The meteoric stones of El Nakhla El Baharia (Egypt).[1]

(*With Plates IX and X.*)

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Fall of the Stones.

According to the accounts which have been published by members of the Egyptian Geological Survey,[2] a number of meteoric stones fell to earth on June 28, 1911, at about 9 in the morning, in the hamlets[3] to the west and north of the village of El Nakhla El Baharia (31° 19′ N., 30° 21′ E.) in the district of Abu Hommos, about twenty-four miles east of Alexandria, Egypt.

The stones, in number about forty and in weight nearly 10 kilograms, fell over an area about 4½ kilometres in diameter, and were derived apparently from the explosion of a single large meteorite which, according to the evidence of many eye-witnesses, approached from the north-west along a track marked by a column of white smoke and inclined to the horizontal about 30°. Several explosions were heard, and the stones buried themselves in the ground to depths of from 10 to 30 cm., leaving holes inclined to the vertical.

Many of the stones were completely coated with a very brilliant, black, fused crust, while others were only partially covered. The weight of the individual stones varied from 1,813 grams to 20 grams.

Through the kindness of Dr. W. F. Hume, Director of the Geological Survey of Egypt, two fragments of stones of this, the first Egyptian meteorite, weighing respectively 725 and 274 grams, have been presented

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

[2] W. F. Hume, 'The first meteorite record in Egypt.' Cairo Scientific Journal, 1911, vol. v, no. 59, pp. 212-215. J. Ball, 'The meteorite of El Nakhla El Baharia.' Survey Department (Egypt), 1912, Paper no. 25, pp. 1-20, with three plates.

Descriptions of the meteorite have also been published by S. Meunier, Compt. Rend. Acad. Sci. Paris, 1911, vol. cliii, pp. 524, 785; and by F. Berwerth, Min. Petr. Mitt. (Tschermak), 1912, vol. xxxi, p. 107.

[3] The hamlets near which stones were seen to fall are Ezbet Abdalla Zeid, Ezbet Abdel Malek, Ezbet el Askar, and Ezbet Saber Mahdi.

to the British Museum by the Egyptian Government. The smaller of the two specimens is part of a stone which fell in a cotton-field about 200 metres north-east of the village of Abdel Malek. From this specimen has been taken the material for the present investigation.

External Characters.

The larger of the two specimens has roughly eight sides, two of which present a fresh fracture, finely crystalline and of a greenish-grey colour, while the rest are coated with a thin, black, varnish-like, fused crust, as glossy as that of the Sherghotty and Juvinas meteorites.

Except for one or two broad 'thumb-marks', three of the coated sides (two are seen on the right in Pl. IX, fig. 1) are fairly flat and smooth, and are probably primary faces: on them the fused surface shows under the lens a fine network of ridges with minute pittings in the intervening spaces. The four other coated sides (on the left in Pl. IX, fig. 1) are rough and uneven, and are probably secondary faces: the fused surface on these is much more glossy, with ridges wider apart and not forming such a regular network as on the smooth surfaces. On the smaller specimen, some of the surfaces show a partial fusion, sufficient only to form a few ridges of black, fused material, with interspaces still crystalline.[1]

Mineral Composition.

Under the lens the stone is seen to consist mainly of a medium-grained crystalline aggregate of two minerals, a green pyroxene, and, in smaller amount but larger grains, a reddish-brown olivine.[2]

No metallic iron or chondrules are visible, and the few grains attractable by a magnet from the powdered stone consist only of magnetite. The material is very friable and can be reduced to a coarse powder simply by rubbing between the finger and thumb.

Examined in thin sections under the microscope (Pl. IX, fig. 2) the material appears at first to consist simply of a holocrystalline aggregate of diopside and olivine, the diopside for the most part in fairly well-defined prismatic crystals, and the olivine in larger irregular grains showing no sharp outlines of crystal-faces. On closer investigation of

[1] See J. Ball, loc. cit., p. 4.

[2] The descriptions hitherto published of the meteorite contain varying statements of its mineral composition. In one, three-quarters of the stone is considered to consist of augite and the rest of hypersthene; in another, over 80 per cent. of the stone is regarded as hypersthene. That there is no reason, however, to doubt the general uniformity in character of the different stones of the fall is clear from the descriptions themselves, and from the chemical analyses which have been made of the stones (see p. 279).

the slides, however, between the main constituents can be detected in many parts interstitial material which, with a high power, resolves itself into a crystalline aggregate of felspar-laths with grains of augite and magnetite, like the matrix of a fine-grained basalt (Pl. X, fig. 1).

The felspar may be referred to oligoclase-andesine as it shows twin-lamellae, in one case giving symmetrical extinctions of about 20°, and has refractions slightly higher than that of the Canada-balsam.

Besides the felspathic interstitial material, F. Berwerth[1] describes also a grey interstitial breccia consisting mainly of augite and showing occasionally minute bronzite chondrules. This could not be detected in the particular slides examined, but enclosed in some of the olivines were seen minute perfectly spherical grains of pyroxene, often surrounded by a fringe of magnetite (Pl. IX, fig. 2, in the olivine at the top of the slide on the right): in some cases the rounded grain consisted of a single individual of pyroxene, but occasionally it appeared to be of composite character suggestive of a chondrule.

Diopside.

The green pyroxene (diopside), comprising about three-quarters by weight of the stone, is nearly colourless in thin section, and, although without very sharply defined crystal-outline, generally shows prismatic sections, mostly about 1 mm. in length and 0·3 to 0·5 mm. in breadth.

Twinning on the orthopinacoid (100) is very common and is often repeated in the same individual; many of these twins also exhibit the well-known 'herring-bone' structure due to repeated twinning on the basal plane (001) (Pl. IX, fig. 2 at the bottom on the right). In twins of this kind giving symmetrical extinction about the line of junction, the extinction ($c : \mathfrak{c}$) is about 40° to 44°, and the angle between the lamellae twinned on (001) and the same line 74° to 76°.

In an uncovered slide, a few sections twinned on (100) were found to be cut so that one half of the twin showed the emergence of an acute positive bisectrix. Measurements of the optic axial angle with an eye-piece micrometer gave $2E = 80°–87°$ (corresponding to $2V = 44°–48°$). The double refraction in this half of the twin was low (about 0·005), whereas in the other half it amounted to about 0·030. Measurements of refraction in such sections by the Becke method, combined with determinations of the double refraction by means of a quartz-wedge, gave the following numbers as rough approximations of the refractive indices:

$$\alpha = 1{\cdot}685,\ \beta = 1{\cdot}69,\ \gamma = 1{\cdot}72.$$

[1] F. Berwerth, loc. cit., p. 110.

The chemical composition of the diopside, as calculated from the results of the bulk-analysis of the stone (p. 279) and of the analysis of the olivine (p. 278), is as follows:

SiO_2	... ...	52·73
FeO	... ...	14·93
CaO	... ...	19·22
MgO	... ...	13·12
		100·00
Specific gravity [1]	...	3·42

The numbers correspond approximately to a formula $3MgSiO_3 . 3CaSiO_3 . 2FeSiO_3$, which may be written $2MgCa(SiO_3)_2 . CaFe(SiO_3)_2 . MgFe(SiO_3)_2$, as representing a combination of diopside, hedenbergite, and bronzite molecules.

Olivine.

The brown olivine, the other principal constituent of the meteorite, is closely related to hortonolite and is much more ferriferous than any olivine previously described in meteorites.[2]

In weight it amounts to about 13–15 per cent. of the stone, but it occurs in larger and more irregular grains (up to 2 mm. across) than the diopside. In thin sections under the microscope a very slight pleochroism from colourless (for vibrations parallel to *b*) to very pale brown (for vibrations parallel to *c*) can sometimes be detected.

It appears to be of later consolidation than the augite, for it is often embayed by augite prisms and occasionally contains included grains of augite.

A characteristic feature is the presence of dark-brown to black inclusions. In sections cut at right angles to an obtuse positive bisectrix these inclusions appear as lenticular plates with their long axes directed parallel to the line joining the optic axes. Such sections, which are parallel to the orthopinacoid (100), generally show the traces of the fairly well-marked brachypinacoidal cleavage at right angles to the long axis of the inclusions (Pl. X, fig. 2). In sections cut at right angles to the acute negative bisectrix the inclusions appear only as short, sharply defined, black lines, all directed at right angles to the line joining the

[1] As determined on 1·0610 gram of the portion of the meteorite insoluble in hydrochloric acid (see p. 280).

[2] The Ensisheim meteoric stone, according to an analysis of the soluble portion by F. Crook (Inaug.-Diss., Göttingen, 1868, p. 22), is supposed to have 50 per cent. of olivine containing as much as 53 per cent. of FeO. In an uncovered slide of this stone in the Museum Collection the olivine, however, presents no unusual character, is quite colourless, and has refractions not higher than that of methylene iodide.

optic axes (Pl. X, fig. 3). Such sections, which are parallel to the brachypinacoid (010), generally show no well-marked cleavage. The inclusions appear, therefore, to be lenticular plates arranged with their flat surfaces parallel to the orthopinacoid (100) and their long axes parallel to *b* and their short axes to *c*. Under a high power the apparent plates resolve themselves into radiating black rods, and are probably skeletal crystals of magnetite or ilmenite (Pl. X, fig. 4).

Measurement of the optic axial angle of the olivine by means of an eye-piece micrometer gave $2E = 160°$ (corresponding to $2V = 67°$). From measurement of the refraction by the Becke method, and of the double refraction by the quartz-wedge in sections cut at right angles to the two bisectrices, the following numbers as rough approximations of the refractive indices were obtained:

$$\alpha = 1{\cdot}75,\ \beta = 1{\cdot}785,\ \gamma = 1{\cdot}80.$$

A chemical analysis was made of the olivine on grains picked out under the lens from the coarsely powdered stone. The material, weighing 0·2048 grams, was digested in hydrochloric acid (sp. gr. 1·06) and the small amount (0·0340 gram) of insoluble residue was treated in the usual way with sodium carbonate solution to remove silica, &c. The result of the analysis of the soluble portion is given under I. Under II and III are given for comparison analyses of hortonolite and fayalite respectively.

	I. (Olivine of El Nakhla.)		II. (Hortonolite.[1])		III. (Fayalite.[2])
SiO_2 ...	32·59	...	33·59	...	32·41
FeO ...	51·80 [3]	...	44·37	...	65·49
MnO ...	—	...	4·35	...	—
CaO ...	1·11	...	—	...	2·10
MgO ...	15·60 [4]	...	16·68	...	—
	101·10	...	98·99	...	100·00
Specific gravity	3·98 [5]	...	4·038	...	4·318

[1] G. J. Brush, Amer. Journ. Sci., 1869, vol. xlviii, p. 17.

[2] F. A. Gooch, Amer. Journ. Sci., 1885, vol. xxx, p. 58.

[3] The whole of the iron is here reckoned as FeO: the result of the bulk-analysis (p. 279) showed that the amount of Fe_2O_3 in the meteorite is small.

[4] The excess of 1 per cent. in the analysis is probably mainly due to excess of magnesia. The chemical composition of the olivine is better represented by the analysis of the soluble part of the meteorite which was made on a larger amount of material (see p. 280).

[5] Calculated from the specific gravity of the grains (3·842) and that of the portion of the meteorite insoluble in hydrochloric acid (3·415).

The chemical composition corresponds fairly closely to the formula $2Fe_2SiO_4.Mg_2SiO_4$.

The following table shows the relation between the characters of the olivine and those of hortonolite and fayalite:

	Olivine of El Nakhla.	Hortonolite.	Fayalite.
α	1·75	1·7684	1·8236
β	1·785	1·7915	1·8642
γ	1·80	1·8031	1·8736
$\gamma-\alpha$	0·05	0·0347	0·0500
2V	67°	69°	50½°
Sp. gr.	3·98	4·038	4·318

CHEMICAL COMPOSITION.

A bulk-analysis of the meteorite was made by the usual methods of rock-analysis. For the determination of ferrous iron and water the material was crushed (not powdered) until the whole passed through a sieve of 80 meshes to the inch. No barium, zirconium, or strontium was detected. The result of the analysis is given under I. Under II and III are given the results obtained by W. B. Pollard[1] and S. Meunier[2] respectively.

	I.	II.	III.
SiO_2	48·96	49·98	47·40
TiO_2	0·38	—	—
Al_2O_3	1·74	1·65	0·69
Cr_2O_3	0·33	0·23	—
Fe_2O_3	1·29	—	—
FeO	19·63	19·58	20·80
MnO	0·09	—	0·85
CaO	15·17	15·12	15·20
MgO	12·01	12·20	14·61
Na_2O	0·41	—	0·05 (Na₂O + K₂O)
K_2O	0·14	—	
S	0·06	—	—
H_2O at 110°	0·07	0·35 (H_2O at and above 110°)	—
H_2O above 110°	0·17		—
	100·45	99·11	99·60
Specific gravity[3]	3·47	3·40	3·388

[1] J. Ball, loc. cit., p. 8.

[2] S. Meunier, Compt. Rend. Acad. Sci. Paris, 1911, vol. cliii, p. 786.

[3] In I as determined on 1·0065 gram of the coarsely powdered stone.

Weight of material used in analysis: for main analysis, 1·0078 gram; for alkalis, 0·5368 gram; for ferrous iron, 0·5170 gram; for sulphur, 0·9545 gram; for water, 0·5366 gram.

In order to determine the proportion of soluble to insoluble silicates in the meteorite, 4·6782 grams were digested in hydrochloric acid of sp. gr. 1·06 in the usual way,[1] except that for the decomposition of the olivine two digestions of about twenty minutes' duration were considered sufficient. The insoluble, after treatment with sodium carbonate to remove silica, amounted to 3·9851 grams. The analysis of the soluble portion gave the following result, confirming the composition of the olivine given on p. 278:

SiO_2	...	...	33·06
FeO	...	...	51·67[2]
CaO	...	...	1·86
MgO	...	...	13·03
			99·62

The mineral composition of the meteorite, as calculated from the results of the bulk-analysis and from the known composition of the olivine is as follows:

$Na_2O . Al_2O_3 . 6SiO_2$	...	3·46				
$K_2O . Al_2O_3 . 6SiO_2$	...	0·83	...	6·76	...	Felspar
$CaO . Al_2O_3 . 2SiO_2$	...	2·47				
$FeO . Fe_2O_3$	...		...	1·87	...	Magnetite
$FeO . TiO_2$	...		...	0·73	...	Ilmenite
$FeO . Cr_2O_3$	...		...	0·49	...	Chromite
FeS	...		...	0·17	...	Troilite ?
$CaSiO_3$	...	30·54				
$FeSiO_3$	...	21·00	...	76·70	...	Diopside
$MgSiO_3$	...	25·16				
Fe_2SiO_4	...	9·87	...	13·25	...	Olivine
Mg_2SiO_4	...	3·38				
H_2O	...		...	0·24	...	Water
				100·21		

As regards classification, the meteorite of El Nakhla approaches most closely to the angrite group as represented by the meteorite of Angra dos Reis, Brazil. Like the Egyptian meteorite, this stone contains no

[1] L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 288.

[2] All the iron is estimated as ferrous oxide.

metallic iron and consists mainly of augite and olivine: the augite, however, is a dark purple, titaniferous variety, and amounts to more than 90 per cent. of the stone.

Explanation of Plates.

(The drawings have been made by Mr. W. Campbell Smith, Assistant in the Mineral Department, British Museum.)

Plate IX.

Fig. 1. Reproduction of photograph (taken from above) of a stone, weighing 725 grams, of the El Nakhla meteorite (see p. 275), showing encrusted surfaces: those on the right, smooth faces with fine network of fused ridges; those on the left, rough faces with more glossy crust. $\frac{3}{4}$ natural size.

Fig. 2. Thin section of meteorite of El Nakhla (see p. 275), showing diopside in prismatic sections twinned on (100) and (001); olivine in larger clear irregular grains with black inclusions; and interstitial felspathic material, of which two patches can be seen below the diopside showing herring-bone structure at the bottom of the slide on the right. Magnification, 23 diameters.

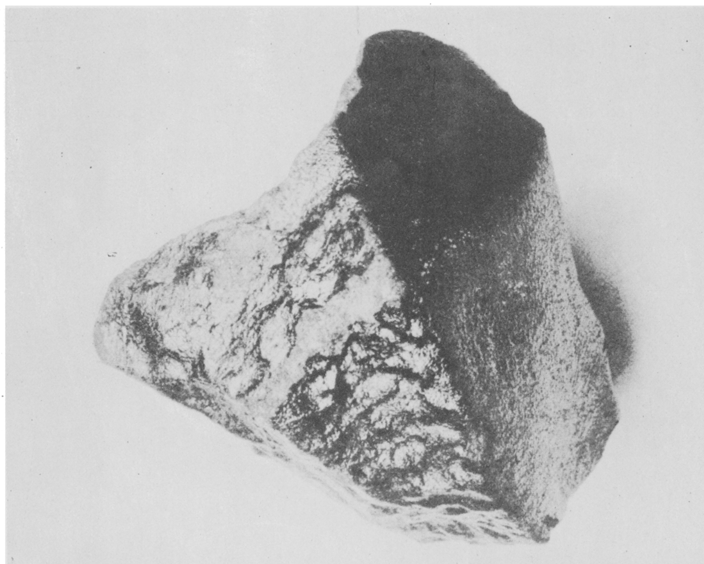
Plate X.

Fig. 1. Thin section of meteorite of El Nakhla (see p. 276), showing interstitial material consisting of felspar-laths, grains and sub-ophitic plates of diopside, and grains of magnetite. Magnification, 165 diameters.

Fig. 2. Section of olivine normal to obtuse positive bisectrix (see p. 277), showing inclusions as lenticular plates with long axes parallel to the line joining the optic axes. Magnification, 30 diameters.

Fig. 3. Section of olivine normal to acute negative bisectrix (see p. 277), showing the traces of the inclusions as sharp lines, all directed at right angles to the line joining the optic axes. Magnification, 30 diameters.

Fig. 4. One of the inclusions in the olivine as seen highly magnified in a section normal to obtuse positive bisectrix (see p. 278). Magnification, 365 diameters.



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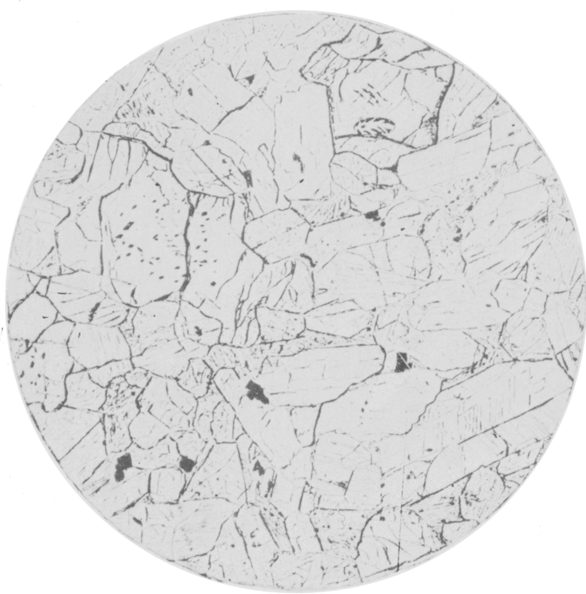
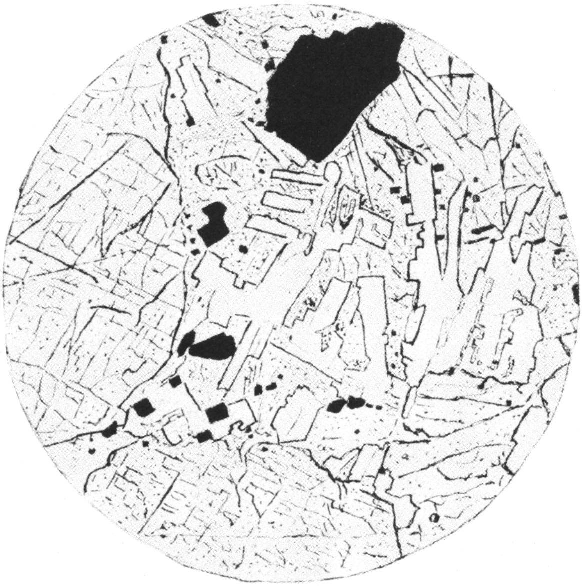


W. C. S. del.

2.

G. T. PRIOR: THE EL NAKHLA METEORIC STONE



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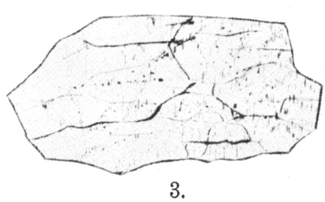

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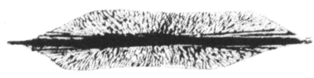

W. C. S. del.

4.

G. T. PRIOR: THE EL NAKHLA METEORIC STONE.