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Mboziite, a new sodic amphibole end-member

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Summary. An amphibole occurring in the Mbozi syenite–gabbro complex in SW. Tanganyika approaches very closely to the theoretical end-member $Na_2CaFe_3^{\cdot\cdot}Fe_2^{\cdot\cdot\cdot}Al_2Si_6O_{22}(OH)_2$; it has α 1·705, pale to light yellow, β 1·713, deep blue-green, γ 1·715, deep blue to green to black, with $\gamma \parallel [010]$ and $\beta : [001]$ about 7 to 14°; absorption $\gamma > \beta \gg \alpha$, with the maximum absorption on (010) at 9 to 12° to [001]. The mineral shows anomalous bright orange-red interference colours and incomplete extinction in sections parallel to (010) even in monochromatic light. X-ray powder data are given. A very similar amphibole occurs in the Darkainle nepheline-syenite complex, Borama district, Somali Republic.

While studying the Mbozi syenite–gabbro complex in south-west Tanganyika, one author (P. W. G. B.) noted a deep blue-green amphibole whose optical properties do not conform with those of the common sodic amphiboles (Brock, 1963). On analysis this amphibole was found to approach very closely the theoretical end-member $Na_2CaFe_3^{\cdot\cdot}Fe_2^{\cdot\cdot\cdot}Al_2Si_6O_{22}(OH)_2$. An amphibole from the Darkainle Nepheline-Syenite Complex, Borama District, Somali Republic (Gellatly, in preparation) was found to have similar optical properties, and on analysis proved to be of similar composition.

In this paper the distinctive optical properties, the compositions, and the X-ray data (O. v. K.) of these amphiboles are listed and compared with those of the common sodic amphiboles.

Occurrence. The type specimen comes from the *Mbozi Complex,* which is situated on the edge of the Tunduma branch of the Rukwa Rift Valley, 50 miles south-west of Mbeya, the capital of the Southern Highlands Region of Tanganyika. The complex consists of a suite of basic rocks intruded and metasomatized by alkaline rocks of late Pre-Cambrian age. The amphibole occurs most commonly as discrete grains in late stage nepheline-syenite dykes but is also found as a rim on other amphiboles in some of the metasomatic rocks. The mineral on which the optical determinations and analyses were carried out comes from a 15-foot dyke intruding nepheline-bearing gneisses in the south-western part of the complex.[1]

The dyke consists largely of oligoclase, potash feldspar (some showing microcline twinning), nepheline, amphibole, and aegirine-augite, with traces of biotite, sphene, apatite, iron ore, zircon, and pyrochlore also present. The felsic minerals are fine-grained (0·04 to 0·8 mm) and anhedral, while the mafic minerals occur as prismatic grains up to 3 mm long and from 0·5 to 2 mm thick, which are commonly sub- to euhedral. The amphibole and the aegirine-augite poikilitically enclose a few small rounded grains of feldspars and nepheline. The prismatic mafic minerals show a near-perfect alignment so that in a thin section cut perpendicular to the flow lineation only one grain in fifty lies with its *c*-axis within 45° of the plane of the section.

TABLE I. Analysis of the nepheline-syenite dyke from which the type specimen of mboziite was obtained.

Analysis		Norm		Mode	
SiO_2	56·90	or	36·62	Oligoclase	36·4 %
TiO_2	0·27	ab	32·04	Potash Feldspar	28·0
Al_2O_3	20·41	an	0·76	Nepheline	14·5
Fe_2O_3	2·96	ne	20·01	Sodalite	0·8
FeO	2·75	di	2·01	Mboziite	13·3
MnO	0·27		0·39	Aegirine-augite	6·5
MgO	0·24		1·77	Biotite	0·2
CaO	1·20	ol	0·14	Sphene	0·2
Na_2O	8·16		0·69	Apatite	0·1
K_2O	6·20	mt	4·28	Iron ore	tr.
H_2O^+	0·36	*il*	0·50	Zircon	tr.
H_2O^-	0·06	ap	0·13	Pyrochlore	tr.
P_2O_5	0·05	zr	0·03		
	99·83				

Analyst: Miss J. R. Baldwin.

An analysis of the dyke is given in Table I. The dyke is a foyaite, according to the C.I.P.W. classification, that plots fairly close to the nepheline-syenite eutectic of the Ne-Kp-Si system and also to Nockolds' average foyaite (see fig. 1). The high MnO to MgO and Fe_2O_3 to FeO ratios and the low MgO and CaO contents of the dyke all indicate that it is a highly differentiated rock.

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[1] Map coordinates on D.O.S. 1:50 000 Preliminary plot, Tanganyika, No. $\frac{\text{South C–36}}{\text{I–II–NE}}$ (257/11): 3485390 N. × 445150 E.

The *Darkainle Complex* is situated in the Borama District about 80 miles north-west of Hargeisa in the north-western part of the Somali Republic. It is a laccolithic complex of Pre-Cambrian age consisting principally of early syenites and nepheline-syenites intruded by late stage dykes of aplite, nepheline-syenite (which is locally pegmatitic), and carbonatite.

The amphibole is found in the early syenites, and both the early and late nepheline-syenites. Its optical properties vary slightly with host-rock composition. The amphibole from the late nepheline-syenites is the most similar to that from Mbozi. The Darkainle nepheline-syenites are subsolvus rocks compositionally similar to those of Mbozi.

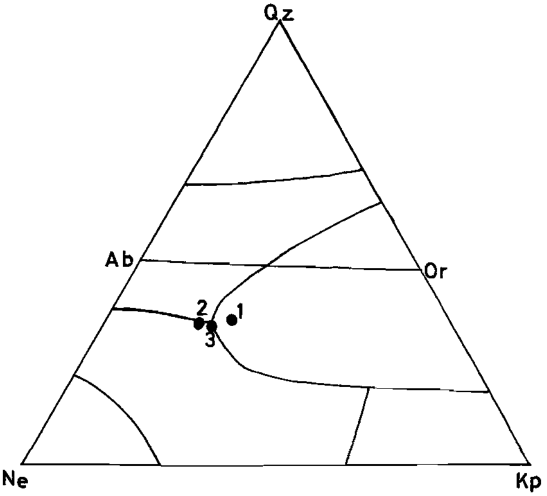

FIG. 1. Composition of the Mbozi nepheline-syenite dyke (1) compared with Bowen's nepheline-syenite eutectic (2) and Nockold's average foyaite (3).

The analysed amphibole comes from a late pegmatitic nepheline-syenite dyke intrusive into early syenites about half a mile north-east of Mohlileh Hill (43° 18′ E., 10° 25′ N.). This pegmatite consists principally of albite, microcline, and nepheline up to 1 cm, with subhedral to euhedral amphibole crystals, black in hand specimen, up to 10 cm long and 4 cm thick. The amphiboles are poikilitic, with irregularly disseminated inclusions of albite, microcline, calcite, magnetite, allanite, and garnet, and also thin parallel rods of exsolved aegirine. The enclosing rock, in addition, contains nepheline and cancrinite, and accessory zircon and pyrochlore.

Experimental

Refractive indices were determined by the immersion method using sodium light. Because of the strong absorption, however, the refractive indices were measured only with difficulty and they may not have an accuracy much better than ±0·003.

The amphiboles were separated for analysis, after crushing to −90 mesh, by use of bromoform and a Cooke magnetic separator. After this separation, biotite, amphibole, and aegirine, and a few mixed grains of amphibole and feldspar were the only visible impurities. These were removed by hand picking. As the inclusions in the Mbozi amphibole are relatively large (0·2 to 0·5 mm), most if not all the inclusions should have been broken free or at least exposed in grains of −90 mesh. The purity of the Darkainle amphibole was checked by microscopic examination of mounted grains. These grains were found to be free from aegirine inclusions—the most probable impurity. Thus both samples are thought to have been very nearly pure.

TABLE II. Optical properties of the Mbozi and Darkainle amphiboles

	Mbozi Amphibole	Darkainle Amphibole
α	near [100], pale to light yellow	near [100], pale brown
β	near [001], deep blue-green	near [001], greenish-blue
γ	$\parallel$ [010], deep blue to green to black	$\parallel$ [010], deep grey-green
absorption	$\gamma > \beta \gg \alpha$	$\gamma > \beta \gg \alpha$
α	1·705±0·003	1·708±0·003
β	1·713±0·004	1·715±0·004
γ	1·715±0·003	1·718±0·003
extinction	β: [001] ? ? 7–14°	β: [001] ? ca 14°
maximum absorption in (010)	β: [001] 9 to 12°	β: [001] 13 to 16°

Incomplete extinction even in monochromatic light and anomalous bright orange-red birefringence colours, at a maximum in sections parallel to (010).

X-ray powder diffraction data were obtained by Dr. G. Hornung with Siemens Crystalloflex IV equipment, using Cu-$K\alpha$ radiation and with NaCl as internal standard.

The amphiboles have several distinctive *optical properties*, the most obvious of which are their anomalous bright orange-red birefringence colours and incomplete extinction in sections parallel to (010), and their deep blue-green to black pleochroism colours (see table II). In addition, their high refractive indices and optical orientation ($\gamma \parallel$ [010] and β near [001]) distinguish them from most of the commoner sodic amphiboles.

Because of the imperfect extinction in sections parallel to (010), even in monochromatic light, the extinction angle β: [001] cannot be determined accurately. The maximum absorption in sections parallel to (010) occurs at β: [001] 9–12° and 13–16° for the two amphiboles. Several authors have noted the failure of iron-rich alkali amphiboles to extinguish completely (e.g. Eskola and Sahlstein, 1930; Shoda, 1954; Sahama, 1956; Borley, 1963). Sahama and Eskola have noted a faint striation on (100) and attribute the anomalous extinction to a perthitic intergrowth of two amphiboles of slightly different composition. Shoda and Borley, however, report no striations. Shoda suggests that elliptical polarization due to the strong absorption might cause the anomalous extinction, and Frost (1963), doing X-ray work on the Nigerian amphiboles described by Borley, reports that the X-ray patterns do not indicate an intergrowth between two amphiboles. The anomalous extinction of the Mbozi and Darkainle amphiboles, which show no striations on (100), appears to be more similar to that described by Shoda and Borley than that of Sahama and Eskola.

TABLE III. Chemical composition and atomic ratios to 24 (O, OH, F) of the Mbozi and Darkainle amphiboles

	1	2		1a		2a	
SiO_2	38·56	37·13	Si	6·20	Z = 8·00	5·99	8·00
Al_2O_3	10·31	12·50	Al	1·80 0·15		2·01 0·36	
TiO_2	0·96	0·30	Ti	0·11	$Y^{\cdots}$ = 1·85	0·04	1·75
Fe_2O_3	13·12	11·15	$Fe^{\cdots}$	1·59		1·35	
FeO	18·72	21·55	$Fe^{\cdot\cdot}$	2·52		2·90	
MnO	1·91	0·60	Mn	0·26	$Y^{\cdot\cdot}$ = 3·08	0·08	3·18
MgO	1·24	0·83	Mg	0·30		0·20	
CaO	5·78	7·54	Ca	1·00		1·30	
Na_2O	4·71	3·84	Na	1·47	X = 3·03	1·20	3·08
K_2O	2·73	2·81	K	0·56		0·58	
H_2O^+	1·66	1·85	OH	1·78		1·99	
H_2O^-	0·00	0·10	F	0·15	24	—	24
F	0·30	nil	Cl	0·04		—	
Cl	0·15	—	O	22·03		22·01	
	100·15	100·20					
Less O for F+Cl	0·16						
	99·99						

Spectrographic analyses by Miss J. M. Rooke show that both amphiboles contain traces of Li and Zr.

1. Mbozi amphibole. Analyst: Mrs. M. H. Kerr.
2. Darkainle amphibole. Analyst: O. von Knorring.

The *analyses* of the amphiboles are shown in table III together with the formulae calculated on the basis of 24(O,OH,F). It will be seen that the composition of the Mbozi amphibole is very close to the theoretical end-member $\mathrm{Na_2CaFe_3^{\cdot\cdot}Fe_2^{\cdot\cdot\cdot}Al_2Si_6O_{22}(OH)_2}$. It is proposed that this end-member should be called *mboziite*. The Darkainle amphibole lies between mboziite and hastingsite, but is closer to mboziite than to hastingsite.

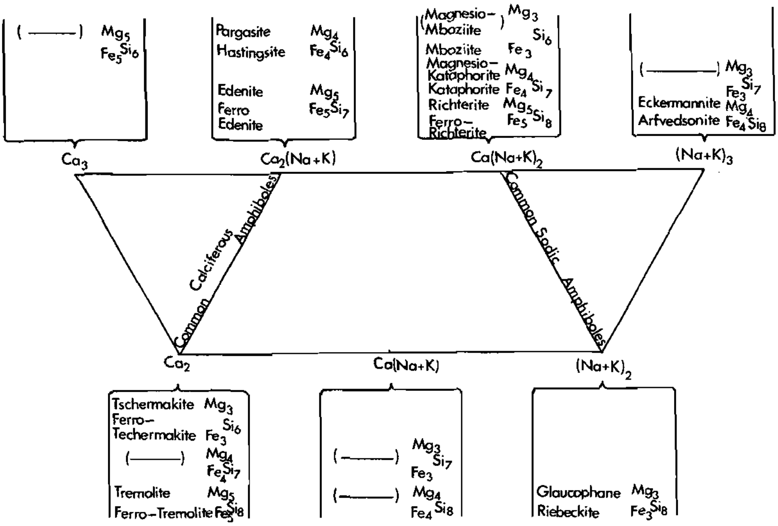

FIG. 2. Graphical representation of the compositions of the monoclinic amphiboles, based on the standard formula $X_{2-3}\ Y''_{3-5}\ Y'''_{0-2}\ \mathrm{Al^{iv}_{0-2}\ Si_{6-8}\ O_{22}(OH)_2}$, where $X = \mathrm{Ca+Na+K}$, $Y'' = \mathrm{Fe''+Mg+Mn}$, and $Y''' = \mathrm{Fe'''+Al^{vi}+Ti}$; $\mathrm{Al^{iv}+Si} = 8$, and $Y''+Y''' = 5$.
The complete formula for each end member can be deduced from its position on the diagram, e.g. Pargasite: $\mathrm{Ca_2(Na+K)}$ (from its position); $\mathrm{Mg_4(Al^{vi}, Fe)}$ (because $Y''+Y''' = 5$); $\mathrm{Al_2^{iv}Si_6}$ (because $\mathrm{Al^{iv}+Si} = 8$); and finally, unless otherwise specified (e.g. Magnesio-Reibeckite, Ferri-Hastingsite, &c.), the ratios of $\mathrm{Fe''}/Y''$ and $\mathrm{Fe'''}/Y'''$ are assumed to be equal; thus Pargasite $= \mathrm{Ca_2(Na, K)Mg_4Al^{vi}Al_2^{iv}Si_6O_{22}(OH)_2}$.

The relationship between the compositions of mboziite and of the commoner amphiboles is shown graphically in fig. 2. The names in this diagram conform with those used by Sundius (1946). Also shown on the diagram are all the electrostatically balanced formulae within the limits $\mathrm{(Ca+Na(+K))_{2-3}}$, $\mathrm{(Fe+Mg)_{3-5}}$, and $\mathrm{Si_{6-8}}$. For simplicity only the Si and Mg or Fe contents of the end-members are named. The other components can be readily deduced, however, since the Ca and Na (+K) contents are defined by the position of the amphibole on the diagram, also $Y^{\cdot\cdot}+Y^{\cdot\cdot\cdot}$ in the standard formula $(\mathrm{Ca}+\mathrm{Na}\,(+\mathrm{K}))_{2-3}$ $Y^{\cdot\cdot}_{3-5}Y^{\cdot\cdot\cdot}_{0-2}(\mathrm{Al},\,\mathrm{Si})_8\mathrm{O}_{22}(\mathrm{OH})_2$ must equal 5 where $Y^{\cdot\cdot} = \mathrm{Fe}^{\cdot\cdot}+\mathrm{Mg}+\mathrm{Mn}$ and $Y^{\cdot\cdot\cdot} = \mathrm{Fe}^{\cdot\cdot\cdot}+\mathrm{Al}^{\mathrm{vi}}+\mathrm{Ti}$, and $\mathrm{Si}+\mathrm{Al}^{\mathrm{iv}}$ must equal 8.

From the diagram it will be seen that mboziite (Si_6) lies on the extension of the ferro-richterite (Si_8)–catophorite (Si_7) series and has the same relationship to hastingsite as catophorite has to ferro-edenite. Besides the major variables shown on fig. 2, it should be noted that the potash content is relatively high, that the $\mathrm{Fe}^{\cdot\cdot}/Y^{\cdot\cdot}$ and $\mathrm{Fe}^{\cdot\cdot\cdot}/Y^{\cdot\cdot\cdot}$ ratios are high in both, but particularly in the Darkainle amphibole, and that Mn and F are present in significant quantities in the Mbozi amphibole.

TABLE IV. X-ray powder diffraction data for the Mbozi and Darkainle amphiboles

Mbozi		Darkainle		Mbozi		Darkainle	
d	*I*	*d*	*I*	*d*	*I*	*d*	*I*
11·06 Å	3	12·67 Å	4	2·033 Å	25	2·035 Å	20
11·04	3	11·81	4	1·904	4	1·904	10
8·53	70	10·19	8	1·880	6	1·829	7
4·81	10	9·59	5	1·809	5	1·662	20
4·53	8	8·51	60	1·762	4	1·600	10
4·06	3	4·79	20	1·712	3	1·551	9
3·89	5	4·52	10	1·663	25	1·514	8
3·42	20	3·41	15	1·645	4	1·465	6
3·29	25	3·29	25	1·601	10	1·451	25
3·15	100	3·15	100	1·574	4	1·378	7
2·97	10	2·97	10	1·548	6	1·347	7
2·732	50	2·724	50	1·531	5		
2·605	30	2·602	30	1·512	7		
2·572	15	2·565	20	1·484	7		
2·392	10	2·394	20	1·461	7		
2·347	30	2·351	30	1·447	30		
2·301	10	2·309	6	1·420	5		
2·176	25	2·177	30	1·379	10		
2·070	7	2·068	8	1·350	5		

X-ray data. The *d* and I/I_0 values for the two amphiboles are given in table IV. The three strongest lines (3·15, 8·51–3, and 2·73) correspond closely with three of the stronger lines present in the patterns of most other amphiboles listed in the X-ray powder data file up till 1962. In addition many of the weaker lines in the Mbozi and Darkainle amphiboles correspond to stronger lines in other amphiboles. Thus the patterns are generally similar to those of other amphiboles and are particularly similar to that of richterite given in the X-ray powder data file. Information on the X-ray patterns of the amphibole series

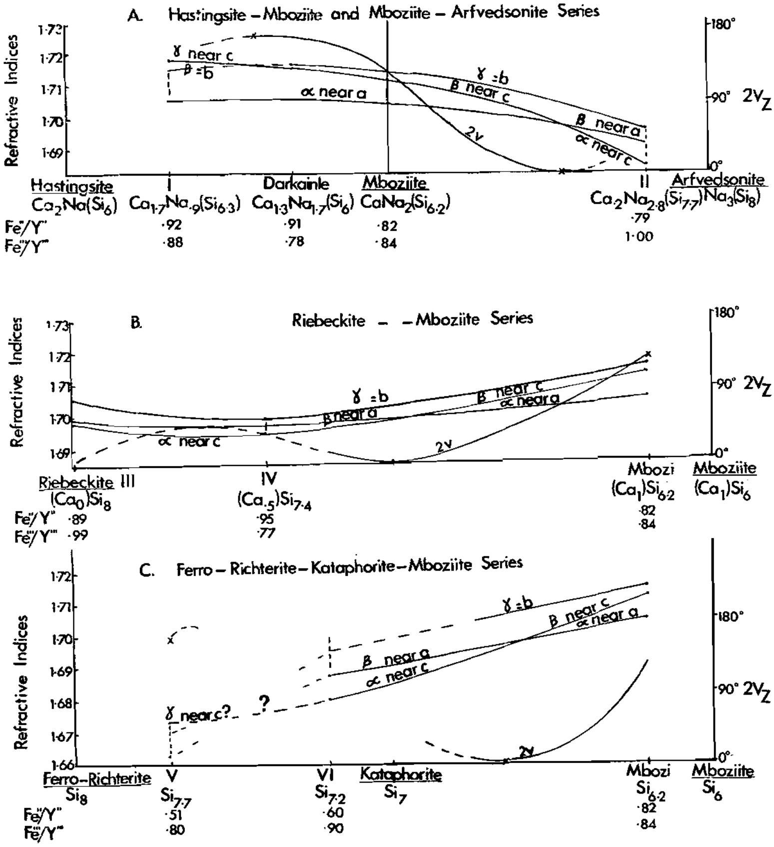

FIG. 3. The variations in optical orientation, refractive index, and 2V between Mboziite and other iron-rich alkaline amphiboles.

I. Hastingsite, Nigerian Younger Granites, Borley, 1963 (No. A. 19).

II. (Arfvedsonite), Nigerian Younger Granites, Borley, 1963 (No. A. 9). (If the proportions of Ca and (Na+K) are taken to be definite of the amphibole type, then this amphibole, which Borley calls riebeckite, actually lies very much closer to the arfvedsonite than the riebeckite end-member ($Ca_{0\cdot2}(Na+K)_{2\cdot8}$).)

III. Riebeckite, Kliphuis, South Africa (Peacock), Miyashiro, 1957 (No. 4).

IV. 'Arfvedsonite', Urmavaralia, Kola Peninsula (Kupletskij), Miyashiro, 1957 (No. 39).

V. Ferro-richterite, Mivula Syenite, N. Rhodesia, Newton & Drysdall, 1960.

VI. Catophorite, Fuenta Vaca (Kunitz), Miyashiro, 1957 (No. 50).

is too limited, however, for any general conclusions to be reached on the significance of the variations in the patterns.

Discussion

The refractive indices and optical orientations of mboziite are compared with those of the other alkali amphiboles in fig. 3. The changes in optical orientation shown imply the existence of specific compositions at which the amphibole would appear uniaxial. Thus 2V, even if it could be measured, would not be a useful optical property by which to identify the end-member since slight differences in composition would produce large changes in the 2V. Similar cross-over points have been noted by Miyashiro (1957) and Garson (1961) in the glaucophane–riebeckitic series.

In general the optical properties of alkali amphiboles are only rarely sufficiently distinctive to determine the composition with certainty. However, the optical orientation of mboziite is different from that in each of the other iron-rich alkali amphiboles, and when this feature is considered together with the high refractive indices, the anomalous extinction and birefringence, and the strong absorption, the resulting combination of properties is apparently unique.

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