

THE TANCO PEGMATITE AT BERNIC LAKE, MANITOBA. IX. BERYL*

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ABSTRACT

Beryl occurs in 4 out of 9 zones and replacement units of the Tanco pegmatite. The major accumulations are in the wall zone and central intermediate zone, and they are concentrated in the footwall parts of the pegmatite. Six paragenetic varieties of primary beryl are recognized, but most have the same range of chemical composition and may be genetically related. The alkali contents of the majority of primary beryl are among the highest known (ΣR_2O about 6 to 7 wt. %, including 2.5 to 3.75 wt. % Cs_2O); the secondary beryl in the hydrothermal alteration assemblages is extremely enriched in alkalis, with ΣR_2O up to 11.05 wt. %, including 7.16 wt. % Cs_2O . All beryl varieties display strong compositional zoning, with alkali contents increasing outwards. Compositions of three fully analyzed samples conform to be $Be_{IV}^{2+} Li_{IV}^{1+} + R^{1+}$ channel substitution mechanism established by Bakakin *et al.* The persistent association of beryl with albite±muscovite indicates a late metasomatic origin during albitization which also carries tantalum mineralization.

SOMMAIRE

Dans la pegmatite de Tanco, on trouve du béryl dans quatre zones et unités de remplacement sur neuf. Il s'accumule surtout dans la zone des épointes et la zone centrale intermédiaire; il se trouve concentré dans la paroi inférieure de la pegmatite. Des six variétés paragénétiques du béryl primaire reconnues ici, la plupart se situent dans le même domaine de composition chimique, et il se peut qu'elles soient génétiquement apparentées. Les teneurs en métaux alcalins y sont parmi les plus élevées que l'on connaisse (ΣR_2O ~6 à 7% en poids, y compris 2.5 à 3.75% de Cs_2O). Le béryl secondaire des assemblages d'altération hydrothermale est encore plus riche en alcalins (ΣR_2O jusqu'à 11.05%, y compris 7.16% de Cs_2O). Tous les cristaux de béryl sont fortement zonés, la teneur en alcalins augmentant vers la périphérie. Trois échantillons ont été soumis à l'analyse chimique complète; celle-ci confirme le mécanisme de remplacement du béryl par les alcalins établi par Bakakin *et al.* La persistance de l'association béryl-albite, avec ou sans muscovite, indi-

que une origine métasomatique tardive, au cours de l'albitisation, qui est accompagnée d'une minéralisation en tantale.

(Traduit par la Rédaction)

INTRODUCTION

Very limited data on beryl from the Tanco pegmatite have been collected and published to date. Physical properties of some primary rock-forming varieties were quoted in an unpublished report by Černý & Ferguson (1971), and secondary beryls exceptionally enriched in alkalis were described by Černý (1972). Physical properties suggested that the primary beryl is also rich in alkalis, and that its composition is rather variable. A systematic study of compositional variations in the Tanco beryl was desirable in order to contribute to the knowledge of the general geochemistry and petrology of the pegmatite. The potential economic significance of the primary beryl was another factor stimulating this investigation.

This study, a continuation of a series of papers on the Tanco pegmatite started in 1972, draws most of the data from a M.Sc. thesis by the second author (Simpson 1974). These are partly revised, supplemented by additional information collected since the completion of this thesis, and re-interpreted.

Table 1 presents a brief review of the characteristics of individual zones of the pegmatite, arranged in the appropriate order of crystallization. Crouse & Černý (1972) give a more detailed petrographic account and cross-sections of the deposit showing the zoning pattern. A longitudinal section through the Tanco pegmatite is also shown by Černý & Simpson (in prep.).

SAMPLING AND EXPERIMENTAL METHODS

A total of 135 beryl specimens was collected underground and from drill cores. Suites from zones (2), (6), and (9) are believed to be fairly representative of the beryl populations in their assemblages. Beryls from zones (4) and (5) represent all specimens found in them so far.

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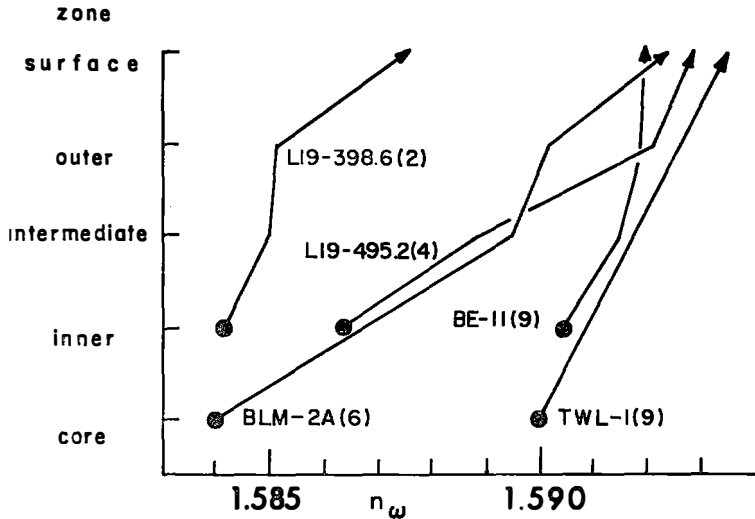


FIG. 1. Increase in n_{ω} , indicative of general increase in ΣR^{1+} and H_2O , from cores (solid circles) to surfaces (arrowheads) of several beryl crystals from different zones of the Tanco pegmatite (zone number given in parentheses after the sample symbol). Center-to-surface distances arbitrarily divided into five zones. Lengths of traverses range between 15 and 45 mm.

All 135 beryls collected were checked for their n_{ω} ; 42 specimens were selected for partial chemical analyses, and 3 samples considered representative for the beryls in the Be-rich zone (6) were chosen for a detailed mineralogical study.

Most beryl crystals show strong compositional zoning, invariably with the alkali content increasing outwards (Fig. 1). Refractive index n_{ω} was thus checked on the outermost parts of beryl crystals, to achieve a standard of homogeneity in comparing the populations. Material separated for partial and full chemical analyses also came from surface parts of crystals (except for a few cores which were separated intentionally). Despite this effort, it is probable that some values of n_{ω} are lower than those representative of the outermost crystal zones, and that some chemical analyses reflect contamination of the outermost material by alkali-poorer adjacent zones. Both types of error affect geochemical considerations as well as correlations of physical properties with chemistry. Although the latter correlations are difficult to adjust, the influence of the errors on geochemical correlations can be reduced by averaging within cogenetic specimen groups.

The refractive index n_{ω} was determined by the immersion method, using a Na-light source. A series of immersion liquids with 0.001 increments was prepared, and the fourth decimal

place was estimated from the intensities of the Becke lines.

Density was determined on a Berman balance, using toluene as the displacement liquid. Three to four separate grains were taken from each hand-separated sample, and two to three readings were taken of each.

Readings from three X-ray powder diffractograms, calibrated with fluorite admixture to the beryl samples (a 5.4620Å), were averaged and then processed by the Evans *et al.* (1963) least-squares program, modified by D. E. Appleman, to obtain unit-cell dimensions.

Chemical analyses were performed mostly by atomic absorption spectroscopy; X-ray fluorescence spectrography was used for SiO_2 , Al_2O_3 , and Fe_2O_3 , and water contents were determined gravimetrically.

DISTRIBUTION AND CHARACTERISTICS OF BERYL TYPES

Six different types of primary rock-forming beryl, and one secondary variety, can be distinguished according to their location in the pegmatite, their color, crystal habit, n_{ω} , and alkali contents. Histograms of n_{ω} frequencies found in the different types, assumed to be indicative of alkali contents, are shown in Figure 2. In this Figure, and the descriptions which follow below, the beryl types are designated by zone numbers

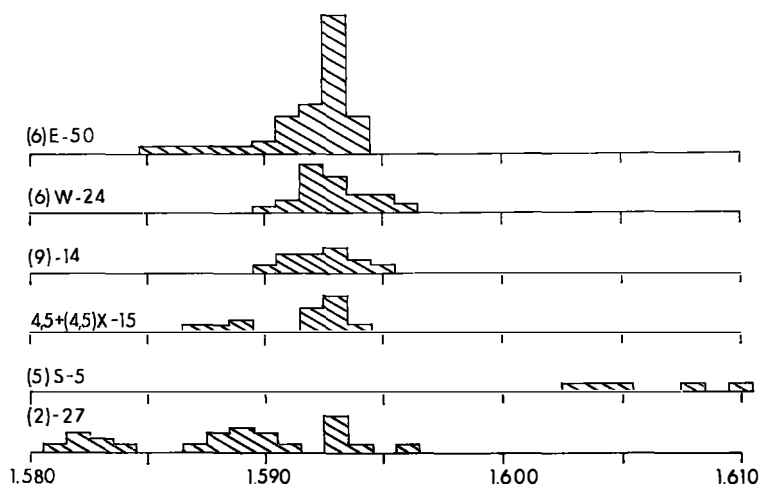


FIG. 2. Frequencies of the refractive index n_{ω} in the surface zones of beryl crystals from various zones of the Tanco pegmatite. Number of samples measured follows the hyphen after zone symbol. The shortest columns equal one sample (e.g., all those in line (5)S). Note the coincidence of maxima in zones (4,5), (6), and (9), and the extremely high values in (5)S.

TABLE 1. ZONING OF THE TANCO PEGMATITE

Zone	Main constituents	Characteristic subordinate and accessory minerals	Textural and structural characteristics	Average BeO content (wt. %)	Total range of BeO (wt. %)	Predominant range of BeO (wt. %)
(1) border zone	albite, quartz	tourmaline, apatite	fine-grained aplitic	---	---	---
(2) wall zone	albite, quartz, muscovite, Li-muscovite, microcline-perthite	tourmaline, <u>beryl</u>	medium-grained, giant K-feldspar crystals	eastern hanging-wall part: 0.07 eastern footwall part: 0.15 western footwall part: 0.20	---	30% within 0.11-0.19 28% over 0.20
(3) albitic aplite	albite, quartz	muscovite, Ta-oxide minerals, (apatite, tourmaline)	fine-grained, rounded blebs and undulating layers	---	---	---
(4) lower intermediate zone	microcline-perthite, albite, quartz, spodumene, ambygonite	Li-muscovite, lithiophilite ((lepidolite, petalite, Ta-oxide minerals))	medium to coarse grained, inhomogeneous	0.05	---	---
(5) upper intermediate zone	<u>spodumene</u> , quartz, <u>ambygonite</u>	pollucite, lithiophilite, microcline-perthite, (albite, Li-muscovite), ((petalite, eucryptite, Ta-oxide minerals))	giant crystal size of major and subordinate minerals	0.02	---	---
(6) central intermediate zone	microcline-perthite, quartz, albite, muscovite	<u>beryl</u> , (Ta-oxide minerals, cassiterite, lithiophilite, apatite, ((zircon-hafnon, ilmenite, spodumene, sulphides)))	fine-to-medium grained, inhomogeneous	eastern part: 0.15 western part: 0.10	tr.-1.02 0.00-0.31	50% within 0.20-0.29 ---
(7) quartz zone	<u>quartz</u>	((spodumene, ambygonite))	monomineralic	---	---	---
(8) pollucite zone	<u>pollucite</u>	quartz, spodumene((petalite, muscovite, lepidolite, albite, microcline, apatite))	almost monomineralic	---	---	---
(9) lepidolite zone	<u>Li-muscovite</u> , <u>lepidolite</u> , microcline-perthite	albite, quartz, <u>beryl</u> , (Ta-oxide minerals, cassiterite), ((zircon-hafnon))	fine-grained metamorphic unit replacing zone (6)	---	---	---

Zones (1) and (2) shell-like concentric, all other zones layer-shaped.

BeO contents based on drillcore assays by the Tantalum Mining Corporation of Canada, Ltd. (R. A. Crouse, private communication, 1975). Segments of individual zones with different BeO contents quoted separately.

Except zone (6), all spodumene secondary after petalite.

Underlined minerals occur in economic quantities in the given zones; minerals in parentheses occur in very small to trace amounts.

as well as letters suggestive of additional prominent characteristics.

(2) — greenish to white beryl from the wall zone (2), mostly associated with muscovite, quartz and albite. Columnar prismatic (length to width ratio 6:1 to 3:1, max. length about 8 cm), usually without termination. Greenish color is particularly characteristic of beryl from near the wall-rock amphibolite. Highly variable $n\omega$; high values are typical of beryl from the grey-colored albite+quartz matrix which is widespread in western footwall parts of the pegmatite, whereas most low-refracting beryls come from the beige albite + clear to whitish quartz + muscovite assemblage, which is more common in all other parts of zone (2).

(4,5) — white beryl from the lower and upper intermediate zone (4) and (5), associated with cleavelandite veinlets in quartz, amblygonite, and aggregates of spodumene+quartz after petalite. Short columnar prismatic (length to width ratio 2:1 to 1.5:1, max. length about 10 cm), or in almost anhedral grains. Both groups of samples in Figure 2, centered at $n\omega$ 1.588 and 1.593, contain specimens from both zones. Since these zones show gradual mutual transitions, and do not display any distinct differences in the properties of their beryls, the latter are treated as a single type.

(4,5)X — is a subtype of the preceding one, rather than a distinct variety. This subtype is associated with grey quartz, grey albite, apatite, and triphylite near amphibole xenoliths enclosed in zones (4) and (5). White, columnar prismatic

(length to width ratio 8:1 to 3:1, max. length about 6 cm), with no terminal crystal faces. Refractive indices fall within the same range as those of the higher-refracting group of beryls (4,5).

(6)E — colorless, white, or faintly pinkish beryl of the eastern wing of the central intermediate zone (6). Bands of beryl crystals usually separate feldspar-bearing assemblages from quartz pods; larger accumulations which overlie contorted layers of albitic aplite are exceptional (Fig. 3). Beryl is short columnar (max. length about 20 cm) or thick tabular (max. diameter about 18 cm) parallel to basal pinacoid (length to width ratio 2:1 to 0.15:1). Prominent {0001} and faces of first and second-order bipyramids in combination with prism. Mostly high $n\omega$; the sporadic low values shown in Figure 2 are suspected to represent inner zones. Many samples have extreme compositional zoning (*cf.* specimen BLM-2A in Fig. 1).

(6)W — milky white to very pale pinkish beige beryl of the western part of the central intermediate zone (6). Associated mainly with white albite veinlets randomly penetrating grey microcline and quartz. Less frequently in direct association with banded streaks of albite+wodginite +microlite. Mostly anhedral equidimensional grains, rarely stubby prismatic with poorly developed prism faces. Most values of $n\omega$ are the same as those of beryl (6)E, but some exceed the upper limit found in (6)E (Fig. 2).

(9) — pinky beige beryl of the lepidolite replacement zone (9), associated with albite, mi-

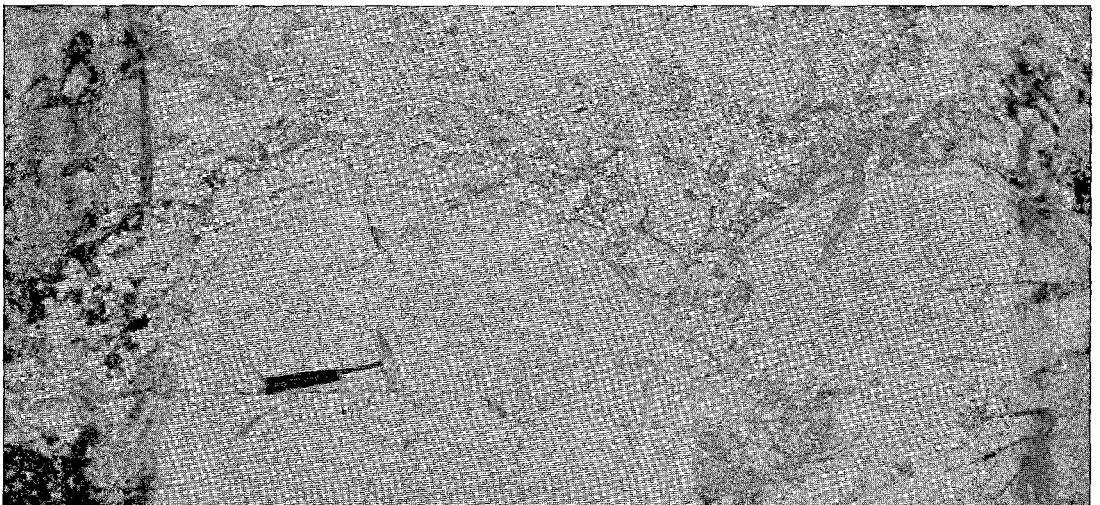


FIG. 3. Two lobes of fine-grained albite (whitish, bottom) with stringers of Ta-oxide minerals along their upper margins (discontinuous black lines) overlain by subhedral beryl (white) in a muscovite + quartz matrix (mottled grey). Eastern zone (6) of the Tanco pegmatite. The hammerhead is 20 cm long.

crocline, and quartz that are largely replaced by fine-grained lithian muscovite and lepidolite. Subhedral short prismatic to thick tabular and whitish in eastern parts of this zone, but mostly anhedral and more colored in its western parts. The ranges of $n\omega$ coincide with those of beryls (6)E and (6)W.

(5)S — tiny crystals of colorless to pink secondary beryl from zone (5), associated with quartz, albite, adularia, cookeite, cesian analcime, and apatite, lining leaching cavities in spodumene+quartz pseudomorphs after petalite (Černý 1972). Columnar prismatic (length to width ratio 5:1 to 3:1, max. length about 12 mm), terminated with basal pinacoid. Frequently somewhat corroded. Some crystals show the highest refractive indices recorded for the species ($n\omega=1.610$; Fig. 2).

In general, beryl seems to be absent in border zone (1), albitic aplite (3), quartz cores (7), and pollucite bodies (8). The largest concentrations are found in both parts of zone (6), and in the western footwall parts of zone (2) which is partly transitional here into zone (4). Although beryl is more difficult to recognize in zones (4) and (5), it seems to be relatively rare. Within the zones (2), (4) and (5), the most conspicuous local concentrations of beryl are found near the wall-

rock amphibolite or around its xenoliths inside the pegmatite.

The only type of beryl affected by late processes is that in eastern zone (6). Deep corrosion and leaching of this beryl type leaves the associated quartz, albite, and muscovite intact, but no secondary Be minerals or other hydrothermal phases have been encountered. The only low-temperature Be mineral found to date is the secondary beryl (5)S which shows no obvious spatial relationship to the corroded primary beryls of zone (6).

ALKALI DISTRIBUTION

Partial analyses of 42 beryl specimens (Table 2, Fig. 4a,b) confirm that the variations in $n\omega$ are caused solely by variable alkali contents. Several analyses for FeO, MnO, and MgO showed that these components are lower than 0.2 wt. %, even in the greenish beryls (2). Thus, their influence on $n\omega$ can be neglected, at least in evaluation of the alkali variations of large beryl populations.

Figure 4a,b shows that the alkali contents of the Tanco beryls closely follow the general trends established for pegmatitic beryl (Černý 1975). In the Na/Li versus Cs plot of Figure 4b,

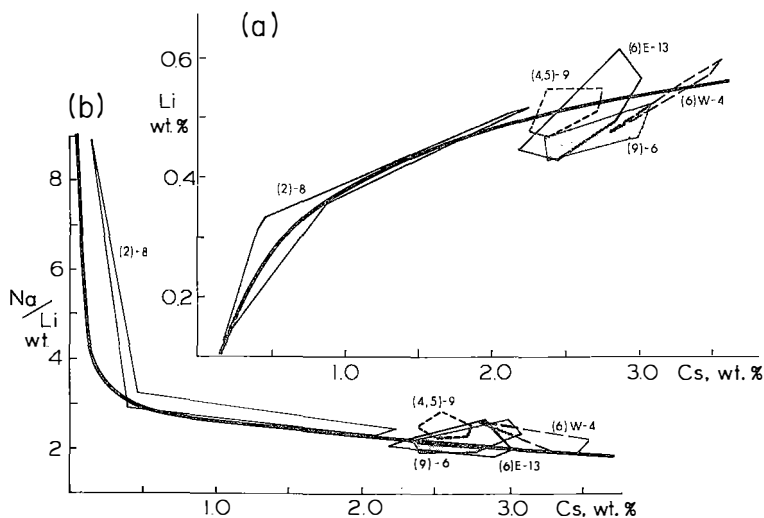


FIG. 4. Alkali contents of the primary Tanco beryls plotted in the Li versus Cs (a) and Na/Li versus Cs (b) diagrams. Heavy general trend lines after Černý (1975). Compositional fields of beryls from individual pegmatite zones marked by zone symbol followed by number of samples examined. Note the stretching of zone (2) whose population starts at very low alkali contents and almost reaches the widely overlapping fields of zones (4,5), (6), and (9). The coincidence of the general trend with the Tanco data is good.

TABLE 2. CHEMICAL COMPOSITION AND n_w OF THE TANCO BERYLS

Zone	Sample #	Li ₂ O	Na ₂ O	K ₂ O	Rb ₂ O	Cs ₂ O	Tl ₂ O*	Na/Li	ΣR_2O	n_w	
(2)	L13-555.9	.29	1.62	.067	.025	.18	1.0	8.96	2.18	(1.580)	
	L19-398.6	.68	1.26	.024	.034	.45		2.96	2.45	1.5878	
	M9-284.4	.69	1.30	.052	.036	.47	2.5	3.01	2.55	(1.5814)	
	M9-257.5	.72	1.48	.031	.035	.50		3.29	2.77	(1.5816)	
	A-229.2	.70	1.32	.029	.036	.55		3.01	2.64	1.589	
	TG-1	.78	1.44	.027	.034	.93	1.0	2.95	3.21	1.590 ²	
	M20-314.2	1.10	1.63	.049	.056	2.23		2.37	5.06	1.5912	
	T-244.4	1.13	1.76	.022	.044	2.38		2.49	5.34	(1.590)	
(4)	L19-495.2	1.19	1.84	.043	.056	2.53	4.5	2.47	5.66	(1.5864)	
	L16-512.0	1.09	1.86	.149	.065	2.67	7.0	2.72	5.83	1.593	
(5)	BE-8	1.03	1.55	.053	.063	2.63		2.36	5.32	1.592	
	BE-6	1.11	1.64	.062	.087	2.90		2.40	5.80	1.593	
	BE-9	1.04	1.48	.037	.066	2.70		2.27	5.32	1.5923	
(4,5)X	L9-393.3	1.02	1.58	.037	.053	2.53		2.48	5.22	1.593	
	L9-399.0	1.07	1.53	.032	.057	2.66		2.28	5.35	1.533	
	L19-510.5	1.08	1.92	.034	.058	2.71	2.2	2.84	5.80	1.5926	
	L9-388.4	1.17	1.89	.057	.061	2.91		2.56	6.10	1.593	
(6)E	+BLM-2AW	.59	1.10	.066	.061	.46		2.98	2.28	1.584	
	++BLM-2AP	1.22	1.51	.230	.100	3.20		1.98	6.26	1.5922	
	BLM-1	.97	1.25	.043	.095	2.32		2.06	4.68	1.591	
	**U10-11.5	.99	1.40	.046	.072	2.51		2.25	5.02	1.589	
	BE-5	.95	1.20	.038	.068	2.60		2.02	4.86	1.5932	
	VEIN	1.17	1.52	.031	.061	2.78	3.0	2.07	5.56	1.593	
	U10-5.7	1.06	1.26	.029	.070	2.83	6.2	1.90	5.25	1.593	
	C62-405.0	1.05	1.60	.050	.066	2.86	3.9	2.44	5.63	1.593	
	BLN-1C	1.21	1.51	.120	.089	2.96		1.99	5.89	1.5925	
	CONT-6	1.21	2.02	.034	.054	3.09		2.66	6.32	1.5931	
	BE-1	1.08	1.34	.061	.091	3.01	4.0	1.98	5.58	1.5935	
	**BE-3	1.34	1.74	.073	.064	3.04		2.07	6.26	1.591	
	U21-2.0	1.27	1.46	.270	.104	3.06		1.84	6.16	1.5928	
	(6)W	T-15	1.03	1.70	.031	.054	2.98		2.63	5.79	1.593
		T-23	1.20	1.50	.027	.079	3.49		1.99	6.30	1.5935
T-24		1.25	1.50	.057	.082	3.68	3.1	1.91	6.57	1.5948	
T-18		1.29	1.80	.041	.075	3.79	4.0	2.22	7.00	1.5952	
(9)	+TWL-1A	.89	1.14	.065	.117	1.84		2.04	4.05	1.590	
	++TWL-1B	1.03	1.60	.073	.121	3.13		2.53	5.94	1.5935	
	T-10	1.01	1.40	.026	.079	2.50		2.21	5.02	1.592	
	TWL-4	.92	1.12	.370	.154	2.53		1.94	5.09	1.591	
	TWL-3	.95	1.30	.200	.134	2.56		2.18	5.14	1.591	
	TWL-2	.95	1.22	.043	.109	2.61	5.2	2.05	4.93	1.591	
	TWL-5	1.04	1.28	.068	.112	2.95	6.8	1.96	5.45	1.5925	
	**B-188.8	1.13	1.69	.266	.109	3.28		2.38	6.47	1.5935	
(5)S +++SCN-1	1.61	1.30	.80	.18	7.16		1.29	11.05	1.604		

Analysts, R. M. Hill and R. Chapman (Dept. Earth Sciences, Univ. of Manitoba)

Zone symbols: (2) wall zone; (4) lower intermediate zone; (5) upper intermediate zone; (4,5)X - contacts of zones (4) and (5) with amphibolite xenoliths; (6)E - eastern part of central intermediate zone; (6)W - western part of central intermediate zone; (9) - metasomatic lepidolite zone; (5)S - secondary beryl from Zone (5).

* Thallium determinations by C. Dallaire (Laboratoire de Géochimie Analytique, Ecole Polytechnique, Montreal); data given in ppm.

** Full analyses of these specimens are given in Table 3.

+ Cores and ++ surfaces of crystals BLM-2A and TWL-1

+++ From Černý (1972); contains 9.58 BeO, 0.32 MgO, 0.01 CaO, 0.12 FeO, 0.02 MnO (wt. %)

() Refractive indices quoted in parentheses were probably determined on material not representative of the chemically analyzed sample.

a small but persistent shift can be observed towards higher-than-average Cs contents at any given Na/Li ratio. Characteristically, beryl (2) covers a wide range of relatively low alkali contents and high Na/Li ratios; beryls from the other zones are clustered in a small region of high Li and Cs, and low Na/Li. Histograms of n_w frequencies in Figure 2 suggest that the composition of beryl from zones (6)E, (6)W, and (9) may be much more uniform than indicated by the relatively few analyzed specimens plotted in Figure 4.

Beryls (4,5) and (4,5)X fall within a very small

field on each of the graphs. They are close to, and are partly superposed on, the (6)E and (9) fields, but have lower Cs and higher Na/Li.

The alkali contents of most of the primary beryls from Tanco are among the highest known: ΣR_2O reaches 7 wt. % and Cs₂O contents exceeding 3 wt. % are rather common. These beryl compositions reflect the extreme enrichment of their parent pegmatite in rare alkalis, particularly cesium (Černý & Simpson in prep.).

Because of lack of pure material, only one partial chemical analysis of a secondary beryl (5)S is available (SCN-1 in Table 2; Černý

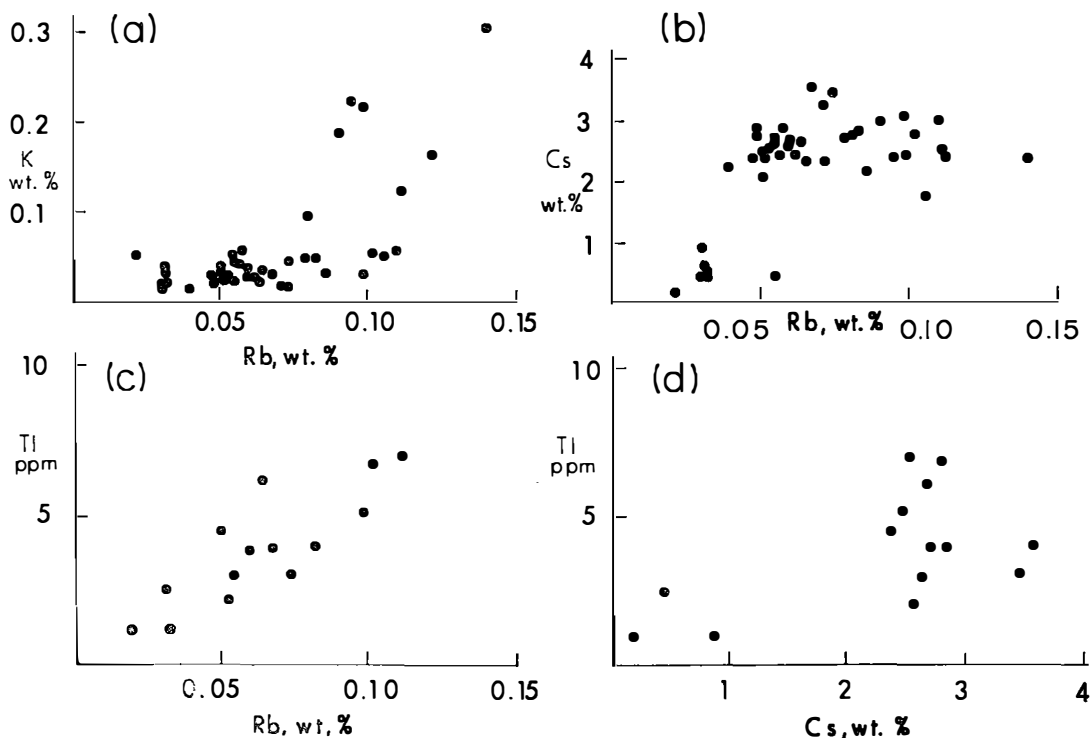


FIG. 5. Some minor alkali correlations in the Tanco beryl. Cs versus Rb is very poor, K and Rb show a possibly bimodal trend (see text for comments). Tl displays a widely scattered positive correlation with Cs, but a well-defined increase with Rb.

1972). It shows the second highest alkali contents recorded in beryl. Another sample of secondary beryl with $n\omega$ 1.610 should have alkali contents at least as high as those of the alkali-richest crystal known, which has $n\omega$ 1.608 and 11.3 wt. % Cs_2O (Evans & Mrose 1966).

The Rb content of the Tanco beryls shows a rough positive correlation with K and Cs (Fig. 5a,b). The K/Rb ratio appears to change from values predominantly lower than 1 at low concentrations to higher than 1 at high concentrations of both elements. K seems to be preferred to Rb in Cs-rich beryls, as also found by Borovik-Romanova & Sosedko (1958). This trend is also shown by secondary beryls (K/Rb=4 in SCN-1). However, K_2O values in excess of 0.1 wt. % are characteristic mainly of beryl (9), and a possible contamination by microscopic mica must be taken into consideration. In Figure 5a, a relatively dense band of K/Rb values <1 continues well under the scattered plots with K/Rb >1, and it may be more representative of the true K/Rb relationship.

The Rb/Tl trend is defined rather well, but Cs/Tl shows a broad scatter (Fig. 5c,d). Sam-

ples richest in Rb generally have lower Rb/Tl ratios (100 to 150) than specimens poor in Tl (200 to 300). However, all Rb/Tl ratios fall within the usual range of values for terrestrial magmatic rocks (65-300; Albuquerque & Shaw 1972).

MINERALOGY OF THREE SPECIMENS

Three samples considered representative of beryls with intermediate, low, and high $n\omega$ were selected for a detailed study: inner parts of crystal U10-11.5 ($n\omega$ 1.586), outer parts of crystal B-188.8 ($n\omega$ 1.594), and outer parts of sample BE-3 ($n\omega$ 1.589). Averages of the bulk of the analyzed material were found to deviate by +0.003, -0.000, and +0.002, respectively. This shift was evidently due to inadvertent contamination from adjacent crystal zones. The data obtained are summarized in Table 3 and Figure 6.

Chemical analyses show compositions typical of beryls enriched in rare alkalis, except sample BE-3 which has a high $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio. X-ray diffraction revealed about 1 wt. % quartz in this sample. Atomic contents conform well to the the

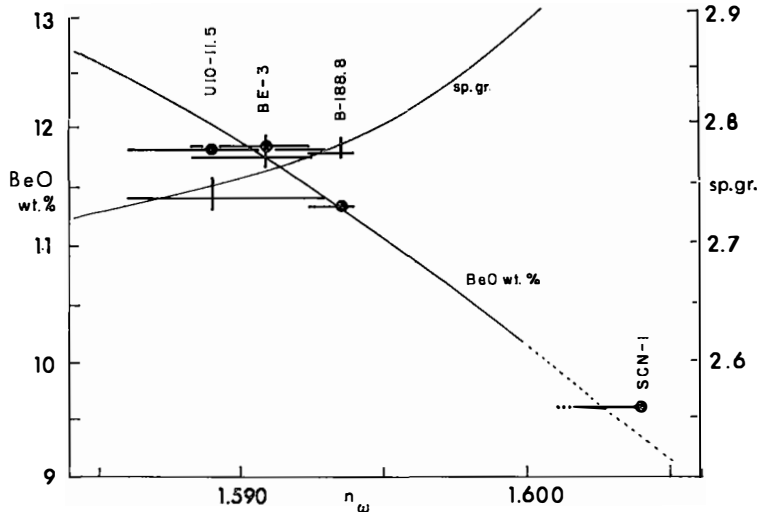


FIG. 6. A section of the Schaller-Stevens graph (after Norton *et al.* 1958) correlating BeO content and density of beryl with its n_w . For Tanco beryls, crosses indicate the maximum variation of the measured values for the density versus n_w plot and solid dots with horizontal bars show the range of n_w for the BeO versus n_w graph. Density is not available for sample SCN-1.

substitution mechanism $\text{Be}^{2+} \text{Li}^{1+} + \text{R}^{1+}$ channel established by Bakakin *et al.* (1969, 1970). This mode of alkali substitution was also confirmed by structure refinement (Hawthorne & Černý 1977). Most of the available Li enters the Be tetrahedra. Both recalculated analyses show channel alkalis in excess of the amount necessary to balance the Be/Li substitution; this excess balances the slight deficiencies in Si and Al.

Comparison of density, n_w , and BeO content is shown in Figure 6. Considering the somewhat inhomogeneous nature of the analyzed samples, the match with trend-lines averaged by Schaller and Stevens from data on about 100 beryls (Schaller *et al.* 1962, Norton *et al.* 1958) is good. The plot of BeO versus n_w for secondary beryl SCN-1 falls fairly close to the extrapolation of the Schaller *et al.* curve.

Unit-cell dimensions determined for the bulk of the chemically analyzed material compare well with those expected from the graphs of Bakakin *et al.* (1970). The low values of a are about equal in all three specimens and reflect the almost ideal Al population of octahedral sites, whereas c is closely dependent on the Be deficiency and alkali substitution.

In general, the correlation of chemical composition with unit-cell dimensions is very good, because both were established on the same material. The fit of compositional versus optical data is satisfactory only when the almost full

range of n_w is considered. Attempts to correlate the measured specific gravities with any other property lead to the worst results, notably because the differences among materials used for different determinations are the largest.

ECONOMIC CONSIDERATIONS

The BeO contents of different zones of the Tanco pegmatite quoted in Table 1 indicate that the deposit contains more than 1,000,000 short tons of beryl-bearing ore which averages 0.22 wt. % BeO. However, the feasibility of beryl extraction may be adversely affected by several factors:

(i) In the footwall part of western wall zone (2), which contains the largest reserve of Be in the pegmatite, beryl is presently the only economically interesting mineral. Low-cost extraction of beryl as a by-product of existing concentration processes would be possible only in zone (6), which is mined for tantalum oxide minerals.

(ii) Beryl crystals cannot be hand-cobbed because of their small size. The wide range of densities (2.70 to 2.80) present in crystals and their segments from a single pegmatite zone precludes separation by heavy media. The densities overlap those of mica and/or feldspar intergrown with quartz. Flotation would be the only means of effective concentration of beryl.

(iii) A marketable beryl concentrate should be

TABLE 3. CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF THREE BERYL SAMPLES

	U-10-11.5	B-188.8	BE-3		U10-11.5	B-188.8
SiO ₂	62.35	62.00	63.35	Al	3.959	4.010
Al ₂ O ₃	17.50	17.71	16.77	Fe	.004	.003
Fe ₂ O ₃	.027	.018	.073	Mg	---	.005
MnO	.007	.004	.001	Mn	---	.001
CaO	.007	.030	.120			
MgO	.001	.017	.003	Σ oct.	3.963	4.019
BeO	11.66	11.32	11.21			
Li ₂ O	.98	1.13	1.29	Be	5.376	5.225
Na ₂ O	1.38	1.68	1.68	Li	.624	.775
K ₂ O	.046	.269	.069	Si	11.976	11.911
Rb ₂ O	.071	.109	.068			
Cs ₂ O	2.47	3.27	2.92	Σ tetra.	17.976	17.911
H ₂ O-	.08	.07	.05	Na	.513	.626
H ₂ O+	1.96	2.06	2.10	Cs	.202	.268
				Li	.132	.098
Total	98.54	99.68	99.70	K	.011	.065
D meas. (g/cm ³)	2.74*	2.78	2.77 ₅	Rb	.009	.013
	(2.72 ₉ -2.75 ₃)+	(2.77 ₄ -2.78 ₇)	(2.765-2.79)	Ca	.001	.006
D calc. (g/cm ³)	2.78	2.81	-			
n _E	1.583**	1.585 ₅	1.585	Σ cat. chan.	.868	1.076
	(1.580-1.585)**	(1.585-1.586)	(1.583-1.586)	H ₂ O	1.254	1.319
n _{wr}	1.589	1.593 ₅	1.591			
	(1.586-1.593)	(1.592 ₅ -1.594)	(1.588 ₅ -1.592 ₅)	Σ chan	2.122	2.395
E - ω	.006	.008	.006	a ₀ (Å) ^x	9.211(1)	9.211(1)
	(.006-.007 ₅)	(.007 ₅ -.008)	(.005 ₅ -.006 ₅)	c ₀ (Å)	9.223(7)	9.231(4)
				v (Å ³)	677.7	678.2
				c ₀ /a ₀	1.001	1.002

Analysts: K. Ramial and R. Chapman (Dept. Earth Sciences, University of Manitoba).

Atomic contents based on 36 oxygens of anhydrous unit cell.

*averages of 3 to 4 grains of analyzed material; + ranges of the same grains.

**refractive indices considered representative for analyzed material; ++ranges for the parent specimens.

x u.c.d.'s for sample BE-3: a₀=9.214(1)Å, c₀=9.220(5)Å, V=677.9Å³, c₀/a₀=1.000.

highly purified to conform to the minimum BeO specifications of most consumers. The high alkali content of the Tanco beryl makes it a possible source of cesium (1.5-2.5 wt. % Cs₂O), but considerably reduces its BeO content (from about 13 wt. % BeO in much more common alkali-poor beryl to about 11.5-12.0 wt. % BeO in Tanco samples).

GEOCHEMICAL AND PARAGENETIC RELATIONS

In most beryl-bearing zones the average content of BeO is higher than the critical concentration of 0.018 wt. % Be (0.050 wt. % BeO) derived by Solodov (1971) as minimal for crystallization of beryl (Table 1). In fact, BeO in the beryl-rich zones ranks among the highest known in granitic pegmatites of the Tanco type (compare with Solodov 1971). In beryl-poor zones (4) and (5), BeO averages are marginal to the above value but locally can be expected to be distinctly higher than critical.

The BeO assays quoted in Table 1 and discussed above cannot be taken as directly indicative of the percentage of beryl present. In pegmatites with high Nb, Ta, Ti, Zr contents there is a well-established tendency towards dissemination of Be in rock-forming minerals, main-

ly micas (Beus 1960; Solodov 1971), and dispersed Be may amount to 6% of total Be in the pegmatite.

The association of all beryl varieties with albite±muscovite is persistent. In wall zone (2), beryl is disseminated in an albite+quartz (+ lithian muscovite) assemblage. Veinlets of cleavelandite accompany beryl in zones (4) and (5). In the western part of zone (6) and in the lepidolite bodies (9), beryl follows veinlets of fine- to medium-grained albite. In the lower parts of the eastern wing of zone (6), beryl is concentrated above the arcs and lobes of albitic aplite (3) (Fig. 3), and in the muscovite±albite which pervade K-feldspar and quartz.

The composition of beryl is *variable* in wall zone (2). It ranges from alkali-poor to alkali-rich with high Cs-content, which is the type predominant and rather *uniform* in all other zones (Figs. 2,4).

The above characteristics are consistent with the distribution of beryl found in similar pegmatite types by Beus (1960), Solodov (1971), and others. These authors relate the crystallization of most beryl types with albitization proceeding at various but generally late stages of pegmatite consolidation. The uniform composition of a part of beryl in zone (2) and of practically all

beryl in other zones speaks for a common origin of all these types (subject to minor variations in shape and color caused by differences in local environment of crystallization). The high alkali and Cs contents, together with the close association with albite and muscovite, favor a late crystallization during albitic metasomatism*.

The properties and distribution of beryl strongly indicate that the concept of albitic aplite (3) as a product of crystallization from residual sodic melt (Crouse & Černý 1972) should be reconsidered. This spectacular banded and undulating sodic aplite is absent in the recently opened western part of the deposit. However, the western part of zone (6) is penetrated by a mesh of abundant albite veinlets which carry the same type of Be,Ta,Sn,Zr-Hf mineralization as that associated with the eastern albitic aplite (3) (unpublished data by E. E. Foord, J. Siivola and the first author). Thus the difference between the two albite types may be purely textural, and zone (3), judged by Hutchinson (1959) and Wright (1963) to be metasomatic, could be identical with the "saccharoidal albite" of Russian authors (Zalashkova 1957; Beus 1960; Ginsburg 1960). This concept of beryl formation during late metasomatic events would also couple Be precipitation with the Ta, Nb and Ti mineralization whose metasomatic character was recognized earlier (Grice *et al.* 1972). Recent observations suggest that most, if not all, minerals of Nb,Ta,Ti,Zr-Hf,Sn and evidently also Be, in the Tanco pegmatite belong to a single mineralization stage. This conforms to the conclusions of Cameron *et al.* (1949), Beus (1960), and others, derived from countless pegmatite occurrences. The common migration and precipitation patterns of Be,Nb,Ta,Ti, and Zr can be explained by the amphoteric nature of all these metals which are transported mainly in the form of complex anions of about the same stability (Beus 1957, 1960).

The nature of the wall zone (2) whose eastern

footwall has been exposed by recent mining also becomes questionable. The presence of two muscovite varieties, two beryl types, and possibly two types of albite, suggests that some parts of this zone may be of metasomatic origin, corresponding to the quartz+muscovite replacement complex (frequently beryl-bearing) recognized by, for example, Jahns (1953), Beus (1960), Ginsburg (1960), and Solodov (1971). This metasomatic assemblage frequently occurs in the outer zones of granitic pegmatites, corresponding to the wall zone (2) of the Tanco body.

One conspicuous deviation of the beryl distribution from the pattern predominant in most other localities deserves notice. The Tanco pegmatite carries most of its beryl in the footwall and central parts, whereas the most common loci of beryl accumulation in other pegmatites are the upper margins of quartz cores and the hanging-wall parts of the outer zones (Beus 1960; Solodov 1971). A similar "anomalous" footwall concentration of beryl is also found in the Bikita deposit in Rhodesia (Cooper 1964). This only emphasizes the general similarity between the Tanco and Bikita pegmatites recognized earlier (Crouse & Černý 1972). Unfortunately, the information on beryl from the analogous Varuträsk pegmatite (Quensel 1937, 1956) is too sketchy to provide a meaningful comparison with the Tanco deposit.

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*Beryl associated with albite veinlets in the lepidolite replacement unit (9) shows the same properties as that found in central intermediate zone (6). This zone provides a matrix from which the lepidolite unit originates by Li- and F-metasomatism (Wright 1963; Crouse & Černý 1972). It is highly probable that the beryl of zone (9) is, along with much of the quartz, albite and accessory minerals, a relict from the earlier assemblage of zone (6). No recrystallization and change in chemistry due to lepidolite metasomatism, similar to those described by Beus (1960), have been observed. The only noticeable change occurs in coloring, from white to pinkish beige.

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