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THE TANCO PEGMATITE AT BERNIC LAKE, MANITOBA.
III. AMBLYGONITE-MONTEBRASITE

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ABSTRACT

Amblygonite-montebrasite occurs in three successively younger zones of the Tanco pegmatite: as rare grains in the medium-grained albitic wall zone (2), where it occurs in coarser-grained nests of microcline-perthite, quartz, beryl, and mica; in subordinate amounts in the lower coarse-grained intermediate microcline-perthite + albite + quartz + spodumene (+ amblygonite) zone (4), as large crystals and irregular masses; and as a main concentration in the very coarse-grained upper intermediate spodumene + quartz + amblygonite (+ petalite) zone (5), in crystals and aggregates up to 3 metres in diameter embedded in quartz. All these primary amblygonite-montebrasites are veined and rimmed by a late secondary montebrasite.

Full chemical analyses were carried out on 12 specimens, and some physical properties determined for these. Na_2O, K_2O, and CaO were determined in 37 samples, and found to be negligible in all varieties. The F-contents of 138 specimens were determined by an *x*-ray powder diffraction method, and were found to vary from about 1.4 to about 7.1 wt. %. They differ in different zones of the pegmatite, and within individual crystals in a single zone; the latter variations result from either primary zoning or secondary alteration.

In the course of crystallization of the pegmatite, amblygonite-montebrasite of the early wall zone (2) seem to be F-poor (4%); the F-content increases to 4.0 - 6.8% in zone (4), and to 5.4 - 7.1% in zone (5), but decreases within the upper parts of this zone to 4.5 - 6.4%. Within each individual zone, zoned crystals show a decrease in F during their growth. Secondary montebrasite contains much less F than its parent phase, and mostly less than any primary phase within its parent zone.

INTRODUCTION

Minerals of the amblygonite-montebrasite series, $LiAlPO_4F$-$LiAlPO_4OH$, are fairly widespread constituents of lithium-bearing pegmatites. In many such pegmatites these minerals are abundant, they occur in more than one petrogenetic unit, and in a single pegmatite body their compositions may vary substantially in the F/OH and Li/Na ratios. Despite their potential petrological importance, detailed studies of variations in amblygonite-montebrasite within individual pegmatites are rare.

This is due mainly to first, the unavailability of fresh specimens in surface outcrops, second, the relatively difficult determination of high F contents in the presence of high P, and third, to very inconspicuous changes in hand-specimen characteristics with chemical composition. This uniformity in the hand specimens calls for a detailed examination of numerous samples if a representative suite of all the amblygonite-montebrasite occurrences throughout the pegmatite are to be studied. Because the physical properties are considerably influenced by both F/OH and Li/Na substitutions, all varieties in a given pegmatite should be chemically analyzed for at least Na, in which case the F/OH ratios could likely be determined by some physical method. Thus it is not surprising that, to the best of our knowledge, only the studies by Landes (1925), Quensel (1937, 1956), Ginzburg (1950), and Boruckij (1966) contain some useful information about the changes in the amblygonite-montebrasite chemistry during the evolution of pegmatites.

The present paper contains the results of our study of the amblygonite-montebrasite series from the Tanco (Chemalloy) pegmatite, located at Bernic Lake, in southeastern Manitoba. This Li-rich body carries differently coloured amblygonite-montebrasite in several zones, and it is well suited to their detailed study thanks to the extensive underground workings of the Tanco Mine that opened all petrogenetic units of the pegmatite. The only mineralogical data on amblygonite-montebrasite from this locality were published by Nickel (1961).

SAMPLING AND EXPERIMENTAL METHODS

An area in the mine which includes all zones carrying amblygonite-montebrasite was sampled, and is shown in Figs. 2 and 3 of Crouse & Černý (1972); 150 specimens were collected, many of them containing more than one variety of amblygonite-montebrasite. In each zone, the sampling was aimed at obtaining a representative coverage of all colour varieties, with particular attention being paid to the immediately adjacent phases. Samples were taken across large blocks that occur in some zones, and from cross-cutting veinlets and rims showing secondary alteration along with the neighbouring primary amblygonite-montebrasite.

Twelve specimens from the Tanco pegmatite were chemically analyzed and some of their physical properties were determined during a broader study of the amblygonite-montebrasite series (Černá 1970; Černá *et al.* 1972b). The results obtained on them are presented in Table 1, and show all the relations between the chemical composition, *i.e.* the fluorine and hydroxyl proportions, and the physical properties as established and/or confirmed in the quoted studies. Table 1 may thus serve as a descriptive mineralogical chapter in the present paper, and the discussion of these and other data as well as the description of the chemical analytical methods and other experimental techniques may be found in the other papers.

Besides the complete analyses of the twelve specimens, the Na_2O, K_2O, and CaO contents of another 37 specimens were determined by atomic absorption spectrometry (Table 4). Since these contents proved to be negligible in all varieties of the Tanco amblygonite-montebrasite, it was possible to use an *x*-ray powder diffraction method for estimating the F-content of all the samples that were not directly analyzed for F. This method, developed by Černá (1970) and Černá *et al.* (1972b) and based on the prominent changes in unit cell dimensions with varying fluorine content (as established by Moss *et al.* 1969), is believed to be accurate within ± 0.5 wt. % F. The results are summarized in Table 3, and illustrated diagrammatically in Fig. 4.

DISTRIBUTION WITHIN THE PEGMATITE

Two basic types of amblygonite-montebrasite can be distinguished in the Tanco pegmatite : primary amblygonite-montebrasite which crystallized more or less contemporaneously with other rock-forming minerals of its zone, and secondary montebrasite which originated by alteration of the primary phase and may be accompanied by other late minerals. To simplify the description, the primary amblygonite-montebrasite is treated first, and the secondary phases separately.

The minerals occur in at least four zones of the Tanco pegmatite (for a complete list of zones see Crouse & Černý 1972) p. 598 : in the wall zone (2), the lower intermediate Kf + ab + qtz + spd (+amb) zone (4), the upper intermediate spd + qtz + amb (+pet) zone (5), and in the quartz cores (7). We collected representative series of specimens from the first three zones, and examined some additional samples found on dumps that come from different assemblages. This last group is briefly discussed in a separate section.

Primary amblygonite-montebrasite

The wall zone (2) consists predominantly of medium-grained platy albite (3-6mm) with subordinate quartz; this matrix encloses rounded "bubbles", and is transected by lenticular veinlets, composed of coarse-grained microcline-perthite, quartz, muscovite, beryl, and rarely also montebrasite. This latter mineral is pale beige in colour, with dull luster and poor cleavage.

The lower intermediate zone (4) consists mainly of microcline-perthite, albite, quartz, lithian muscovite, spodumene, and amblygonite-montebrasite in rather complicated textural relations. The most widespread pattern, which is also most characteristic of the amblygonite-montebrasite occur-

Table 1. Chemical Composition and Some Physical Properties of Amblygonite-montebrasites from the Tanco Pegmatite.

	A-13		A-3		A-29		A-60		A-1		A-5		A-4a		A-4b		A-2		A-98		A-72		A-22	
Al_2O_3	34.18		34.63		32.86		33.53		34.53		34.86		34.45		34.75		34.53		34.46		34.10		35.10	
Fe_2O_3	n.d.		.007		n.d.		n.d.		.11		.028		.02		n.d.		.11		n.d.		n.d.		n.d.	
CaO	.015		.22		.132		.146		.17		.074		n.d.		.166		.17		.030		.111		.085	
MgO	.000		.008		.002		.003		.005		.002		n.d.		.014		.002		.002		.003		.003	
Li_2O	9.52		10.22		9.90		9.90		9.86		10.29		10.14		9.47		9.86		9.90		9.90		9.52	
Na_2O	.085		.039		.047		.128		.054		.044		.055		.039		.025		.015		.034		.139	
K_2O	.005		n.d.		.004		.005		n.d.		n.d.		n.d.		.003		n.d.		.004		.013		005	
P_2O_5	49.11		49.22		49.26		48.85		49.32		49.26		49.48		48.98		49.21		49.26		49.52		49.11	
H_2O-	.06		.08		.06		.05		.10		.08		.08		.07		.04		.05		.07		.07	
H_2O+	3.37		2.70		3.21		3.32		3.39		3.30		3.85		4.34		4.09		4.43		4.96		5.25	
F	6.43		6.30		6.30		6.17		5.56		4.51		3.65		4.05		3.65		3.44		3.17		1.40	
	102.775		103.424		101.775		102.102		103.099		102.448		101.725		101.882		101.687		101.591		101.881		100.682	
-O=2F	-2.70		-2.65		-2.65		-2.59		-2.341		-1.898		-1.536		-1.71		-1.536		-1.45		-1.33		-0.59	
	100.075		100.774		99.125		99.51		100.758		100.550		100.189		100.172		100.151		100.141		100.551		100.092	
Li	.934		1.001		.980		.977		.964		1.010		.995		.928		.959		.969		.963		.933	
Na	.004	.938	.002	1.009	.002	.985	.003	.984	.004	.972	.002	1.014	.002	.997	.002	.934	.001	.964	-	.970	.002	.966	.007	.944
Ca	-		.006		.003		.004		.004		.002		-		.004		.004		.001		.003		.004	
Fe^{3+}	-	.982	-	.994	-	.954	-	.969	.002	.991	-	1.003	-	.992	-	.998	.002	.987	-	.989	-	.972	-	1.008
Al	.982		.994		.954		.969		.989		1.003		.992		.998		.985		.989		.972		1.008	
P	1.013		1.015		1.026		1.014		1.015		1.018		1.023		1.010		1.008		1.015		1.013		1.013	
O	3.956		4.076		3.983		3.977		4.025		4.116		4.092		3.984		4.062		4.033		3.958		4.039	
F	.496	1.044	.486	.924	.490	1.017	.479	1.023	.427	.975	.348	.884	.282	.908	.312	1.016	.279	.938	.265	.967	.242	1.042	.108	.961
(OH)	.548		.438		.527		.544		.548		.536		.626		.704		.659		.702		.800		.853	
Sp.gr.	3.032		3.048		3.039		3.031		3.037		3.037				3.022		3.008		3.022		3.008		2.992	
	± .009		± .020		± .007		± .012		± .010		± .008				± .002		± .008		± .003		± .003		± .005	
γ'	1.616		1.614		1.616		1.614		1.615		1.626				1.624		1.626		1.626		1.634		1.638	

a (Å)	5.1705	5.1668	5.1691	5.1694	5.1681	5.1792	5.1783	5.1798	5.1801	5.1888	5.1896
	± 15	± 11	± 12	± 19	± 10	± 9	± 7	± 8	± 7	± 9	± 8
b (Å)	7.1799	7.1807	7.1782	7.1815	7.1816	7.1736	7.1770	7.1685	7.1755	7.1715	7.1685
	± 14	± 9	± 11	± 12	± 10	± 14	± 12	± 13	± 11	± 13	± 10
c (Å)	5.0509	5.0482	5.0513	5.0507	5.0501	5.0451	5.0468	5.0438	5.0448	5.0424	5.0407
	± 11	± 7	± 9	± 10	± 9	± 10	± 9	± 7	± 6	± 7	± 7
α	113°4.9'	113°4.7'	113°5.8'	113°9.1'	113°5.6'	112°45.5'	112°49.3'	112°41.9'	112°43.7'	112°28.4'	112°27.1'
	± 1.0'	± 0.6'	± 1.1'	± 0.8'	± 0.7'	± 0.9'	± 0.7'	± 1.0'	± 0.7	± 0.7'	0.7'
β	98°9.6'	98°8.8'	98°10.7'	98°11.2'	98°11.2'	98°0.5'	98°4.8'	98°0.4'	98°0.1'	97°56.0'	97°55.9'
	± 1.4'	± 0.9'	± 1.3'	± 1.5'	± 0.9'	± 1.0'	± 0.9'	± 0.9'	± 0.7'	± 0.8'	± 0.7'
γ	67°36.3'	67°37.3'	67°35.4'	67°32.6'	67°35.6'	67°43.6'	67°42.5'	67°45.1'	67°43.8'	67°49.2'	67°48.5'
	± 1.2'	± 0.9'	± 1.0'	± 1.2'	± 0.7'	± 1.0'	± 0.7'	± 0.7'	± 0.6'	± 0.9'	± 1.0
V(Å^3)	159.48	159.32	159.38	159.32	159.39	159.94	159.95	159.91	160.04	160.55	160.46
	± .05	± .04	± .04	± .05	± 0.3	± .04	± .03	± .03	± .03	± .03	± .03

A-13:	white, paragenesis not known
A-3:	colourless waterclear crystal in quartz, zone (5)
A-29:	colourless to white, lower part of zone (5)
A-60:	white, lower part of zone (5)
A-1:	pink, zone (4)
A-5:	yellow, paragenesis not known
A-4a:	white, paragenesis not known; analyzed by P. Povondra
A-4b:	identical white A-4a, analyzed by J. L. Dalton, K. Ramlal, and R. M. Hill
A-2:	yellow, zone (4), outer zone of A-1
A-98:	yellow, zone (4)
A-72:	beige, zone (4), contaminated by a F-rich amblygonite
A-22:	brownish, zone (4)

First ten specimens primary amblygonite-montebrasites, last two samples secondary montebrasites. Samples arranged according to decreasing F-content. Atomic contents calculated for 5 (O, OH, F) per half unit cell. Analysts: P. Povondra, Prague (complete analyses of samples A-1, A-2, A-3, A-4a, A-5); J. L. Dalton, Ottawa (F in all other samples); K. Ramlal and R. M. Hill, Dept. Earth Sciences, Univ. of Manitoba (all other determinations).

Specific gravity measured on the Berman balance (average of 3 to 6 determinations).

Refractive index γ' estimated to be within ± 0.002 of the true γ.

Unit cell dimensions refined by a least-squares computer program (Evans et al. 1963, modified by D. E. Appleman and D. B. Stewart) from x-ray powder diffractometer data.

For details on analytic and other experimental techniques see Černá et al. (1972b).

rences within this zone, consists of large clusters of coarse microcline-perthite with medium-grained albite, quartz, and mica, rimmed by cleavelandite and mica against quartz pods with amblygonite-montebrasite. Spodumene + quartz pseudomorphs after petalite (*cf*. Černý & Ferguson 1972) occur in both these associations. The orientation of the tapered crystals of amblygonite-montebrasite normal to the cleavelandite/quartz contacts suggests that this mineral crystallized after the feldspathic masses, and grew from their surfaces into the quartz pods (Fig. 1). This is also suggested by the zonal arrangement of colours in these crystals. They display pink, white and yellow zones whose spatial relations indicate that they originated in this sequence.

The feldspar-poor upper intermediate zone (5) contains the highest lithium concentration in the Tanco pegmatite, and consists mainly of quartz and spodumene + quartz pseudomorphs after petalite. Amblygonite-montebrasite is subordinate, and microcline-perthite, petalite, albite, and pollucite

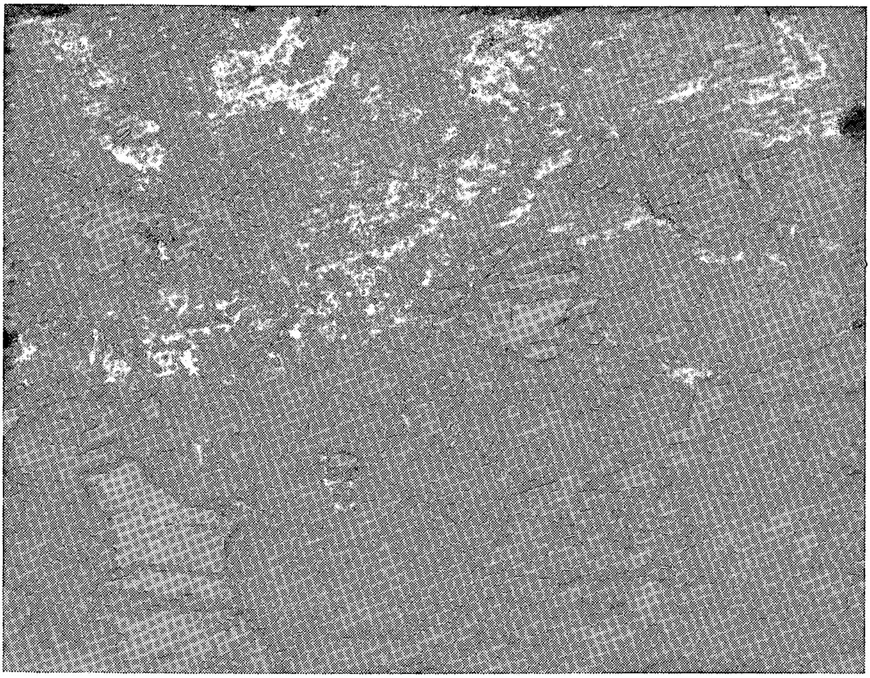


Fig. 1. Albite and quartz (upper left quadrant) rimmed by cleavelandite and lithian muscovite against quartz (grey) with radial stumpy crystals of amblygonite-montebrasite (light grey to white) ; characteristic mode of occurrence of amblygonite-montebrasite in zone (4). The amblygonite-montebrasite crystals are 25 to 40 cm long.

are rather accessory. As already recognized by Wright (1963), this zone shows gradual depletion in feldspars and enrichment in spodumene from the lower to the upper parts. The content of amblygonite-montebrasite seems to be fairly uniform in this direction but the character of the mineral changes.

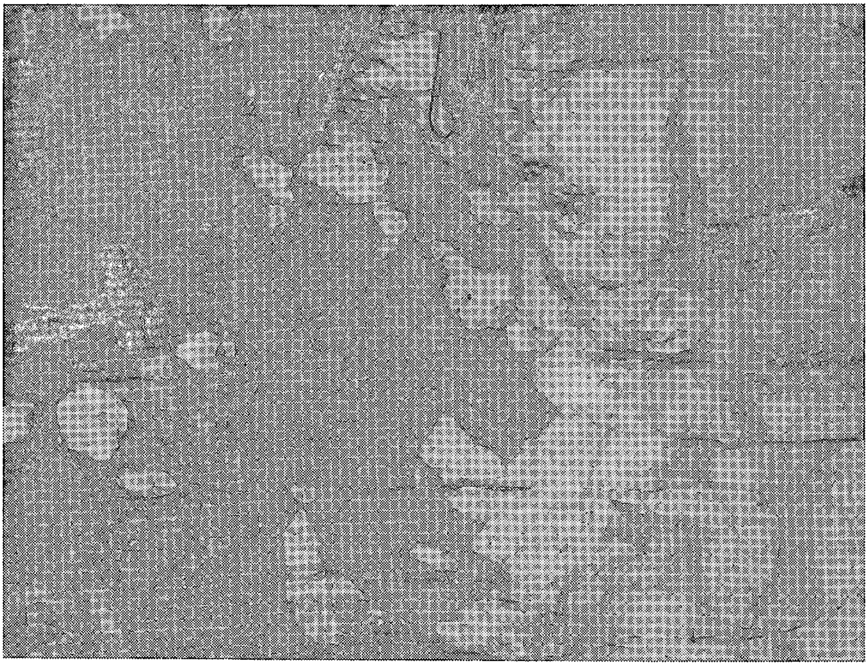
In the lower and central parts of this zone (5), masses of white amblygonite-montebrasite reach up to 1.5 metres in maximum dimension (Fig. 2). These large accumulations are usually irregular, but small crystals are frequently well bounded by crystal faces. Amblygonite-montebrasite "floats" freely in quartz or is attached to spodumene + quartz aggregates. It is either euhedral against them, (Fig. 9 in Černý & Ferguson 1972), or surrounds them and fills interstices among these pseudomorphs. In the upper parts of zone (5) adjacent to the pollucite body (8), amblygonite-montebrasite forms smaller irregular blocks imbedded in quartz or located along the pollucite/quartz contact (Fig. 3). Its individual crystals show colour zoning again, with white cores and yellow rims.

The only quartz core (7) accessible to sampling at the time of writing does not carry any amblygonite-montebrasite; Wright (1963) quotes amblygonite from this zone, found most probably in drill cores.

Secondary montebrasite

All types of primary amblygonite-montebrasite described above are frequently rimmed or penetrated by late secondary montebrasite, which is brownish, grey, or greenish in colour and always darker than its parent phase. Its luster is dull and cleavage poor. It always forms at the expense of the primary amblygonite-montebrasite, without penetrating the neighbouring minerals, and in most instances the replacing montebrasite maintains a crystallographic continuity with the primary amblygonite-montebrasite. In thin sections one can see that there is either gradual change of the primary to the secondary mineral (Figs. 4, 5), or veining of the primary mineral by a fine network of the secondary phase (Fig. 6). These veinlets are frequently superimposed upon the gradual transition (Fig. 6).

The crystallographic continuity of the two generations is particularly well illustrated in Fig. 8, which shows a network of secondary montebrasite cross-cutting a primary phase with a series of coarse twinning lamellae. The original twinning is perfectly preserved in the secondary phase. Inside the fully altered masses beyond the transitional and veined margins, the secondary montebrasite develops, however, a fine polysynthetic lamellar twinning of its own (Fig. 6). These lamellae seem to originate without any mechanical strain or cataclastic effects, and have a quite different character from the coarse primary twinning shown in Fig. 7.



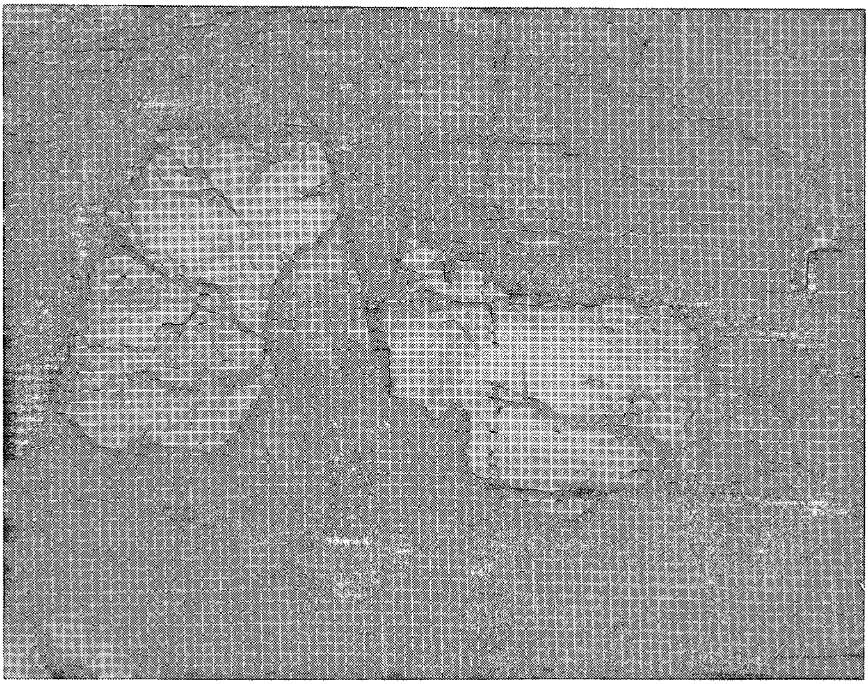
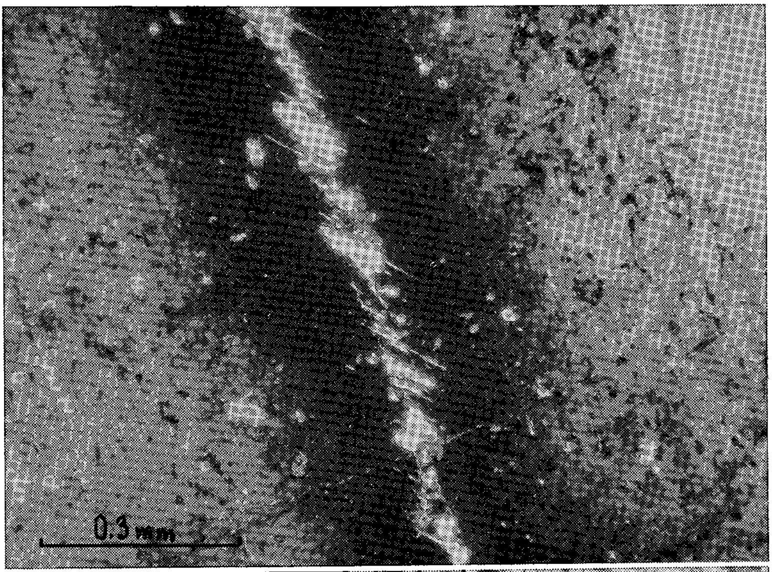


Fig. 2 (Top) Marginal parts of a large amblygonite-montebrasite block (white, at right) and small crystals of the same phase scattered in quartz (grey, at left) ; lower parts of zone (5) adjacent to zone (4). The hammer head is 15 cm long.

Fig. 3. Irregular monocrystalline blocks of amblygonite-montebrasite (light grey, central parts) at the contact of pollucite (dark grey, top) and quartz (grey, bottom) ; contact of the upper part of zone (5) with a pollucite body (8). The hammer head is 20 cm long.



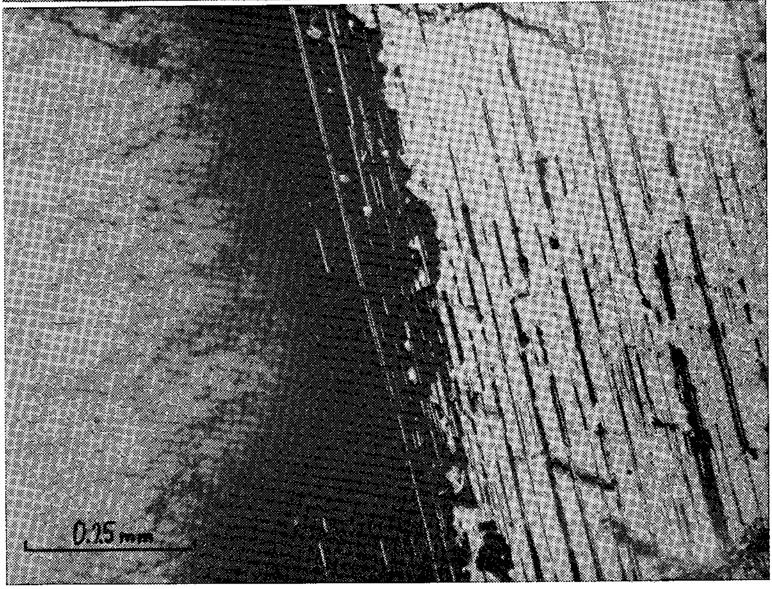


Fig. 4. (Top) Thin section of sample A-46 in crossed nicols, showing a single crystal of primary amblygonite-montebrasite (left and right side) replaced by secondary montebrasite from a fissure (centre). Note the gradual change of extinction from the primary into the secondary phase; the later is finely twinned in the centre.

Fig. 5. Thin section of sample A-22 in crossed nicols, showing a single crystal of primary amblygonite-montebrasite (grey, left side) passing gradually into a secondary montebrasite (black, left of centre), which becomes polysynthetically twinned (black and white, centre and right side). Note the black veinlets of secondary montebrasite penetrating the primary phase.

The secondary montebrasite is usually not accompanied by any other late minerals, but fine-grained fluorapatite and lithium micas occur sparsely associated with it around the altered rims of the primary amblygonite-montebrasite.

Chemical Composition of Amblygonite-Montebrasite

The variations of the fluorine contents of the amblygonite-montebrasite from zone to zone, and within different zones, are shown in Table 2 and Fig. 8, and the Na, K and Ca contents are given in Table 3.

Fluorine in the primary phases

Montebrasite from the wall zone (2) contains about 3.7% F. As an indication of the fluorine content of the pure primary phase, this figure should, however, be taken with some caution because the material resembles the altered phases from zones (4) and (5).

The lower intermediate zone (4) carries pink, white, and yellow amblygonite-montebrasite formed in this sequence. The fluorine content decreases

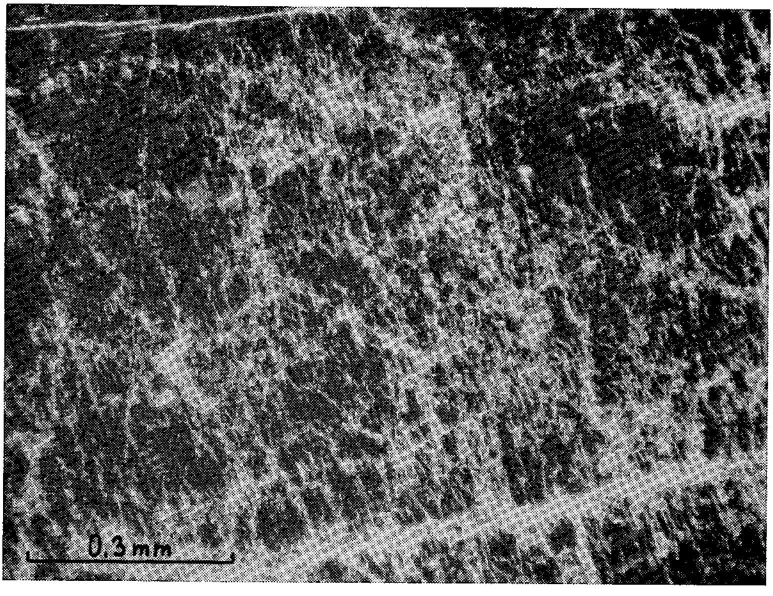


Fig. 6. Thin section of sample A-42 in crossed nicols, showing a network of secondary montebrasite (white), similar to that in the left part of Fig. 6, penetrating a single crystal of primary amblygonite-montebrasite (grey). Note the sharp boundaries and absence of any gradual transitions between the optical orientation of the veinlets and matrix.

gradually during this sequence. The F-content ranges of the white and yellow phases, 5.0 – 6.6% F and 4.0 – 5.6% F respectively, are fairly well separated, but the range of the pink specimens, 5.6 – 6.8% F, overlaps most of that of the white material. However, in individual specimens the F-content of the earliest pink mineral is always higher than that of the white and/or yellow overgrowths, as shown in the following examples: 6.0, 5.6 (pink) – 5.2 (white) – 4.4% F (yellow); 5.56 (pink) – 3.65% F (yellow); 6.8 (pink) – 5.6, 5.4% F (white).

In the lower parts of upper intermediate zone (5), the huge blocks as well as smaller crystals of white amblygonite-montebrasite show a rather narrow range of F contents, 5.4 – 7.1%. No regularity in the variations of the F-content was found here, either within individual crystals or on a larger scale. In the central parts of this zone, the fluorine content seems to decrease, and it is undoubtedly much lower in the upper part. Here the

Fig. 7. Drawing from a thin section showing primary amblygonite-montebrasite (white) with coarse twinning lamellae (black) penetrated by a very irregular veinlet of late montebrasite (dotted and cross-hatched in the white and black primary individual, respectively). The secondary phase preserves the original twinning of, and remains in crystallographic continuity with, both parts of the primary twin, and it shows only a slight change of optical orientation in relation to the corresponding primary individuals. Sample A-4, linear magnification 50×.

primary phases contain 4.5 – 6.4% F, with the earlier white material always showing a higher F-content (5.0 – 6.4% F) than the younger yellow phase (4.5 – 5.4% F). This relation is maintained in all zoned crystals, despite the small overlap of the full ranges quoted above.

Fluorine in the secondary montebrasite

In all zones and all specimens, the secondary montebrasite cross-cutting and rimming the primary phases is considerably depleted in fluorine. This can be observed not only in individual specimens but also in the complete compositional ranges ; the only small overlap of the F-contents in secondary montebrasite is with a late F-poor primary phase occurring in zone (4). The difference in fluorine content between the parent and the secondary minerals in a single specimen reaches as much as 4%.

Sodium, potassium, and calcium

The Na_2O, K_2O, and CaO contents in relation to colour and zone of occurrence shown in Table 3 indicate that these oxides are present in negligible amounts in representatives of all types of the amblygonite-montebrasite. A detailed scrutiny of all the data failed to reveal any systematic trends in the minor variations that could have some genetic significance. It

TABLE 2. FLUORINE CONTENT OF AMBLYGONITE-MONTEBRASITE VARIETIES IN INDIVIDUAL ZONES OF THE TANCO PEGMATITE

	Zone (2)	Zone (4)	Zone (5)		
			lower	central	upper
beige	3.7 (1 ?)				
pink		5.6 — 6.8 6.04 (5)			
white to colourless		5.0 — 6.6 5.84 (45)	5.4 — 7.1 6.11 (28)	5.5 — 6.1 6.10 (4)	5.0 — 6.4 5.71 (8)
yellow		4.0 — 5.6 4.51 (15)			4.5 — 5.4 4.82 (8)
secondary	3.7 (1 ?)	1.4 — 5.0 2.64 (20)	2.0 — 4.1 3.03 (6)	2.7 — 4.8 3.75 (2)	2.0 — 2.4 2.20 (5)

? — the paragenetic classification of the specimen is uncertain.
Upper figures — range of F-contents (wt.%).
Lower left figure — average F-content (wt.%).
Lower right figure (in brackets) — number of specimens examined.

is interesting to note that the secondary montebrasites are as poor in Na, K, and Ca as their parent primary phases.

OTHER SPECIMENS

Some samples collected on the mine dumps show associations and characteristics different from any specimens found *in situ.* It is not possible to correlate them definitely with any particular zone of the pegmatite, but they deserve a brief description since they represent different genetic varieties ; their paragenetic position may be established in the future.

The first group of specimens consists of pale-beige crystals associated with, and partly replaced by, coarse platy cleavelandite. Other associated minerals are quartz, beryl, lithiophilite, pseudo-ixiolite, and spodumene. The F-content of these montebrasites is very low, 1.0 – 1.3%. The Na_2O, K_2O and CaO percentages are the highest known for the amblygonite-montebrasites of the Tanco pegmatite and the Li_2O percentages correspondingly low : Na_2O 0.08 – 0.47%, K_2O 0.03 – 0.30%, CaO 0.16 – 0.75%, and Li_2O 8.52 – 9.04%.

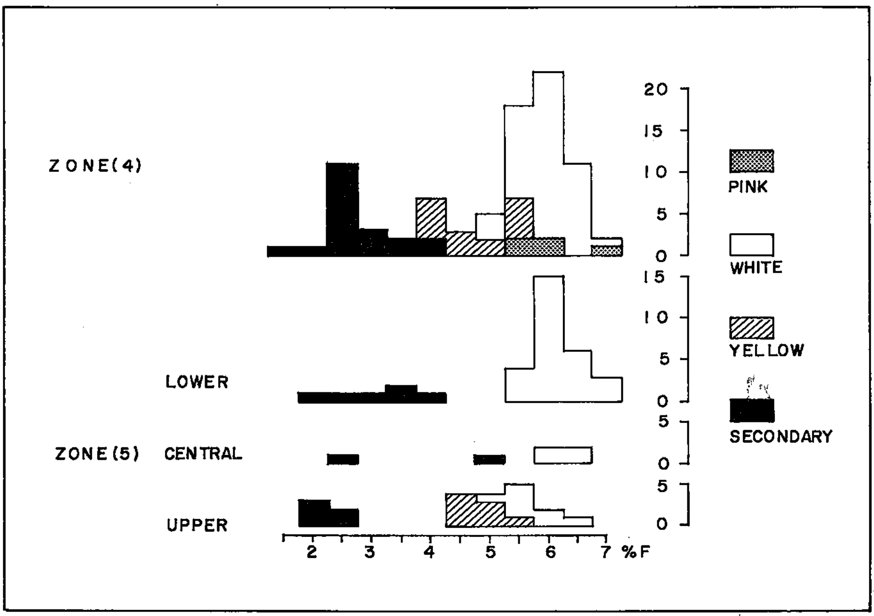


Fig. 8. Frequency of the F-contents in different varieties of amblygonite-montebrasite in individual zones of the Tanco pegmatite, taken at 0.5% intervals centred at X.0 and X.5 wt. % F.

Another type of amblygonite-montebrasite forms irregular blebs or transecting veinlets in white to bluish albitic aplite. This phase contains about 6% F in the white cores, and 2 to 3% in the beige-coloured altered margins. The white material contains 0.03% Na_2O, 0.02% K_2O, 0.02% CaO, and 9.73% Li_2O.

A single specimen was found showing amblygonite-montebrasite coexisting with quartz, cleavelandite, and lithian muscovite. Pinkish amblygonite contains 6.9% F, and white material 6.5 and 6.0% F; a mixture with predominant white phase contains 0.07% K_2O, 0.06% Na_2O, 0.08% CaO, and 9.73% Li_2O. This specimen seems to belong to zone (4), resembling a miniature of the association shown in Fig. 1.

DISCUSSION

Considering the F-contents of the primary amblygonite-montebrasites in the sequence in which they were likely crystallized, they seem to be low (~4%) in zone (2), much higher in zone (4), 4.0 to 5.8%, still higher in the lower parts of zone (5), 5.4 to 7.1%, but decreasing gradually

TABLE 3. THE CONTENTS OF Na_2O, K_2O, AND CaO IN AMBLYGONITE-MONTEBRASITE VARIETIES IN INDIVIDUAL ZONES OF THE TANCO PEGMATITE

		Zone (4)	Zone (5)		
			lower	central	upper
pink	Na_2O	.138 (3)			
	K_2O	.015 (2)			
	CaO	.033 (3)			
white to colourless	Na_2O	.068 (8)	.046 (7)	.041 (3)	.060 (3)
	K_2O	.006 (8)	.007 (6)	.007 (3)	.006 (3)
	CaO	.054 (8)	.025 (7)	.122 (3)	.020 (3)
yellow	Na_2O	.068 (8)			.043 (3)
	K_2O	.048 (6)			.015 (3)
	CaO	.025 (6)			.030 (3)
secondary	Na_2O	.072 (5)	no data	no data	.032 (2)
	K_2O	.022 (5)			.017 (2)
	CaO	.075 (3)			.000 (1)

Left figures — average content of the oxide (wt.%).

Right figures (in brackets) — number of specimens examined.

towards the upper parts of this zone where they drop to 4.5 to 6.4%. All primary amblygonite-montebrasite is very poor in Na, K, and Ca. No data are available at present about the composition of amblygonite-montebrasite from the quartz cores (7) ; its study depends on the progress of the mining operations.

The decrease of fluorine in amblygonite-monterbrasite towards the uppermost parts of zone (5) is suggestive of related vertical changes in the mineralogy of this zone observed by Wright (1963) and verified recently : K-feldspar and particularly albite also decrease in this direction, whereas the spodumene (± petalite) content increases. These vertical changes in mineral contents could reflect different diffusion rates of elements during their partitioning between the magmatic-looking, finer-grained and albite-rich zones in the lower parts of the pegmatite and the coarser upper zones crystallized probably from gaseous fluids (*cf.* Jahns & Burnham 1958, 1969, Černý & Ferguson 1972). The high concentration of fluorine in amblygonite-montebrasite of the finer-grained, geochemically and mineralogically "mixed" zone (4) and in the adjacent lower parts of zone (5) reminds one of the experimental studies of Wyllie & Tuttle (1961, p. 139) and Koster van Groos & Wyllie (1968, p. 69) who showed that in granitic liquids fluorine tends to remain in the magma and not to escape into a coexisting gaseous phase.

The meaning of the relatively rapid decrease in fluorine during the growth of the zoned crystals from zone (4) and from the upper parts of zone (5) is yet to be determined. Boruckij (1966) observed a similar zonal decrease in fluorine in the amblygonite-montebrasites from Siberia. It could indicate either a temperature control of the F/OH ratio, the F-rich compositions being preferred at higher temperatures, or a rapid change in availability of fluorine during the crystallization of the amblygonite-montebrasite and associated phases. It should be noted that in most cases the only minerals competing for fluorine are the spatially separated micas.

In all zones examined, the primary amblygonite-montebrasite is replaced by secondary montebrasite ; the F-contents decrease considerably during this alteration, but the Na, K, and Ca contents remain negligible. This change in chemistry can be compared with the compositional difference between early blocky amblygonite-montebrasites and late, hydrothermal, cavity-filling montebrasites described from Maine (Landes 1925, Černá *et al.* 1972b). Secondary replacement of amblygonite-montebrasite in Siberian pegmatites also produced F-poor montebrasite (Boruckij 1966).

The relatively broad and smooth transitions between the primary and secondary phases (Fig. 5) suggest a diffusional anionic exchange of fluorine and hydroxyl, producing a gradual change in the F/OH ratio. The sharply bounded veinlets that are superimposed over these transitional areas and that penetrate the primary phase (Figs. 5, 6 and 7) indicate an abrupt compositional change produced by a different mechanism. The fine lamellar twinning associated with all larger areas of secondary montebrasite showing gradual transitions (Figs. 4, 5) deserves further study. It may be produced by the anionic exchange effect on the structure, or it may be a response of the amblygonite-montebrasite structure to the slight volume increase during the hydroxyl enrichment (*cf.* Table 1).

It is interesting to note that very similar twinning effects were described by Ginzburg (1950) in a late sodium-enriched generation which replaces a similar montebrasite. The chemical analyses quoted in his study suggest, however, that an increase in fluorine during this reaction is much more remarkable than the increase in Na, K, and Ca.

The F-poor secondary montebrasite is often associated with fine-grained fluorapatite. This suggests that apatite can accumulate fluorine under conditions that produce F-poor montebrasite, but it does not necessarily mean that the general cause of the origin of the secondary montebrasite was a Ca-metasomatism competing for fluorine. In most cases the secondary montebrasite is not accompanied by any other contemporaneous minerals, and the released fluorine was completely removed from the local systems.

The paragenetic position of the alkali-enriched montebrasites collected on the dumps is yet to be determined. These specimens could represent primary amblygonite-montebrasites re-equilibrated during a cleavelandite-producing sodium metasomatism (as described by Ginzburg 1950), or primary sodium-bearing phases associated with albitization (similar to those reported by Quensel 1937, 1956).

CONCLUSIONS

The present study shows the importance of the amblygonite-montebrasite minerals as geochemical indicators, and it indicates the necessity of checking a statistically significant number of specimens in order to establish all the chemical variations and their ranges in a given pegmatite. The examination of only a few samples (which is tempting in most cases because of no readily observable differences among different types) leads to the danger of non-representative sampling and consequent false conclusions.

In the Tanco pegmatite, the establishment of the compositional ranges has already proved useful in the industrial separation of the amblygonite-montebrasite from refractory-grade spodumene. From the genetic viewpoint, all the obtained data cannot yield more information at present than that given in the preceding section. The geochemical role of amblygonite-montebrasites and the significance of their compositional variations will be incorporated into the entire petrological history of this pegmatite after similarly detailed data have been obtained on other mineral groups and their quantitative relations.