Sinhalite ($MgAlBO_4$), a new mineral.

(With Plate XXVII.)

By G. F. CLARINGBULL, B.Sc., Ph.D., F.G.S., and MAX H. HEY, M.A., D.Sc.

Department of Mineralogy, British Museum (Natural History).

[Read January 24, 1952.]

INTRODUCTION.

THE investigation which has led to this description of a new mineral began because of a suggestion by Dr. W. F. Foshag, when on a visit in 1951 to the Mineral Gallery of the British Museum (Natural History), that a brown cut gemstone exhibited as olivine had perhaps been incorrectly determined. More recently, Dr. Foshag has stated that the idea came from Dr. George Switzer, who as a result of an X-ray powder photograph taken in June 1950 of a similar specimen in the collection of the United States National Museum in Washington concluded that his material was not olivine and was likely to be a new species. The present work would not have been pursued had it been realized at the time that Dr. Switzer intended to continue the study when he had suitable material for analysis.

It became apparent on discussion with members of the staff of the Laboratory of the Diamond and Pearl Testing Section of the London Chamber of Commerce that both Mr. B. W. Anderson and Mr. C. J. Payne had suspected these brown supposedly iron-rich 'olivine' gemstones for many years, because their physical properties, in particular the β refractive index, did not fit the olivine graph,[1] and also because the pale colour of some of them seemed inconsistent with a high iron content.

[1] A. N. Winchell, Elements of optical mineralogy, pt. II, 1933, p. 191.

3 I

Cut stones were kindly loaned to us by the gentlemen whose names are listed in table I, and these have been extremely useful in exploring the range of properties of the new mineral. Special mention must be made of a generous gift by Mr. Robert Webster of the smaller part (76·4 mg.) of a broken stone (table I, no. 5) of the new species because it is on this material that the single crystal measurements and the chemical analysis have been made. The remainder of the stone has

TABLE I. Known specimens of sinhalite.

(Nos. 1–6 in the mineral collection of the British Museum; nos. 7–9 in the gem collection of the Geological Survey Museum.)

Serial no.	Weight in grams.	Registered number.	Previous determination.	Acquisition.
1.	3·474	B.M. 67976	Chrysoberyl re-named olivine in 1905	Purchased from W. Schmidt, 1892.
2.	4·142	B.M. 1915,315	Peridot	Presented by Lady Church, 1915.
3.	3·515	B.M. 1915,317	Peridot	Presented by Lady Church, 1915.
4.	2·038	B.M. 1934,889	Olivine	T. B. Clarke-Thorn-hill bequest, 1934.
5.	0·424	B.M. 1952,36	Olivine	Presented by R. Webster, 1951.
6.	0·794	B.M. 1952,37	(uncut pebble)	Presented by Dr. E. H. Rutland, 1952.
7.	0·457	5991	Chrysoberyl re-named chryso-lite in 1912	Purchased from S. Henson, 1890.
8.	8·593	9821	Chrysoberyl (un-checked)	Acquired, 1912.
9.	1·619	16603	Olivine	Presented by H. Stanley Jackson, 1930.
10.	0·560		Olivine	—
11.	1·368		Olivine	—
12.	4·140	Private collection of B. W. Ander-son	Olivine	Purchased from K. Parkinson, 1950.
13.	0·480		Olivine	—
14.	5·120		Olivine	Purchased from K. Parkinson, 1950.
15.	0·740		Olivine	—
16.	0·432	Private collection of A. E. Farn	Olivine	—
17.	0·440		Olivine	—
18.	0·330		Olivine	—
19.	3·700	Priv. coll. of Dr. E. H. Rutland	Olivine	—
20.	0·258	Priv. coll. of Sir James Walton	Olivine	—

now been presented by Mr. Webster to the British Museum. Further examples of the mineral were found in the collection of this Museum and also in that of the Geological Survey of Great Britain. It is pertinent to note here an entry made in 1912 by Dr. A. F. Hallimond in a register of the Geological Survey about a stone (table I, no. 7) originally called chrysoberyl and altered by him to chrysolite: 'This stone is to be further examined.'

Of the cut stones examined, two (table I, nos. 12 and 14) were brought from Ceylon in 1950 by Mr. Kenneth Parkinson and one (table I, no. 7) in the Geological Survey collection is localized as Ceylon. Confirmation of locality has been provided by Dr. E. H. Rutland, who has found a piece of rough sinhalite (table I, no. 6) in a sample of Ceylon illam imported by Chas. Matthews, Ltd. This pebble has now been presented by Dr. Rutland to the British Museum. The source of the other specimens is unknown. For this new mineral the name *sinhalite* is proposed, from Sinhala the Sanskrit name for Ceylon.

PHYSICAL PROPERTIES.

The authors are grateful for permission to include in table II data determined by Mr. B. W. Anderson and Mr. C. J. Payne (nos. 5, 6, 10–20), and by Mr. E. A. Jobbins and Dr. P. A. Sabine (nos. 7–9).

Where refractive indices are recorded to four decimal places they have been measured on Abbe-Pulfrich refractometers. The comparatively small negative 2V (56° measured for the analysed specimen; calculated mean 55° from eleven determinations of refractive indices) makes relatively easy the distinction between the new mineral and olivine (2V about 90°). Pleochroism in the darker stones is α deeper brown, β green, γ lighter brown. It will be noted that the analysed specimen is one of the lightest in colour. Probably the darker stones owe their enhanced absorption to increased iron content; but since the range of refractive indices is not directly related to colour further chemical information is desirable.

Specific gravities have been determined by hydrostatic weighing in water (nos. 1–4, 7–9) or ethylene dibromide. All determinations have been corrected to water at 4° C. and rounded off to the second decimal place.

There is little difference between the hardness of sinhalite and olivine. No cleavage was observed when crushing the specimen used for chemical analysis.

TABLE II. Optical data (sodium-light) and specific gravity of sinhalite.

Serial no.	Colour.	Refractive indices.			Birefringence.	Specific gravity.
		α	β	γ	$\gamma-\alpha$	
1.	brown	1·6691	1·6984	1·7064	0·0373	3·48
2.	pale brownish-yellow	1·6667	1·6966	1·7048	0·0381	3·47
3.	pale yellowish-brown	1·6682	1·6986	1·7064	0·0382	3·47
4.	brownish-yellow	1·6693	1·7000	1·7076	0·0383	3·48
5.	yellow	—	1·6969	1·7065	—	3·48
6.	greenish-brown	1·6690	1·6993	1·7069	0·0379	3·48
7.	light brown	1·6688	1·6979	1·7051	0·0363	3·50
8.	dark greenish-brown	1·670	—	1·706	0·036	3·50
9.	pale greenish-brown	1·669	—	1·707	0·038	3·49
10.	straw-yellow	1·6670	1·6968	1·7050	0·0380	3·47
11.	light brown	1·6693	1·6981	1·7062	0·0369	3·48
12.	brown	1·6691	1·6988	1·7069	0·0378	3·48
13.	brown	1·6711	1·7002	1·7081	0·0370	—
14.	dark brown	1·6708	1·7000	1·7081	0·0373	3·50
15.	brown	1·6688	1·6985	1·7059	0·0371	—
16.	pale yellowish-green	1·6680	1·6973	1·7060	0·0380	3·48
17.	yellow	1·6708	1·6978	1·7076	0·0368	—
18.	greenish-brown	1·6765	1·7038	1·7121	0·0356	—
19.	brown	1·6680	1·6982	1·7062	0·0382	3·48
20.	pale yellow	1·6678	1·6981	1·7055	0·0377	—

X-RAY INVESTIGATION.

Powder photographs of six stones (table I, nos. 1, 5, 11, 14, 16, 18) were made in 6-cm. diam. cameras with Cu-$K\alpha$ radiation. With the exception of no. 5 the material was obtained by scraping the girdle of the cut stone with a diamond. Samples of 0·1–0·2 mg. were used in the form of roughly spherical specimens mounted on glass fibres in conjunction with cylindrical collimators. The powder diagram is remarkably constant despite the wide variation of colour.

Two X-ray powder patterns of sinhalite (table I, nos. 5 and 18) are compared in text-fig. 1 and table III with those of forsterite, olivine, and fayalite. Powder photographs of sinhalite and forsterite are reproduced in pl. XXVII.

One small brown gem olivine (B.M. 64187) thought from appearance to be sinhalite was photographed and found to give a pattern close to St. John's Island olivine; it has α 1·653, γ 1·689, sp. gr. 3·35. It must

not therefore be assumed that all brown gemstones formerly identified as olivine are sinhalite.

TABLE III. X-ray powder data for fayalite, olivine, forsterite, and sinhalite.

Fayalite		Olivine		Forsterite		Sinhalite (no. 18)		Sinhalite (no. 5)		Sinhalite (no. 5)	
d_{obs}.	I.	d_{obs}.	I.	d_{obs}.	I.	d_{obs}.	I.	d_{obs}.	I.	d_{calc}.	hkl.
5·26	vw	5·12	w	5·12	m	4·97	m	4·93	ms	4·94	020
4·40	vvw	—	—	4·28	vw	4·00	mw	3·97	mw	3·96	110
3·97	w	3·90	ms	3·91	s	3·77	w	3·73	vw	3·73	021
3·80	vvw	3·73	w	3·74	mw	3·45	vw	3·43	vvw	3·44	101
3·55	ms	3·49	mw	3·50	ms	3·26	s	3·24	s	3·25, 3·26	111, 120
3·05	vvw	3·00	w	3·01	m	2·84	vvw	2·82	vvw	2·84, 2·82	002, 121
2·82	s	2·77	s	2·78	s	2·64	ms	2·62	s	2·62	130
2·63	w	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	2·47	vvw	2·46	vw	2·46, 2·47	022, 040
2·57	ms	2·52	ms	2·52	s	2·40	m	2·38	ms	2·37, 2·38	102, 131
2·50	s	2·46	s	2·46	vs	2·32	m	2·30	ms	2·31	112
2·41	vw	—	—	2·36	vw	—	—	—	—	—	—
—	—	—	—	—	—	2·27	vvw	—	—	2·26	041
2·35	vvw	2·34	vvw	2·32	vvw	—	—	—	—	—	—
2·30	w	2·27	m	2·27	ms	2·15	vs	2·14	vvs	{ 2·16, 2·11 / 2·14, 2·15	200, 210 / 122, 140
—	—	2·25	vw	—	—	—	—	—	—	—	—
2·193	vw	2·163	w	2·17	mw	—	—	—	—	—	—
2·070	vvw	2·032	vvw	2·04	vw	1·94	vvw	1·93	vw	1·925	132
1·982	vvw	1·952	vvw	1·96	vw	{ 1·876 / 1·824	vw / vvw	1·868 / 1·801	vw / vvw	1·871, 1·863 / 1·808	221, 042 / 230
1·924	vvw	1·893	vvw	1·883	vw	—	—	—	—	—	—
—	—	—	—	—	—	1·785	vvw	1·764	vvw	1·766	023
1·840	vw	—	—	1·800	vvwb	1·716	w	1·705	w	{ 1·707, 1·711 / 1·713	113, 142 / 151
1·776	s	1·749	s	1·751	vs	1·632	s	1·621	vs	1·625, 1·628	222, 240
1·700	vw	1·670	vw	1·673	w	1·592	vvw	} 1·576	vvwb	{ 1·581 / 1·564	061 / 241
1·679	vw	1·640	vvw	1·642	mw	1·568	vvw				
1·649	vw	1·620	vw	1·620	mw	1·541	w	1·534	w	{ 1·534, 1·525 / 1·539	133, 232 / 160
1·626	vw	—	—	1·597	vvw						
1·607	vvw	1·573	vw	1·575	w	1·524	w	1·514	w	1·518	152
1·590	vvw	1·515	vvw	1·514	vvw	1·427	m	1·420	ms	1·428, 1·424	310, 203
1·535	vvw	1·498	w	1·501	ms	1·387	vvw	1·384	vw	1·385, 1·384	320, 311
1·518	m	1·480	mw	1·482	ms						
1·485	vvw	1·438	vvw	1·441	vvw	—	—	1·360	vvw	{ 1·368, 1·364 / 1·351	223, 024 / 104
1·460	vvw										
1·430	vw	1·397	vw	1·399	mw	1·347	vw	1·340	w	1·345, 1·336	321, 114
1·420	vvw	1·350	w	1·352	m	1·324	vvw	1·320	vvw	1·321	330
1·408	vw	1·318	vw	1·318	w						
1·370	vw										
1·340	vw										

Note:—Equivalent lines of the different patterns have been arranged as far as possible in the same rows, except where these are separated by vertical rules.

Order of decreasing intensity: vvs, vs, s, ms, m, mw, w, vw, vvw; b broad. 6 cm. diameter camera, Cu-$K\alpha$ radiation ($\lambda = 1·542$ Å.). Indexing based on calculated d values from single-crystal measurements on specimen no. 5.

Despite the marked differences between the powder patterns of sinhalite and olivine there is a superficial resemblance; and subsequent
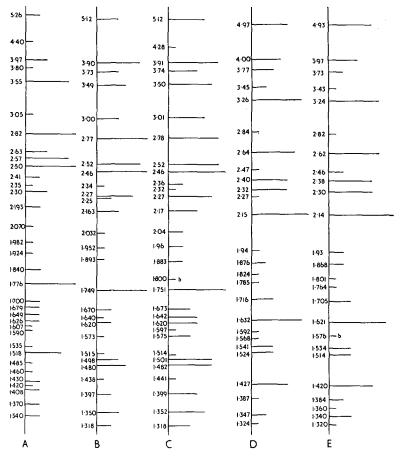

FIG. 1. Spacing intensity plots of X-ray powder photographs of: A, fayalite, Rockport, Essex Co., Massachusetts (B.M. 86609). B, olivine, St. John's Island, Red Sea, Egypt (B.M. 59305). C, forsterite, Monte Somma, Mt. Vesuvius, Italy (B.M. 80936). D, sinhalite (table I, no. 18). E, sinhalite (no. 5).

The d spacings are plotted as reciprocals and their approximate values in Ångström units are given against each line the length of which is an indication of intensity. b indicates broad and probably composite line. Data derived from table III.

indexing of these powder patterns from single-crystal data confirmed the first impression that the two minerals are related structurally. The

relationship is more clearly demonstrated by comparison of the a-axis Weissenberg photographs of sinhalite and forsterite (pl. XXVII, figs. 3 and 4). The structure of sinhalite is being investigated.

Single-crystal measurements for sinhalite were made from oscillation, rotation, and Weissenberg photographs of fragments of the broken stone in 6-cm. and 5·73-cm. diameter cameras. Sinhalite is orthorhombic with unit cell dimensions fairly close to olivine. The cell dimensions were refined by the method of Farquhar and Lipson[1] using back-reflection rotation photographs about the axes a and c indexed for high-order reflections by comparison with zero-layer Weissenberg photographs about the same axes. The axial ratios were first estimated from cell dimensions obtained from reflections of the type $h00$, $0k0$, and $00l$. The results are:

	Sinhalite.			Olivine[2] $(9Mg_2SiO_4.Fe_2SiO_4)$.	
a	...	... 4·328 Å.	a	...	... 4·755 Å.
b	...	... 9·878	b	...	... 10·21
c	...	... 5·675	c	...	... 5·985
$a:b:c$	= 0·4381:1:0·5745		$a:b:c$	= 0·4657:1:0·5862	

Equi-inclination Weissenberg photographs about the a, c, and [011] axes showed the following types of diffraction spectra: hkl in all orders, $0kl$ only with k even, $h0l$ and $hk0$ in all orders. The following space-groups are possible: D_{2h}^5 —$Pbmm$, C_{2v}^2—$Pb2_1m$, and C_{2v}^4 —$Pbm(2)$.

CHEMICAL ANALYSIS.

Sinhalite is insoluble in or only slightly attacked by acids other than hydrofluoric, differing markedly from olivine in this respect. For analysis two procedures were tried. One portion of 27 mg. was fused with sodium carbonate and the fusion distilled with methyl alcohol and sulphuric acid, the distillate being examined for boron,[3] while the residue in the flask was precipitated with 8-hydroxyquinoline, first in acetic acid solution (Al) and then in ammoniacal solution (Mg). The boron figure so obtained was suspected of being seriously low, so a second portion of 6·4 mg. was fused with caustic soda and the fusion dissolved in

---

[1] M. C. M. Farquhar and H. Lipson, Proc. Physical Soc., 1946, vol. 58, p. 200.

[2] W. L. Bragg, Atomic structure of minerals, 1937, p. 147; axial ratios misprinted as 0·4567:1:0·5862.

[3] E. Schulek and G. Vastagh, Zeits. Anal. Chem., 1931, vol. 84, p. 167; 1932, vol. 87, p. 195.

dilute HCl; aluminium and magnesium were precipitated together by 8-hydroxyquinoline and ammonia, and the filtrate from this precipitate was evaporated with a further addition of caustic soda and a little hydrogen peroxide, fused to complete the destruction of organic matter, and the boron titrated in the usual way; the mixed 8-hydroxyquinolates were dissolved and separated by reprecipitation in acetic acid, while iron was determined colorimetrically. This second method gave very satisfactory results. Several authors have reported difficulty in completely distilling boron as methyl borate in presence of considerable amounts of alumina.

The results of the chemical analysis are shown in table IV, together with empirical unit-cell contents calculated from the chemical analysis, specific gravity, and unit-cell dimensions. The small loss of weight on ignition has been assumed to be water, present as an impurity. The limits of probable error cited are calculated on the assumption that the cell-sides a and c are accurate to ± 0.001 and b to ± 0.002, that the specific gravity is accurate to ± 0.020 (including errors due to impurities or voids), and that the maximum probable errors of the analysis are: $B_2O_3 \pm 1.5$, $Al_2O_3 \pm 0.5$, $Fe_2O_3 \pm 0.2$, MgO ± 0.5, $H_2O \pm 0.3$. The iron was assumed to be wholly ferric; if it is all ferrous, the oxygen content will be 0.06 lower.

It will be clear that the ideal repeat formula of sinhalite is $4(MgAlBO_4)$, with an excess of Mg and Al and a deficiency of B that are probably outside the limits of error, and a small replacement of Al or Mg by Fe''' or Fe'' (it was not possible to determine which). The calculated specific gravity for pure $MgAlBO_4$ is 3.446 ± 0.001 (the ± 0.001 arises from the uncertainties in the cell-sides), or for $MgAlBO_4$ with 0.12 atom Fe''' replacing Al, 3.471.

TABLE IV. Chemical composition and unit-cell contents of sinhalite, and calculated percentage composition of $MgAlBO_4$. (Specimen no. 5.)

			Empirical unit-cell contents.			Calculated for $MgAlBO_4$.		
B_2O_3	...	... 24·2	B	...	... 3.55 ± 0.22	B_2O_3	...	... 27·60
Al_2O_3	...	... 41·0	Al	...	... 4.11 ± 0.06	Al_2O_3	...	... 40·44
Fe_2O_3	...	... 2·0	Fe	...	... 0.13 ± 0.01	MgO	...	... 31·96
MgO	...	... 32·3	Mg	...	... 4.10 ± 0.07			
H_2O	...	... 0·3	O	...	... 15.78 ± 0.16			
		——						——
		99·8	$D_4^{16°}$	...	... 3·475	$D_4^{16°}$		3.446 ± 0.001

So far as we know, no borate of Mg and Al has been obtained artifi-

cially; a mixture of MgO, Al_2O_3, and B_2O_3 ignited at 1200° C. gradually loses all B_2O_3 by volatilization, leaving a residue of spinel.[1]

Summary.—Most of the pale yellow to deep brown gemstones previously supposed to be iron-rich olivine[2] are a new mineral, sinhalite, having the ideal formula $MgAlBO_4$. Of 22 brown and yellow stones examined 20 are sinhalite and the remaining two are close to common green olivine. Sinhalite is readily distinguishable from green olivine by its higher refractive indices and specific gravity and its much smaller optic axial angle.

<div align="center">EXPLANATION OF PLATE XXVII.</div>

<div align="center">X-ray photographs of sinhalite and forsterite. Cu-$K\alpha$ radiation ($\lambda = 1·542$ Å.).</div>

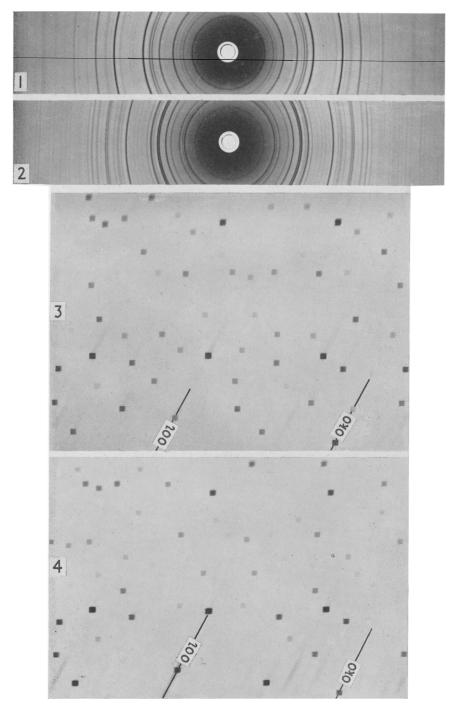FIGS. 1 and 2. Powder photographs on 6-cm. diameter camera.
FIGS. 3 and 4. Integrated Weissenberg photographs about the *a*-axis in 5·73-cm. diameter Nonius camera.
FIGS. 1 and 3. Sinhalite (specimen no. 5, B.M. 1952, 36).
FIGS. 2 and 4. Forsterite, Monte Somma, Mt. Vesuvius, Italy (B.M. 80936).

[1] J. J. Ebelmen, Ann. Chim. Phys., 1848, ser. 3, vol. 22, p. 213; 1851, ser. 3, vol. 33, p. 34.
[2] B. W. Anderson, Gem testing for jewellers, 1942, pp. 151, 183. [M.A. 8–309.]

G. F. CLARINGBULL AND M. H. HEY: X-RAY PHOTOGRAPHS OF SINHALITE
AND FORSTERITE