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On the composition of a stone from the meteoric shower which fell at Dokáchi, Bengal, on October 22, 1903.

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Introduction. (H. L. B.)

ON October 22, 1903, a considerable shower of meteoric stones occurred in the neighbourhood of the village of Dokáchi, situated near the mouth of the Ganges, in the Dacca district of Bengal. Seven of these stones, which had been obtained from natives on the spot by Mr. H. E. Stapleton, M.A., of St. John's College, Oxford, Inspector of Schools in the Dacca district, were recently presented by him to the Oxford Museum.

The circumstances attending the fall have already been described by Dr. L. L. Fermor,[1] who has also given a description of the distribution and external characters of twenty-four stones and fragments (among them those now at Oxford), which had been transmitted to the Geological Survey Office, Calcutta.

Inquiries made by the Indian Geological Survey showed that nearly a hundred stones, of various sizes, had been found in Dokáchi and the neighbouring villages, but that most of these had been carried away by the natives and had not been recovered. Only twenty-four stones and fragments are stated by Dr. Fermor to have reached the Geological Survey, varying from 1570·99 grams to 0·73 gram, and amounting in

[1] L. L. Fermor, Records Geol. Survey, India, 1907, vol. xxxv, pp. 68–78.

all to 3888 grams. It was estimated that in the aggregate the stones which fell 'must have been numbered by the hundred'.

In 1907, the Geological Museum at Calcutta possessed fifteen fragments and slices, weighing in all 2057·35 grams, while the next largest amount (622·55 grams) was in the British Museum (comprising one large stone of 594·04 grams, and a fragment weighing 28·51 grams).

The greater portion of the shower seems to have fallen in and about Dokáchi, from which village three of the largest stones, weighing together 2360 grams, were obtained; and this name is therefore applied by Dr. Fermor to the whole shower.

The stones presented by Mr. Stapleton to the Oxford Museum were found in the villages of Dakhin Paiksha, Bibandi, Háriya, and Rána, and weighed in all 584·28 grams. Their weight and sources are as follows:—

Oxford Registered No.	Indian G. S. Museum Registered No.	Weight in grams.	Found at.
12952	240 C7	486·18	Dakhin Paiksha.
12953	240 F4	9·03	Bibandi.
12954	240 F5	1·97	,,
12955	240 F6	1·76	,,
12956	240 F7	1·32	,,
12957	240 H	66·18	Háriya.
12958	240 J	17·79	Rána.

These are all complete stones, covered with crust, or only slightly chipped. The largest of them was for some time worshipped by the natives, and still shows traces of the vermilion paint with which it was then smeared.

In his paper Dr. Fermor states that most of the stones he examined are more or less completely covered with a dull to slightly glossy crust, varying in colour from brownish-black to black, sometimes with greyish-white or rusty patches. The crust is usually comparatively smooth, but often exhibits numerous small pimples and ridges of a shining black colour, which impart a slightly polished appearance to stones on which they occur in any abundance. One stone shows crust of two ages, indicating the occurrence of a fracture early in its passage through the atmosphere. Some of the stones show well-marked pittings or 'thumb-marks'; and some are traversed by thin black veins, which are seen, where broken open, to be polished and slickensided. On a fresh fracture the stones are pale ash-grey, and a lens reveals darkish-grey chondrules set in a grey and white matrix, and abundant yellowish-white metallic particles of nickel-iron (or ? troilite—H. L. B.).

The specific gravity of three stones examined by Dr. Fermor was 3·62 to 3·65.

Physical Characters of the Rána Stone. (H. L. B.)

The stone No. 12958, weighing 17·79 grams, which fell in Rána, has been cut across, and four thin sections prepared, each having an area of about 20 × 16 mm. One of the two remaining portions of the stone was used for the analysis described below, while the other portion (5·22 grams) remains in the Oxford Museum.

The cut surface of the stone is grey, with a few brownish crystals of iron-stained olivine and fairly numerous bright grains of iron which show only very slight traces of rusting. A little troilite is also visible with a lens, forming minute, granular patches. A lens shows also a few rounded chondrules, mostly of a darker grey than the matrix. On a small broken surface on this stone, one or two dark-grey rounded chondrules project, but this is not noticeable on the chipped corners of other stones.

The crust on the Rána stone is black, while that on the other Oxford specimens is brownish. The shining pimples and ridges, mentioned by Dr. Fermor, appear to be due to projecting granules of nickel-iron.

Under the microscope, the matrix is seen to be a rather finely granular mixture of olivine and bronzite, with irregular grains of nickel-iron and traces of troilite. Chondrules are present, though not very numerous; they consist mostly of granular or porphyritic olivine, and are round or oval in form; a few are composed of radial-fibrous bronzite, and there are one or two examples of monosomatic olivine chondrules with parallel glass-inclusions, of the type shown in Plates IX and X, figs. 5 and 6, of the authors' paper on the Chandakapur stone.[1] Some of the prisms of bronzite show traces of a twin-lamellation like that described on p. 355 of the same paper (β- and γ-bronzite).

The stone examined appears to be referable to the group of Intermediate Chondrites (Ci) of Tschermak, but the veins mentioned by Fermor suggest that some at least of the other stones should be classed as Cia.

[1] H. L. Bowman and H. E. Clarke, 'The structure and composition of the Chandakapur meteoric stone,' Mineralogical Magazine, 1910, vol. xv, pp. 350-376.

Chemical Analysis of the Rána Stone. (H. E. C.)

§ 1. The methods to be adopted in the chemical analysis of meteoric stones have been described in detail by Mr. Fletcher in his papers on the meteorites of Makariwa [1] and Zomba,[2] and by the present authors in their account of the Chandakapur stone.[3] The procedure followed in the present work was, in general, the same as that given in the last communication, and may be sufficiently understood from the notes which follow, with the help of the table on p. 46.

§ 2. It may be noted here that, of the minerals, which occur in most meteoric stones (in addition to the silicates and nickel-iron, and the rust which is commonly present owing to the oxidation of the latter), troilite (FeS) and schreibersite (Fe_2NiP) are unique in containing sulphur and phosphorus, respectively. Their amounts can therefore be deduced directly from determinations of the sulphur and phosphorus present.

Magnetite (Fe_3O_4) is separated from rust with the help of the magnet, and since it is unaffected by mercuric-ammonium chloride solution it is readily separated from the metallic alloys, which are dissolved by that reagent.

Chromite ($FeCr_2O_4$) is unaffected by hydrochloric acid, which gelatinizes olivinic silicates, and it may be separated from silicates not so gelatinized (e. g. pyroxenes and felspars), by the action of fused sodium and potassium carbonates, which decompose the silicates, but leave chromite almost unattacked.

The Material.

§ 3. The stone which fell at Rána weighed, before slicing, 17·79 grams, and was completely covered with crust. The larger of the two portions which remained after the cutting of the sections (weighing 7·2891 grams) was used for the analysis, and weighed 6·8841 grams after removal of the crust [A].[4] It was crushed as finely as possible. and the plentiful metallic grains, some of which were as much as 2 mm. in diameter, removed with a magnet. The 'attracted' material so obtained weighed 2·5809 grams; the 'unattracted' material, 4·3016 grams. The weight actually used for the analysis was, therefore, 6·8825 grams, the loss during crushing and magnetic separation being 0·0016 gram.

[1] L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 287.
[2] L. Fletcher, ibid., 1901, vol. xiii, p. 1.
[3] H. L. Bowman and H. E. Clarke, loc. cit.
[4] The letters in square brackets refer to the tabular summary on p. 46.

EXTRACTION OF THE MATERIAL [A] WITH MERCURIC SOLUTION.

§ 4. The 'attracted' and 'unattracted' portions of [A] were separately treated with mercuric-ammonium chloride solution (cf. vol. xv, p. 360), in flasks through which a slow stream of coal-gas, washed with water, potash, and sulphuric acid, was maintained. The 'attracted' material was extracted with fourteen portions of mercuric solution, each of 50 c.c., and the 'unattracted' material with nine such portions. The process of extraction occupied seventeen weeks, at the end of which time the mercuric residues [A′] were practically free from nickel-iron.

An appreciable amount of rusting of the metallic alloy, as a result of its frequent exposure to air, must undoubtedly have taken place during the extraction. As, however, the stone was at first in a very fresh condition, the rust found may be taken to be wholly due to the oxidation of metal which would otherwise have passed into the mercuric extracts.

The extracts yielded in all 1·5807 grams of Fe_2O_3 and 0·0791 gram of (Ni,Co)O:[1] they contained also traces of copper, manganese, and zinc. The nickel and cobalt were separated by the use of dimethylglyoxime, as recommended by Brunck,[2] and the ratio of their weights was found to be 5·76 : 1.

§ 5. During the extraction of the Chandakapur stone with mercuric solution, the ratio of nickel to iron passing into solution was observed to increase in the successive extracts.[3] Mr. Fletcher attributed the occurrence of a similar phenomenon, observed in the course of his investigation of the stones of Zomba and Makariwa, to the presence of a stable alloy containing 38·5 per cent. of nickel,[4] and this proportion was approached in the later extracts of Chandakapur. No regular variation of this kind has, however, been observed during the treatment of the Dokáchi meteorite with the mercuric solvent; but it seems probable that the abrupt changes which were here observed in the proportion of nickel to iron in successive extracts, may have been due to a distribution of the different constituents in the metallic grains, such that one alloy would for a time screen another, richer or poorer in nickel, from the action of the solvent.

1 viz.: from the 'attracted' portion 1·5004 grams Fe_2O_3; 0·0749 gram (Ni, Co)O.
„ 'unattracted' „ 0·0803 gram „ ; 0·0042 „ „

2 O. Brunck, Zeits. f. analytische Chemie, 1908, vol. xlvii, p. 163.

3 H. L. Bowman and H. E. Clarke, loc. cit., p. 363.

4 L. Fletcher, Mineralogical Magazine, 1908, vol. xv, p. 149.

REDUCTION OF RUST, ETC., IN HYDROGEN.

§ 6. A portion [B], weighing 3·5139 grams, of the mixed dry metal-free mercuric residues [A′] was treated with the magnet, and the two portions so obtained (viz. 0·0603 gram 'attracted', and 3·4536 grams 'unattracted') heated for several hours to dull redness in a stream of hydrogen. By this means rust, magnetite, and schreibersite were wholly, and troilite partly, reduced to the metallic state. The reduced products were then separately extracted with mercuric solution. The extracts from the 'attracted [B]' yielded 0·0428 gram of Fe_2O_3 and traces only of NiO; those from the 'unattracted [B]' yielded 0·2389 gram of Fe_2O_3 and 0·0026 gram of (Ni,Co)O. The ratio Ni : Co was here approximately 9 : 1.

§ 7. In order to decide to what extent the troilite had been reduced by the hydrogen, it was necessary to know the amount of sulphur contained in that portion [B] of the mixed mercuric residue [A′] which had been submitted to reduction, and the amount of sulphur still remaining in the mixed mercuric residue [B′]. For this purpose portions of [A′] and [B′] weighing respectively 1·0241 and 1·1197 grams were taken, and the sulphur contained in them determined in the manner described by Mr. Fletcher.[1] From the results it was calculated that the amount of sulphur contained in [B] was 0·0554 gram before, and 0·0137 gram after the reduction, and that the troilite reduced was equivalent to 0·1042 gram of Fe_2O_3.

§ 8. If the whole of the troilite had been present in the 'attracted [B]', the latter must have weighed at least 0·1146 gram, and the Fe_2O_3 obtained from it as described in § 6 at least 0·1042 gram; whereas the 'attracted [B]' actually weighed only 0·0603 gram, and yielded 0·0428 gram of Fe_2O_3. The deficit cannot be due to incomplete separation of the magnetic portion of the material [B], for this process was carried out as thoroughly as possible, the dry powder being repeatedly worked through in small portions at a time, until the magnet ceased to collect any further particles. It is therefore most probable that the troilite was wholly present in the 'unattracted' portion, and that about three-fourths of it, yielding 0·1042 gram of Fe_2O_3, was reduced to metallic iron on heating in the stream of hydrogen. The iron obtained by reduction of the 'attracted [B]', which yielded 0·0428 gram of Fe_2O_3, must then have been due to magnetite, while the iron obtained by the reduction of the 'unattracted [B]', which yielded 0·2389 gram of Fe_2O_3, was due to

[1] L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 298.

rust and troilite, the former accounting for 0·1347 gram and the latter for 0·1042 gram of Fe_2O_3. The nickel of the 'unattracted [B]' must also probably be attributed to oxide formed during the extraction, and should be considered as part of the metallic content of the meteorite.

Estimation of Phosphorus.

§ 9. A determination, made on that portion of metal-free residue [A′] which had served for the estimation of sulphur, showed that [A′] contained only 0·0018 gram of phosphorus. As this material must have contained the whole of the schreibersite, the value given represents the total phosphorus in 6·8825 grams of the stone.

Composition of Stone as determined by the foregoing Treatment.

§ 10. The following table gives the amount of nickel-iron, troilite, schreibersite, and magnetite in the portion of the meteorite submitted to analysis (6·8825 grams):—

	Grams.	Grams.
Metallic Iron	1·1065	1·2008
Iron from rust	0·0943	
Metallic Nickel	0·0670	0·0704
Nickel from rust	0·0084	
Metallic Cobalt	0·0121	0·0125
Cobalt from rust	0·0004	
Magnetite		0·0763
Troilite		0·2821
Schreibersite		0·0117

Percentage composition of the Nickel-Iron.

§ 11. The metallic alloy present in the meteorite must thus have the following mean percentage composition:—

Fe	93·5
Ni	5·5
Co	1·0
Cu	distinct trace
Mn, Zn	traces
	100·0

Separation of Silicates.

§ 12. The combined mercuric residues [B′], which contained the chromite and unreduced troilite and the silicate minerals, weighed 2·3191 grams, and 1·1994 grams of this weighed, after gentle ignition to remove the mercury, 1·1920 grams. This latter portion was treated successively with hydrochloric acid and sodium carbonate solution, as described in the previous paper (p. 366). The sulphur determinations (§ 7) indicate that this portion would contain 0·0194 gram of unreduced troilite, and from this source the acid solution would afford 0·0177 gram of Fe_2O_3 on precipitation.

The chromite and silicates unattacked by the reagents accounted for 0·5899 gram, and the troilite together with the attacked silicate must therefore have amounted to 0·6021 gram.

Analysis of the 'Attacked' Material and 'Unattacked' Residue.

§ 13. The constituents of the attacked material (other than alkalis) were then determined. For the estimation of the alkalis a separate portion of the residue [A′] was taken, and the results are given in § 16.

§ 14. The greater part (viz. 0·5843 gram) of the unattacked residue was fused with sodium and potassium carbonates and submitted to the ordinary processes for the analysis of silicates. The material was completely decomposed during the fusion, but a small amount of chromium found in the melt is probably to be attributed to chromite, which is slightly attacked by fused alkali carbonates..

§ 15. The following are the results obtained :—

(a) *Attacked Material.*
(0·6021 gram.)

Troilite	... ...	0·0194 gram.
Silicates	SiO_2	0·2068 ,,
	FeO	0·2197 ,,
	CaO	0·0086 ,,
	MgO	0·1346 ,,
	Al_2O_3	0·0039 ,,
	Cr_2O_3	nil
	NiO	0·0014 ,,
	Na_2O, K_2O	not determined

(b) *Unattacked Residue.*

(0·5899 gram.)

A portion of this, weighing 0·5843 gram, gave: –

Chromite	...	... ...	0·0034 gram.
Silicates	SiO_2	... ...	0·3358 „
	FeO	... ...	0·0867 „
	CaO	... ...	0·0204 „
	MgO	... ...	0·1263 „
	Al_2O_3	... ...	0·0030 „
	NiO	... ...	0·0013 „
	Na_2O, K_2O	... ...	not determined

ESTIMATION OF ALKALIS.

§ 16. Two portions of the material [A′] were taken for the determination of alkalis. These weighed 1·0085 grams and 0·9578 gram; and, after gentle ignition, 0·8889 gram and 0·8430 gram respectively.

Exactly half of the first portion, on treatment by Lawrence Smith's method, yielded 0·0120 gram of mixed alkali chlorides; and this, on treatment with chloroplatinic acid, gave 0·0063 gram of K_2PtCl_6. The other half of the material was lost during a second similar determination.

The portion weighing 0·8430 gram was treated with hydrochloric acid, in the manner adopted for the separation of the silicates. The unattacked residue, so obtained, yielded by the same method 0·0174 gram of mixed alkali chlorides, which by treatment with chloroplatinic acid gave 0·0096 gram of K_2PtCl_6.

From these results, after correction for alkalis present in the Lawrence Smith mixture, it is found that, of the portion (0·8430 gram) taken, the material attacked by acid contained 0·0058 gram of Na_2O and 0·0009 gram of K_2O, while the unattacked material contained 0·0072 gram of Na_2O and 0·0018 gram of K_2O.

PERCENTAGE COMPOSITION AND NATURE OF THE SILICATES.

§ 17. The following tables give the percentage composition of the silicates, as calculated from the values given in §§ 15, 16, after deducting the troilite and chromite.

In the third column is shown the weight of oxygen contained in the silica and the several basic oxides combined with it.

(a) *Silicates attacked by Acid.*
(0·5827 gram.)

The material attacked by acid (0·6021 gram) contained 0·5827 gram of silicates, of the following composition:—

			Oxygen. Grams.	
SiO_2	... ...	35·49	... 0·1193	
FeO	... ...	37·72	... 0·0488	
CaO	... ...	1·48	... 0·0024	
MgO	... ...	23·10	... 0·0538	
Al_2O_3	... ...	0·67	... 0·0019	0·1088 gram.
Cr_2O_3	... ...	nil	—	
NiO	... ...	0·26	... 0·0003	
Na_2O	... ...	0·99	... 0·0015	
K_2O	... ...	0·16	... 0·0001	
		99·87		

(b) *Silicates unattacked by Acid.*
(0·5809 gram.)

The portion of the material unattacked by acid, which was analysed (0·5843 gram), contained 0·5809 gram of silicates, of the following composition:—

			Oxygen. Grams.	
SiO_2	... ...	57·60	... 0·1791	
FeO	... ...	14·87	... 0·0192	
CaO	... ...	3·51	... 0·0058	
MgO	... ...	21·68	... 0·0505	
Al_2O_3	... ...	0·51	... 0·0014	0·0794 gram.
NiO	... ...	0·22	... 0·0003	
Na_2O	... ...	1·23	... 0·0019	
K_2O	... ...	0·31	... 0·0003	
		99·93		

The 'attacked' silicates consist for the greater part of olivine approximating in composition to $Fe_2SiO_4 . Mg_2SiO_4$, but containing some calcium. The proportion of iron to magnesium is remarkably high, being comparable with that in the olivine of Bandong (Cwb) and Kakowa (Cga), quoted by Cohen,[1] in which the FeO amounts to 33·49 and 42·23 per cent. respectively.

The 'unattacked' silicates consist mostly of a pyroxene, rich in iron but with very little alumina, and perhaps a little felspar. The latter mineral has apparently suffered attack during the separation of the silicates, as a portion of the alkalis and alumina appears in the attacked material. The pyroxene with nearly 15 per cent. of FeO would (according to Cohen's usage[2]) be on the border-line between bronzite and hypersthene.

General Composition of the Stone.

§ 18. It follows from the above that the general composition of the stone may be expressed as follows:—

	Grams.	Grams.	Per cent.	Per cent.
Nickel-Iron Alloys:—	Fe 1·2008	...	17·45	
	Ni 0·0704	1·2837	1·03	18·66
	Co 0·0125	...	0·18	
Magnetite	...	0·0763	...	1·11
Troilite	...	0·2821	...	4·10
Schreibersite	...	0·0117	...	0·17
Chromite	...	0·0034	...	0·05
Silicates:—				
Attacked	...	2·5955	...	37·71
Unattacked	...	2·6106	...	37·93
		6·8633		99·73

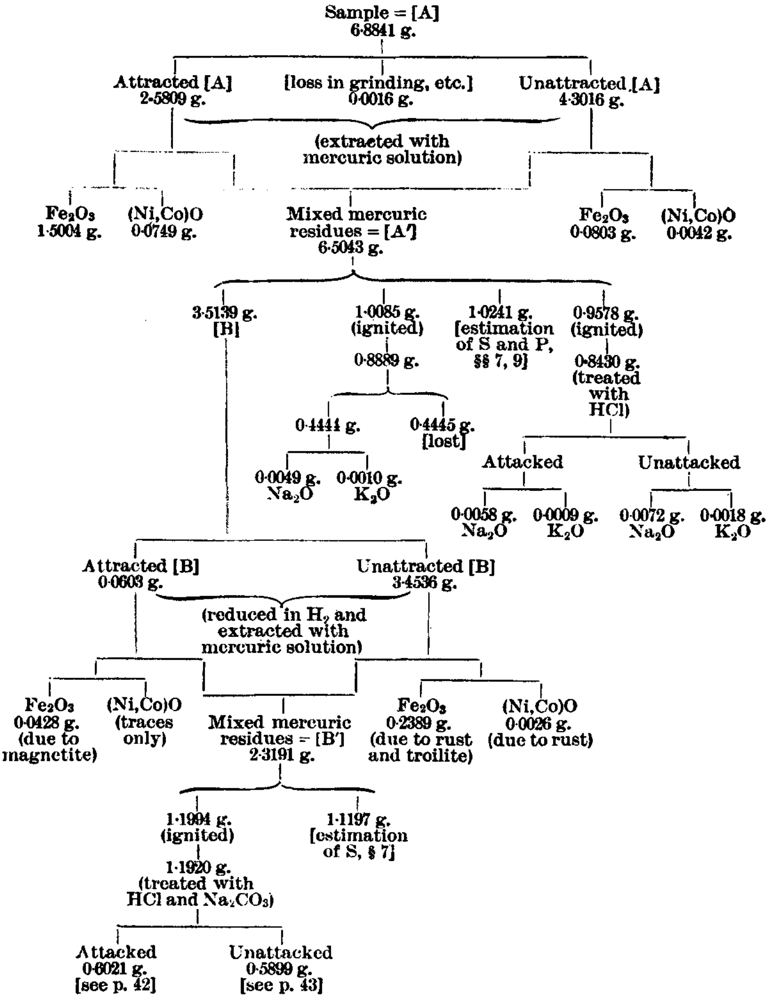
[Weight taken, 6·8825 grams.]

[1] E. Cohen, 'Meteoritenkunde,' 1894, Part I, p. 266.

[2] E. Cohen, ibid., p. 282.

§ 19. The somewhat complicated series of operations involved in the analysis are here set out in tabular form, for convenience of reference.

THE DOKÁCHI METEORITE.



The completion of the present work was delayed by the removal of one of us from Oxford, and our sincere thanks are due to Professor P. Phillips Bedson, M.A., D.Sc., who very kindly placed at our disposal his private laboratory at the Armstrong College, Newcastle-on-Tyne, where a portion of the chemical analysis was carried out.