

*On the South African meteorites Mount Ayliff and Simondium, and the chemical composition of the meteorites Adare and Ensishheim.*<sup>1</sup>

(With Plate IV.)

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[Read March 16, 1920, and March 22, 1921.]

**D**URING the year 1919 specimens of some of the meteorites preserved in the Public Museum of King William's Town, South Africa, were kindly placed by the Curator, the late Mr. F. A. O. Pym, at the disposal of the writer for investigation. One of these specimens was a meteoric iron labelled Mount Ayliff, another a mass of oxidized material labelled Western Cape Province, and a third a small piece of iron labelled 'found on Elandsburg at an altitude of 6,000 ft. in 1888.' Unfortunately Mr. Pym was not in a position to supply very much more information about the specimens. All that was known was that the mass of Mount Ayliff was presented to the King William's Town Museum in June 1907 by Mr. John Taylor of Mount Ayliff, who could give no details as to date of fall or find, as he had supposed it to be a lump of iron smelted by the natives; that the rusted stone from Western Cape Province was from Lower Paarl and had been sent to the Museum by post without even the donor's name; and that the Elandsburg iron had been presented in February 1910 by a Mr. R. Rabbish, a letter of thanks to whom had been returned unclaimed. It may be said at once that this Elandsburg iron proved on examination not to be of meteoric origin, for it contained no trace of nickel and gave no definite figures on etching a polished face. The iron was so hard that it could not be cut with ordinary steel saws.

<sup>1</sup> Communicated by permission of the Trustees of the British Museum.

*Meteoric Iron of Mount Ayliff, Griqualand East.*

This mass of meteoric iron, to judge from a cast sent with the specimen, was of roughly square outline about  $6\frac{1}{2}$  inches in the side, and varying in thickness from 2 to just over 4 inches. Its original weight, therefore, must have been about 30 lb. The broad top and bottom surfaces show few 'thumb-marks' but one or two sharply defined depressions probably due to loss of troilite nodules: one of the side surfaces is much more irregular with deeper depressions. Polished surfaces of the iron (Plate IV, fig. 1) show fairly large (up to 3 cm. in length) nodules of graphite and troilite. In some nodules the two minerals are closely associated, in some cases with a centre of graphite surrounded by troilite, and in others a centre and outer margin of troilite and an intermediate zone of graphite, such as have been described as occurring in other coarse octahedrites. The most striking feature, however, of polished surfaces is the cohenite, plates of which are so regularly distributed in lines parallel to the faces of an octahedron as to make the surface appear as if etched. As seen in Plate IV, figs. 1 and 2, etched surfaces show the meteorite to be a coarse octahedrite, the lamellae of kamacite being mostly about 2 mm. wide. Taenite (clearly seen in fig. 2) in very narrow bands bordering the kamacite is not in large amount, and plessite is almost absent. The cohenite crystals (dark in fig. 1 and bright in fig. 2) are disposed generally along the middle of the kamacite bands. The iron is very similar in its characters to the cohenite-rich parts of Magura (Arva), and also to Brazos River (Wichita County). The result of a chemical analysis made on 6.1405 grams of the iron free from inclusions is as follows:

Fe	...	91.73
Ni	...	6.59
Co	...	0.69
S	...	0.12
P	...	0.12
Carbonaceous	...	0.51
		99.76

About 7 grams of filings dissolved in hydrochloric acid gave no precipitate except sulphur with sulphuretted hydrogen, indicating the absence in the sample of Cu, Pt, Au, &c. In the insoluble portion, consisting mainly of graphitic material, no crystals of cliftonite were

detected. After ignition an extremely small residue was left which, examined under the microscope, appeared to consist of minute splinters of doubly refracting quartz, amongst which no isotropic grains were visible.

*Simondium, Lower Paarl, Western Cape Province.*

The specimen from Lower Paarl is very similar in appearance to the Simondium meteorite which has been referred to in previous papers,<sup>1</sup> and an examination of a thin section under the microscope fully confirmed their identity.

The results of analyses of this meteorite given in the previous papers had shown its close relationship with the mesosiderites, especially Hainholz. The analysis of the attracted material, however, had not been very satisfactory as it was made on material which, although separated by the magnet, consisted almost wholly of oxide. As the new specimen showed on polished surfaces residual grains of metal which had escaped oxidation, an analysis of this actual nickel-iron seemed desirable; and as much as 1.0063 gram of fairly pure material was separated by sieving and the magnet out of 22.0243 grams of the meteorite. The result of analysis made by the method described in a previous paper<sup>2</sup> is as follows:

Insoluble silicate	...	3.02
Soluble silicate	...	2.65
Ni	...	23.79
Fe (+ Co) by diff.	...	(70.54)
		100.00

The nickel-iron, therefore, instead of being poor in nickel as suggested by the previous analysis, is rich in that metal, with a ratio of Fe to Ni of about 3. This result might appear to indicate that a reversion to the original reference of the meteorite to the howardites is advisable. Against this idea, however, is the striking similarity which Simondium presents to the mesosiderite Hainholz. These two meteorites are in fact precisely similar as regards the basaltic structure of the stony matter and the chemical composition of its constituents,

<sup>1</sup> G. T. Prior, *Mineralogical Magazine*, 1910, vol. 15, p. 312; 1918, vol. 18, p. 181.

<sup>2</sup> G. T. Prior, *ibid.*, 1919, vol. 18, p. 349.

the felspar, pyroxene, and olivine. They would appear to differ only in the amount and composition of the nickel-iron. Now as regards the amount of nickel-iron, owing to the extensive oxidation which has taken place it is hardly possible to come to any definite conclusion, but it is certain that the material analyzed represented only a small fraction of the original amount in the specimen, and it is possible also that this specimen represents only a stony-rich part of the meteorite. Again as to the composition of the nickel-iron, it was suggested in a previous paper that in mesosiderites the nickel-poor iron and the olivine were foreign to the rest of the constituents. It is just possible that the nickel-rich iron in the particular specimen of Simondium analyzed is not foreign but is original to the pyroxene and felspar, just as in all probability is the nickel-iron in the howardite Petersburg.<sup>1</sup> It is, however, more probable that the oxidation of the meteorite has had a selective effect in removing the more easily decomposable nickel-poor iron and leaving nickel-rich taenite, for as seen in thin sections the residual metal is in irregular thin threads surrounded by thick zones of oxide. For these reasons the author is still prepared to class Simondium with the mesosiderites.

*The Chemical Composition of the meteorites Adare and Ensisheim.*

In previous papers the author has brought forward evidence in support of the idea that in any meteoric stone the ratio of MgO to FeO in the ferromagnesium silicates in a broad sense varies directly with the ratio of Fe to Ni in the nickel-iron.<sup>2</sup> In testing the idea which had been suggested by his own analyses, it was considered fairest to take into consideration all the previous analyses quoted by O. C. Farrington in his list published in 1911, instead of relying on particular ones which might be considered as the most satisfactory. On the whole a considerable amount of support was afforded the theory by the analyses. It was pointed out, however, in the paper<sup>3</sup> that many of these analyses were of doubtful accuracy; and more recently it has been

<sup>1</sup> An analysis of this iron is desirable, but unfortunately the amount available for investigation of this meteorite in any collection is small.

<sup>2</sup> In a brecciated stone the rule would necessarily apply only to the individual fragments, e.g., in the recently described Cumberland Falls stone, to those of the dark chondrite on the one hand, and to those of the white aubrite on the other.

<sup>3</sup> G. T. Prior, *Mineralogical Magazine*, 1916, vol. 18, pp. 26-86.

realized that as regards most of the older ones the results are not sufficiently exact to be used very satisfactorily as tests of the theory. Under these circumstances it seemed advisable to take two meteorites, one containing a large amount of iron poor in nickel and the other a small amount very rich in nickel, and by complete analyses determine as accurately as possible the chemical composition of the ferromagnesium silicates in each. The determinations of the amount and composition of the nickel-iron in Ensisheim and Adare, as given in a previous paper,<sup>1</sup> suggested that these would be suitable meteorites for the purpose. In the case of two such well-known stones, one so historically interesting and the other one of the few British meteorites, it was also desirable to put on record analyses made by modern methods, and therefore presumably more accurate than those which had been published so far back as 1868 and 1874 respectively.

The analyses were conducted by the methods described in a previous paper. The separation of the attracted and unattracted portions was by the magnetic comb as described in the paper quoted above. Iron and nickel were separated by a combination of the sodium acetate and ammonia methods, two separations by sodium acetate followed by one with ammonia being used in the case of the attracted material, and one with sodium acetate and two with ammonia in the case of the unattracted. The determinations of nickel made by precipitation as oxide, after separation from iron by sodium acetate, were checked against those obtained by precipitation with dimethylglyoxime.

#### *Adare.*

This meteoric fall took place on September 10, 1813. A shower of stones, the largest of which weighed 65 lb., fell after detonations in the neighbourhood of Adare, Co. Limerick. The meteorite is represented in the British Museum collection by three fragments only, weighing respectively 82, 47, and 21 grams. For the analysis about 9 grams of specimen 33910a was divided into 2.7384 grams of attracted and 6.1524 grams unattracted. Separate analyses were made of the attracted, the unattracted, and the insoluble part of 2.1983 grams of the unattracted material, and the results, together with that of the soluble (by difference from the analysis of the total unattracted) are given in the following table:

<sup>1</sup> G. T. Prior, *Mineralogical Magazine*, 1919, vol. 18, p. 353.

	Attracted.	Unattracted.	Insoluble of Unattracted.	Soluble of Unattracted	Bulk- analysis.
	(by difference).				
Fe ...	54.61	—	—	—	16.81
Ni ...	4.93	—	—	—	1.51
Co ...	0.40	—	—	—	0.12
Fe ...	1.23	4.20 <sup>1</sup>	—	4.20	3.57
S ...	0.70	2.40	—	2.40	2.03
SiO <sub>2</sub> ...	6.40	45.89	30.12	15.77	36.88
Al <sub>2</sub> O <sub>3</sub> ...	—	1.97	1.97	—	1.50
Cr <sub>2</sub> O <sub>3</sub> ...	—	0.78	0.78 <sup>2</sup>	—	0.59
FeO ...	2.88	11.91	4.56	7.35	9.94
MnO ...	—	0.19	0.19	—	0.15
NiO ...	—	0.25	nil	0.25	0.19
CaO ...	—	2.45	1.80	0.65	1.86
MgO ...	6.40	28.07	12.16	15.91	23.82
Na <sub>2</sub> O ...	—	0.99	0.99 <sup>2</sup>	—	0.95
K <sub>2</sub> O ...	—	0.18	0.18 <sup>2</sup>	—	0.14
H <sub>2</sub> O ...	—	0.90 <sup>3</sup>	—	0.90	0.68
P <sub>2</sub> O <sub>5</sub> ...	—	0.35	—	0.35	0.27
Insoluble	22.35	—	—	—	—
	99.90	100.53	52.75	47.78	100.51

Not a trace of nickel was detected in the insoluble material.

The percentage composition of the soluble and insoluble silicates, as calculated after deducting chromite, apatite, troilite, and water from the analyses, is as follows under I, as compared with that given by the previous analyses of R. Apjohn<sup>4</sup> under II.

	Insoluble silicate.		Soluble silicate.	
	I (Prior).	II (Apjohn)	I (Prior).	II (Apjohn).
SiO <sub>2</sub> ...	58.36	59.48	39.93	42.91
Al <sub>2</sub> O <sub>3</sub> ..	3.82	3.24	—	2.35
FeO ...	8.12	7.94	18.61	16.93
MnO ...	0.37	8.84	—	6.26
CaO ...	3.49	4.62	1.17	5.34
MgO ...	28.56	13.17	40.29	24.32
Na <sub>2</sub> O ...	1.92	1.86	—	0.29
K <sub>2</sub> O ...	0.36	0.30	—	0.02
Loss ...	—	0.55	—	1.58
	100.00	100.00	100.00	100.00

<sup>1</sup> By calculation to form FeS with the S.

<sup>2</sup> These determinations were made on a separate portion of the total unattracted.

<sup>3</sup> This somewhat high number, combined with the high summation of the analysis, suggests that possibly some at least of the water was absorbed during the interval of more than a year which elapsed between the preparation of the material and the determination of the water.

<sup>4</sup> R. Apjohn, Journ. Chem. Soc., 1874, vol. 12, p. 104.

Apjohn's analyses show extraordinarily high percentages of manganese, due no doubt to inaccurate separation from magnesium. If the oxide of manganese and part of the lime be added to the magnesia, the results accord fairly well with the analyses made by the writer and give in both cases very much the same ratio of MgO to FeO, viz. for the insoluble silicate about 5 and for the soluble about 4.

The approximate mineral composition of Adare, as deduced from the analyses, is as follows:

$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6 \text{SiO}_2$	...	6.87	}	...	7.52	...	Felspar.	
$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6 \text{SiO}_2$	...	0.84						
$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2$	...	0.81						
$\text{FeO} \cdot \text{Cr}_2\text{O}_3$	...	...	...	...	0.87	...	Chromite.	
$3 \text{Ca}_3\text{P}_2\text{O}_8 \cdot \text{CaO}$	...	...	...	...	0.63	...	Apatite (Merrillite?).	
$\text{CaSiO}_3$	...	...	3.00	}	...	88.88	...	Bronzite (in which MgO:FeO = about 5).
$\text{FeSiO}_3$	...	...	6.82					
$\text{MgSiO}_3$	...	...	24.01					
$\text{Fe}_2\text{SiO}_4$	...	...	8.68					
$\text{Mg}_2\text{SiO}_4$	...	...	23.96					
Fe	...	...	16.82	}	...	18.46	...	Nickel-iron (in which Fe: Ni = 11).
Ni	...	...	1.52					
Co	...	...	0.12					
Fe	...	...	3.57	}	...	5.60	...	Troilite.
S	...	...	2.03					
Total (incl. $\text{H}_2\text{O}$ & NiO)					100.42			

*Ensisheim.*

The fall of this, the oldest well-authenticated meteoric stone, took place on November 16, 1492. The stone weighed about 260 lb. and was long kept hanging by a chain in the parish church of Ensisheim, Alsace. The meteorite is represented in the British Museum collection by two pieces weighing respectively 441 and 10 grams. For the analysis a fragment from specimen 90241 was divided into 0.4955 gram attracted and 11.9291 grams unattracted. Separate analyses were made of the attracted, and of the portions soluble and insoluble in hydrochloric acid of 2.4246 grams of the unattracted material, and the results, together with that of the total unattracted (combined result of insoluble and soluble), are given in the following table:

	Attracted.	Insoluble of Unattracted.	Soluble of Unattracted.	Total Unattracted.	Bulk- analysis.
Fe ...	63.13	—	—	—	2.51
Ni ...	18.26	—	—	—	0.72
Co ...	1.67	—	—	—	0.06
Fe ...	—	—	4.85 <sup>1</sup>	4.85	4.18
S ...	trace	—	2.50 <sup>2</sup>	2.50	2.41
SiO <sub>2</sub> ...	3.11	21.78	19.52	41.30	40.00
Al <sub>2</sub> O <sub>3</sub> ...	—	1.59	0.39	1.98	1.90
Cr <sub>2</sub> O <sub>3</sub> ...	—	0.36 <sup>2</sup>	—	0.36	0.34
FeO ...	1.37	4.23	14.47	18.70	18.05
MnO ...	—	0.07	0.24	0.31	0.30
NiO ...	—	trace	0.49	0.49	0.46
CaO ...	1.51	1.78	0.33	2.06	2.04
MgO ...	3.03	6.93	19.06	25.99	25.14
Na <sub>2</sub> O ...	—	0.98 <sup>2</sup>	—	0.98	0.94
K <sub>2</sub> O ...	—	0.13 <sup>2</sup>	—	0.13	0.12
H <sub>2</sub> O ...	—	—	0.28 <sup>2</sup>	0.28	0.27
P <sub>2</sub> O <sub>5</sub> ...	—	—	0.28 <sup>2</sup>	0.28	0.26
Insoluble	7.51	—	—	—	—
	<u>99.59</u>	<u>37.80</u>	<u>61.91</u>	<u>99.71</u>	<u>99.70</u>

In the insoluble material only a minute trace of nickel, just detectable by a pink colour given by dimethylglyoxime, was found.

The percentage composition of the soluble and insoluble silicates, calculated from the above analyses after deducting chromite, apatite, troilite, and water, is as follows under I, as compared with the results of the older analyses by F. Crook<sup>3</sup> under II:

	Insoluble silicate.		Soluble silicate.	
	I (Prior).	II (Crook).	I (Prior).	II (Crook).
SiO <sub>2</sub> ...	58.45	58.72	36.23	31.81
Al <sub>2</sub> O <sub>3</sub> ...	4.27	6.05	0.72	0.61
FeO ...	10.89	10.32	26.86	52.89
MnO ...	0.17	0.63	0.45	—
CaO ...	4.64	3.88	0.36	0.98
MgO ...	18.60	18.56	35.38	13.71
Na <sub>2</sub> O ...	2.63	1.17	—	—
K <sub>2</sub> O ...	0.35	0.67	—	—
	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

Comparison of the old and new analyses shows that as regards the insoluble silicates both are in fairly close agreement and give practically

<sup>1</sup> By calculation to form FeS with the S.

<sup>2</sup> These determinations were made on separate portions of the total unattracted.

<sup>3</sup> F. Crook, Inaug.-Diss., Göttingen, 1868.



the same ratio of MgO to FeO (=about 3). In the case of the soluble silicate, however, there is little agreement. In the older analysis, as in so many others, the soluble portion probably contained admixed metal and sulphide: the result has been quoted as indicating the presence in Ensisheim of an olivine extraordinarily rich in iron. The new analysis lends no support to this idea, the ratio of MgO to FeO being not much less than  $2\frac{1}{2}$ .

The approximate mineral composition of Ensisheim, as deduced from the analyses is as follows:

Na <sub>2</sub> O.Al <sub>2</sub> O <sub>3</sub> .6SiO <sub>2</sub> ... ..	7.99				
K <sub>2</sub> O.Al <sub>2</sub> O <sub>3</sub> .6SiO <sub>2</sub> ... ..	0.72	...	9.32	..	Felspar.
CaO.Al <sub>2</sub> O <sub>3</sub> .2SiO <sub>2</sub> ... ..	0.61	}			
FeO.Cr <sub>2</sub> O <sub>3</sub> ... ..	...	...	0.51	...	Chromite.
3Ca <sub>3</sub> P <sub>2</sub> O <sub>8</sub> .CaO ... ..	...	...	0.59	...	Apatite (Merrillite?).
CaSiO <sub>3</sub> ... ..	3.28	}	23.64	...	Hypersthene (in which MgO : FeO = 3).
FeSiO <sub>3</sub> ... ..	6.65				
MgSiO <sub>3</sub> ... ..	13.71				
Fe <sub>2</sub> SiO <sub>4</sub> ... ..	20.71	...	55.03	...	Olivine (in which MgO : FeO = 2½).
Mg <sub>2</sub> SiO <sub>4</sub> ... ..	34.32	}			
Fe ... ..	2.51	}	3.29	...	Nickel-iron (in which Fe : Ni = 3½).
Ni ... ..	0.72				
Co ... ..	0.06				
Fe ... ..	4.18	}	6.59	...	Troilite.
S ... ..	2.41				
Total (incl. H <sub>2</sub> O & NiO) ... ..			99.70		

The preceding analyses were made with due care by modern methods, and, since for the two meteorites precisely the same methods were employed, the results in the two cases are strictly comparable. They afford very strong corroborative support to the idea suggested by previous analyses that in meteoric stones the ratio of MgO to FeO in the silicates varies, in general,<sup>1</sup> directly with the ratio of iron to nickel in the nickel-iron.

As seen in the following table the data drawn from the analyses show how close is the similarity in chemical composition between Adare and Kroonstad (Cronstadt) on the one hand, and between Ensisheim and Soko-Banja on the other, although in the case of the last two meteorites the structural features (as indicated by the Brezina symbols) are so different.

<sup>1</sup> That such a relationship should be mathematically exact for slight differences in chemical composition is hardly to be claimed in view of our ignorance as to the mode of origin of chondritic stones.

	Percentage of nickel-iron.	Ratio of Fe to Ni.	Ratio of MgO to FeO in Pyroxene.	Ratio of MgO to FeO in Olivine.	Symbol.
Adare ...	18½	11	5	4	Cga
Kroonstad ...	18½	11	6	4	Cga
Ensisheim ...	8	8½	8	2½	Ck
Soko-Banja..	4	8	8	2½	Cc

In the analyses of both meteorites the small amount of nickel found in the soluble portion of the unattracted is reckoned as oxide, for in view of the prolonged magnetic separation it seems unlikely that more than fractional percentages of nickel-iron could escape removal. The fact that practically no nickel was found in the insoluble material suggests that what was found in the soluble was mainly due to some slight oxidation of the nickel-iron. The nickel oxide of 1 per cent. and over recorded in some analyses of the silicates of meteorites is probably due to the same cause or to imperfect separation of nickel-iron, and not to its really entering to such a large extent into the composition of the pyroxene and olivine as is sometimes assumed.<sup>1</sup>

Attention may also be drawn to the fact that neither these nor previous analyses of the author lend any support to the idea suggested by some recent analyses of chondritic stones (e.g. McKinney and Ochansk) that alumina may enter largely into the composition of the pyroxenes of meteorites. The only meteorite which appears to contain a really aluminous pyroxene is Angra, and the purple titaniferous augite in this stone is certainly like that in some terrestrial basalts and unlike the pyroxene in any other meteorite. The case is so exceptional, however, that it would be satisfactory to have the result of analysis confirmed. With this exception, the pyroxenes of meteorites appear to be practically free from alumina and, apart from the calcium-rich diopsides of Bustee and Nakhla, they are also poor in lime.<sup>2</sup>

<sup>1</sup> See G. P. Merrill, *Mem. Nat. Acad. Sci. Washington*, 1919, vol. 14, Mem. 4, p. 9.      <sup>2</sup> See G. T. Prior, *Mineralogical Magazine*, 1920, vol. 19, p. 56.

#### EXPLANATION OF PLATE IV.

FIG. 1.—Photograph of the specimen of the Mount Ayliff (Griqualand East, South Africa) meteoric iron in the Public Museum, King William's Town, South Africa.  $\times \frac{2}{3}$ .

The polished and etched surface shows large, irregularly-shaped nodules composed mainly of graphite and troilite, and plates of cohenite disposed along the middle of the kamacite bands.

FIG. 2.—Photograph of a thin slice in the British Museum collection (Reg. no. 1920, 214) of the Mount Ayliff meteoric iron. Natural size.

The polished and etched surface shows the bright, very narrow bands (sometimes broadening at the ends) of taenite, and the very numerous, larger, and more irregularly-shaped plates of cohenite in the kamacite bands.



FIG. 1

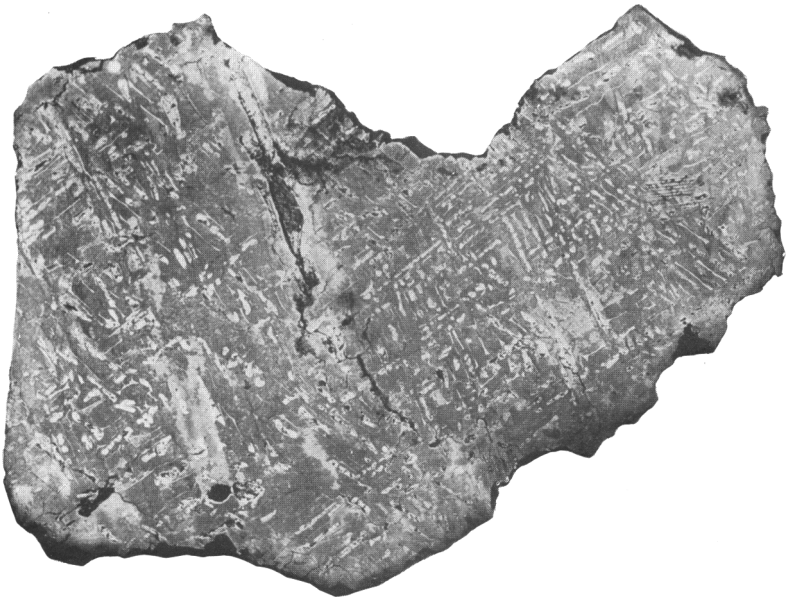


FIG. 2