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Some minerals from the leucite-rich rocks of the West Kimberley area, Western Australia.

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IN the investigation of a suite of leucite-lamproites from the West Kimberley area of Western Australia, carried out in the Department of Mineralogy and Petrology, Cambridge, during the period 1937–38, a number of unusual minerals were noted. Three of these were isolated and analysed and two of them proved to be new species. The present paper deals mainly with the three minerals analysed. They are—

(1) Magnophorite, a new amphibole allied to katophorite.
(2) Wadeite, a new potassium-zirconium silicate.
(3) Titaniferous phlogopite.

Field occurrence.

The leucite-bearing rocks occur at a number of isolated volcanic vents, nineteen of which have been examined and mapped by Dr. A. Wade. They have in every instance broken through sedimentary deposits of Permian age. Considerable diversity is to be seen in the rock types developed, but they are all characterized by high potash, magnesia, and titania, with low alumina and soda. Analyses of some types which indicate the general chemical character of these rocks are given in table I.

The minerals noted in this suite of rocks were leucite, phlogopite, diopside, katophoritic amphibole, rutile, and (?) nontronite (pseudomorphous after olivine), with wadeite, perovskite, and apatite as minor accessories, and serpentine, calcite, baryte, chalcedony, and various zeolites as secondary minerals and amygdales. A full account of the petrography and petrogenesis of this very unusual suite of rocks will be published shortly (Wade and Prider, 1939). In the present paper the unusual minerals mentioned above will be described.

TABLE I. Chemical analyses of some leucite-lamproites from the West Kimberley area, Western Australia.

	I.	II.	III.
SiO_2	45·82	52·45	54·48
TiO_2	7·34	5·85	5·57
Al_2O_3	6·86	8·64	9·87
Fe_2O_3	6·07	5·48	4·89
FeO	1·98	0·94	1·70
MnO	0·10	0·13	0·09
MgO	10·90	6·42	5·35
CaO	4·70	2·01	1·89
Na_2O	0·84	0·38	0·88
K_2O	8·82	10·42	11·06
H_2O+	0·75	1·99	1·36
H_2O-	2·40	2·89	0·89
CO_2	0·08	nil	nil
P_2O_5	1·83	1·58	0·40
BaO	1·27	1·19	0·64
SrO	n.d.	n.d.	0·16
ZrO_2	n.d.	n.d.	0·07
SO_3	n.d.	nil	0·10
FeS_2	0·07	n.d.	0·20
Cr_2O_3	0·07	n.d.	trace
V_2O_3	0·03	n.d.	n.d.
F	present	n.d.	0·09
	99·93	100·37	99·69
Less O= F	—	—	0·04
			99·65

I. Diopside-phlogopite-magnophorite-leucite-lamproite. Analyst, C. R. Le Mesurier.

II. Phlogopite-leucite-lamproite. Analyst, D. G. Murray (E. S. Simpson, 1926, p. 59.).

III. Magnophorite-leucite-lamproite. Analyst, R. T. Prider.

Magnophorite, a new amphibole allied to katophorite.

This mineral occurs as an essential and abundant constituent of most of the lamproites examined. It has invariably been the last essential mineral to separate and usually has a poikilitic structure enclosing euhedra of leucite and diopside (fig. 1). In one specimen from the Wolgidee Hills locality the amphibole is comparatively free from inclusions, except for calcite which frequently occurs as a coating on the cleavages. In this specimen the amphibole is idiomorphic towards a carbonated serpentinous groundmass and the forms developed are (110) and (010). The characteristic amphibole cleavages are well developed.

By fine crushing, treatment in acetic acid, and centrifuging in heavy liquids, followed by a separation with the electromagnet, it was possible to obtain a pure product for analysis. The analysis together with the calculation of the structural formula on a basis of 24(O,OH,F) (Warren, 1930, p. 493) appears in table II.

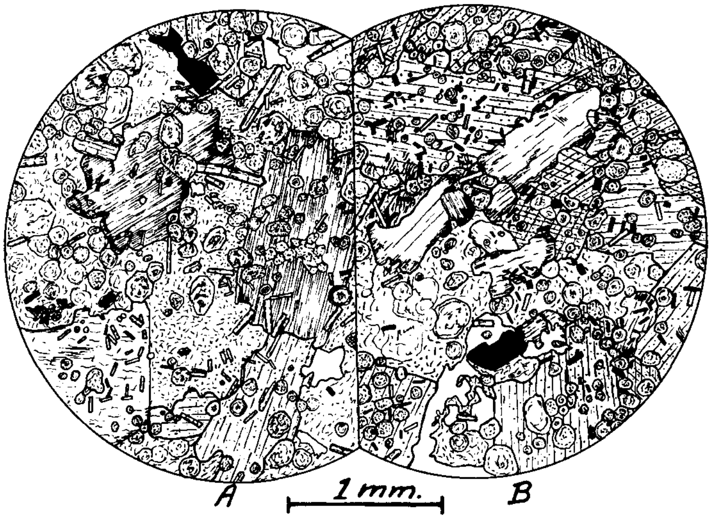

FIG. 1A. Lamproite (specimen no. 116a) from Moulamen Hill. Showing poikilitic inclusions of diopside and leucite in katophoritic amphibole (good prismatic cleavage; dotted) and phlogopite, the latter showing a dark resorption border. In lower left a well-shaped phlogopite plate is somewhat corroded. The groundmass is mainly greenish serpentine. Rutile as opaque rods and prisms.

FIG. 1B. Lamproite (specimen no. 456a) from Mt. North. Showing phlogopite (with dark resorption border) free from inclusions, and katophoritic amphibole (forming the greater part of the field) with poikilitic inclusions of diopside, leucite, and rutile. The groundmass is of serpentine. Irregular clear skeletal areas of zeolite.

The characteristics of this mineral are:

Specific gravity 3·12. Colour, pale reddish-brown.

Pleochroism: α colourless to pale yellow; β reddish, like α in hyper; sthene and increasing rapidly in intensity with increasing thickness; γ pale to bright yellow, occasionally slightly greenish. Absorption $\beta > \gamma > \alpha$.

Optic axial plane (010), $\beta = b$, $\gamma : c = 26°$, 2V 70°. Dispersion rather strong, $r < v$.

Refractive indices: α 1·616, γ 1·632, $\gamma - \alpha$ 0·016.

The absorption and pleochroism are indicative of a member of the katophorite group, but the analysis shows that the FeO and Fe_2O_3 of the normal katophorite have been replaced almost entirely by MgO. Another notable feature of this amphibole is the marked dominance of K_2O over Na_2O. The above calculation in table II shows that the structural formula of the mineral is:

TABLE II. Chemical analysis and calculation of katophoritic amphibole from specimen no. 242a, Wolgidee Hills, West Kimberley, Western Australia. Analyst, H. C. G. Vincent.

	Wt. %	Molecular proportions.	No. of metal atoms on basis of 24(O,OH,F).		
SiO_2 ...	52·67	0·878	7·582		8·000
Al_2O_3 ...	1·72	0·017	0·294		
TiO_2 ...	3·53	0·044	0·380	0·124	
				0·256	5·222
Fe_2O_3 ...	0·58	0·004	0·069		
FeO ...	2·41	0·033	0·285		
MnO ...	0·06	0·001	0·009		
MgO ...	21·32	0·533	4·603		
CaO ...	6·95	0·124	1·071		... 3·152
SrO ...	0·15	0·001	0·009		
BaO ...	nil	—	—		
Na_2O ...	3·64	0·059	1·019		
K_2O ...	5·70	0·061	1·053		
Li_2O ...	n.d.	—	—		
ZrO_2 ...	nil	—	—		
H_2O- ...	nil	—	—		
H_2O+ ...	0·46	0·026	0·449		... 1·036
F ...	1·29	0·034	0·587		
	100·48				
Less O = F	0·54				
	99·94				

$$(OH,F)_{1\cdot04}\ (Ca,Na,K)_{3\cdot15}\ (Mg,Fe,Ti,Mn)_{5\cdot22}\ (Si,Al,Ti)_{8\cdot00}O_{22}.$$

This agrees fairly well with the typical amphibole structural formula, the main points of difference being the low value of 1·04 for (OH,F) and the high value of 3·15 for (Ca,Na,K).

In table III are set down the analyses and optical properties of various amphiboles which show some affinities to that described above. From this table it will be seen that, optically, the Western Australian amphibole appears to be a katophorite; chemically, however, the closest relatives are imerinite, szechenyiite, and richterite. The two former amphiboles differ from the Western Australian mineral in having a considerable Na_2O content and very little K_2O. Richterite, the manganese-rich metamorphic amphibole, differs only in having a considerable amount of MnO and no TiO_2. The normal katophorite and anophorite have a high iron content, which in the Western Australian mineral has been replaced

TABLE III. Chemical analyses and optical data of various alkalic amphiboles showing affinities to the Western Australian amphibole.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	52·67	46·87	41·53	53·73	55·02	49·79	55·64	54·15
TiO_2	3·53	1·03	1·12	0·41	—	5·37	nil	—
Al_2O_3	1·72	7·97	10·27	2·72	4·53	1·98	1·08	0·52
Fe_2O_3	0·58	5·52	25·02	4·72	1·04	7·54	—	1·77
FeO	2·41	8·57		4·70	3·28	9·18	6·35	2·80
MnO	0·06	1·18	—	—	—	0·36	0·77	5·09
MgO	21·32	13·22	6·32	20·60	20·36	11·59	22·09	20·18
CaO	6·95	7·69	9·34	2·73	8·00	3·16	7·64	6·06
SrO	0·15	—	—	—	—	trace	—	—
BaO	nil	—	—		—	—	nil	—
Na_2O	3·64	4·46	3·62	7·42	6·71	7·92	2·89	2·77
K_2O	5·70	1·75	1·21	1·82	1·52	1·85	0·98	6·37
H_2O+	0·46	1·87	1·65	0·85	0·51	1·52	2·95	0·12
F ...	1·29	—	—	0·92	—	—	nil	—
	100·48	'100·33'	100·08	100·62	100·97	100·26	100·39	99·83
Sp. gr.	3·12	3·201	3·408	3·02	3·033	3·166	3·0	—
α	1·616	1·655	—	—	—	—	—	—
γ	1·632	1·662	—	—	—	—	—	—
$\gamma-\alpha$	0·016	0·007	—	—	—	—	0·020–0·030	—
Extinction	$\gamma : c$ 26°	$\alpha : c$ 56°	$\alpha : c$ 66°	$\gamma : c$ 50°	16°16′	$\beta : c$ 20–28°	$\alpha : c$ 16–70°	—
2V	70°	small	—	small	—	2E 33–40°	—	—
Dispersion	strong $r < v$	—	—	strong	—	strong $r > v$	—	—

	Pleochroism.			
	α	β	γ	Absorption.
I.	pale yellow	reddish	yellow	$\beta > \gamma > \alpha$
III.	clear green	brownish-red	reddish-yellow	$\beta > \gamma > \alpha$
IV.	pale yellowish-green	bluish-violet	pale bluish-green	$\beta > \gamma = \alpha$
VI.	pale yellow	greenish	reddish-brown	$\gamma > \beta < \alpha$
VII.	pinkish-lilac	paler lilac	blue	—

I. Amphibole from lamproite specimen no. 242a, Wolgidee Hills, West Kimberley area, Western Australia.
II. Katophorite, Khibina, Kola Peninsula, Russia. (Kunitz, 1930, pp. 219, 245.)
III. Katophorite, Grouvsletten, Norway. (Kunitz, 1930, pp. 219, 245.)
IV. Imerinite, Madagascar. (Lacroix, 1910, p. 787; 1922, p. 538.)
V. Szechenyiite, Burma. (Krenner, 1899, p. 503.)
VI. Anophorite, Katzenbuckel, Odenwald, Germany. (Freudenberg, 1908, p. 76; Rosenbusch, 1910, p. 201.)
VII. Winchite, Jhabua State, Central India. (Fermor, 1909, p. 149.)
VIII. Richterite, Långban, Sweden. (Magnusson, 1930, p. 45.)

almost entirely by MgO. Also the katophorite has much of its SiO_2 replaced by Al_2O_3. The alkalis in the Western Australian mineral differ considerably from those of katophorite and anophorite, which both have soda dominant over potash. The richterite from Långban is the only amphibole in the above table which has a similar content and relative proportion of soda and potash to the Western Australian mineral.

This mineral is therefore best described as a kali-magnesio-katophorite, and as it differs considerably from the normal katophorite in chemical composition it appears to warrant a new name. In an earlier summary report (Wade and Prider, 1938; Prider, 1939) on these leucite-rocks the name simpsonite was proposed for this mineral. Almost simultaneously the name simpsonite was proposed by H. Bowley for a new hydrous tantalate of calcium and aluminium from Tabba Tabba, Western Australia (Bowley, 1938, 1939), so the name *magnophorite* is now suggested for this mineral.

From the analyses of the leucite-rocks which contain magnophorite (analyses I and III in table I) it will be seen that this mineral, which has been invariably the last to crystallize, has separated from a residuum (after crystallization of the earlier phlogopite, diopside, and leucite) which was rich in potash, magnesia, titania, and silica, and which contained very little alumina.

A similar mineral to the above has been recorded from two localities. Osann (1906, p. 295) has described an amphibole with similar pleochroism and absorption from the jumillites of Murcia, Spain, and Cross (1897, p. 125) records the presence of a similar amphibole in the rock orendite from the Leucite Hills, Wyoming. In both instances the mineral was considered to be katophorite, but in neither case was the mineral examined chemically. With regard to the amphibole occurring in the orendite of the Leucite Hills, Cross (1897, p. 126) states: extinction seems to be always parallel to the length axis; $\alpha = a$, pale yellow; $\beta = b$, red similar to hypersthene; $\gamma = c$, bright yellow; absorption $\beta > \gamma > \alpha$; almost uniaxial with the arms barely separating in the 45° position.

An examination of the amphibole in the orendite specimen in the Petrology Museum at Cambridge shows that this mineral is often zoned, with extinction-angles $\gamma : c = 5°$ for the periphery and 17° for the centre. Extinction is rarely straight (as stated by Cross) and frequently is as much as 25°. The mineral has the same pleochroism, absorption, and strong dispersion as noted in the mineral described above as magnophorite, but has slightly higher refringence, β measured on several minute prisms being 1·643. This mineral, therefore, is essentially the same as magnophorite. Its paragenesis is the same as for the Western Australian mineral, as it is associated with diopside, phlogopite, and leucite, and has separated from a potash-silica-rich and alumina-poor residuum after the formation of diopside, phlogopite, and leucite.

Cross (1897, p. 131) suggests, in view of the considerable zirconia content (0·22 %) of the orendites, 'that the peculiar amphibole of orendite is perhaps zirconia-bearing, analogous to låvenite, wöhlerite, and hiortdahlite'. Acting on this suggestion I determined zirconia on a slightly impure sample of magnophorite (containing not more than 5% impurity) and found this constituent to be absent.

Wadeite, a new potassium-zirconium silicate.

This new mineral was found in the rocks from the Wolgidee Hills, and amongst all the specimens examined it has only been noted from this locality. The material analysed was separated from the same specimen as the magnophorite described above, viz. no. 242a. In this rock the wadeite is present to the extent of about 1 or 2%, occurring as highly birefringent prisms up to 1 mm. in length and as hexagonal-shaped basal sections. It has crystallized before the magnophorite and is invariably idiomorphic towards it, but its relations with the diopside are not visible in any of my slices. It is invariably replaced in part (especially along the poor pyramidal cleavages) by calcite.

It appears to be hexagonal and is usually as well-shaped crystals flattened on the base, the sections then appearing to have elongation of a negative character. The faces developed are the base, prism, and occasionally a pyramid. Poor pyramidal cleavages intersecting at angles of nearly 90° are present in some crystals and are rendered visible because of the presence of secondary calcite which has entered along these directions. Typical sections of the mineral are shown in fig. 2.

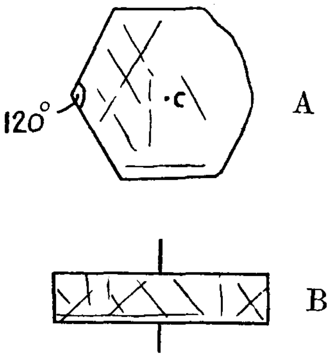

FIG. 2. Wadeite, showing forms developed.

A. Basal section showing imperfect (?) prism cleavages.

B. Section parallel to the c-axis, showing poor pyramidal cleavages intersecting at approximately 90°. A poor basal and prismatic cleavage also present.

The mineral is colourless, uniaxial, optically positive, and has ϵ 1·655, ω 1·625, $\epsilon-\omega$ 0·030.

It has a specific gravity of 3·10, is non-magnetic and insoluble in hot acids.

The mineral was separated by centrifuging the fine-powdered, acid-treated rock in heavy liquids and later purified by separation with the electromagnet and finally by hand-picking. In all, only 0·5 gram was obtained and that included slight impurity (estimated at less than 5%). The analysis must therefore be regarded as correct only to the nearest whole number. Water above 110° C. was determined by loss on ignition on the main portion. The result of the analysis is shown in table IV. This table also shows the calculation of the analysis. In the third column the proportions of the groups of metal atoms has been worked out as shown and are found to be approximately:

$$(Si,P,Al):(Al,Ti,Mg,Zr):(Ca,Sr,Na):(K,Ba) = 4:1:1:2,$$

from which the formula (omitting the small amounts of Sr, Mg, and Ba) appears to be:

$$K_2(Ca,Na)\ (Zr,Ti,Al)\ (Si,P,Al)_4O_{12}(OH)$$

or ideally $K_2(Ca,Na)Zr(Si,Al)_4O_{12}(OH)$.

In the fourth column the number of metal atoms on a basis of 13(O,OH) is given, and it will be seen that the values obtained closely approach the ideal proportions of 4:1:1:2:1.

Regarding the 'loss on ignition' assumed in the above to be water above 110° C., the mineral was heated to redness and then examined microscopically. It suffered no apparent change during the heating, no signs of incipient fusion were present and the mineral retained its clarity. It is doubtful, therefore, whether any water is present in the structure of the mineral. The analysis has been recalculated on a basis of 12(O) and the 1·30% loss on ignition disregarded. The results of this calculation are shown in table V. The formula of the mineral according to this calculation is:

$$K_{2\cdot05}\ (Ca,Na)_{0\cdot95}(Zr,Ti,Al)_{1\cdot23}(Si,Al)_{4\cdot00}O_{12}.$$

Acting on the suggestion of Professor Tilley, attempts were made to synthesize the mineral. This work was conducted by Mr. H. C. G. Vincent to whom I am indebted for the following notes. An initial charge of K_2CO_3 1·382, $CaCO_3$ 1·001, ZrO_2 1·232, SiO_2 2·402 grams was heated for $\frac{3}{4}$ hour in the electric furnace to drive off the CO_2. After several attempts at heating in the Fletcher gas-furnace a pure glass was obtained. This was crushed and crystallized at a temperature of approximately 900° C. for 14 hours in the electric furnace, giving a crystalline mass plus a little glass. Microscopical examination showed the crystals to be in sheaf-like masses with negative elongation, straight extinction, uniaxial of positive optical character with a refractive index slightly greater than 1·608. This material appeared to resemble pseudo-wollastonite, but it was insoluble in HCl. (Note: the natural mineral is similar in its optics to pseudo-wollastonite). These crystals must have had a composition approaching $K_2CaZrSi_4O_{12}$, as there was very little glass left after crystallizing for 14 hours: optically they are similar (but with somewhat lower refractive indices and different habit) to the natural

Table IV. Chemical analysis and calculation of wadeite. Analyst, R. T. Prider.

	Wt. %	Molecular proportions.	No. of metal atoms × 1000.			No. of metal atoms. on basis 13(O,OH).		
SiO_2	39·43	0·657	657			3·544		
P_2O_5	3·15	0·022	44		800	0·237		4·000
Al_2O_3	5·98	0·059	118	99 19		0·636	0·417 0·219	
$(Ce,Yt)_2O_3$	nil	—	—			—		
Fe_2O_3	trace	—	—			—		
TiO_2	1·63	0·020	20		219	0·108		1·298
MgO	0·28	0·007	7			0·038		
ZrO_2	21·29	0·173	173			0·933		
CaO	5·22	0·093	93			0·502		
SrO	0·16	0·002	2		… 185	0·011		… 0·998
Na_2O	2·82	0·045	90			0·485		
K_2O	18·40	0·196	392		… 400	2·114		… 2·157
BaO	1·20	0·008	8			0·043		
H_2O-	nil	—	—			—		
H_2O+	1·30	0·072	144		144	0·777		
	100·86							

Table V. Calculation of analysis of wadeite, assuming that no hydroxyl is present in the structure.

	Molecular proportions.	No. of oxygens.	No. of metal atoms on a basis of 12(O).			
SiO_2	0·657	1·314	3·372			
P_2O_5	0·022	0·110	0·226			4·000
Al_2O_3	0·059	0·177	0·605	0·402 0·203		
TiO_2	0·020	0·040	0·103			
MgO	0·007	0·007	0·036			1·230
ZrO_2	0·173	0·346	0·888			
CaO	0·093	0·093	0·477			
SrO	0·002	0·002	0·010		0·949	
Na_2O	0·045	0·045	0·462			3·002
K_2O	0·196	0·196	2·012		2·053	
BaO	0·008	0·008	0·041			
		2·338				

mineral. Another sample of the glass was now crystallized at 1300° C. (i.e. above the transition-point of pseudo-wollastonite) and the result was a colourless prismatic mineral (very similar to that obtained at 900° C.) plus some very highly refracting and highly birefringent rounded granules plus some glass.

A little of the natural mineral (slightly impure) was fused in a small platinum capsule in the Fletcher gas-furnace for $\frac{3}{4}$ hour. On quenching the melt the result was glass plus some very highly refringent granules (? similar to those obtained in crystallizing the artificial material at 1300° C.). The glass of the natural mineral melt was now crystallized at 1300° C. giving small prismatic crystals plus some glass.

The fusion experiment on the natural mineral appears to indicate that it melts incongruently to glass plus a very highly refringent material. Attempts at synthesizing the mineral gave at low temperatures of 900° C. a mineral very similar in optics but differing in habit. At higher temperatures of 1300° C. crystals plus highly refringent globules similar to those in the quenched melt of the natural mineral were obtained, thus supporting the suggestion that the natural mineral melts incongruently.

Returning to a consideration of the natural mineral, it is distinct from any previously described. Its closest relative is catapleiite from which it differs mainly in its low water and high potash content. The name proposed for this new mineral is *wadeite*, in honour of Dr. Arthur Wade, who was responsible for the collecting of this suite of rocks, and who discovered the new Wolgidee Hills intrusion where this mineral has been found.

Titaniferous Phlogopite.

This mineral occurs as a constant constituent of most of the leucite-bearing rocks. It appears to be fairly constant in character throughout the suite of rocks examined, except that in the more basic types it has a somewhat stronger absorption. One group of these rocks of widespread occurrence is made up entirely of this mineral plus leucite plus a very siliceous glassy groundmass. The phlogopite is usually phenocrystal, and the rocks appear to be surface flows as they usually show a flow orientation of the phlogopites or an elongation of the chalcedony-filled vesicles. The material for analysis was separated from an amygdaloidal phlogopite-leucite-lamproite from the Howe's Hill locality. The phlogopite in this rock is present as parallel alined, usually somewhat corroded, lath-shaped phenocrysts up to 2 mm. in length, which have crystallized earlier than the leucite and rutile which occurs as innumerable minute prisms in the glassy base. It is a deep reddish-brown colour, and is characterized by strong pleochroism after the scheme: α practically colourless to pale salmon-pink, β bright yellow, γ reddish-brown.

It has a comparatively large axial angle and always shows polysynthetic twinning parallel to the base, which, owing to the marked difference in absorption along β and γ, is visible without the aid of the analyser, as the alternate lamellae show different pleochroism, one set of lamellae from pale salmon-pink to bright yellow and the alternate lamellae from pale salmon-pink to deep reddish-brown.

TABLE VI. Chemical analysis and calculation of phlogopite from phlogopite-leucite-lamproite, Howe's Hill, Western Australia. Analyst, H. C. G. Vincent.

	Wt. %.	Molecular proportions.	No. of metal atoms on basis 12(O,OH,F).		
SiO_2 ...	40·78	0·680	2·986		4·000
Al_2O_3 ...	10·95	0·107	0·940		
TiO_2 ...	8·97	0·113	0·496	0·074 0·422	2·925
Cr_2O_3 ...	trace	—	—		
Fe_2O_3 ...	2·18	0·014	0·123		
FeO ...	3·73	0·051	0·224		
MnO ...	trace	—	—		
MgO ...	19·66	0·491	2·156		
CaO ...	0·11	0·002	0·009		... 1·028
SrO ...	trace	—	—		
BaO ...	0·35	0·002	0·009		
Na_2O ...	0·11	0·002	0·018		
K_2O ...	10·59	0·113	0·992		
Li_2O ...	nil	—	—		
H_2O- ...	0·19	—	—		
H_2O+ ...	1·87	0·106	0·931		... 1·080
F ...	0·66	0·017	0·149		
	100·15				
$-O = F$	0·27				
	99·88				

The analysis of this mineral is shown in table VI and the optical properties are:

Colour, deep reddish-brown.

Pleochroism: α pale salmon-pink to practically colourless, β bright yellow, γ reddish-brown. Absorption $\alpha<\beta<\gamma$.

α 1·599, γ 1·643, $\gamma-\alpha$ 0·044; $\alpha{:}c$ to 5°.

2V 38°, negative; dispersion very strong, $r<v$.

The structural formula (calculated in table VI):

$$(OH,F)_{1\cdot08}(Ca,Ba,Na,K)_{1\cdot03}(Mg,Fe'',Fe''',Ti)_{2\cdot92}(Si,Al,Ti)_{4\cdot00}O_{10}$$

agrees with the general structural formula for biotite with the exception of the (OH,F) group, which is very low in the above mineral. This appears to be a constant feature of the micas in these rocks. A determination of the water and fluorine content of a phlogopite separated from a similar rock from the Bruton's Hill locality gave H_2O 1·51, F 1·13%. The water was determined by the Penfield method in a silica tube, and in view of the fluorine present is, if anything, a little high.

It will be remembered that in the calculation of the structural formula for magnophorite it was found that the (OH,F) content was considerably lower than that required in the amphibole structure. This deficiency of (OH,F) in the two important hydroxyl-bearing minerals seems to be significant and to point to the deficiency as being due to *(a)* a loss of volatiles from these minerals during the period of intrusion of the rocks under low-pressure conditions at or near the surface, or *(b)* the separation of these minerals from an extremely 'dry' magma.

With regard to the possibility of loss of volatiles from these minerals during their crystallization at shallow depths, a possible clue is presented by the analysis of the phlogopite from the wyomingite of the Leucite Hills, Wyoming (table VII, analysis IV). This phlogopite is similar in occurrence and association to the Western Australian mineral and, with the exception of the high titania in the latter, these two analyses are very similar. The structural formula for the Wyoming phlogopite is:

$$(OH,F)_{2\cdot18}(Ca,Ba,Na,K)_{1\cdot06}(Mg,Fe'',Fe''',Ti)_{2\cdot67}(Si,Al,Ti)_{4\cdot00}O_{10}.$$

There is no deficiency here in the (OH,F) content. Also, an optically similar mica is noted in the jumillites of Spain, and although a complete analysis has not been made of this mineral, a determination of its fluorine content of 2·16% (Osann, 1906, p. 293) indicates that there has been little loss of volatiles. These two similar occurrences of phlogopite appear to indicate the improbability of loss of volatiles as the explanation of the very low hydroxyl-fluorine content of the Western Australian mineral.

A glance at table VII, in which are set down the analyses of other micas comparable in composition with that described above, shows that in the titania-rich types the hydroxyl content is low, as in the Western Australian phlogopite. Unfortunately fluorine has not been determined in either of these analyses. The mica from the Howe's Hill rock differs from that in wyomingite only in its high TiO_2, which has replaced some of the SiO_2, Al_2O_3, and MgO. Both of these micas show the same peculiar twinning and pleochroism, but the absorption of the Howe's Hill mica is much stronger than that of the Wyoming phlogopite and its refringence is much higher. (A determination on the phlogopite from the wyomingite in the Cambridge collection gave β 1·595).

In view of the very high TiO_2 content, together with the high MgO and K_2O, the mica in the Western Australian leucite-rocks is best described as a titaniferous phlogopite.

TABLE VII. Micas comparable in composition with the West Kimberley phlogopite.

	I.	II.	III.	IV.
SiO_2	40·78	37·47	36·12	42·56
Al_2O_3	10·95	12·91	14·89	12·18
TiO_2	8·97	10·86	7·68	2·09
Cr_2O_3	trace	—	—	0·73
Fe_2O_3	2·18	0·88	7·25	2·73
FeO	3·73	11·64	5·93	0·90
MnO	trace	—	—	—
MgO	19·66	14·68	15·12	22·40
CaO	0·11	—	0·68	0·20
SrO	trace	—	—	—
BaO	0·35	1·52	—	1·00
Na_2O	0·11	0·94	1·56	0·44
K_2O	10·59	8·66	9·35	10·70
Li_2O	nil	—	—	trace
H_2O-	0·19	—	0·45	—
H_2O+	1·87	1·80	1·05	2·35
F	0·66	n.d.	n.d.	2·46
	100·15	101·36	100·08	100·74
$-O = F$	0·27			1·03
	99·88			99·71

I. Titaniferous phlogopite from phlogopite-leucite-lamproite Howe's Hill, West Kimberley area, Western Australia.

II. Biotite (meroxene) from shonkinite, Katzenbuckel, Odenwald, Germany. (Rosenbusch, 1910, p. 201.)

III. Biotite from mica-peridotite, Kaltenthal, Harzburg, Germany. (Rosenbusch, 1910, p. 212.)

IV. Phlogopite from wyomingite, Leucite Hills, Wyoming. (Cross, 1897, p. 130.)

Other minerals.

Other minerals from the West Kimberley leucite-rocks include diopside, leucite, and (?) nontronite. Of these the diopside is interesting as it appears to be an almost pure diopside with γ 1·700. It is usually euhedral and the forms developed are (110), (100), and occasionally (010). Most of the diopside shows lamellar twinning on (100). This mineral has not yet been isolated for analysis.

The leucite is also very interesting as it shows alteration to a turbid material not unlike kaolin in appearance. Fresh leucite showing the characteristic complicated twinning has been observed in one specimen only. The analyses of these rocks indicate an excess of SiO_2 over that required to satisfy all the K_2O and Al_2O_3 in the form of orthoclase; the fine-grained base of these rocks must therefore be of very siliceous nature or the turbid alteration product of the leucite must contain much more SiO_2 than leucite. This material has certainly not had any K_2O removed from it by leaching. Further examination of this interesting mineral will be made when more material is available.

The remaining mineral of interest (? nontronite) occurs in the form of fibrous pseudomorphs after olivine. It is a bright green mineral with high birefringence and pleochroism after the scheme:

α yellow-green, $\beta = \gamma$ bright green. Absorption $\alpha < \beta = \gamma$.
α 1·595, γ 1·625, $\gamma - \alpha$ 0·030.

This mineral, therefore, appears to be a nontronite, and this is supported by the occurrence of cores of opal or quartz in the pseudomorphs.

Of the minerals described in the above pages, leucite, phlogopite, magnophorite, and an almost pure diopside, which are all abundant constituents of the West Kimberley lamproites, are present in the lamproites of the Leucite Hills, Wyoming, and Murcia, Spain. Occurrences of lamproites are rather rare and the common mineral associations in the three known lamproitic provinces mentioned above is interesting. The mineral magnophorite appears to be restricted to the lamproitic rocks, as no similar amphibole has been recorded from any igneous rocks other than the lamproites mentioned above. Phlogopite is also a rather rare mineral in igneous rocks, but the high potash and magnesia content of the lamproitic magma provides a favourable chemical environment for the separation of this mineral. No mineral similar to wadeite has been recorded from the Spanish or Wyoming areas, but the considerable zirconia content (0·22%) of the Wyoming rocks indicates the possibility of the occurrence of wadeite in these rocks.

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References.

BOWLEY (H.), 1938. Rep. Dept. Mines Western Australia, for 1937, pp. 93, 88.

—— 1939. Simpsonite (sp. nov.) from Tabba Tabba, Western Australia. Journ. Roy. Soc. Western Australia, vol. 25 (for 1938–39), pp. 89–92.

CROSS (W.), 1897. The igneous rocks of the Leucite Hills and Pilot Butte, Wyoming. Amer. Journ. Sci., ser. 4, vol. 4, pp. 115–141.

FERMOR (L. L.), 1909. The manganese-ore deposits of India, Part 1. Mem. Geol. Surv. India, vol. 37.

FREUDENBERG (W.), 1908. Der Anophorit, eine neue Hornblende vom Katzenbuckel. Mitt. Badisch. Geol. Landesanstalt, vol. 6, pp. 45–83.

KRENNER (J. A.), 1899. Jadeïtsteine aus Birma. Zeits. Kryst. Min., vol. 31, p. 503.

KUNITZ (W.), 1930. Die Isomorphieverhältnisse in der Hornblendegruppe. Neues Jahrb. Min., Abt. A, Beil.-Bd. 60, pp. 171–250. [M.A. 4–200.]

LACROIX (A.), 1910. Minéralogie de la France, vol. 4.

—— 1922. Minéralogie de Madagascar, vol. 1.

MAGNUSSON (N. H.), 1930. Långbans malmtrakt. Avh. Sveriges Geol. Undersökn., Ser. Ca, no. 23.

OSANN (A.), 1906. Über einige Alkaligesteine aus Spanien. Festschr. Rosenbusch.

PRIDER (R. T.), 1939. The leucite-bearing rocks of the West Kimberley area, Western Australia. Abstr. Diss. Univ. Cambridge, for 1937–38.

ROSENBUSCH (H.), 1910. Elemente der Gesteinslehre.

SIMPSON (E. S.), 1926. Contributions to the mineralogy of Western Australia, Ser. 1. Journ. Roy. Soc. Western Australia, vol. 12, pp. 58–59.

TAYLOR (L. E. R.), 1939. X-ray studies on simpsonite. Journ. Roy. Soc. Western Australia, vol. 25 (for 1938-39), pp. 93–97.

WADE (A.) and PRIDER (R. T.), 1938. The geology and petrology of the Kimberley district, Western Australia. Rep. Brit. Assoc. Adv. Sci., Cambridge, 1938, p. 419.

—— —— 1939. The leucite-bearing rocks of the West Kimberley area, Western Australia. Abstr. Proc. Geol. Soc. London, 1938–39, pp. 103–105.

WARREN (B. E.), 1930. The crystal structure and chemical composition of the monoclinic amphiboles. Zeits. Krist., vol. 72, pp. 493–517. [M.A. 4–278.]