A new meteoric stone from Suwahib, Arabia.[1]

(With Plate V.)

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STARTING in December 1930, Mr. Bertram Thomas made the crossing of the Rub' al Khali, the desert region of Arabia lying between the mountains of the south coast and the Persian Gulf. Never before had this desert been crossed by any European, and probably rarely even by Arabs. The material collected on this expedition has been presented by Mr. Thomas for preservation in the British Museum.

On January 14, 1931, he was at Buwah, in the region of Suwahib (lat. 20° 3′ 20″ N., long. 51° 25′ E.), and near here one of his Arab escort picked up and brought to Mr. Thomas what the latter at once supposed to be a meteoric stone. The Arabs called it 'Guthr al Hadid' meaning 'drop of iron'. No rocks outcrop in the vicinity, and the stone was found lying on the surface of the sand. Mr. Thomas thought that this might indicate that it had fallen rather recently, otherwise sand would have covered it. However, we cannot be sure of this, for in the shifting sands a small solid body might be buried and swept clear again many times. Further evidence that the stone fell some time previous to its discovery is afforded by the coating of limonite which covers the whole stone so effectively that at first the author took the stone to be a piece of 'iron pan'. The coating of limonite is somewhat glazed, presumably by wind action, and grains of sand are firmly cemented in it.

The stone is bounded by seven irregular surfaces, and measures about $8\frac{1}{2} \times 4\frac{1}{2} \times 4$ cm. along three directions at right angles. Only one of the bounding surfaces shows anything resembling the outer crust of a complete stone, and that is doubtful owing to the coating of limonite.

As found the stone weighed 241 grams. A small piece was broken

[1] A preliminary account was given in an appendix to Mr. Thomas's paper, 'A camel journey across the Rub' al Khali', in the Geogr. Journ. London, 1931, vol. 78, p. 236. There the specific gravity is given incorrectly.

off for preliminary examination, and a larger piece for analysis, and preparation of a thin section and of a polished surface for microscopic examination. The weight of the remaining portion of this polished piece is 5½ grams and that of the main portion of the stone 232 grams.

The broken surface shows the characters of a black spherical chondrite traversed by minute veinlets and patches of nickel-iron and troilite. The largest chondrule seen is 1·5 mm. in diameter, but their average diameter is about 0·75 mm. Plate V, fig. 1, from a photograph of the polished surface, magnified 8 diameters, gives a fair idea of the distribution of nickel-iron and troilite, which appear as the lightest patches in the grey mass of chondrules.

The specific gravity of the stone, determined by hydrostatic weighing of the main mass by Mr. M. H. Hey, is 3·52.

Under the microscope the section shows many spherical chondrules consisting mainly of bronzite and olivine, the latter associated with some glass and a plagioclase felspar (Plate V, fig. 2). The bronzite chondrules are fibrous with eccentric radiating structure; some are cryptocrystalline and opaque. The optical properties of the bronzite could not be fully determined.

Chondrules containing olivine are porphyritic for the most part, but several kinds can be distinguished: chondrules consisting of single crystals (monosomatic); idiomorphic crystals of olivine in a granular matrix of olivine or pyroxene; crystals of olivine with interstitial brown glass; and rather rounded crystals of olivine poecilitically enclosed in plagioclase. Measurements made on olivine crystals on the Fedorov stage indicate a value of 2V near 85°, and the optical sign is negative. The acute bisectrix is normal to a good cleavage parallel to *b* (010). There is also a well-marked fracture parallel to *c* (001), and faces in the zone [001,110] are well developed.

The felspar is present in many of the chondrules and is optically positive with a rather low extinction-angle and a refractive index above that of balsam. This would agree with andesine which is the felspar calculated from the analysis. The same mineral appears to form the main mass of a few chondrules, and these contain many opaque inclusions, some of which are troilite.

Troilite within the chondrules is mainly restricted to the outer edges of some olivine chondrules where it is sometimes quite abundant filling interstices between the silicate grains, or forming a very narrow ring round the chondrule. Much more rarely it forms a sort of lamellar arrangement alternating with one of the silicates (Plate V, fig. 1), but this was not seen in the thin section, so that it could not be decided whether olivine or bronzite was involved.

The interstices between the chondrules are occupied entirely by nickel-iron and troilite, the proportion of the latter being quite considerable. Small pieces of troilite are seen enclosed by nickel-iron, and the two minerals are very closely associated. Occasionally there are seen small chondrules which are completely surrounded by a plate of troilite, but chondrules surrounded by nickel-iron are much more frequent. The troilite is easily distinguished from the nickel-iron in reflected light by its yellower colour. This distinction was kindly confirmed by Dr. W. R. Jones of the Department of Geology, Imperial College of Science, who examined the polished slice in polarized light with a vertical illuminator. On rotating the specimen between crossed nicols the anisotropic character of the troilite was clearly shown and contrasted with the isotropic behaviour of the numerous neighbouring patches of nickel-iron.

No structure was brought out in the nickel-iron by etching with dilute nitric acid.

	Suwahib.	Cronstad.	Hedjaz.
Fe	17·54	16·71	12·98
Ni	0·96	1·55	0·94
Co	0·12	0·23	—
S	1·98	{ Fe 3·29 S 1·88 }	1·61
P	nil	—	—
SiO_2	38·48	37·24	37·30
TiO_2	0·20	0·30	0·05
Al_2O_3	4·42*	2·41	3·78
Cr_2O_3	—	0·37	0·08
FeO†	10·16	9·17	11·50
MnO	0·28	0·04	trace
NiO	—	0·10	—
CaO	1·90	1·45	2·95
MgO	21·25	23·61	27·50
Na_2O	1·33	0·67	0·40
K_2O	0·25	0·07	0·50
P_2O_5	n.d.‡	0·25	—
H_2O	n.d.‡	0·34	—
	98·87	99·68	99·59
Sp. gr.	3·52	3·61	3·53

* Probably includes Cr_2O_3. † Total iron in combination with silicates.

‡ P_2O_5 and H_2O together, 0·6–0·8, by analogy with Cronstad.

The results of a chemical analysis made on a small portion of the stone by Mr. M. H. Hey (using a method which he describes in a note below) are given in the table (p. 45). For comparison are also given the analyses of the Cronstad meteorite[1] and of the Hedjaz meteorite,[2] the latter being the only other stony meteorite that has been described from Arabia.

An analysis of the portion of the silicates (freed from nickel-iron and troilite) soluble in hydrochloric acid (sp. gr. 1·06) gave the following result:

		Calculated percentage composition of olivine.	Molecular ratios.
SiO_2	18·86	37·53	0·622
FeO	12·18	24·24	0·337
MgO	19·21	38·23	0·948
TiO_2	absent	100·00	
Insoluble	49·43		
	99·68		

This gives for the ratio MgO : FeO in the olivine 2·81, the composition of the olivine being, therefore, approximately $3Mg_2SiO_4.Fe_2SiO_4$. Assuming this as the composition of the olivine, and allowing 0·5 % of apatite for the undetermined P_2O_5, the mineral composition calculated for the meteorite is as given in the table on p. 47. The calculated mineral composition of the Hedjaz meteorite is given for comparison.

The nickel-iron, 15·15 %, has a ratio of Fe : Ni of 14·7. The ratio of MgO to FeO in the olivine is 3, in the pyroxene 8, in the ferromagnesium silicates taken together 4.

The corresponding figures for the Cronstad meteorite are: nickel-iron 18·5 %, Fe : Ni 11, MgO : FeO in olivine 4, in pyroxene 6, in the ferromagnesium silicates 4·5.

Compared with these figures, and with several others tabulated by Prior (loc. cit., p. 29) for chondrites of the Cronstad type the Fe : Ni ratio for Suwahib, calculated from the bulk analysis, is abnormally high. However, considering the very small quantity of material used for the bulk analysis the figures are sufficiently accurate to show that the Suwahib meteorite, like the Hedjaz stone, belongs to Prior's Cronstad type. The mineralogical constitution and structure of the stone are quite in agreement with this result.

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 11.
[2] J. Couyat, Compt. Rend. Acad. Sci. Paris, 1912, vol. 155, p. 916.

The only other meteorites known from Arabia [1] are the famous 'black stone' set in the wall of the Ka'ba at Mecca of which the history goes back beyond the seventh century; a meteoric iron of which two large masses were found in 1863 in the Wadi Bani Khaled in Nejd (Nejed); and a grey bronzite-chondrite which fell in the spring of 1910 at Et Tlahi in the Hedjaz.

Frequent reference has been made above to the Hedjaz meteorite which has been briefly described by J. Couyat and analysed by F. Pisani. That it belongs to the same type as the Suwahib stone is probably nothing more than a coincidence, and it is satisfactory that the chemical analyses show sufficiently considerable differences to allay any suspicion that the two stones might belong to the same fall. This would be most improbable as the two localities are over a thousand miles apart. The differences in mineral composition are quite apparent in thin sections and even in the fragments of the stones themselves, the Hedjaz stone being grey, whereas the Suwahib meteorite is a black spherical chondrite; also the chondrules in the Hedjaz stone as described by Couyat are much larger.

	Suwahib.		Hedjaz.		
$NaAlSi_3O_8$	11·53		3·10		
$KAlSi_3O_8$	1·11	17·9	2·78	13·11	Felspar
$CaAl_2Si_2O_8$	5·28		7·23		
$FeO.TiO_2$		0·3	trace		
$3Ca_3P_2O_8.CaO$		[0·5]	—		Apatite
$CaSiO_3$	1·39		3·13		
$FeSiO_3$	3·17	24·4	2·64	14·47	Pyroxene
$MgSiO_3$	19·80		8·70		
Fe_2SiO_4	11·93	35·2	14·30	56·30	Olivine
Mg_2SiO_4	23·31		42·00		
Fe	3·47	5·45	2·79	4·40*	Trolite
S	1·98		1·61		
Fe	14·07		10·19		
Ni	0·96	15·15	0·94	11·13*	Nickel-iron
Co	0·12		—		
		98·9		99·41	

* The percentages of troilite and nickel-iron in the Hedjaz meteorite as printed in J. Couyat's paper (loc. cit.) were incorrectly given as FeS 11·20 and (Fe,Ni) 4·40. The percentage of nickel-iron was given correctly by G. T. Prior (loc. cit., p. 29), but the ratio Fe : Ni is there given as 9. The calculated value, from Couyat's figures, is 10·8.

[1] E. de Oliveira lists a meteorite [N. 2640] from 'Arabia' in the collection of the Museu Nacional at Rio de Janeiro, Brazil, but he gives no description. (Ann. Acad. Brasileira Sci., 1931, vol. 3, p. 52, and Min. Abstr., 1932, vol. 5, p. 14). This is probably a piece of the Hedjaz stone. A pseudo-meteorite from 'Yafaee Mountains, Arabia' was included in the British Museum lists of 1886 (p. 69) to 1896 (p. 86).

Note on the Method of Analysis by M. H. Hey.

The amount of material available for analysis was very small; it was impossible to take the 10 grams, or more, necessary for a good magnetic separation without spoiling the stone as a specimen, but since the iron is finely divided and very evenly disseminated throughout the mass, it appeared that a sample of 1–2 grams would be sufficient for a fairly complete and representative analysis, provided the difficulty of the complete separation of the nickel-iron alloy from the silicates could be overcome. The method of distillation in chlorine seemed a possibility, and has proved eminently successful.

Preliminary experiments proved that the silicates are quite unaffected by heating to 250–300° C. in dry chlorine, provided that hydrogen chloride is absent; the latter, as F. W. Clarke has shown, is capable of attacking silicates. But if the chlorine is free from hydrogen chloride, and dry, there is no attack. A quantity of olivine from the Alice Springs pallasite showed no change in weight, nor did any portion become water-soluble, when heated in chlorine. As a further test, a partial analysis was made of the non-magnetic portion of the Cronstad meteorite, using the material previously separated and analysed by Dr. G. T. Prior.[1] The troilite present is, of course, attacked, both iron and sulphur distilling; the amount of sulphur found in the distillate (2·25 %) agrees exactly with Dr. Prior's figure, but the iron (5·06 %) is 1·12 % in excess of that needed to combine the sulphur. The residue gave off 0·10 % of nickel on extraction with water, but nothing else. That the silicates were really unaffected is shown by the results obtained on digestion of the residue from the distillation with hydrochloric acid of sp. gr. 1·06, followed by extraction of the liberated silica with sodium carbonate solution; 51·67 % (on the total unattracted, including troilite) remained insoluble, while 15·75 % of silica was liberated; Dr. Prior's figures are 54·78 % and 14·85 %, a good agreement considering the approximate nature of the process.

The excess of iron in the distillate beyond that required to form troilite comes undoubtedly from a small amount of nickel-iron alloy left in the unattracted material. A small loss of this kind is t be expected, and it is significant in confirmation of this that the 0·10 % of nickel left as chloride in the residue after distillation is in almost exactly the correct ratio to the excess of iron in the distillate to be

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 10.

accounted for in this way. The calculated amount of nickel would be 0·11 %; and Dr. Prior found 0·13 % nickel oxide in the unattracted portion. It is therefore probable that the greater part of the nickel shown in the analyses of the non-magnetic portion of most meteorites is derived from a small residue of nickel-iron alloy in the material.

The preliminary experiments proving so satisfactory, the method was adopted for the analysis of the Suwahib meteorite. A fragment was crushed and finely powdered, with particular care to avoid loss, and the whole (1·5 gram) weighed into a porcelain boat, placed in a glass tube connected with a pair of trap flasks containing water, and heated to 250–300° C. in dry chlorine free from hydrogen chloride. It must be emphasized that whereas in the analysis of silicate-free nickel-iron the presence of hydrogen chloride is a distinct advantage and renders a small amount of moisture quite harmless, both hydrogen chloride and water must be carefully removed when meteoric stones are under examination. The chlorine is best generated from manganese dioxide or other oxidizing agent and aqueous hydrochloric acid, the gas washed through water and then thoroughly dried.

After two hours, the distillation was apparently complete, the boat was withdrawn (from the end of the distillation tube by which the chlorine stream enters), its contents stirred with a glass rod, and returned to the chlorine stream for a further half-hour. Then the boat was removed, cooled, and weighed. The distillate in tubes and flasks was washed out into a measuring flask, a trace of ferric oxide formed being dissolved with hydrochloric acid, and the tubes well rinsed; iron, sulphur, and phosphorus were determined in the usual way on aliquot parts of this solution. The residue in the boat was extracted rapidly with warm water containing a few drops of dilute hydrochloric acid, filtered quickly on a glass filter-crucible, well washed with hot water, dried at 100° C., and weighed. The filtrates were analysed for nickel and cobalt. The silicates on the filter-crucible were thoroughly mixed with a platinum spatula, and divided into three portions. The major portion, 0·8 gram, was fused with sodium carbonate and analysed in the ordinary way for SiO_2, TiO_2, Al_2O_3, FeO, CaO, and MgO. A second portion of 0·3 gram was used for an alkali determination by the Lawrence Smith method, and on the residue from the water extraction, manganous oxide was determined. For this purpose the residue was dissolved in hydrochloric acid, and filtered from silica; the filtrate was evaporated down with sulphuric acid, cooled, diluted, and filtered from the bulk of the calcium sulphate, then manganese determined by the colorimetric periodate method. The third portion, 0·2 gram, was digested with hydrochloric acid, sp. gr. 1·06, for two hours on the water-bath, filtered, and the filtrate analysed for SiO_2, FeO, CaO, MgO, and TiO_2 in the usual manner. The dissolved material (together with a certain amount of silica left with the insoluble silicates, and recovered by extraction with sodium carbonate solution) gives, as usual, the composition of the olivine of the meteorite. The quantity of material was insufficient for the determination of phosphoric acid or water.

This new process is not intended to supplant the magnetic separation, but to supplement it. The effect of the chlorination on the minor constituents has not yet been determined, the present experiments only going to show that olivine and pyroxene are not affected. Until the behaviour of the minor constituents to reagents has been investigated, no chemical method of separation can replace the magnetic for investigations in which it is desired to take account of them.

Explanation of Plate V.

Meteoric stone from Suwahib, Arabia.

Fig. 1. Portion of a polished surface taken in reflected light. ×8. The lightest patches are nickel-iron and troilite. Near the top on the right is a chondrule consisting of lamellae of troilite and olivine or bronzite. (Photograph by H. G. Herring.)

Fig. 2. Photomicrograph of thin section. ×39. Showing two fibrous bronzite chondrules and several porphyritic chondrules with idiomorphic olivines. The black areas consist of nickel-iron and troilite. (Photomicrograph by F. N. Ashcroft.)

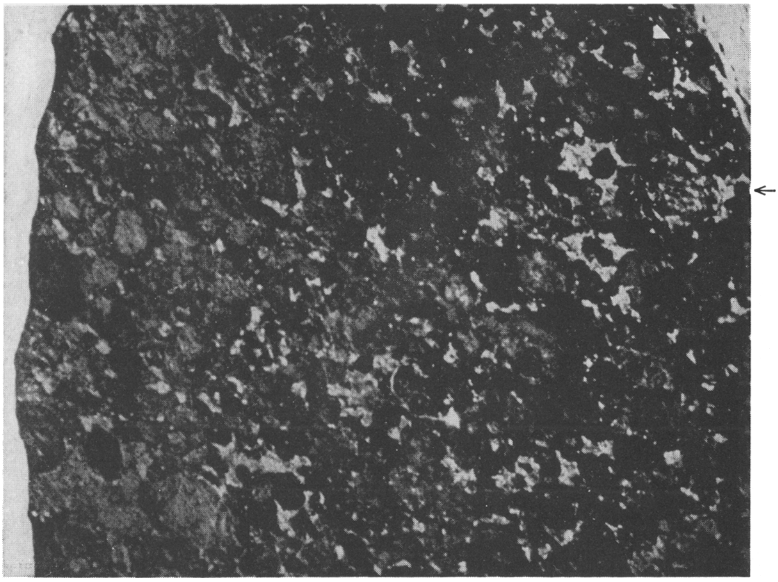

FIG. 1.

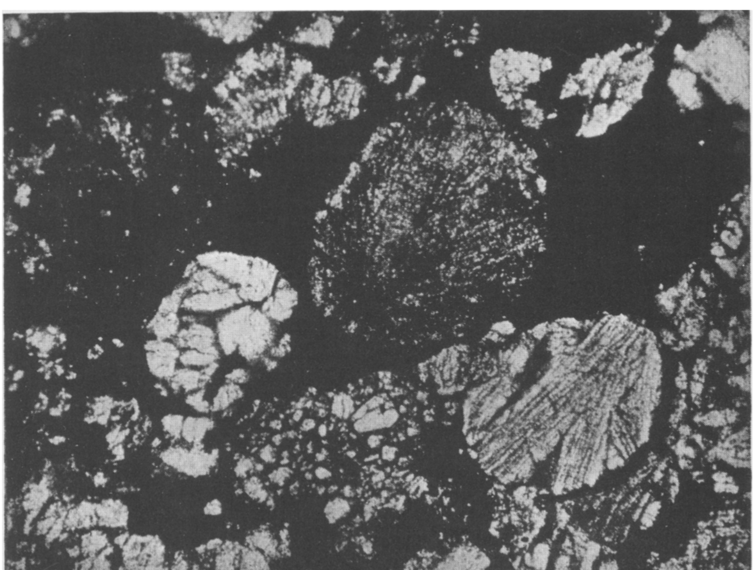

FIG. 2.

W. CAMPBELL SMITH: METEORIC STONE FROM SUWAHIB, ARABIA.