Si_2O_8$	2.64		
$FeO . TiO_2$	—	0.27	Ilmenite.
$FeO . Cr_2O_3$	—	0.65	Chromite.
$FeO . Fe_2O_3$	—	0.51	Magnetite.
$8\,Ca_3P_2O_8 . CaCl_2$	—	0.56	Chlor-apatite.
Fe_2SiO_4	12.62	41.13	Olivine.
Mg_2SiO_4	28.51		
$FeSiO_3$	6.63		
$MnSiO_3$	0.54	30.91	Bronzite.
$CaSiO_3$	2.14		
$MgSiO_3$	21.60		
Fe	4.00	6.29	Troilite.
S	2.29		
Fe	7.31		
Ni	1.26	8.62	Nickel-iron.
Co	0.05		
H_2O	—	0.17	Water.
		100.04	

Specific gravity, 3.53.

The above results indicate that the Strathmore meteorite belongs naturally to Group 3, Baroti type, of Dr. Prior's classification.[1] In composition it bears a striking resemblance to the Launton stone, as shown by the following comparative table:

	Strathmore.	Launton.
Percentage of nickel-iron	8·62	8·5
Ratio of Fe to Ni in nickel-iron	5·80	6·0
Ratio of MgO to FeO in olivine	3·27	3·3
,, ,, ,, pyroxene	4·25	4·4
,, ,, ,, ferromagnesian silicates ...	3·47	3·5

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 30; 1920, vol. 19, p. 61.