Phosphates and other minerals in pegmatites of Rhodesia and Uganda

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Summary. In the rich mineral assemblage found in the pegmatites of Rhodesia and Uganda are members of the amblygonite–montebrasite series with α 1·592–1·615, γ 1·612–1·638, the highest values corresponding to montebrasite, $Li_{1.98}Al_{2.00}(P_{1.95}O_{7.90})(OH_{1.90}F_{0.20})$; apatite with up to 8·8 per cent MnO; heterosite (new analysis) and other manganese-iron phosphates; and a variety of niobium–tantalum and uranium minerals.

STUDIES of pegmatites in Rhodesia and SW. Uganda, made in connexion with a programme of beryl reserve assessment by the U.K. Atomic Energy Authority (Ackermann *et al.*, in press), have resulted in the identification of about 80 mineral species, the great majority of which are minor constituents of the pegmatites. Brief descriptions of some of these minor minerals are recorded here with new chemical analyses of several phosphates. Related studies have dealt with the rare beryllium minerals found in the pegmatites (Gallagher and Hawkes, 1966) and with a new uranium mineral, meta-ankoleïte (Gallagher and Atkin, 1966); further work on the bulk composition of some of the pegmatites and on the distribution and chemical composition of beryl is in progress.

The information has been obtained from detailed mineralogical studies of about 40 pegmatites in Rhodesia and 10 in SW. Uganda, but specimens were collected from more than 100 pegmatites in all. Most of the pegmatites are exposed in shallow surface workings of limited extent and even where there has been underground exploitation internal structure is seldom well defined. In Rhodesia, however, large-scale mining operations at Bikita for lithium minerals (Cooper, 1961; Wilson and Martin, 1964), at Kamativi for cassiterite (Fick, 1960), and to a lesser extent at the Benson mine for tantalum minerals (von Knorring and Hornung, 1963), have yielded excellent exposures from which much of the information given here has been obtained. The geographical coordinates of all the pegmatites referred to in the text are given in an appendix; details of the location of some of the more important Rhodesian pegmatites can be found in the full descriptions given by Ackermann *et al.* (in press).

Amblygonite–montebrasite. Small amounts of amblygonite–montebrasite are known in about a dozen pegmatites in Rhodesia and at three localities in Ankole, Uganda. The refractive indices of 13 specimens are in the range α 1·592–1·615, γ 1·612–1·638, pointing to a range in montebrasite ($LiAlPO_4OH$) content from 50 to 100 %. In Rhodesia, amblygonite–montebrasite is accompanied by other lithium minerals except in the Mterikati pegmatite. Lithiophorite is the only other lithium mineral occurring in the Ankolean pegmatites. The amblygonite–montebrasite is usually medium or coarse-grained and white or yellow-white in colour. Sugary-grained montebrasite occurs in Rhodesia in one of the Kamativi pegmatites and in a pollucite unit of the Dam Site pegmatite.

The refractive indices of montebrasite from the Benson 2 pegmatite (no. 13, table I) are the highest known. The formula $Li_{1\cdot98}Al_{2\cdot00}(P_{1\cdot95}O_{7\cdot90})(OH_{1\cdot90}F_{0\cdot20})$ was obtained from the chemical analysis after correction for intergrown quartz and apatite (see table III). Montebrasite of lower fluorine content and higher hydroxyl content is known from Kimito, Finland (Pehrman, 1945, p. 34), but the refractive indices are distinctly lower than those of the Benson 2 montebrasite. The sodium content of the Benson 2 montebrasite is the lowest recorded. Apatite replaces montebrasite in a sample from the Bikita pegmatite and members of the goyazite and possibly of the variscite groups (containing traces of beryllium) are alteration products of montebrasite in the Ankolean pegmatites (Gallagher and Hawkes, 1966).

Apatite. Most of the pegmatites contain small amounts of apatite. The refractive indices of 28 apatite specimens from 17 pegmatites in Rhodesia and two in Kigezi, Uganda, show a limited variation, ω 1·633–1·649 (determinations mainly $\pm$0·002), indicating that fluorapatite is the main variety present. Dark green apatite with ω 1·647 found in six perthite-rich pegmatites from the Miami district of Rhodesia appears to be manganoan fluorapatite. This variety forms large crystals and contains numerous capillary gas–liquid inclusions. Two fluorapatite crystals from the Bulema pegmatite (Kigezi, Uganda) have ω 1·633 and 1·639. In the Bikita pegmatite, the grain-size of apatite varies from 0·1 mm to 20 cm. In the banded unit near the foot-wall, sugary apatite grains may occur in small groups concentrated around large crystals. Some crystals have very irregular margins and can be compared with

TABLE I. Some properties of amblygonite and montebrasite from the pegmatites. Refractive indices reported here (and throughout the paper) were determined in sodium light using a temperature-controlled stage coupled to an Abbé refractometer.

Pegmatite	Grain-size	Colour	α	γ	
1. Bikita Main (R)‡, petalite quarry	coarse	cream	1·592	1·612	±0·001
2. Bikita Main (R), western intermediate unit	fine	yellow-white	1·597	1·619	±0·001
3. Mauve, near Salisbury (R)	medium	cream	1·599	1·621	±0·001
4. Nyanga Main (U), loose block*	coarse	white	1·600	1·622	±0·002
5. Kazumu Main (U), core*	coarse	white	1·602	1·623	±0·002
6. Ronmau, near Mtoko (R)	medium	pearl-white	1·604	1·627	±0·001
7. Bikita Main (R), eastern intermediate unit	fine	yellow-white	1·605	1·627	±0·001
8. Mterikati (R)	medium to coarse	white	1·606	1·628	±0·002
9. Sheshe (U)*	medium	yellow-white	1·609	1·631	±0·002
10. Sheshe (U)*	medium	grey-white	1·609	1·631	±0·002
11. Kamativi (R)	medium	cream	1·609	1·631	±0·002
12. Kamativi (R)	medium	cream	1·610	1·632	±0·002
13. Benson 2, near Mtoko (R)†	fine to coarse	pinkish-white	1·615	1·638	±0·001

* Partly altered to other phosphates. † Chemical analysis in table III. ‡ R—Rhodesia; U—Ankole district, Uganda.

'skeletal' apatite (Olson and Hinrichs, 1960, plate 7B). Sugary-grained fluorapatite is the chief accessory mineral in the intermediate unit directly above the banded unit. The refractive indices of eight apatite specimens are, with one exception, in the range ω 1·635–1·640 indicating fluorapatite. A prismatic apatite crystal from the mica band at the base of the banded unit has much higher refractive indices. It is 15 cm

TABLE II. Manganese content of apatite from Bikita Main pegmatite, Rhodesia; MnO determinations by G. H. Smith, National Physical Laboratory.

Specimen	1	2	3	4
Pegmatite unit	mica band	lower part of banded unit	upper part of banded unit	hanging-wall intermediate unit
colour of apatite	faintly bluish-grey	grey	grey	bluish-grey
$\omega \pm 0{\cdot}001$	1·649	1·636	1·637	1·636
% MnO	8·80	5·10	3·45	3·90

in length and projects into a small amphibolite xenolith. Analyses of this apatite and of three other specimens for manganese are given in table II. Not only is there a considerable tenor of manganese in fluorapatite (specimens 2–4), but the content in the high-index apatite (specimen 1) is one of the highest known (cf. Cruft, 1966, p. 392).

Manganese–iron phosphates. A new analysis of heterosite from an albite-perthite pegmatite in Rhodesia is given in table III. The black heterosite forms fragments up to 15 cm across in the pegmatite dumps and the large amounts of Mn^{4+} and combined water shown by the analysis are probably a result of surface weathering. The X-ray powder spacings of the Sabi Star heterosite determined by D. Atkin are closely comparable with those of heterosite from the Varuträsk pegmatite given by Quensel (1956). A number of additional spacings are reported by Quensel, however, including all those not indexed on A.S.T.M. card 11–447, plus the important spacing at 2·73 Å, which is questionably indexed as an 031 spacing. The Mn^{2+} and lithium in the Varuträsk heterosite are attributed by Quensel to admixture with ferrisicklerite but the *d*-spacings in question suggest that the impurity may be varulite.

Complex assemblages of manganese–iron phosphates such as those in the Varuträsk pegmatite, Sweden (Quensel, 1956), and in the Buranga pegmatite, Rwanda (Thoreau and Safiannikoff, 1957), are developed in the Kabira pegmatite of Uganda (von Knorring, 1962) and in a pegmatite at the Chiwya Claims in Rhodesia. Work by R. K. Harrison has shown that the Chiwya pegmatite carries psilomelane, graftonite, strengite, arrojadite, and an amorphous manganese–iron phosphate, accompanied by minor uraninite and quartz. The amorphous phosphate encloses graftonite and other manganese minerals poikilitically and is cut by minute fractures filled with pale yellow secondary uranium minerals.

TABLE III. Chemical analyses of two phosphate minerals from Rhodesia.

	1	2	3	4	
SiO_2	0·6	1·14	—		
Al_2O_3	0·6	33·57	35·22	Al	1·996
Fe_2O_3	31·2	0·04	—		
FeO	—	0·41	—		
CaO	0·9	1·54	—		
MgO	0·8	0·35	—		
K_2O	0·5	n.d.	—		
Na_2O	0·1	0·02	0·02	Na	0·002
Li_2O	0·2	9·74	10·22	Li	1·976
P_2O_5	37·8	46·70	47·87	P	1·949
Mn_2O_3	15·3	—	—		
MnO_2	5·2	—	—		
$H_2O^{+105°C}$	5·7	5·65	5·92	(OH)	1·899
$H_2O^{-105°C}$	1·9	0·15	—		
F	tr.	1·33	1·29	F	0·196
	100·8	100·64	100·54		
Less O for F		0·56	0·54		
		100·08	100·00		
G	3·3±0·1	3·00			

1. Heterosite (weathered), Sabi Star pegmatite, Buhera district, Rhodesia. New analysis by G. A. Sergeant, Geological Survey and Museum, Lab. no. 1869.
2. Montebrasite, Benson 2 pegmatite, Mtoko district, Rhodesia. New analysis by W. H. Evans, Geological Survey and Museum, Lab. no. 1890. Refractive indices given in table I.
3. Analysis 2 recalculated free of SiO_2, minor oxides, and P_2O_5 (1·08 %), F (0·10 %) and $H_2O^{+105°C}$ (0·01 %), equivalent to CaO (1·54 %) in apatite.
4. Atomic ratios for analysis 3 referred to 10(O,OH,F).

Graftonite was found in several perthite-rich pegmatites in the Miami district of Rhodesia. Some specimens are weakly radioactive due to uranium adsorbed on secondary oxides that vein or rim the pale yellow, glassy graftonite. Occurrences of triplite, childrenite, and griphite in Rhodesian pegmatites are accompanied by the beryllium phosphate hurlbutite (Gallagher and Hawkes, 1966). Alluaudite is developed in the Mterikati pegmatite. Fine-grained constituents of the triphylite–lithiophilite and sicklerite series occur in one of the Kamativi cassiterite–spodumene pegmatites.

It is interesting to note that manganese–iron phosphate has not been detected in pegmatites containing lithium micas. In pegmatites of this type manganese is located in apatite, manganoan tantalite, and in lithium micas. Chemical analyses and approximate spectrographic determinations by G. A. Sergeant and K. L. H. Murray show that ten lithium muscovites and mixed-layer micas averaged 2·5 % Li_2O and 2·7 % MnO, whereas nine muscovites, mixed-layer micas of low lithium content, paragonite, and biotite with an average Li_2O content of 0·1 % only averaged 0·6 % MnO. The preferential concentration of manganese in lithium micas is further illustrated by a comparison of 37 muscovite analyses from Rankama and Sahama (1955), which average 0·05 % MnO, with 34 lithium micas with less than 3 % Li_2O, averaging 0·62 % MnO, and 54 lithium micas with more than 3 % Li_2O, averaging 0·95 % MnO (from Foster, 1960, tables 6–7).

Lithiophorite is a conspicuous accessory in the deeply decomposed Kazumu pegmatites in Ankole, Uganda, and was also found in a pegmatite of the Nyanga group in the same district. At Kazumu, poorly crystalline lithiophorite forms ring structures up to 5 cm in diameter and 1 cm in thickness in the wall units of the main pegmatite. They may have developed by limited migration of manganese and other elements outwards from the sites of original small grains of manganese–iron phosphate. Minor amounts of poorly crystalline lithiophorite were also found in three Rhodesian pegmatites, usually intergrown with altered spessartine.

Niobium and tantalum minerals. Columbite or tantalite forms 0·01–0·02 % in most of the beryl-pegmatites examined and is often a by-product of beryl mining; in several lithium pegmatites in Rhodesia, of which the Benson group is best known (von Knorring and Hornung, 1963), varieties of tantalite occur with microlite, usually in sugary-grained units containing lithium micas. Microlite has been produced from the Bulema pegmatite in Uganda. Rare-earth niobium-tantalum minerals of the samarskite, fergusonite, and euxenite groups (identified by J. E. T. Horne) have been found in about 15 Rhodesian pegmatites; small amounts of fergusonite have been hand-picked from the Beb pegmatite (together with native bismuth) and from other perthite–albite pegmatites in the Fort Victoria–Bikita area.

Semi-quantitative X-ray fluorescence analyses by R. I. Lawson of 24 columbites and tantalites from the pegmatites show a wide variation in composition. Manganese-rich varieties are characteristic of pegmatites containing lithium micas in Rhodesia, but are seldom found in the main beryl-pegmatites of SW. Uganda. Ferro-columbite occurs in cassiterite–spodumene pegmatites at Kamativi and ferro-tantalite in the petalite-bearing Portree pegmatite. The minor elements of the specimens analysed are usually Zr and Zn, sometimes Pb and Ti, and occasionally U and Th.

Yttrotantalite and bismutotantalite have been identified in Rhodesian pegmatites. Yttrotantalite from the Donsa pegmatite occurs in parallel growth with tantalite with which microlite is intimately associated. It contains U and Nb together with minor amounts of Th, Pb, Ca, Ti, Fe, Sr, Sn, and Mn; with Yt are Dy, Gd, Er, Sm, Ho, and Tb. Bismutotantalite from the Melsetter district is replaced by microlite. Microlite is also associated with a ferro-tantalite in the Star Turn perthite-rich pegmatite. The replacement of columbite and tantalite by microlite in the pegmatites contrasts with the alteration of pyrochlore to columbite found in carbonatites (James and McKie, 1958).

Samarskite and fergusonite are found more frequently than euxenite in the Rhodesian pegmatites. In the Fungwe Gem lithium pegmatite (Mtoko district), samarskite forms large masses containing up to 14 % equivalent U_3O_8. Samarskite is closely associated with ferro-tantalite in the Star Turn pegmatite noted above. Small inclusions and thin veins of samarskite were observed in a specimen of columbite from the Kigezi district of Uganda. Fergusonite from Rhodesia contains up to 21 % equivalent U_3O_8 and is sometimes titanium-rich. Fine to medium-grained fergusonite is scattered through the Beb and No Beer pegmatites of the Fort Victoria–Bikita area. Formanite (containing 1·5 % equivalent U_3O_8) is known from the Bikita pegmatite. A tantalian polycrase was tentatively identified from a pegmatite in the Mtoko district. The buff-coloured, weathered specimen contains major Ti and Y, subsidiary Ta and the lanthanons (chiefly Dy, Gd, and Er), and only minor Nb; Th and U are present in approximately equal amounts.

Uranium and thorium minerals. A number of radioactive minerals are present in the central lithium mineral units of the Gooddays pegmatite in Rhodesia. Green metatorbernite and pale yellow phosphuranylite coat beryl and albite, and β-uranophane is associated with fluorite. Thorogummite and grayite (Bowie, 1959, p. 306) occur in places with zircon and tantalite. In a nearby albite-perthite pegmatite (Ntebeni), uranothorite, orangite, kasolite, and zircon (identified by R. K. Harrison) are closely associated with one another. Uraninite is known from pegmatites in the Miami district, usually with encrustations of secondary uranium minerals. Monazite has been found in a number of pegmatites.

Meta-ankoleïte occurs with phosphuranylite, grayite, and zircon in muscovite-rich pegmatite from Mungenyi, Uganda (Gallagher and Atkin, 1966).

Topaz is known from about a dozen Rhodesian pegmatites, most of which also contain lithium micas. It occurs as coarse, subhedral crystals (Benson 1 pegmatite), medium-grained prisms (Python Eggs pegmatite), or small grains in sugary units of the pegmatites (the Bikita and Mauve pegmatites). Coarse topaz was found in a single non-lithium pegmatite (the 'R. & R.' body) and fine-grained topaz was detected in the Bulema pegmatite of Uganda. The refractive indices of topaz from 8 Rhodesian pegmatites exhibit little variation, α 1·615–1·617, γ 1·623–1·626 (all $\pm$0·001), and indicate a fluorine-rich composition.

Prisms of topaz from the Python Eggs (south) pegmatite in the Bikita district are replaced by sugary-grained muscovite and a mica of paragonite type. The micas form successive concentric zones differing in texture and grain-size around central cores of topaz, pointing to replacement of the prisms from the edges inwards. Identification of the paragonites is based on X-ray powder spacings and the determination of 2·5–3·0 % Na_2O by spectrographic analysis. The mica also contains approximately 2–2·5 % K_2O which can be partly attributed to intergrown muscovite, and minor lithium. The edges of a topaz crystal from the Benson 1 pegmatite are intricately veined by sugary-grained lithium mica and the veins coalesce to form a thick rim to the crystal.

Other minerals. Accessory spessartine is present in the majority of pegmatites examined. In zoned lithium pegmatites in Rhodesia it is usually sugary-grained and widely distributed but anhedral, fine-grained spessartine is locally common in the lithium mineral units of the Gooddays pegmatite. The proportion of garnet occurring in the Mistress pegmatite from observations on bulk samples is of the order of 0·5 %. Fine- to medium-grained garnet is fairly susceptible to weathering but despite the release of considerable amounts of manganese the garnet structure is never completely destroyed. Conspicuous amounts of garnet of this type were found in several albite-perthite pegmatites in Rhodesia (e.g. the Bepe 4 and in members of the Beryl Rose group). An early estimate of approximately 20 % HfO_2 in zircon from the Benson pegmatites made by J. E. T. Horne in 1960 has been confirmed by subsequent chemical analysis (von Knorring and Hornung, 1961). Traces of bismutite occur with zircon in an intermediate unit of the Benson 4 pegmatite. Schorl is particularly conspicuous in coarse-grained pegmatites of the Miami district, Rhodesia, and is generally present in most non-lithium pegmatites. Other varieties of tourmaline sometimes occur in lithium pegmatites. At Bikita, pink tourmaline occurs characteristically in radiating clusters of fine prisms up to 15 mm in length. A semi-quantitative spectrographic analysis of one specimen gave 2 % Na_2O and 0·1 % Li_2O. Arsenopyrite and tetrahedrite are known from the Bikita pegmatite, and covelline is associated with sphalerite in lithium mineral units of the Gooddays pegmatite.

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Appendix

Approximate geographical coordinates of pegmatite localities

Rhodesia

Beb pegmatite	19° 56′ S., 30° 52′ E.
Benson 1, 2, and 4 pegmatites	17° 01′ S., 32° 16′ E.
Bepe 4 pegmatite	19° 14′ S., 31° 56′ E.
Beryl Rose pegmatites	16° 50′ S., 31° 50′ E.
Bikita main pegmatite	19° 57′ S., 31° 26′ E.
Chiwya Claims	16° 45′ S., 29° 45′ E.
Dam Site pegmatite	19° 56′ S., 31° 26′ E.
Donsa pegmatite	17° 09′ S., 32° 27′ E.
Fungwe Gem pegmatite	17° 01′ S., 32° 09′ E.
Gooddays pegmatite	17° 24′ S., 32° 30′ E.
Kamativi tin mines	18° 19′ S., 27° 04′ E.
Mauve pegmatite	17° 38′ S., 31° 07′ E.
Mistress pegmatite	17° 38′ S., 31° 06′ E.
Mterikati pegmatite	17° 09′ S., 29° 09′ E.
No Beer pegmatite	19° 54′ S., 31° 25′ E.
Ntebini pegmatite	17° 24′ S., 32° 30′ E.
Portree pegmatite	19° 05′ S., 32° 06′ E.
Python Eggs pegmatite	20° 01′ S., 31° 21′ E.
R. & R. pegmatite	19° 56′ S., 30° 53′ E.
Ronmau pegmatite	17° 02′ S., 32° 17′ E.
Sabi Star pegmatite	19° 13′ S., 31° 57′ E.
Star Turn pegmatite	16° 51′ S., 29° 21′ E.

Uganda

Bulema pegmatite	0° 50′ S., 29° 44′ E.
Kazumu pegmatite	0° 54′ S., 30° 21′ E.
Nyanga pegmatite	0° 58′ S., 30° 09′ E.
Sheshe pegmatite	0° 57′ S., 30° 10′ E.