XIV. *On the Mineral Constituents of Meteorites.* *By* NEVIL STORY-MASKELYNE, *M.A., F.R.S., Professor of Mineralogy, Oxford, and Keeper of the Mineral Department, British Museum.*

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XII. *The Breitenbach Meteorite.*

THE Siderolite of Breitenbach was acquired for the British Museum in the year 1863. It was found (in 1861) at Breitenbach in Bohemia, at a spot not very far distant from the Saxon frontier, or indeed from Rittersgrün, in Saxony, a place in which a very fine mass, that bears a close resemblance to the Siderolite of Breitenbach, was almost contemporaneously found. A little way to the west of the centre of the line joining Rittersgrün and Breitenbach lies Steinbach, a village in the environs of Johanngeorgenstadt, near Schwartzenberg; and here in 1751 was also found a mixed meteoric mass in which, as in the two already mentioned, iron, sponge-like in its structure, encloses siliceous minerals that do not present a familiar aspect. The three meteorites are, in fact, so similar to one another and so dissimilar to any others in European collections, that there can be little doubt they belonged originally to the same meteoric fall.

STROMEYER* in the year 1825 examined a siderolite in which he found as much as 61·88 per cent. of silica. This remarkable result, together with the numbers of his analysis, he interpreted as indicating the presence of a magnesian trisilicate, probably meaning thereby a sesquisilicate (magnesium epideutosilicate). The specimen which he analyzed he described as coming from Grimma, in Saxony. This specimen was, in fact, a portion of a mass preserved in the collection of the Duke of Gotha, and doubtless believed by STROMEYER to be a portion of a stone which was known to have fallen in the middle of the sixteenth century in a wood near Naunhof in the neighbourhood of Grimma. CHLADNI†, however, held this view to be untenable, grounding his opinion on the completeness of the meteorite preserved at Gotha, both as regards its form and its crust, while he adds that the Naunhof mass must have been far too great to allow of its being transported, and, indeed, that it had never been rediscovered. It is in every way probable that the material STROMEYER really had to work upon was from a Saxon locality, and in fact a specimen from a fall, to which the Rittersgrün and Breitenbach siderolites belong. BREITHAUPT‡ believes the fall in question to have been the "*Eisenregen*" which occurred at Whitsuntide, 1164, in Saxony, when a mass of iron fell in the town of Meissen§.

An inspection of a polished surface of either of these masses reveals the iron in patches of irregular form, which exhibit the characteristic crystalline structure of meteoric irons

* POGG. Ann. iv. p. 195.

† Feuer-Meteore, pages 326 & 212.

‡ Berg. und Hütt. Zeitung, xxi. p. 322.

§ Feuer-Meteore, p. 198.

when etched. The interspaces are partly filled by meteoric pyrites (troilite) in small patches, recognizable by its pinchbeck brown colour, the rest of the surface being occupied by a greenish and greyish-brown crystalline magma. It is of the ingredients of the last-mentioned portion of the meteorite that I shall first speak. On treating the whole mass with mercuric chloride at 100° for some hours the iron and the troilite are dissolved, and the magma before alluded to remains unattacked. But it has now lost its compound structure, and is found to consist of three substances:—1, highly crystalline, bright green, or else greenish-yellow grains; 2, rusty brown, sometimes nearly black, sometimes also nearly colourless grains of a mineral that presents crystalline features, but on which definite crystalline planes are of great rarity; and 3, crystalline grains of chromite.

The first of these three minerals proved to be a ferriferous enstatite, or bronzite, the second is a mineral to which I do not at present assign a name, for it corresponds in all respects, except its crystalline form, with the tridymite of Professor Vom Rath. In respect of their forms, however, it is difficult to suppose that the two minerals are identical.

XIII. *Bronzite of the Breitenbach Siderolite.*

My friend Professor Von Lang measured crystals of the bronzite of the Breitenbach meteorite at the British Museum so long ago as 1863, and during last year he published his results*,—results that were mineralogically important as affording for the first time satisfactory and complete data for the crystallography of a rhombic mineral with the formula of an enstatite. This investigation was made exceptionally difficult by the very partially developed or merohedral character of the crystals on which Professor Von Lang had to experiment. A similar difficulty attended the crystallography of the silica of this meteorite. I need only recapitulate of Dr. Von Lang's results the elements and some of the important angles of the crystal.

Elements:—$a:b:c=0{\cdot}89568:0{\cdot}84960:1$,

which give the following angles by calculation:—

$$\begin{aligned} 110.010 &= 44^\circ\ 8' \\ 101.100 &= 41\ 11 \\ 011.010 &= 40\ 16 \end{aligned}$$

The mineral often presents itself in little spherules, invariably green in their tint and crystalline in their structure, as revealed by their optical characters, and sometimes, but very rarely, carrying here and there a crystal face. In fact the faces thus presenting themselves seem to do so almost fortuitously, and on the grains, which present a nearer approach to a true crystalline superficies, the faces that are developed exhibit very little of the symmetrical correspondence with other faces, or of the prevalence of those of any special forms, such as is ordinarily met with in crystals.

The specific gravity of this mineral is 3·238, that of the silicates in the Steinbach siderolite, as determined by Stromeyer, having been 3·276, and as estimated by Rumler 3·23. The hardness is 6.

* Bericht der Akad. Wiss. Wien, Bd. 59, ii. p. 848.

The blackened aspect of some of the bronzite was due to a mere superficial coating of iron oxide, arising doubtless from the oxidation of a portion of the nickeliferous iron. It was invariably found that this film was easily removed by hydrogen chloride, leaving the bronzite of a bright green colour, and that the action of the acid on the mineral extended no further.

Two analyses of this mineral were made, the one by the hydrogen fluoride method of distillation*, the other by fusion with mixed alkaline carbonates, and the results were as follow:—

	I.	II.	Mean.	Oxygen.
Silicic acid	56·101	56·002	56·051	29·89
Magnesium oxide . .	30·215	31·479	30·847	12·34
Iron protoxide . . .	13·583	13·295	13·439	2·97
	99·899	100·776	100·337	

These numbers correspond very closely with the formula $(Mg_{\frac{4}{5}} Fe_{\frac{1}{5}}) Si O_3$.

XIV. *Silica crystallized in the Rhombic System, as a Constituent of the Breitenbach Siderolite.*

It has already been stated that the second mineral associated with the bronzite in this meteorite is free silica, possessing the lighter specific gravity presented by quartz after fusion, and crystallized in forms that belong to the orthorhombic system. To this mineral, which is distinct in its system and forms from the tridymite of Vom Rath, I propose to give the name Asmanite A'sman, being the Sanscrit term (corresponding to the Greek ἄκμων) for the thunderbolt of Indra. In bulk it forms about one-third of the mass of mixed siliceous minerals. The grains of this mineral are found mixed with those of the bronzite after the iron, the troilite, and the chromite have been removed. They are very minute and much rounded, and, though entirely crystalline, they very rarely indeed present faces that offer any chance for a result with the goniometer; indeed out of the several thousand of these little grains comprised in some two grammes that were isolated of the mineral, it was only possible to find with a lens about a dozen specimens with sufficiently distinct crystallographic features; and of these only four or five proved to be available for examination and comparison. In several, however, the optic axes were plainly to be distinguished when properly examined with a Nörrenberg's polarizing microscope; and by this means the angles given by planes belonging to zones otherwise too incomplete for a reliable result were brought into comparison on different crystals.

Fortunately one minute crystal was met with in which the consecutive planes in half of the zone [1 0 0, 0 0 1] were complete enough to give reliable data for two of the parametral ratios, while the planes of the form (1 1 0) in the zone [0 0 1, 0 1 0] were all present, and one of them sufficiently brilliant to give an image by reflection.

This crystal, designated by the letter C in the subjoined Table (p. 363), enabled me to make use with confidence of the approximate measurements obtained on the other crystals, and the more so as in the polariscope it was easy to recognize in the normal to the plane 1 0 0 the first mean line of the optic axes.

* Philosophical Transactions, 1870, p. 189.

The rounded character which this mineral, in common with its companion mineral the bronzite, presents, suggests at the first view the idea that the sudden and intense heating which the mass must have undergone in its rapid course through the atmosphere may have fused, or at least softened, the surfaces of the two minerals. The rapid conduction of this heat into the interior of the meteorite, to which ordinary stone aërolites present much resistance by reason of the non-conducting character of their material, would in the case of a siderolite, where the iron forms a sponge-like and continuous mass, be greatly facilitated by the conductive character of the metal. This view is encouraged by the extraordinary brittleness of the surfaces of some of the larger rounded specimens, which often, with the most careful handling, will fly into fragments, an outer crust which formed the rounded parts splitting away from a sort of inner core. This inner portion is found to be far less brittle, and sometimes presents an irregular crystalline surface with one tolerably good cleavage-plane, parallel to the plane 0 0 1, and others extremely irregular, but following approximately the directions of the planes of the form (1 1 0), sometimes associated with the plane 1 0 0, the edges of which, however, are still often rounded. And yet it seems difficult to reconcile this explanation of the rounded forms and curiously merohedral character of the faces of these minerals, but especially of the bronzite, with the crystalline integrity of the entire grains to which the polarizing microscope bears evidence.

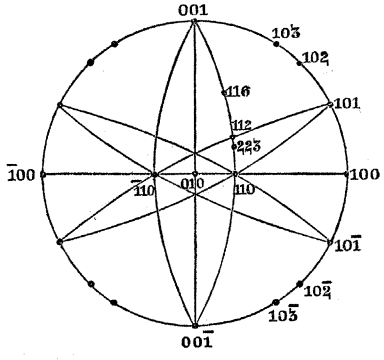
The bronzite, indeed, will sometimes be seen in the form of little spherules like fused drops with no faces at all, or at times with but one or two. The silica has usually a more barrelled aspect, the octaid planes in particular being almost invariably, and those in the zone [0 0 1, 1 0 0] being too usually, curved from this cause. But both exhibit birefringent characters, and the orientation of these accords with the symmetry of the crystals.

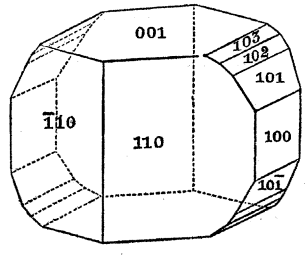
The crystallographic elements of the silica under notice are as follow:—

The parametral ratios are

$$a : b : c = 1{\cdot}7437 : 1{\cdot}0000 : 3{\cdot}3120.$$

The angles, as calculated from these data and as found on seven different crystals, are given in the following Table, in which the different letters serve to designate the different crystals. The majority of these angles were measured by repeatedly observing the direc-





tion of maximum illumination of the planes by the telescope of the goniometer, converted by a lens in front of the object-glass into a microscope.

The measurements thus obtained are necessarily therefore only approximative.

The faces 1 0 0, 0 0 1, 1 0 1 on the crystals A, C, and F gave images by reflection, and in the case of the crystal C the face $\bar{1}$ 1 0 gave also a fairly good image. The crystallographic elements were determined from the last-named crystal.

Calculated Angles.	A.	B.	C.	D.	E.	F.	G.
1 0 0 . 4 0 3 = 21° 33′	.....	.....	21° 31′				
1 0 1 = 27 46	27° 40′	27° 48′	27 46	27° 49′	27° 25′	27° 55′	27° 44′
1 0 2 = 46 29	46 18	.....	46 31	.....	46 2		
1 0 3 = 57 40	.....	.....	57 34	.....	.....	57 25	57 35
0 0 1 = 90 0	90 0	.....	90 0				
0 0 1 . $\bar{1}$ 0 3 = 32 20	32 22	.....	32 19				
2 0 3 = 51 42	51 32						
$\bar{1}$ 0 2 = 43 31	43 34						
$\bar{1}$ 0 1 = 62 14	62 17	.....	62 14				
1 0 0 . 0 1 0 = 90 0							
1 1 0 = 60 10	.....	60 13	60 10	.....	.....	60 10	
$\bar{1}$ 1 0 = 119 50							
1 1 0 . 1 $\bar{1}$ 0 = 120 20	.....	120 23	.....	.....	.....	120 10	
0 0 1 . 0 1 1 = 73 12							
0 1 0 = 90 0	.....	.....	90 0				
1 0 1 . 1 1 0 = 63 53	.....	.....	63 54				
$\bar{1}$ 1 0 = 116 7	.....	.....	116 7				
0 0 1 . 1 1 6 = 32 28	.....	.....	32 56				
1 1 2 = 62 21	.....	.....	62 21				
2 2 3 = 68 33	.....	.....	68 36				
1 1 0 = 90 0	.....	.....	90 0				
5 4 8 . 0 0 1 = 63 52	.....	.....	64 0				
1 0 0 = 58 28	.....	.....	58 30				
1 0 1 = 52 18	.....	.....	51 48				

The measurements in the zone [1 0 0, 1 1 0] are of a very uncertain character, it being difficult to determine accurately the angle which the plane 1 0 0 makes with even the

reflecting plane $\bar{1}\,1\,0$ on the crystal C. In fact the faces of the form (1 1 0), though parallel to what appears to be a somewhat difficult cleavage, never present a good even reflecting surface, being generally more or less conchoidal when cleavage-surfaces, and dull when natural faces.

The cleavage-plane 0 0 1 has a vitreous lustre; the lustre on the planes of the forms 1 0 0 and 1 0 1, as also of the rounded surface in the zone with them, is usually of a resinous character, strongly recalling that of opal.

It has already been observed that the faces of the octaid forms are almost invariably rounded. Fair approximate measurements, however, of three of the faces in the zone [0 0 1, 1 1 0] on the crystal C were obtained; and one octaid plane on that crystal, repeated in two octants, gave measurements that accord fairly with the somewhat complex symbol 5 4 8. This face, though not giving a reflected image, is the best octaid plane upon the crystal.

That the mineral belongs to the rhombic and not to a uniaxal system is emphatically evidenced, independently of these measurements, by its optical characters, as shown in its very distinct and widely separated optic axes. As has been said, the first mean line is the normal of the face 1 0 0, that to face 0 0 1 is the second mean line. The first mean line is parallel to the axis of least optical elasticity, so that the crystal is positive in its optical character. The apparent angle, as measured in air, of the optic axes was approximately determined as 107° to 107° 30′. The axes for the red rays are slightly more dispersed than those for the blue.

The crystalline grains which constitute this ingredient of the meteorite, when first obtained, are of a rusty brown and sometimes even black colour; treatment for a short time with dilute hydrogen chloride, however, entirely removes this iron stain and leaves the granules in a state of colourless purity, in which state they are readily distinguished from the grains of the accompanying bronzite.

The specific gravity of the mineral gave the number 2·245. Its hardness is 5·5.

Two analyses were made by different methods, and the results are given below.

I. 0·3114 substance, distilled with pure hydrogen fluoride, gave 1·1136 gramme of potassium fluosilicate, 0·0035 gramme iron oxide, 0·0018 calcium oxide, and 0·0132 gramme magnesium phosphate.

These determinations denote the following percentages:—

Silicic acid	97·43
Iron oxide	1·124
Calcium oxide	0·578
Magnesium oxide	1·509
	100·641

II. 0·2653 gramme of carefully selected substance, evaporated with an excess of ammonium fluoride, left 0·0021 gramme residue, chiefly iron oxide.

This determination denotes the following percentage composition:—

Silicic acid	[99·21]
Iron oxide &c.	0·79
	100·00

Besides the distinct cleavage parallel to the plane 0 0 1 already alluded to, and the other, less distinct, parallel to the planes of the form (1 0 1), there seem also to be divisional planes or, rather, surfaces along which the crystals break up with the greatest facility; even drying them on blotting-paper proving often sufficient to destroy the integrity of specimens that might otherwise seem to promise good results to the goniometer.

Partsch*, in his description of the Vienna Collection of Meteorites, identifies as a specimen of the Steinbach siderolite a fragment with a label, "Native iron, jagged and hackly, with quartz in grains and a yellow fluor-spar" (*gediegenes, zahnicht und zackicht gewachsenes Eisen mit körnichtem Quarz und gelblichtem Flussspath*).

Breithaupt†, in his paper describing the Rittersgrün Siderolite, makes its chief silicate to be peridot. It is doubtless bronzite. In addition to troilite and schreibersite, he records the presence of "another mineral the composition of which is not yet determined."

It should be mentioned that, with a view to test the relative solvent action of alkaline carbonates on quartz and the meteoric silica, weighed portions of each were digested with a ten per cent. solution of sodium carbonate for ten hours at 100° C. under precisely similar conditions. Of the quartz 7·843 per cent. had dissolved, of the Breitenbach silica 9·437 per cent.

XV. *Iron of the Breitenbach Siderolite.*

Of the other minerals forming the mass of this meteorite, namely troilite, some little schreibersite, chromite, present only in minute quantities, a crystal of which, however, was measured and gave angles corresponding to a regular octahedron, and, finally, the nickeliferous iron, which forms the sort of sponge-like skeleton that unites the whole, the last alone demands detailed investigation.

Two analyses, the former by the lead process, the latter by the barium method, gave the following results:—

	I.	II.	Mean.	Equivalent ratios.
Iron . . .	89·975	90·878	90·426	3·229
Nickel . .	9·642	8·927	9·284	0·314
Cobalt . .	0·383	0·195	0·29	0·01
	100·000	100·000	100·000	

The equivalent ratios, it will be seen, differ but slightly from Fe : (Ni, Co)=10 : 1. Some small amount of the above iron will have been present as troilite, which dissolved with the nickeliferous iron in the mercuric chloride. Copper occurs in the Breitenbach iron, but only as a trace.

Rube‡, who analyzed the Rittersgrün iron, found iron 87·31, nickel 9·63, and cobalt 0·58 per cent. The material appears not to have been entirely free from silicate.

* Die Meteoriten im k. k. Hof-Mineralien-Kabinette. Wien, 1843, p. 95.

† Berg. und Hütt. Zeitung, xxi. p. 321. ‡ Ibid. p. 72.

XVI. *The Shalka Aërolite.*

In the year 1860 the Ritter von HAIDINGER* first gave an account of the very remarkable meteorite that fell at Shalka, in Bancoorah, Bengal, on the 30th of November, 1850. The ash-like dark grey substance which forms the mass of this meteorite was described by the illustrious Viennese authority as a new silicate, to which he gave the name of Piddingtonite. He was, in fact, led to do this in consequence of an analysis of the mineral by K. VON HAUER, which yielded oxygen ratios corresponding to "a compound of bisilicate and trisilicate of iron and magnesium."

This assumed sesquisilicate, however, which has haunted the mineralogy of meteorites under the names of Chladnite, Shepardite, and, subsequently, of Piddingtonite, was surmised by GUSTAV ROSE† to be in this case a mixture of more than one silicate, while in the similar instance of the Bishopsville meteorite Dr. LAWRENCE SMITH‡ had already proved the supposed Chladnite to have been no other than an augitic mineral, in fact one with the composition and characters of enstatite. The mineral, however, which forms the mass of Shalka does not seem to be so easily disposed of; for Professor RAMMELSBERG§ has recently published an analysis of the mineral or minerals under discussion, and asserts the Shalka meteorite to contain something like 12 per cent. of olivine of the composition $2Fe_2SiO_4+3Mg_2SiO_4$||, the remainder being bronzite.

This meteorite had been examined some time back in the British Museum Laboratory with a very different result, and the discrepancies between this result and those as well of RAMMELSBERG as of VON HAUER induced me to have the analysis confirmed by further investigation. The conclusion, however, to which these experiments have led still leave the discrepancy where it was. In fact the selection out of the débris of the meteorite of the different ingredient minerals, or what seemed to be such, had at first led to the belief that it might indeed consist, first, of a grey silicate; secondly, a more mottled grey and possibly mingled mineral; and thirdly, chromite, which is present in considerable quantity, and often in very perfect crystals. An analysis, however, of the mixed silicates gave a result so nearly in accordance with that of a definite enstatite, that the view seemed hardly tenable. Furthermore, the analysis of the mottled variety gave as its result that this mineral is no other than bronzite.

The analysis of a very small amount of the débris of the meteorite gave the following numbers:—

		Oxygen.
Silicic acid	45·37	24·197
Iron protoxide	19·06	4·236
Calcium oxide	2·214	0·632
Magnesium oxide . . .	15·636	6·254
Chromite	17·717	
	99·997	

* Ber. Akad. Wiss. Wien, xli. p. 251.

† Beschreibung und Eintheilung der Meteoriten, p. 125.

‡ SILLIMAN'S Am. Journ. Sc. xxxviii. p. 225.

§ Ber. der Deutsch. Chem. Gesellschaft. Berlin, iii. p. 522.

|| POGG. Ann. cxl. p. 312.

Two analyses of the mottled variety of silicate furnished the results given below.

	I.	Oxygen.	II.	Oxygen.
Silicic acid	52·831	28·176	52·725	28·12
Iron protoxide . . .	21·863	4·859	22·992	5·109
Calcium oxide . . .	0·502	0·143	——	
Magnesium oxide . .	24·266	9·706	24·085	9·63
Chromite	0·643		——	
	100·105		99·802	

These numbers correspond with the formula $(Mg\frac{2}{3}\ Fe\frac{1}{3})Si\,O_3$, which is identical with the bronzite of the Manegaum meteorite*.

In fact the olivine found by RAMMELSBERG does not exist in the sample of the meteorite analyzed at the British Museum. This is probably due to the portions of the meteorite examined in his laboratory and mine being from different parts of the mass.

To check these determinations, a portion of the mottled variety was submitted to the action of acid in the cold, and subsequent treatment with alkali to remove the liberated silicic acid. The results now given show this action to have been confined to that of a solvent.

I. By treatment with a mixture of one part of strong hydrogen chloride and two of water for sixty-six hours in the cold, and subsequently with soda, there were removed the following percentages of

		Oxygen.
Silicic acid	1·507	0·804
Iron protoxide . . .	0·974	0·216
Magnesium oxide . .	1·058	0·423
	3·539	

II. A corresponding treatment of another portion with a mixture of one part of strong hydrogen sulphate and two of water, for 240 hours, gave the numbers:—

		Oxygen.
Silicic acid	3·900	2·08
Iron oxide	1·799	0·399
Magnesium oxide . .	1·877	0·75
	7·576	

The slight excess of iron found in both cases was doubtless the result of a little unseparated meteoric iron. It certainly would not justify my assigning any appreciable portion of the silica to the constitution of an olivinous ingredient of the meteorite.

In recording the results detailed in the analyses here given, I have to express my obligations to Dr. WALTER FLIGHT, Assistant in my Department at the British Museum, for his skilful and zealous cooperation.

* Philosophical Transactions, 1870, p. 189.