

## THE TANCO PEGMATITE AT BERNIC LAKE, MANITOBA X. POLLUCITE\*

P. ČERNÝ AND F. M. SIMPSON†

Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2

### ABSTRACT

Pollucite forms large lenticular bodies and pods in the upper intermediate zone of the Tanco pegmatite, in association with quartz, microcline perthite, petalite (spodumene + quartz) and amblygonite. It was formed as a late constituent of primary zonal crystallization and shows no evidence of metasomatic origin. The composition of pollucite, established chemically or estimated optically on 148 samples, is centred at 32 wt.% Cs<sub>2</sub>O (approximately Poll<sub>73</sub>Anal<sub>27</sub>). Some pollucite bodies tend to be enriched in Na along their margins. Cs and Na are the only major alkalis; K, Rb and Li are subordinate. Negative Cs/Na and positive Rb/Tl correlations are the only well-defined trends among the alkalis. Refractive indices can be roughly correlated with the (Cs, Na) substitution. Pollucite bodies are veined by quartz, mostly non-perthitic microcline ( $\Delta$  0.92), low albite ( $\psi$  1.10°) locally rimmed by cesian analcime, and purple lithian muscovite (2M<sub>1</sub>) with lepidolite (1M). A late network of braided veinlets carries white lithian muscovite (2M<sub>1</sub>) and some spodumene, followed by sanidine-type adularia. Greenish kaolinite and montmorillonite ( $\pm$  calcite) formed last in the alteration sequence.

### SOMMAIRE

La pollucite se présente en amas lenticulaires dans la zone moyenne supérieure de la pegmatite Tanco, accompagnée de quartz, microcline perthitique, pétalite (spodumène + quartz) et amblygonite. Elle s'est formée tardivement lors de la cristallisation zonale primaire et ne montre nul indice d'origine métasomatique. Sa composition, établie par analyse chimique ou déduite des propriétés optiques de 148 échantillons, se situe vers 32% (en poids) de Cs<sub>2</sub>O, à peu près Poll<sub>73</sub>Anal<sub>27</sub>. Certains amas de pollucite ont tendance à s'enrichir en sodium, en bordure. K, Rb et Li sont nettement subordonnés à (Cs + Na); les corrélations Cs/Na (négative) et Rb/Tl (positive) sont les seules nettes pour les métaux alcalins. Les indices de réfraction dépendent

*grosso modo* du degré de substitution (Cs,Na). Les amas de pollucite sont recoupés par des filons de quartz, microcline non-perthitique ( $\Delta$  0.92), albite ordonnée ( $\psi$  1.10°) (bordée localement d'analcime césique) et muscovite lithique violacée (2M<sub>1</sub>) avec lépidolite 1M). Des entrelacs de filonnets tardifs contiennent de la muscovite lithique blanche (2M<sub>1</sub>) et un peu de spodumène, suivis d'adulaire désordonnée. Le dernier stade d'altération est représenté par de la kaolinite verdâtre et de la montmorillonite (avec ou sans calcite).

(Traduit par la Rédaction)

### INTRODUCTION

Pollucite was discovered in the Tanco pegmatite in 1960 when Dr. R. W. Hutchinson noticed peculiar physical characteristics of what had been previously logged as a quartz-feldspar intergrowth. Subsequent laboratory examination by Dr. W. Moorhouse led to its correct identification (Frohberg 1967). A substantial pollucite body in the pegmatite was established shortly afterwards. Recent underground excavations in the western part of the pegmatite have established the shape and size of several other bodies detected earlier by drilling. The total reserve of pollucite in the deposit exceeds 350,000 tons averaging 23.3 wt.% Cs<sub>2</sub>O; this represents the largest accumulation of this mineral known in the world today.

With the exception of Nickel's (1961) description, there are no mineralogical data on the Tanco pollucite available in the literature, and its paragenetic position in the pegmatite is rather poorly understood (Hutchinson 1959, Wright 1963, Crouse & Černý 1972). Also, mining and exploration at Tanco offer a unique opportunity to study compositional and alteration patterns of pollucite bodies in three dimensions; all extant descriptions of pollucite from individual localities are based on examination of one or two specimens. These considerations initiated the present study; it is based partly on a thesis by Simpson (1974), partly on the investigations of the first author before and since the completion of this thesis.

\*Publication No. 26, Centre for Precambrian Studies.

†Present address: 75 Linden Avenue, Winnipeg, Manitoba R3K 0M7.

SAMPLING AND EXPERIMENTAL METHODS

Underground and drill-core sampling yielded 148 specimens of pollucite for laboratory study. An additional 30 specimens were collected to examine the alteration processes. The suite of 148 samples was checked for refractive indices (*n*) and 41 specimens were then selected for partial chemical analyses. Three samples considered representative of pollucite with low, average, and high *n* were chosen for a detailed mineralogical study.

Pollucite from Tanco is generally homogeneous on a small scale. Four randomly selected hand specimens were checked for *n* at 3 to 5 spots on their surfaces. The ranges of *n* in individual samples did not exceed 0.001, the equivalent of about 0.6 wt.% Cs<sub>2</sub>O. The only exceptions are the specimens veined by late alteration products; these were excluded from the study. Fine veining by mica and spodumene proved to be much more of an obstacle for obtaining reliable compositional data than any inhomogeneity in the pollucite itself. Seven of the 41 partial analyses had to be discarded because of complex contamination of the sample, and 17 other analyses were adjusted for admixtures of spodumene or muscovite, quantitatively determined by X-ray powder diffraction.

The methods of optical study, density determination, chemical analyses, and X-ray powder diffraction are as described by Černý & Simpson (1977), with the only exception that the standards used for determination of common constituents were heavily spiked with cesium, to balance the Cs content of pollucite and its effects on determination of other elements.

OCCURRENCE IN THE PEGMATITE

Pollucite is restricted to the upper parts of the eastern and western flanks of the pegmatite where it occurs within, or adjacent to, the upper intermediate zone (5 in Fig. 1). This zone consists mainly of quartz and giant-size crystals of microcline perthite, petalite altered to spodumene + quartz, and amblygonite (*cf.* Černý & Simpson 1977, Table 1 for detailed mineralogy of all zones). Pollucite forms numerous pods and nodules 1 to 2 m in diameter and several large lenticular bodies that constitute pollucite zone (8). The largest of these, 180 × 75 × 12 m in size, is located in the eastern flank of the pegmatite, and three smaller bodies are found in the western part; their positions are projected on the section plane in Figure 1.

Masses of pollucite show simple smooth boundaries against quartz, and are anhedral

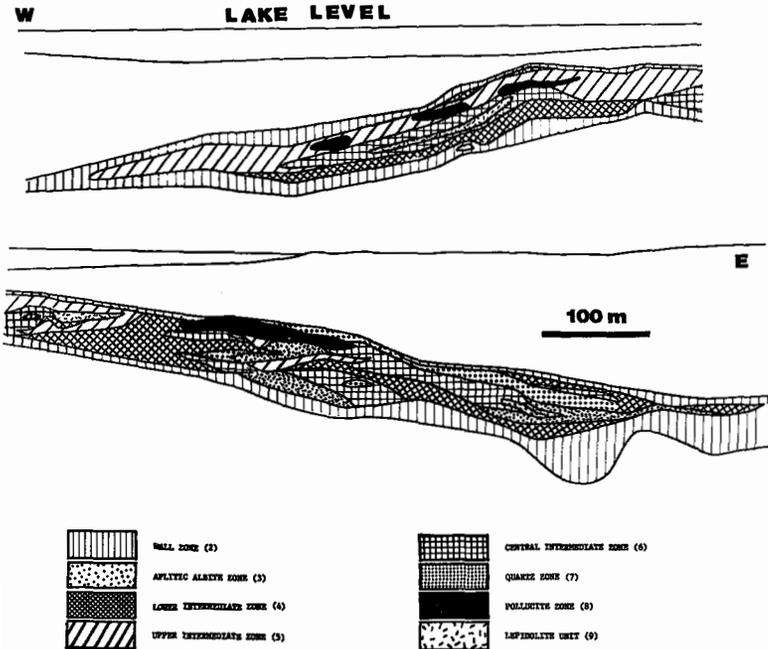


FIG. 1. Longitudinal section through the Tanco pegmatite. Most of the eastern pollucite body is exposed in this section; some of its boundaries shown here and all the western pollucite bodies are projected on this section to show their full extent.

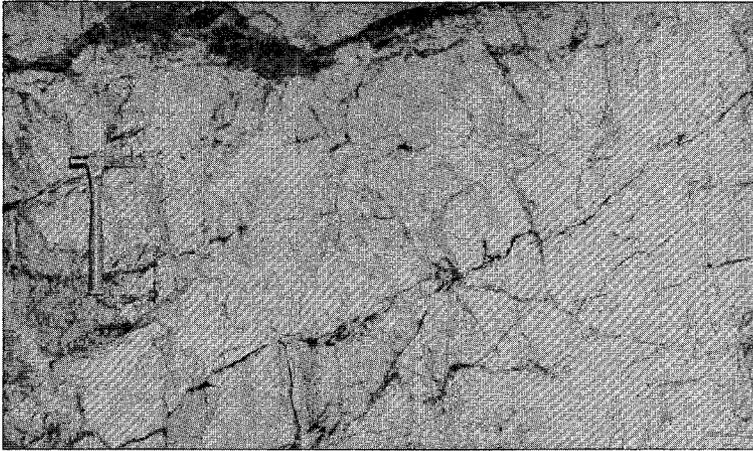


FIG. 2. Typical veining pattern in the eastern pollucite body, shown here separated from blocky microcline perthite (upper left) by a dark selvage of quartz. Dark veinlets of quartz, feldspars and lepidolite dissect pollucite into polygonal blocks. Faintly visible system of subparallel whitish veinlets, gently sloping to the right, carries muscovite and spodumene. The hammerhead is 20 cm long.

with respect to all other primary constituents of zone (5). Pollucite may locally cement fractured or brecciated silicate assemblages but it is never observed as a replacement.

Veining and replacement by quartz, feldspars, micas and spodumene described later in this article are widespread, though minor in volume (Fig. 2). These constitute the only major contaminants of the bulk of the pollucite bodies; these were essentially monomineralic before the onset of secondary processes.

COMPOSITIONAL VARIABILITY

The variation of refractive index of pollucite with the Cs/(Na+H<sub>2</sub>O) substitution has been well established (e.g., Richmond & Gonyer 1938, Nel 1944, Černý 1974). Thus an optical survey of 148 pollucite specimens was undertaken as a first step in determining their compositional range.

The mean value of *n* is 1.5206, with a standard deviation ± 0.0013 that encompasses most primary pollucites from other pegmatites (Černý 1974, Fig. 1). Extreme values are 1.517 and 1.524. Frequency distributions of *n* values in eastern and western bodies are very similar and close to gaussian when combined.

Chemical analyses of 37 specimens yield a mean of 31.96 wt.% Cs<sub>2</sub>O, with standard deviation ± .96 and extreme values of 29.67 and 34.10 (Table 1). This mean is also close to the Cs<sub>2</sub>O content most frequently quoted for primary pollucites. However, frequency distributions of Cs<sub>2</sub>O in the eastern and western bodies and in all the bodies combined are asymmetric,

TABLE 1. ALKALI CONTENTS AND *n* OF THE TANCO POLLUCITE

Zone	Sample #	Li <sub>2</sub> O	Na <sub>2</sub> O	K <sub>2</sub> O	Rb <sub>2</sub> O	Cs <sub>2</sub> O	Tl*	<i>n</i>
Eastern body	R-H	.09	1.88	.12	.71	32.90		1.522
	R-2-3	.06	1.70	.52	.94	32.65	105	1.5224
	R-3-4	.11	1.65	.09	.79	34.10		1.524
	R-4-2	.09	1.85	.05	.89	31.35		1.5198
	R-2-6	.15	1.68	.37	.86	31.50		1.522
	P-1-5	.19	1.64	.11	.97	33.04		1.5224
	P-2-4	.11	1.87	.15	.88	33.20		1.5225
	P-4-6	.23	1.63	.19	.74	32.00		1.5205
	P-3-2	.08	1.72	.07	.72	32.20		1.5198
	P-4-4	.15	1.73	.15	.85	31.56		1.5192
	834-147.5	.18	1.84	.08	.80	31.52		1.5185
	834-157.5	.20	1.76	.10	1.10	32.00		1.5205
	834-187.5	.14	1.62	.25	.59	31.60		1.522
	834-206.6	.09	1.68	.10	.73	32.40		1.5202
	M5-205.5	.23	1.46	.19	.82	32.26		1.5202
	M4-165.5	.16	1.43	.20	.80	31.67		1.5206
	M4-163.5	.24	1.34	.19	.82	32.03		1.5218
	**U39-95.8	.28	1.98	.17	.77	30.60	100	1.517
	U39-62.5	.31	1.96	.18	.44	29.67		1.518
	U39-75.5	.38	1.73	.23	.86	31.27		1.5204
**812-207.2	.29	1.31	.10	.68	32.57	80	1.5232	
**812-226.2	.43	1.74	.16	.74	32.20		1.5204	
Western bodies	M20-179.5	.53	1.45	.24	.77	33.10		1.5238
	M20-181.2	.41	1.58	.35	.83	30.70		1.5202
	C-202.5	.56	1.45	.15	.67	31.75		1.520
	TL-19	.11	1.51	.22	1.22	31.50	169	1.5185
	TL-20	.15	1.87	.27	.35	30.20	47	1.5176
	TL-21	.21	1.48	.20	.85	33.60	107	1.5228
	TL-84	.16	1.48	.16	.89	33.60	120	1.522
	TL-85	.12	1.31	.25	.94	32.80	108	1.5212
	TL-86	.14	1.48	.19	1.16	32.20	169	1.5208
	CsA-5	.12	1.60	.22	.20	31.40		1.5194
	CsA-8	.17	1.70	.26	.19	30.90		1.5198
	CsA-3	.18	1.70	.20	.51	31.50		1.5214
	CsA-7	.12	1.55	.15	.78	32.30		1.5234
WEX-C	.13	1.48	.21	.81	31.20		1.5196	
WEX-D	.18	1.42	.20	1.06	32.30		1.5214	

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

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

\*\* Full analyses of these specimens are given in Table 2.

## MINERALOGY OF THREE SPECIMENS

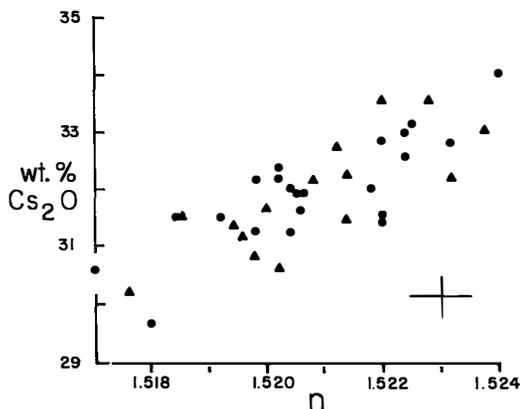


FIG. 3. Plot of wt.%  $\text{Cs}_2\text{O}$  against refractive indices  $n$  of the Tanco pollucites; dots, eastern body; triangles, western bodies. Distinct positive correlation with considerable lateral dispersion. The cross indicates standard errors of compositional and optical data.

skewed towards high values. Correlation of  $n$  with  $\text{Cs}_2\text{O}$  shows that the refractive indices can be used as an approximate measure of the Cs content of Tanco pollucites, despite considerable transversal scatter (Fig. 3).

Optical data were used in assessing possible regularities in spatial distribution of compositional variations. No meaningful patterns were found in horizontal sections. Several vertical profiles through the eastern body reveal Cs/Na ratios decreasing along, or close to, its margins. However, this pattern is not persistent, and some profiles show a rather erratic variation.

Three specimens representative of pollucites with low, intermediate, and high  $n$  were selected for a detailed study. The data obtained are listed in Table 2.

The crystal chemistry of these pollucites corresponds to the general characteristics of the species as derived by Beger (1969) and confirmed by Černý (1974). The Si/Al ratio is typically higher than 2.00, and the charge balance  $\text{Al}^{3+}/(\text{R}^+ + 2\text{R}^{2+})$  deviates from the ideal value of 1.00 only within the limits of analytical error. The sum of Cs +  $\text{H}_2\text{O}$  should equal 1.00 but is somewhat lower, possibly due to incomplete dehydration of pollucite on heating (Fleischer & Ksanda 1940, Barrer & McCallum 1951). The unit-cell dimensions show no appreciable variation with the changing cationic content as they are significantly influenced only by the Si/Al ratio.

Generally, the relationships between different crystallochemical and physical properties correspond to those established earlier (Černý 1974, Figs. 3,4,6 and 7). The only noteworthy deviation within individual sets of otherwise well-balanced properties is a difference between the measured and calculated densities. This varies between 0.03 and 0.04, with the measured values invariably higher than the calculated data; a reverse relationship is much more common. This puzzling discrepancy will be investigated in a crystallochemical study of pollucite in progress.

Figure 4 shows relationships between pairs of alkali elements, based on data from Table 1.

TABLE 2. CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF THREE POLLUCITE SAMPLES

	U39-95.8	B12-226.2	B12-207.2		U39-95.8	B12-226.2	B12-207.2
$\text{SiO}_2$	47.80	46.09	47.42	Si	2.161	2.112	2.151
$\text{Al}_2\text{O}_3$	15.70	16.38	16.02	Al	.836	.884	.856
$\text{Fe}_2\text{O}_3$	.01	.01	.01	$\Sigma$ tetr.	2.997	2.996	3.007
MgO	.003	.003	.01	Si/Al	2.58	2.39	2.51
CaO	.04	.01	.06	Cs	.589	.629	.630
$\text{Li}_2\text{O}$	.28	.43	.29	Na	.173	.156	.114
$\text{Na}_2\text{O}$	1.98	1.74	1.30	Li	.051	.079	.053
$\text{K}_2\text{O}$	.17	.16	.10	Rb	.022	.022	.020
$\text{Rb}_2\text{O}$	.77	.74	.68	K	.010	.009	.006
$\text{Cs}_2\text{O}$	30.60	32.20	32.57	Ca	.002	-	.003
$\text{H}_2\text{O}^+$	2.11	1.73	1.37	Mg	-	-	.003
$\text{H}_2\text{O}^-$	.08	.04	.04	$\Sigma (\text{R}^+ + \text{R}^{2+})$	.847	.895	.829
Total	99.54	99.53	99.87	$\text{H}_2\text{O}$	.33	.27	.21
D meas. ( $\text{g}/\text{cm}^3$ ) <sup>a</sup>	2.84	2.88	2.87	Cs+H <sub>2</sub> O	.92	.90	.84
D calc. ( $\text{g}/\text{cm}^3$ )	2.81	2.85	2.83	Pol1 <sup>+</sup>	69.6	70.2	75.7
$n^*$	1.517	1.520 <sub>4</sub>	1.523 <sub>2</sub>	CRK <sup>+</sup>	73.2	73.7	78.7
$A_0(\text{\AA})$	13.674(1)	13.672(1)	13.672(1)				
$V(\text{\AA}^3)$	2556.76(43)	2555.57(43)	2555.57(43)				

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

Atomic contents based on a subcell with 7 oxygens in anhydrous formula.

<sup>a</sup> Averages of 3 to 4 grains of analyzed material.

<sup>\*\*</sup> Average of analyzed material, with fluctuations to  $\pm 0.001$ .

<sup>+</sup> Pol1 =  $(\text{Cs} \times 100)/(\text{Cs} + \text{Li} + \text{Na} + \text{Rb} + \text{K})$ .

<sup>++</sup> CRK =  $[(\text{Cs} + \text{Rb} + \text{K}) \times 100]/(\text{Cs} + \text{Rb} + \text{K} + \text{Li} + \text{Na})$ .

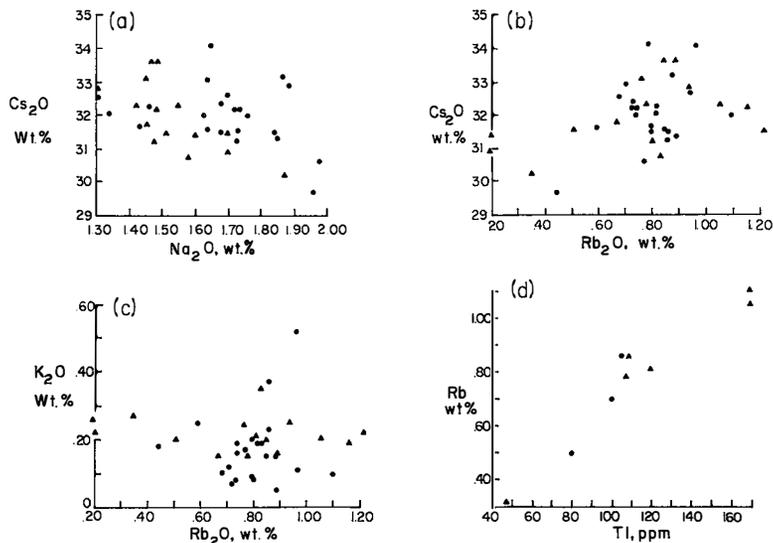


FIG. 4. Major and minor alkalis in the Tanco pollucite. The  $Cs_2O/Na_2O$  and  $Cs_2O/Rb_2O$  correlations are poorly defined, and the  $K_2O/Rb_2O$  plot seems to be inconclusive, whereas the  $Rb/Tl$  diagram shows good positive alignment of data. Symbols as in Figure 3.

The plot of  $Cs_2O$  vs.  $Na_2O$  displays the expected negative correlation but also a wide scatter of points, attributable to either variable contents of other alkalis, to slight variation in the Si/Al ratio which regulates the alkali total, or to relatively high standard deviation in the cesium determination.  $Rb_2O$  shows a poor positive correlation with  $Cs_2O$ , in accordance with other geochemical and crystallochemical data on these alkalis (e.g., Stavrov 1963). Surprisingly, the  $K_2O$  vs.  $Rb_2O$  diagram shows a random scatter of data, unless we accept the predominant horizontal belt of points as indicative of variable Rb at a constant K content. In contrast, the  $Rb/Tl$  ratio shows a well-defined correlation, with individual values ranging from 82 to 63. These are the lowest found in the silicates of the Tanco pegmatite (Černý, unpubl. data) but still lie within the range of 300–65 given by de Albuquerque & Shaw (1972) for terrestrial igneous rocks.

ALTERATION PROCESSES

As in most other localities, the pollucite bodies in the Tanco deposit underwent several stages of low-temperature hydrothermal alteration. Three consecutive alteration stages may be distinguished: (i) coarse polygonal veining by microcline, albite, quartz and lepidolite; (ii) fine braided veining which carries spodumene, lithian muscovite and adularia, and (iii) replacement by kaolinite and montmorillonite ( $\pm$  quartz, calcite).

Coarse veins

Coarse veins, 5 to 40 mm across, fill in polygonal fracture patterns as shown in Figures 1 and 5a. Microcline is usually confined to the marginal parts of pollucite bodies, whereas albite and quartz penetrate farther. Telescoping of these three minerals along a single fracture is common. Columnar spodumene is a rare constituent of some of the quartz veins. Albite is

TABLE 3. PROPERTIES OF MICROCLINE

	$Na_2O$	$K_2O$	$Rb_2O$	$Cs_2O$	CaO	PbO
PMI-17	1.77	13.00	2.19	.24	.07	.002
PMI-19	1.08	13.63	2.42	.28	.17	.001
PMI-20	.25	13.00	3.61	.21	.004	.001
obliquity*	(11):	.92	(.86 - .95)			
(Ab+An) <sub>ss</sub> **	(11):	2%	(7 - 0)			
U.c.d's of PMI-19:						
$a_{meas.}$	8.594(4)Å		$\alpha$			$90^{\circ}33.7(1.8)$
( $a_{pred.}$ ***)	8.48Å		$\beta$			$115^{\circ}56.6(1.6)$
b	12.951(3)Å		$\delta$			$87^{\circ}53.1(1.7)$
c	7.211(2)Å		$\nu$			$721.3(3)Å^3$

\* (number of samples): arithmetic mean (range).

\*\* by X-ray diffraction (Orville 1967); otherwise as under\*.

\*\*\* from Stewart & Wright (1974, Fig. 1).

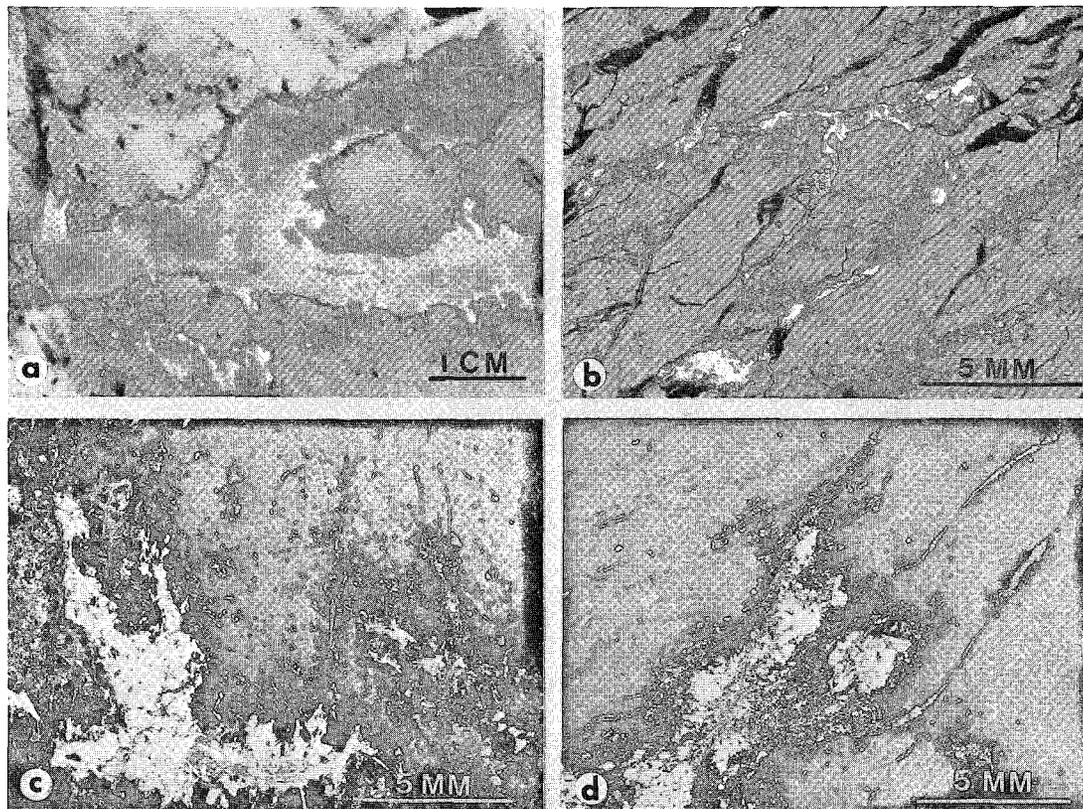


FIG. 5. Late veining in the Tanco pollucite: (a) dark nonperthitic microcline in whitish pollucite, locally with a black halo of adularia and clay minerals (polished hand specimen); (b) dark veinlets of muscovite and spodumene penetrating clear pollucite (thin section, polarized light); (c) white microcline corroded by grey adularia along contacts with isotropic pollucite (thin section, crossed polars); (d) grey fine-grained adularia on white coarsely granular granular microcline and along white veinlets of muscovite in isotropic pollucite (thin section, crossed polars).

occasionally accompanied by manganotantalite or wodginite. Lepidolite penetrates those parts of pollucite bodies located close to lepidolite masses of unit (9). Where associated with the feldspars, lepidolite is always of later origin, filling central parts or margins of the feldspar veins.

Compositional and physical characteristics of the microcline are given in Table 3; representative veinlets are shown in Figures 5a, c. The erratic variation in the  $\text{Na}_2\text{O}$  content found by chemical analyses seems to be caused by variable contamination of the analyzed material by granular albite. The nonperthitic nature of this microcline, and the rather low and uniform (Ab + An) content determined by X-ray diffraction support this explanation.

Albite shows an almost constant  $\alpha' = 1.529$  on (001) cleavage fragments; this corresponds to  $\text{An}_{0.1}$  (Morse 1968). Its average obliquity value is  $1.10^\circ$ , with variations from  $1.05^\circ$  to

$1.13^\circ$ , indicating a well-ordered structure (Smith 1974, Fig. 7-43).

Pollucite in the immediate vicinity of the albite veinlets occasionally shows changes in X-ray powder diffraction intensities, and refractive indices as low as 1.500. These properties indicate cation exchange or recrystallization into cesian analcime Černý 1974, Figs. 1, 8), due to the action of albite-producing solutions from the adjacent veins.

Lepidolite consists of a mixture of  $2M_1$  and  $1M$  polytypes; it is deep reddish purple, fine flaked to massive, with refractive indices in the cleavage plane between 1.570 and 1.580. These properties match those of massive lithian muscovite + lepidolite of zone (9) (Rinaldi *et al.* 1972, samples R7, R9, REN5).

#### *Fine-braided veining*

A network of subparallel, locally braided veinlets of white muscovite with spodumene

penetrates most bodies of pollucite (Fig. 5b). Its orientation shows no relation to the boundaries of polygonal blocks framed by the preceding vein type, and it often holds for several metres without significant change. The micaceous veinlets occasionally penetrate and cross-cut the feldspar veins.

Lath-shaped crystals of spodumene are irregularly dispersed or clustered in the mica veinlets, and are partly replaced by them. Spodumene may represent early inclusions in pollucite, connected later (as centres of mechanical weakness) by the braided fracture system invaded by mica-generating solutions. This spodumene, however, has never been found outside the micaceous veinlets, and most of it is oriented subparallel to their course. Thus it most probably represents an early replacement product that preceded muscovitization.

Muscovite yields X-ray powder diffraction patterns of the  $2M_1$  polytype, and the average  $n$  on its cleavage flakes varies between about 1.600 and 1.590. This indicates that the secondary mica varies between typical and somewhat lithian muscovite in composition.

The muscovite veining was locally followed by a second generation of K-feldspar. Fine-grained adularia replaces microcline of the coarse vein system and pollucite along their contacts, and it also grows from the margins of nearby muscovite veinlets into the pollucite (Figs. 5c, d). Gandolfi X-ray diffraction photographs show the adularia to be of a high sanidine structural state.

#### *Argillic replacement*

Clay minerals occur in two major forms. Most abundant are white spheres up to 3 mm in size, randomly disseminated through the muscovite-veined pollucite. These consist of dusty "clouds" producing faint  $14\text{\AA}$  and  $7\text{\AA}$  reflections in Gandolfi photographs. Restricted to the margins of pollucite bodies are apple-green patches and veinlets of illite, montmorillonite and kaolinite, determined by optical, X-ray powder diffraction and differential thermal methods (Černý 1978). Larger pods of the green clay minerals usually contain some quartz and calcite. Partial chemical analysis of the green clay, in part contaminated by residual pollucite, gave  $\text{Cs}_2\text{O}$  5.00,  $\text{CaO}$  4.95,  $\text{K}_2\text{O}$  4.94,  $\text{Na}_2\text{O}$  1.92,  $\text{MgO}$  1.76,  $\text{Rb}_2\text{O}$  0.18 and  $\text{Li}_2\text{O}$  0.09 wt. %.

#### GENETIC CONSIDERATIONS

##### *The position of pollucite in the crystallization sequence*

The timing of pollucite crystallization in peg-

matites has been discussed in literature since the recognition of pollucite as a mineral species. Amongst modern authors Dymkov (1953), Quensel (1956), Ginzburg (*e.g.*, 1960) and Solodov (1960) advocate a late metasomatic origin whereas Beus (1960), Melentyev (1961), Symons (1961), Cooper (1964) and Heinrich (1976) consider pollucite as a primary constituent of central parts of pegmatite bodies.

In the Tanco pegmatite, Hutchinson (1959) and Wright (1963) interpreted pollucite bodies as late metasomatic features, in a close spatial relationship with the obviously metasomatic lepidolite units (9), developed at the expense of microcline-rich zone (6). Wright also observed pollucite replacing spodumene on a microscopic scale. As previously indicated (Crouse & Černý 1972), the evidence is questionable; more recent work supports the primary nature of pollucite.

The distribution of lepidolite units generally follows, though not closely, that of the pollucite bodies. Large segments of pollucite segregations are not underlain by lepidolite, and some lepidolite units lack the overlying pollucite. Lepidolite and pollucite bodies rarely come into direct contact; they are usually separated by a quartz selvage, and lepidolite veins commonly criss-cross pollucite. Lepidolite bodies are found mainly within the K-feldspar-rich central intermediate zone (6) and along the lower margins of the upper intermediate zone (5), whereas pollucite bodies are confined to the latter. Thus the differences in distribution and relative age rule against common origin.

The pollucite-like mineral observed by Wright (1963) as a replacement of spodumene is most probably cesian analcime, a late hydrothermal alteration product (Černý 1972). It was recently found to vein and replace eucryptite and amblygonite. Primary pollucite has never been observed to replace petalite or spodumene + quartz aggregates formed by its retrograde thermal breakdown.

The evidence pointing to the primary nature of the Tanco pollucite may be summarized as follows: (i) Pollucite occurs in lenticular, loaf-shaped or ellipsoidal bodies, within or in direct contact with the upper intermediate zone (5). This zone consists of giant-size petalite, amblygonite and microcline perthite imbedded in abundant quartz. Small rounded blebs of pollucite "float" in quartz among crystals of the above-mentioned minerals without any textural indication of a late origin. (ii) Simple outlines and rather straight boundaries of even the largest pollucite bodies show no indication of cross-cutting or metasomatic relationships with other

minerals or assemblages. Pollucite is anhedral against other minerals but does not replace them. Petalite adjacent to the pollucite bodies locally contains round grains of pollucite, regularly distributed, and somewhat graphic in outline. This may suggest a simultaneous crystallization of both minerals. (iii) In close vicinity to the albitized zone (6), pollucite is veined by albite containing manganotantalite and wodginite. Fine-flaked lithian muscovite and lepidolite filling fractures in pollucite show the same physical properties as the micas in lepidolite units (9). Thus, both well-established metasomatic events in the pegmatite, the (Ta,Be,Sn,Zr,Hf) enrichment associated with albitization and the lepidolite units, postdate the crystallization of pollucite.

#### Compositional variations

Most of the Tanco pollucite is rather uniform in composition but a considerable percentage of samples covers a range of about  $\text{Poll}_{88}\text{Anal}_{17}$  –  $\text{Poll}_{70}\text{Anal}_{30}$ . Na-rich compositions occasionally tend to be located close to the margins of pollucite bodies; otherwise their distribution is rather erratic. Available evidence suggests that at least some of the variation in Cs/Na comes from alkali exchange along feldspar-bearing veins; the presence and extent of primary variations cannot be evaluated at present.

#### Late alterations

High density of veining in the marginal parts of pollucite bodies, and a roughly zoned sequence of alteration products from the margins inward suggest an external source of alteration fluids. The principal veining and replacement assemblages found in the Tanco pollucite are remarkably similar to those described from other occurrences (Ginzburg 1946, Quensel 1956, Neuvonen & Vesasalo 1960, Melentyev 1961). Albite, lepidolite and late muscovite ("gilbertite", "oncosine") veining is most widespread. K-feldspar veins seem to be typical of Tanco, whereas veinlets of fine spodumene and spodumene-bearing symplectites with other phases seem to be more characteristic of other localities. The somewhat varied but recurrent pattern of pollucite alteration at many localities stresses the fixed position occupied by this mineral in the crystallization sequence of complex granitic pegmatites and the qualitatively uniform character of low-temperature hydrothermal processes.

#### SUGGESTIONS FOR FUTURE RESEARCH

A review of the compositional variations and

physical properties of the natural members of the analcime-pollucite series is in progress, under the guidance of the first author. New finds of pollucite-like minerals should be checked for physical properties and thoroughly examined when sodium-rich compositions are indicated.

Laboratory synthesis of pollucite has been successful over a wide range in temperature (Barrer & McCallum 1953, Barrer *et al.* 1953, Plyushev 1959, Kume & Koizumi 1965, Kopp & Clark 1966, Richerson & Hummel 1972, Suito *et al.* 1974, Martin & Lagache 1975). The stability field, however, has never been established for either pure Cs-pollucite or Na-bearing phases comparable to natural minerals. Similarly, pollucite crystallization in simplified lithium pegmatite systems has never been simulated experimentally. Research projects into these aspects are highly desirable.

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