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BERYL FROM THE GRANITIC PEGMATITES AT GREER LAKE, SOUTHEASTERN MANITOBA*

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ABSTRACT

Twenty-six samples of beryl from 12 pegmatite bodies, representative of the Greer Lake pegmatite group, were analyzed for Na, Li, K, Rb, Cs, Ca, Fe and Mg, and examined for some physical properties. Specific gravity, n_ω, and chemical composition of beryl vary in accordance with previously established trends.

The Na, Li and Cs contents of beryl show positive mutual correlation. They are closely dependent on the bulk chemical composition and paragenesis of, and on their location within, the parent pegmatites. Individual crystals show alkali enrichment in their outer zones. Within a single pegmatite, the alkalis are usually lower in beryl from the outer zones than in those from the cores. In the different pegmatites of the Greer Lake group, the Na, Li and Cs contents of beryl generally increase from pegmatites with Fe, Mg, *RE*, Nb, Ti, Zr-bearing accessory minerals to those with Li-enriched micas.

No relationship exists between K and any other elements, but the low contents of Rb increase slightly with Na, Li and Cs. Fe and Mg have a positive but poor correlation with each other, and a poor negative correlation with Na, Li, and Cs.

INTRODUCTION

This paper describes the properties and paragenesis of beryl from a group of pegmatites at Greer Lake, Manitoba. It is based on examination of crystals collected from 12 of the pegmatite bodies during field work in 1968, 1969, and 1972.

The location of the Greer Lake pegmatite group, 132 km ENE of Winnipeg, its position with regard to other pegmatite groups of southeastern Manitoba, and the petrologic structure of the area (chiefly the Bird River greenstone belt) have been described by Černý & Turnock (1971a). The petrogenesis of the acidic plutonic rocks of the area was interpreted by McRitchie (1971).

Figure 1 shows that the beryl-bearing pegmatites are clustered in an area about 1 by 3 km. Only 12 bodies that have been explored are shown, but the area (and farther to the east) is known to contain at least 80 pegmatites. Most are in the gneissic-tonalitic rocks south of the lake, but No. 11 is in a small isolated outcrop of the "pegmatitic granite".

The Huron Claim and Silverleaf pegmatites, included in a previous report on the Nb, Ta-oxide minerals of the Greer Lake pegmatites (Černý & Turnock 1971b), are not considered here. They have been recognized to be members of paragenetically and geochemically different pegmatite groups (*cf.* Černý & Turnock 1971a).

TEXTURAL AND PARAGENETIC CHARACTERISTICS OF THE PEGMATITES

Most of the pegmatites are well-zoned in an irregular concentric manner. The *border zone* (plg > K-fsp + qtz) is fine-grained, thin, and continuous. The *wall zone* (mostly coarse graphic K-fsp + qtz, in a finer matrix of ab + qtz + bio) is thicker but more patchy. The *core* (predominantly K-fsp + qtz, with ubiquitous but uncommon muscovite and cleavelandite) is characteristically coarse-grained to blocky; only rarely it is separated into a blocky band of K-

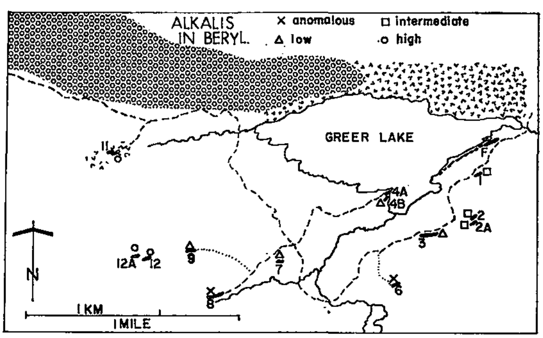

FIG. 1. Map of the Greer Lake area, from aerial photographs and the geological map of Davies (1957). Old truck roads and pegmatite bodies are shown. Checks — pegmatitic granite; circles — greenstone; unmarked — gneissic-tonalitic area. The numbers and letters label the pegmatite bodies shown as black bars; the symbols indicate the ranges of alkali contents of their beryls.

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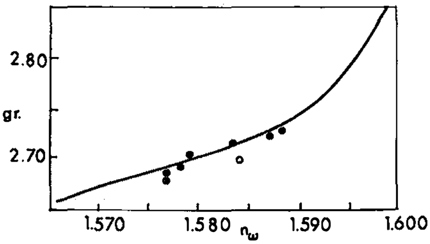

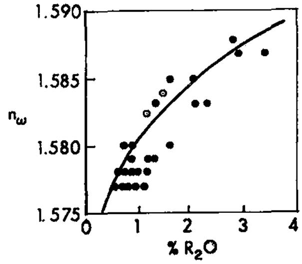

FIG. 2. (left) Specific gravities of the Greer Lake beryls plotted against $n\omega$. General trend line after Beus (1960). The open circle designates the Fe-enriched sample GL-6-11.

FIG. 3. The sums of alkali oxides of the Greer Lake beryls compared to their $n\omega$. The two open circles designate the Fe-enriched samples from the GL-6 pegmatite. The general trend line is after Feklitchev (1964, Fig. 12).

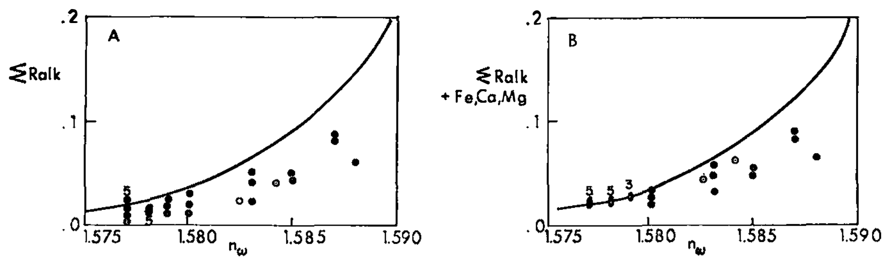

FIG. 4. (A) The sum of specific refractivities of alkalis (Σ *R* alk) of the Greer Lake beryls plotted against their $n\omega$. (B) The sum of specific refractivities of alkalis, Cs, Fe, and Mg (Σ *R* alk + Ca, Fe, Mg) plotted against $n\omega$. In both diagrams, open circles stand for the two GL-6 samples; overlapping points shown by elongated symbols with number of samples given. Note the good alignment of data in Figure 4B; their trend deviates slightly from that established by Feklitchev (1964, Fig. 13), shown as a solid line.

fsp + qtz surrounding a lenticular core of quartz. Bands of irregular patches of a medium-grained assemblage (ab + qtz + msc, commonly garnet-bearing) are located at the outer margins of the blocky core, and may be classified as a locally developed *intermediate zone*. Striped bands of garnetiferous albitic aplite, with phenocrysts of coarsely graphic K-fsp + qtz, are an exceptional feature found in the wall zones of some pegmatites.

The most abundant accessory minerals are garnet, beryl, and altered cordierite. Pseudo-ixiolite, microlite, gahnite, niobian rutile, monazite, cassiterite, zircon, and Li-enriched micas are rare.

Beryl occurs in two distinct associations: (1) most of it is found in the ab + qtz + msc intermediate zone, as prismatic greenish or yellowish crystals up to 2 × 10 cm in size; (2) lesser amounts are found in the blocky cores (if a discernible quartz core is developed, then along its margins), where it is yellowish, bluish or colourless, associated with either K-fsp + qtz + msc or cleavelandite + qtz, and displays a short-prismatic habit (up to 5 × 12 cm in size). These crystals are commonly broken across the prism, the fragments articulated by separation and relative movement, and the breaks healed by quartz filling.

Exceptions to the above characteristics are the rare anhedral, milky to pinkish beryls typical of the ab + qtz + msc assemblages of those pegmatites that carry Li-enriched micas (GL-11, GL-12, and GL-12A), and the bright yellowish-green long prismatic beryls from the GL-6 pegmatite that grew from near the border zone into the core of this pegmatite without much change in external appearance.

Except for occasional muscovite flakes penetrating along the planes of basal parting, no alteration of beryl was observed in any of the pegmatites examined.

Experimental Methods

The refractive index ω of the beryls was determined in immersion liquids using the Becke method, in sodium light. Specific gravities were determined on a Berman torsion balance with toluene as the liquid medium. Samples for chemical analysis were selected considering their n_ω and location within the parent pegmatite. The material separated for chemical analysis was hand-picked under a binocular microscope and checked for impurities in polarized light. Except for occasional clusters of fluid and gaseous inclusions the analyzed material was free of inclusions. All the oxide contents were determined by atomic absorption spectrometry, using the GA, GH, NBS 70a, and NBS 82 standards. All the physical properties, chemical data, and paragenetic characteristics of the examined samples are given in Table 1.

Chemical Composition and Physical Properties

Figures 2, 3 and 4 show the relations between n_ω, specific gravity, and chemical composition of the Greer Lake beryls, in comparison with the general trends for these relationships.

Figure 2 illustrates the change of n_ω with specific gravity as established by Beus (1960). The Greer Lake beryls follow the trend line fairly closely, within the scatter of the original data on which the relationship was established (Beus 1960, Fig. 9a on p. 67). They plot in a rather restricted segment of intermediate values in the known range of these physical variables. Iron-rich sample GL-6-11 exhibits the largest deviation from the trend line. Its content of 1.23 wt. % Fe_2O_3 evidently influences the refractive index much more than the specific gravity, thus producing the largest deviation from the trend.

The plot of n_ω *vs.* wt. % R_2O (Fig. 3) shows a slightly broader scatter than the original data from which Feklitchev (1964) derived the general relationship. This should be expected as the proportions of different alkali oxides are not considered but grouped as a single variable.

Figures 4A and 4B are much more meaningful as the chemical composition is represented in them by the total of specific refractivities of individual cations, weighed by their wt. percentages (specific refractivities after Batsanov 1959, as quoted in Feklitchev 1964). The plots in Figure 4A, based on alkali contents only, show a relatively wide scatter and are displaced from Feklitchev's general trend. Incorporation of specific reflectivities of Ca, Mg, and Fe reduces the scatter and improves somewhat the alignment of data (Fig. 4B). This seems to be due to differences between the materials used for determination of n_ω (chips from the surface of crystals), and for chemical analysis (fragments inadvertently separated from alkali-poorer subsurface portions of the crystals).

Variations in Alkali Contents of Beryls

Table 1 shows that the alkali contents of the Greer Lake beryls vary within wide limits, from

TABLE 1. LOCATION, PHYSICAL AND CHEMICAL PROPERTIES OF THE GREER LAKE BERYLS

pegm.	sample	assemblage	colour	ω	sp.gr.	Li_2O	Na_2O	K_2O	Rb_2O	Cs_2O	Na/Li	Fe_2O_3	MgO	CaO
GL-1	18	cleav.+qtz+msc,at core	greenish-yellow	1.580		.37	.85	.044	.037	.284	3.68	.15	.006	.000
GL-2	12	K-fsp+ab,core	greenish	1.585		.40	1.11	.113	.029	.462	4.44	.25	.024	.013
GL-2	13	qtz+msc,interm. zone	greenish	1.578		.11	.49	.089	.012	.089	7.11	.42	.080	.000
GL-2A	14	K-fsp+qtz,blocky zone	yellowish	1.577		.12	.57	.102	.012	.108	7.67	.41	.084	.000
GL-2A	15	ab+qtz+msc,interm. zone	yellowish	1.583	2.721	.53	1.27	.066	.029	.407	3.82	.26	.008	.000
GL-3	13	qtz,core	green	1.577	2.681	.09	.46	.068	.017	.121	8.31	.51	.072	.000
GL-4B	7	qtz+K-fsp+gar,blocky zone	greenish	1.577		.11	.35	.121	.011	.136	5.07	.23	.019	.002
GL-6	10	K-fsp+qtz,blocky zone	pale-green	1.5825		.06	.81	.076	.012	.202	22.22	1.05	.414	.003
GL-6	11	K-fsp+qtz+ab,blocky zone	green	1.584	2.699	.06	.75	.051	.019	.600	20.59	1.23	.330	.005
GL-7	11	K-fsp+qtz,at core	yellow	1.577	2.683	.08	.37	.030	.010	.051	7.40	.44	.030	.000
GL-8c	17	ab+qtz+msc-interm. zone	greenish	1.578		.10	.49	.105	.008	.061	7.89	.39	.068	.003
GL-8c	18	ab+atz+msc,interm. zone	bluish	1.585		.20	.37	.081	.017	.89	2.97	.16	.005	.000
GL-8(w)	19	ab+qtz,interm. zone	bluish-green	1.579		.09	.47	.051	.011	.178	8.48	.64	.093	.005
GL-8(w)	20	altered cordierite,blocky zone	greenish	1.578		.09	.47	.036	.010	.060	8.48	.45	.089	.000
GL-9	14*	K-fsp+ab+qtz,blocky zone	bluish-green	1.577		.21	.51	.035	.010	.264	3.89	.41	.016	.000
GL-9	15**	K-fsp+ab+qtz,blocky zone	yellowish-green	1.583		.29	.78	.028	.012	.204	4.31	.55	.054	.000
GL-11	7	ab+qtz+msc,interm. zone	bluish-green	1.578	2.693	.26	.68	.037	.021	.123	4.20	.50	.072	.001
GL-11	8a**	K-fsp+qtz+ab,blocky zone	bluish	1.587		.60	.94	.050	.089	1.24	2.50	.12	.003	.002
GL-11	8b*	K-fsp+qtz+ab,blocky zone	bluish	1.583		.47	.90	.039	.037	.69	3.05	.40	.075	.006
GL-11	16	cleav.+qtz,core	milky white	1.587	2.725	.74	1.34	.045	.070	1.250	2.89	.22	.023	.000
GL-12	15A*	cleav.+qtz,at core	yellowish-green	1.578		.26	.43	.035	.023	.089	2.65	.32	.003	.000
GL-12	15B**	cleav.+qtz,at core	yellowish-green	1.579		.29	.71	.050	.026	.172	3.92	.39	.002	.000
GL-12	17	qtz,core	milky white	1.588	2.730	.66	1.33	.028	.041	.760	3.22	.08	.004	.000
GL-12A	13	ab+qtz+msc,interm. zone	yellowish-green	1.580		.10	.52	.188	.012	.054	8.36	.53	.028	.003
GL-12A	15A*	K-fsp+qtz+cleav.,at core	yellowish	1.580		.13	.43	.052	.007	.047	5.31	.59	.060	.008
GL-12A	15B**	K-fsp+qtz+cleav.,at core	white	1.579	2.705	.33	.67	.035	.039	.282	3.24	.08	.004	.000

*core and ** surface of beryl crystals; adjacent samples marked * and ** come from a single crystal.

Chemical analyses by R. M. Hill and R. Chapman, Dept. Earth Sciences, Univ. of Manitoba.

0.5 to 3.6 wt. % Σ R_2O. However, in comparison to the values from 10 other pegmatite groups (Černý 1974), the Greer Lake group beryls are intermediate to low in Σ R_2O, and have a relatively large range.

The abundances of Na, Li, and Cs are particularly interesting because their contents and variations are much greater than those of K and Rb. The graphs presented in Figures 5 to 10 were plotted to investigate several aspects of the distribution and variation of the alkalis as discussed in the following sections.

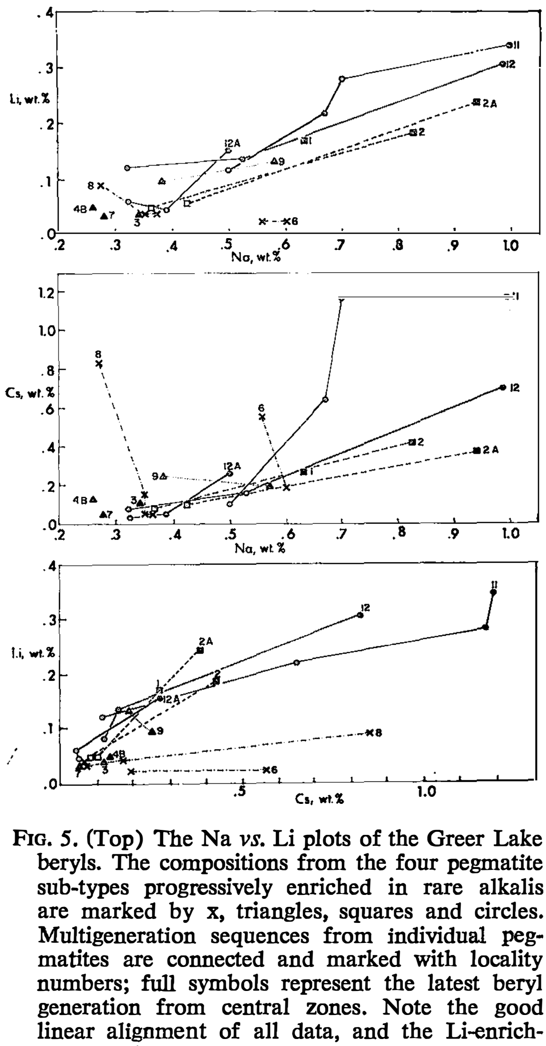

FIG. 5. (Top) The Na *vs.* Li plots of the Greer Lake beryls. The compositions from the four pegmatite sub-types progressively enriched in rare alkalis are marked by x, triangles, squares and circles. Multigeneration sequences from individual pegmatites are connected and marked with locality numbers; full symbols represent the latest beryl generation from central zones. Note the good linear alignment of all data, and the Li-enrichment of the GL-11 and GL-12 sequences as compared to GL-2 and GL-2A.

FIG. 6. (Centre) Plot of Na *vs.* Cs in the Greer Lake beryls. Symbols as in Figure 5. Note the general scatter of data, and the exceptionally Cs-rich compositions of some GL-6 and GL-8 samples.

FIG. 7. (Bottom) The Cs *vs.* Li contents of the Greer Lake beryls. Symbols as in Figure 5. Compare the trend of most data with the Li-poor compositions of the GL-6 and GL-8 samples.

Contents and ratios of Na, Li and Cs

These alkalis in the Greer Lake beryls follow the general trends established earlier (Černý 1974): for most GL beryls, (1) the Na *vs.* Li relationship is close to linear (Fig. 5); (2) the Na *vs.* Cs plots show a wide scatter but generally a positive correlation (Fig. 6); (3) most of the Li *vs.* Cs ratios follow a quasi-logarithmic trend (Fig. 7); and (4) the Na/Li *vs.* Cs plots fall on the sharp turn of the general trend towards Cs-rich compositions (Fig. 8; *cf.* with Fig. 4A in Černý 1974).

Variations of Na, Li and Cs within individual pegmatites

Multigeneration sequences of beryl, crystallizing from the margins to the cores and metasomatic units of pegmatites, are known to increase in alkali contents (Heinrich 1953; —Jahns 1953, 1955, Solodov 1960; Haapala 1966). Most of the beryls in the GL pegmatites also exhibit this increase, as shown in Figures 5, 6, and 7. The individual multigeneration series mostly follow the general trends, frequently in subparallel directions (*cf.* the GL-2, GL-2A, GL-11, GL-12, and GL-12A sequences in the above figures).

Most of the individual beryl crystals are zoned. In keeping with the over-all alkali enrichment during the pegmatite crystallization, the outer parts of such crystals show almost invariably n_ω and alkali contents higher than those of the cores. Four pairs of cores and outer zones of single crystals were analyzed (Table 1).

The alkali variations within single crystals of beryl, and in the multigeneration sequences of individual pegmatites, are consistent with the well-known general enrichment of residual fluids in rare alkalis during crystallization of the pegmatites.

Relation to the bulk chemistry and paragenesis of parent pegmatites

It was shown in the earlier study of the Nb, Ta-minerals from the Greer Lake area that the Fe/Mn ratio, and to some extent the Nb/Ta ratio, vary with the composition of their parent pegmatites (Černý & Turnock 1971b). Both ratios decrease with increasing Li-enrichment of the pegmatites. Figures 5 to 8 show that the Na, Li and Cs contents of beryl reflect the geochemical and paragenetic characteristics of their parent pegmatites even better.

Four sub-types of pegmatites can be distinguished:

(1) The Fe, Mg, Nb, Ti, *RE*-enriched pegmatites that are very poor in rare alkalis (GL-6, GL-8; Fe, Nb-rich pseudo-ixiolite coexisting with microlite) contain beryls with generally low alkali contents but occasional high concentrations of Cs that do not follow the general trends (Figures 6, 7, and 8, marked by x). The reasons for the anomalous behaviour of Cs remain at present obscure.

(2) The pegmatite bodies that show no particular enrichment in either Fe, Mg, Nb, Ti and *RE* or Li, Rb, and Cs (GL-3, GL-4B, GL-7, GL-9; intermediate Fe/Mn and Nb/Ta ratios in pseudo-ixiolite) are characterized by alkali-poor beryls (Figures 5 to 8, triangles), although the GL-9 pegmatite seems to be transitional to the next sub-type.

(3) This is represented by pegmatites with increased Li, Rb, and Cs contents in K-feldspar and muscovite (GL-1, GL-2, GL-2A; intermediate pseudo-ixiolite compositions). The beryls show wide variations in alkali contents that follow the general trends and reach relatively high levels in specimens from the inner pegmatite zones (samples GL-2-12, GL-2A-15; Figures 5 to 8, squares).

(4) The last sub-type of pegmatites is that showing the highest enrichment in rare alkalis; minerals of *RE* and Ti have not been found in them, but Li-rich micas are typical constituents (GL-11, GL-12, GL-12A*; Mn, Ta-enriched pseudo-ixiolite replaced by microlite). In these bodies, beryl not only shows again wide alkali variations but reaches the highest concentrations known in the Greer Lake group (the anhedral milky to pinkish samples GL-11-8a, GL-11-16, and GL-12-17, filled with fluid inclusions). Compared with the trends from the preceding pegmatite type, the multigeneration sequences are characteristically shifted to higher Li and Cs contents in the Li *vs.* Na and Cs *vs.* Na graphs, respectively (Figures 5 and 6, circles). In the Li *vs.* Cs and Na/Li *vs.* Cs diagrams, they are positioned farther up along the general alkali trends (Figures 7 and 8, circles).

*The GL-12A beryls do not represent a full multigeneration sequence because of sampling problems in the poorly exposed pegmatite.

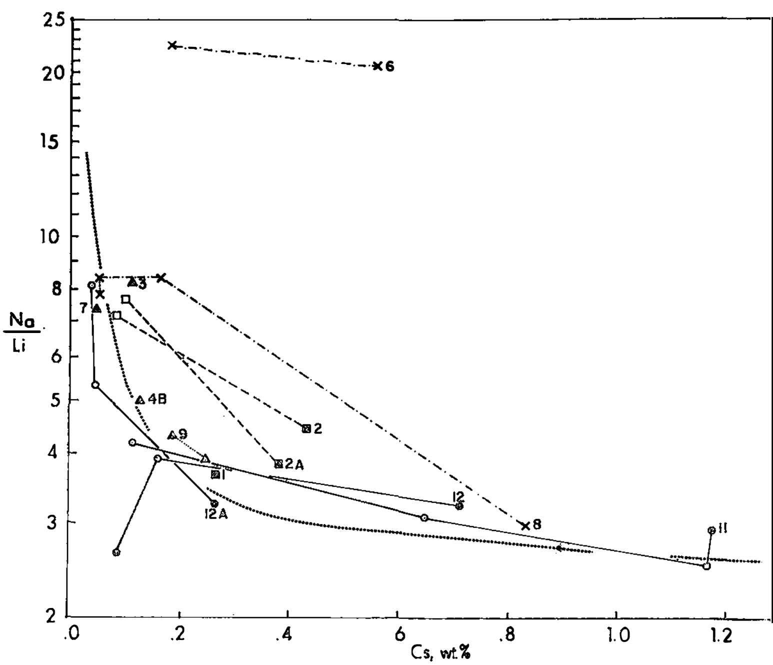

FIG. 8. Plot of the Na/Li *vs.* Cs contents of the Greer Lake beryls. The dotted line represents the average trend after Černý (1974, Fig. 4A). Other symbols as in Figure 5. Note the highly anomalous compositions of the GL-6 samples.

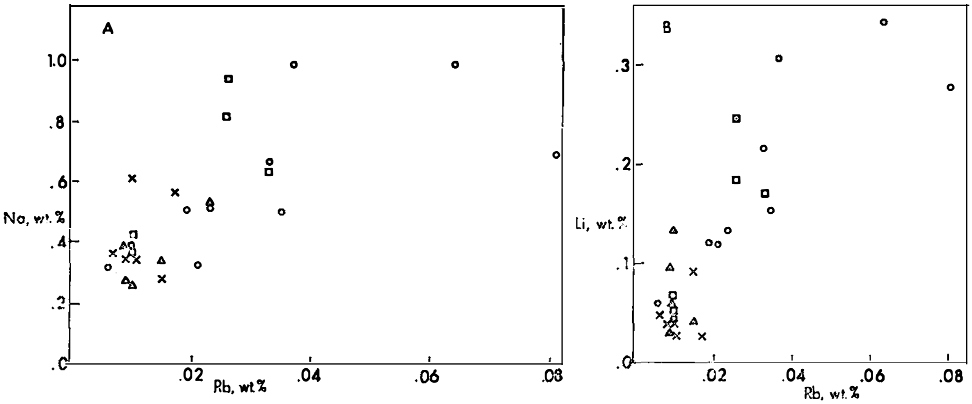

FIG. 9. Rubidium in the Greer Lake beryls. Positive correlations of Rb with Na (A) and with Li (B). Symbols as in Figure 5. Note that the general increase in Rb follows the progressive enrichment of the parent pegmatites in rare alkalis.

Variations in K, Rb, Fe and Mg

No regular variation was found between K and any other alkalis. However, Rb increases with increasing Na and Li (Fig. 9A, B) and, less regularly, with increasing Cs. The plots of Na vs. Rb and Li vs. Rb also show that the Rb content of beryl increases with the general increase of rare alkalis in the parent pegmatite, and with the progressive crystallization of multigeneration sequences. This is in accord with the observations made by Borovik-Romanova & Sosedko (1958) and Sitnin & Sazhina (1959).

As shown in Figure 10, there is a suggestion of a positive correlation between the Fe and Mg contents. The graph also suggests a tendency of the alkali-poor beryls to carry more Fe and Mg than the alkali-enriched samples. This is to be expected because of gradual depletion of crystallizing pegmatitic fluids in Fe and Mg and simultaneous enrichment in rare alkalis.

CONCLUSIONS

In general, the Greer Lake beryls show the same dependence of specific gravity and n_ω on the contents of Na, Li, K, Rb, Cs, Ca, Fe and Mg as was established in earlier studies by Beus and Feklitchev. The observed discrepancies may be explained by slight differences between materials used for determination of physical properties and those chemically analyzed, which seem to be unavoidable in studies of zoned crystals.

The principal correlation between the alkali contents of beryl and the paragenetic and geochemical type of its parent pegmatite has been well-established earlier (see references on p. 59). A recent study (Černý 1974) has demonstrated that a quantitative treatment of this relationship contributes to the geochemical characteristics of, and to the petrogenetic linking or separation among, different pegmatite groups. The present study shows that this correlation can be traced quantitatively on a very small scale, even within homogeneous-looking groups of cogenetic pegmatites. The alkali contents of beryl are indicative of differences between individual pegmatites in the same manner as the rare-alkali contents of feldspars and micas (Černý & Turnock 1972, 1974).

The multigeneration sequences of beryl, crystallizing from the outer zones to the cores of individual pegmatites, follow the same general trend of alkali increase characteristic for the whole pegmatite group. However, the beryl sequences from pegmatites enriched in rare alkalis display slightly lower Na/Li and Li/Cs ratios than those of the Li, Rb, Cs-poorer bodies.

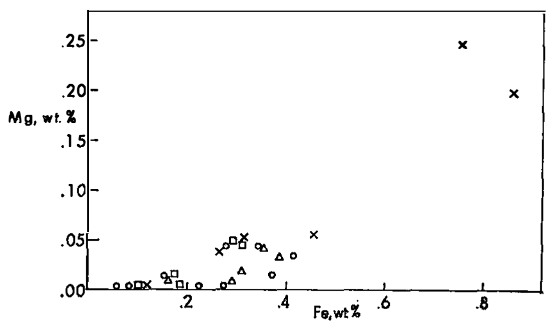

FIG. 10. The Fe and Mg contents of the Greer Lake beryls. Symbols as in Figure 5. The alkali-poor samples contain the highest percentages of Fe and Mg.

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