Contribution to the Crystal Chemistry of Beryl

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Received October 23, 1972

Abstract. Chemical analyses and crystallographic and some optical data have been obtained for 28 samples of beryl from Bahia State, Brazil. The larger range of variability in the chemical composition is shown by Mg, Fe and Li. Sodium is the more diffuse alkali element. Potassium is always very limited. Calcium appears in noticeable amounts only in three samples. The Ti, Cr, Rb, and Cs elements were also tested. The samples studied here can be defined as sodium-potassium beryls with low alkali content. Unit cell parameters show the following ranges: $a=9.210\text{--}9.245$ and $c=9.190\text{--}9.220$ Å. From a statistical analysis of these data it may be seen that: an increase of Fe and (Fe + Mn + Mg) percentage has a positive correlation with a , but no influence on c , which in turn has a close positive correlation with Li and is negatively correlated with Be. Less negative correlations also exist between the pairs {Be, Li}, { a , Al}, {Al, Fe} and {Al, (Fe + Mn + Mg)}. A positive correlation also exists between sodium and the parameter a .

Introduction

Beryl can be considered a framework silicate, as its crystal structure consists of six-membered rings of silicon-oxygen tetrahedra linked together by tetrahedrally coordinated Be ions and octahedrally coordinated Al ions (Bragg and West, 1926; Belov and Matveeva, 1950; Gibbs *et al.*, 1968). The sixfold silicate rings lie one above the other along the c crystallographic axis to form a series of quite large intercommunicating channels which "honeycomb" the structure. It is known from crystallographic studies that significant amounts of zeolitic water (up to 2.5% by weight) and alkali ions may occur in these channels. The idealized formula of this mineral is $\text{Al}_2[\text{Be}_3\text{Si}_6\text{O}_{18}]$, but the chemical analyses of natural beryls invariably show the presence of significant amounts of water and non essential elements (*i. e.*, Cr, Fe, Mg, Li, Na, K, and Cs) whose isomorphous replacements within the crystal structure determine variations of some physico-chemical properties such as color, specific gravity and lattice constants.

Owing to the characteristic features of beryl structure, varied and quite complex replacements are possible and are normally considered in chemical formula. The presence of alkali ions in the channels is made possible by the lack of negative charges in the lattice produced, for example, by the substitution of Fe^{2+} for Al^{3+} or by the omission of a Be^{2+} ion. Various other isomorphous and non-isomorphous replacements consistent with overall stoichiometry have been suggested and normally related to changes in unit cell constants. In this respect, it is known that parameters c (Ginzburg, 1955; Sosedko, 1957) and a (Schaller *et al.*, 1962) tend

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to rise as alkalinity increases, but what alkalies and what real sites the major units of beryl enter into is still disputed (Frank-Kamenetskii and Sosedko, 1958; Bakakin and Belov, 1962; Feklichev, 1963; Bakakin *et al.*, 1967).

This investigation makes a further contribution to the knowledge of the crystal chemistry of beryls; in particular, the localization of some non-essential elements and their influence on the lattice constants will be considered.

H. de A. S. F. was responsible for sample collecting and optical data, G. P. S. for chemical analysis, E. G. for all X-ray work and G. P. S. and E. G. for data processing.

Table 1. List of specimens with some optical properties

No.	Locality of occurrence	Colour	Streak	ω	ϵ
1	Encruzilhada	light green	white	1.580	1.574
3	Barra de Jibóia	pale green	white	1.580	1.574
4	Barra de Jibóia	pale green	white	1.580	1.574
6	Itambé	light green	white	1.580	1.574
7	Itambé	dark green	white	1.580	1.576
8	Itambé	dark green bluish	white	1.580	1.576
8A	Itambé	dark green bluish	white	1.580	1.576
9A	Itambé	dark green bluish	white	1.580	1.576
11	Barra de Jibóia	very pale green	white	1.582	1.574
13	Água bela	pale grey yellowish	white	1.580	1.574
14	Barra de Jibóia	pale green bluish	white	1.582	1.576
15	Água bela	light grey	pinky-orange	1.580	1.576
16	St. Antônio	sky-blue	white	1.582	1.576
18	Capião	very pale grey	white	1.582	1.582
20	Guanabara	green-yellow greysh	white	1.580	1.576
20A	Guanabara	green-yellow greysh	white	1.580	1.576
22	Guanabara	green yellowish	white	1.580	1.574
23	Guanabara	green yellowish	white	1.580	1.574
24	Guanabara	green yellowish	white	1.582	1.574
25	Água bela	light grey greenish	white	1.582	1.576
25A	Água bela	light grey greenish	white	1.582	1.576
27	Barra de Jibóia	dark green bluish	white	1.580	1.576
29	Nanlisa	light blue	white	1.580	1.576
30	Vila Corgão	pale green yellowish	white	1.580	1.576
31	Nanlisa	pale green bluish	white	1.580	1.576
32	Nanlisa	light grey greenish	grey yellowish	1.580	1.574
34	Vila Corgão	pale green yellowish	white	1.580	1.576
35	Guanabara	green yellowish	white	1.580	1.576

Error for refractive indices of all specimens is ± 0.0015 .

Occurrence and Some Physical Features

All the specimens of beryls studied were collected in the Itambé-Itapetinga area, in the southern part of Bahia State, Brazil. Leucocratic gneisses, frequently kaolinized and intersected by zoned pegmatites of quite different dimensions, are the more diffuse rock type in this area.

The mineralogical paragenesis of these pegmatites is represented by K-feldspar, quartz and muscovite, with garnet, tourmaline, beryl, columbite-tantalite and phenacite as accessories.

The zoning of pegmatites is systematic, the border zone consisting of graphic granite, the core of plain quartz. Beryl is always associated with the orthoclase-rich zone where it occurs as colourless, well-faced prismatic crystals which may be up to 10 cm in length. Small pale blue or green crystals appear in the gneisses near the points of contact with pegmatites.

Table 1 lists the collecting points and some physical properties of the beryls studied.

The refractive indices show the following ranges: $\omega = 1.580\text{--}1.582$; $\varepsilon = 1.574\text{--}1.582$ (average values: $\omega = 1.5805$; $\varepsilon = 1.5755$). According to Winchell's variation diagram (1951) most of the beryls studied have a low alkali content.

Table 2. Lattice constants ($\text{\AA}$) of the Beryls from Bahia State

No.	<i>a</i>	<i>c</i>	No.	<i>a</i>	<i>c</i>
1	9.218 ± 0.001	9.195 ± 0.001	20	9.222 ± 0.002	9.199 ± 0.001
3	9.218 ± 0.001	9.199 ± 0.001	20A	9.222 ± 0.002	9.199 ± 0.001
4	9.222 ± 0.001	9.203 ± 0.001	22	9.219 ± 0.002	9.195 ± 0.001
6	9.224 ± 0.002	9.215 ± 0.001	23	9.215 ± 0.002	9.201 ± 0.001
7	9.223 ± 0.001	9.196 ± 0.001	24	9.216 ± 0.002	9.201 ± 0.001
8	9.245 ± 0.001	9.190 ± 0.001	25	9.217 ± 0.001	9.200 ± 0.001
8A	9.245 ± 0.001	9.190 ± 0.001	25A	9.214 ± 0.001	9.198 ± 0.001
9A	9.238 ± 0.001	9.190 ± 0.001	27	9.222 ± 0.002	9.206 ± 0.001
11	9.228 ± 0.001	9.199 ± 0.001	29	9.230 ± 0.001	9.202 ± 0.001
13	9.215 ± 0.001	9.204 ± 0.001	30	9.215 ± 0.001	9.196 ± 0.001
14	9.225 ± 0.001	9.197 ± 0.001	31	9.234 ± 0.002	9.199 ± 0.001
15	9.214 ± 0.001	9.203 ± 0.001	32	9.210 ± 0.002	9.201 ± 0.001
16	9.233 ± 0.001	9.199 ± 0.001	34	9.215 ± 0.002	9.198 ± 0.001
18	9.221 ± 0.001	9.220 ± 0.001	35	9.214 ± 0.001	9.196 ± 0.001

Experimental

Chemical Analysis. Chemical determinations were performed by Atomic Absorption spectroscopy using the decomposition procedure in a closed teflon vessel suggested by Bernas (1968). Because of the refractory nature of beryl, to achieve a complete decomposition of each sample the teflon vessel was placed in a drying oven for three hours (instead of 40 minutes as suggested) at 150°C . The vessel does not undergo dimensional changes which would result in loss of the sample. A Perkin-Elmer mod. 303 spectrophotometer unit with 165 chart recorder was used. The instrumental conditions for all elements, except Be, are reported by Sighinolfi (1969). An estimate of the precision of the analysis can be seen in Bernas (1968). H_2O was determined by TG using a thermal analyzer manufactured by B. D. L. (Bureau de Liaison, Paris).

Determination of Unit Cell Dimensions. Powder tracings were recorded on a Philips diffractometer ($1/4^\circ$ per min), using a lead nitrate internal standard, cubic with $a = 7.8568 \text{ \AA}$ (Card JCPDS no. 6-0151) and Ni filtered $\text{CuK}\alpha_1$ radiation.

Obtaining precise and refined cell parameters from the powder data of beryl is a difficult task owing to the similarity of *a* and *c* (Bakakin *et al.*, 1967; Radcliffe and Bailey, 1972). In order to measure the cell edges accurately, therefore, we adopted the following procedure:

- 1) cell parameters were assessed approximately from the few (about 12) powder lines which could be uniquely indexed;
- 2) all d_{hkl} (calc) were generated;
- 3) the whole tracing was indexed, duly taking into account the diffraction intensities calculated by Borg and Smith (1969);
- 4) cell parameters were refined by the least-squares method using the indexing obtained in step 3.

Steps 2, 3, and 4 were repeated at least once.

The results obtained are shown in Table 2.

Analytical Results

The chemical analyses of the specimens of beryl from Bahia State are reported in Table 3. The role of water in beryl has been discussed by many authors (*cf.* Ginzburg, 1955; Wickersheim and Buchanan, 1959; Feklichev, 1963; Vorms *et al.*, 1965; Wood and Nassau, 1968) above all with respect to its implications on the structure. Although there is no complete agreement on the subject, a high-temperature "zeolitic" role is generally attributed to water (Bakakin and Belov, 1962; Bakakin *et al.*, 1967), so that water is considered to be neither essentially bound to the framework (Sosedko, 1957; Schaller *et al.*, 1962) nor only slightly bound to it (Wood and Nassau, 1968; Wickersheim and Buchanan, 1959).

Except in the case of two or three specimens, overall observation of the 28 analyses of beryl would indicate that in most of its components no major variation exists. On the basis of their alkali content they can be defined, according to Feklichev (1963), as sodium-potassium beryls with low alkali content (weakly alkaline beryls).

The components which show the widest range of variability are Mg, Fe and Li. Sodium, the most diffuse alkali elements of beryls (Bakakin and Belov, 1962), shows fewer variations in the specimens here analyzed. Potassium is always very limited. Calcium appears in a noticeable amount only in three samples. In addition to the elements listed in Table 3 the presence of Ti, Cr, Rb and Cs, which are known to enter the beryl structure, was also checked. The first three, when present, do not exceed 0.05%; the amount of cesium found was probably slightly greater (no quantitative determinations being carried out) in samples 6 and 18, which were the only ones with high Li contents. This confirms the observation of Bakakin and Belov (1962) that Cs can enter the beryl structure only if the mineral has a very high Li content. Ferrous iron was determined only in those samples which were both high in iron and large enough to allow this further analytical determination; it was found to be negligible, so that iron was always considered as ferric in the calculation of chemical formulas. In their studies on the absorption spectra of beryl Wood and Nassau (1968) concluded that the octahedral presence of Fe^{3+} in Al sites causes the blue colour in the crystals.

Crystalchemistry

According to Bakakin *et al.* (1967), various compositions of beryl can be fitted into the general formula $O_2T'_3T''_6X_{18}(R_n)$, where O stands for octahedral cations, T' and T'' for two different sets of tetrahedral cations, X for anions (O , OH), and R for large cations of low charges, water molecules and inert gases which are situated in the cavities of the structure. These elements compensate for the charges lacking in the structure. The well-known presence of a "tension" in beryl, due to the strong deformation in T' tetrahedron (Bakakin *et al.*, 1967; Gibbs *et al.*, 1968), will in fact be reduced by means of substitutions such as $\text{Be}^{++} + \square \rightarrow \text{Li}^+ (R^+ + \text{H}_2\text{O})$.

Chemical analyses of beryls from Bahia were recalculated on the basis of 18 oxygens, in order to derive detailed structural formulae. The oxygens of water molecules were not included in this calculation. The distributions of the cations among the different sets of crystallographic positions were carried out in accordance

Table 3. Chemical analyses of beryls from Bahia State

No.	SiO ₂	BeO	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	Li ₂ O	Na ₂ O	K ₂ O	CaO	H ₂ O	Total
1	66.03	13.00	17.72	0.88	—	0.026	0.045	0.098	0.57	0.121	—	1.58	100.070
3	66.14	12.34	17.40	0.96	—	0.022	0.037	0.199	0.50	0.241	—	2.44	100.279
4	65.95	12.61	17.45	0.92	—	0.025	0.061	0.188	0.62	0.230	—	2.42	100.474
6	67.20	12.13	17.98	0.30	—	0.012	0.031	0.681	0.92	0.163	—	2.26	101.677
7	66.72	13.37	16.35	1.30	0.05	0.029	0.106	0.015	0.52	0.158	—	1.81	100.428
8	65.41	13.02	16.48	2.39	0.11	0.032	0.274	0.010	1.17	0.354	—	2.14	101.390
8A	65.27	12.55	15.35	2.66	0.12	0.039	0.265	0.012	1.20	0.221	—	2.29	99.977
9A	64.40	13.01	17.29	2.57	nd.	0.050	0.178	0.015	0.77	0.298	—	2.35	100.931
11	66.16	12.80	17.05	1.18	nd.	0.034	0.132	0.214	0.69	0.101	—	1.93	100.291
13	65.52	12.62	18.37	0.36	—	0.001	0.046	0.256	0.55	0.247	0.315	2.02	100.305
14	65.42	12.61	17.28	1.18	0.04	0.036	0.095	0.170	0.78	0.209	0.008	2.35	100.178
15	65.85	12.49	17.95	0.58	—	0.017	0.030	0.227	0.61	0.231	—	1.45	99.435
16	65.04	13.00	16.28	1.74	nd.	0.030	0.240	0.055	0.85	0.350	—	2.27	99.855
18	65.99	11.64	17.93	0.43	—	0.016	0.025	0.902	1.54	0.293	—	1.94	100.706
20	66.38	12.67	18.57	0.82	—	0.012	0.256	0.027	0.43	0.306	—	1.92	101.391
20A	66.14	12.69	17.36	0.96	nd.	0.025	0.299	0.044	0.33	0.304	—	2.19	100.342
22	65.64	13.32	18.47	0.48	—	0.014	0.053	0.023	0.26	0.278	—	1.99	100.528
23	66.74	12.90	18.05	0.53	—	0.018	0.046	0.027	0.24	0.125	—	2.01	100.686
24	65.58	12.04	19.15	0.51	—	0.028	0.047	0.033	0.28	0.381	—	1.37	99.419
25	68.15	12.37	17.64	0.82	—	0.045	0.110	0.179	0.41	0.263	—	2.24	102.227
25A	66.91	12.79	17.36	0.49	—	0.016	0.047	0.147	0.41	0.144	—	1.61	99.924
27	66.15	12.16	17.30	0.81	—	0.077	0.049	0.252	0.70	0.178	0.019	1.92	99.615
29	66.98	12.70	16.71	0.70	0.30	0.026	0.220	0.116	0.85	0.185	—	1.82	100.607
30	67.30	13.04	17.66	0.42	—	0.024	0.013	0.014	0.15	0.114	—	1.25	99.985
31	66.19	12.93	16.64	1.13	0.05	0.022	0.129	0.111	0.78	0.177	—	2.48	100.639
32	67.15	12.49	17.87	0.67	—	0.017	0.034	0.163	0.39	0.178	—	2.25	101.212
34	66.75	13.07	17.21	0.51	—	0.017	0.042	0.014	0.18	0.139	—	1.54	99.472
35	65.96	13.73	17.88	0.49	—	0.001	0.027	0.024	0.19	0.096	—	1.77	100.168

Table 4. Atomic coefficients in the chemical formulae of beryls, based on 18 oxygens

No.	Position <i>O</i>						Position <i>T'</i>		
	Mn	Mg	Fe	Al	Li	Total	Be	Al	Si
1	0.002	0.006	0.061	1.910	0.021	2.000	2.857	—	0.048
3	0.002	0.005	0.061	1.893	0.039	2.000	2.736	—	0.109
4	0.002	0.008	0.061	1.894	0.035	2.000	2.785	—	0.077
6	0.001	0.004	0.016	1.893	0.086	2.000	2.603	—	0.016
7	0.002	0.014	0.088	1.758	0.005	1.867	2.899	—	0.101
8	0.002	0.037	0.171	1.783	0.004	1.997	2.871	—	0.009
8A	0.003	0.036	0.191	1.682	0.004	1.916	2.809	—	0.091
9A	0.004	0.024	0.178	1.794	—	2.000	2.888	0.042	—
11	0.003	0.018	0.077	1.844	0.058	2.000	2.821	—	0.078
13	—	0.006	0.022	1.972	—	2.000	2.783	0.016	0.022
14	0.003	0.013	0.083	1.885	0.016	2.000	2.797	—	0.053
15	0.001	0.004	0.039	1.949	0.007	2.000	2.763	—	0.067
16	0.002	0.033	0.117	1.783	0.021	1.956	2.900	—	0.049
18	0.001	0.003	0.028	1.940	0.028	2.000	2.565	—	0.069
20	0.001	0.034	0.055	1.910	—	2.000	2.770	0.078	0.034
20A	0.002	0.041	0.066	1.885	0.006	2.000	2.803	—	0.086
22	0.001	0.007	0.033	1.959	—	2.000	2.921	0.027	—
23	0.001	0.006	0.033	1.934	0.010	1.984	2.822	—	0.085
24	0.002	0.006	0.033	1.959	—	2.000	2.666	0.120	0.050
25	0.003	0.015	0.054	1.878	0.050	2.000	2.682	—	0.157
25A	0.001	0.006	0.033	1.870	0.053	1.963	2.818	—	0.124
27	0.006	0.007	0.056	1.886	0.045	2.000	2.698	—	0.126
29	0.002	0.030	0.066	1.796	0.042	1.936	2.790	—	0.121
30	0.002	0.002	0.027	1.891	0.005	1.927	2.847	—	0.121
31	0.002	0.018	0.077	1.804	0.041	1.942	2.860	—	0.094
32	0.001	0.004	0.044	1.917	0.034	2.000	2.732	—	0.119
34	0.001	0.006	0.033	1.857	0.006	1.903	2.877	—	0.124
35	—	0.003	0.033	1.918	0.008	1.962	3.008	—	0.015

Table 5. Variability of the atomic coefficients and of the lattice constants in beryls

	Average	Range
Al	1.885 ± 0.081	1.682—2.079
Fe	0.066 ± 0.047	0.016—0.191
Mn	0.002 ± 0.001	0.000—0.006
Mg	0.014 ± 0.012	0.002—0.041
Fe+Mn+Mg	0.082 ± 0.057	0.021—0.230
Si	6.071 ± 0.048	5.953—6.157
Be	2.800 ± 0.099	2.565—3.008
Li	0.055 ± 0.074	0.004—0.334
Na	0.105 ± 0.060	0.022—0.271
K	0.025 ± 0.010	0.011—0.044
Na+K	0.138 ± 0.079	0.038—0.384
<i>a</i>	9.223 ± 0.009	9.214—9.245
<i>c</i>	9.200 ± 0.006	9.190—9.220

Fig. 1. Plot of a against $(\text{Fe} + \text{Mn} + \text{Mg})$ Fig. 2. Plot of Al against $(\text{Fe} + \text{Mn} + \text{Mg})$

with the rules proposed by Bakakin and Belov (1962). The crystallochemical formulae so obtained are given in Table 4. In almost all samples the T'' position is filled completely by silicon; the number of Si ions slightly exceeds 6 with its consequent transposition in T' . Aluminium cations are often less than the stoichiometric 2 (average content: 1.88, *cf.* Table 5) and sometimes the O -group must be completed with lithium. According to the data of Table 4 cation deficiency is also possible in O -position, though not as frequent nor as large as the deficiency in T' position. Frequently, as found by many authors (Bakakin and Belov, 1962; Radcliffe and Bailey, 1972; etc.), the total number of cations in T' -position is less than 3, rarely exceeding 0.130 ions (average of Be content: 2.80). Li is usually present in amounts of less than 0.10 ions; it concentrates abruptly in just a few samples characterized by low Be content. Sodium is the sole alkali element of

Fig. 3. Plot of c against Be

Fig. 4. Plot of Li against Be

any size to commonly appear in amounts higher than 0.10 ions. The latter observations have been made by many other authors (Bakakin and Belov, 1962; Feklichev, 1963; etc.).

Correlation between Chemical Composition and Lattice Constants

A statistical analysis (correlation coefficient and Student's t -test) was carried out, taking into account most of the elements entering into major structural units of the formula and the cell parameters. In this analysis only the amounts of the cations were considered, their distribution in the different positions of unit cell being ignored. The results of the statistical calculations are reported in Table 6. The most significant conclusions that can be drawn from these results may be summarized as follows:

1) Close positive correlations between the pairs $\{\text{Fe}, a\}$ and $\{(\text{Fe} + \text{Mg} + \text{Mn}), a\}$ and smaller negative correlations between the pairs $\{\text{Al}, a\}$, $\{\text{Al}, \text{Fe}\}$ and $\{\text{Al},$

Table 7. Summary of proposed correlations of chemical and crystallographic parameters in beryls

Author	Correlation		No correlation
	Positive	Negative	
Ginzburg (1955)		{Alkalies, Be}	
Sosedko (1957)	{Alkalies, c }	{Alkalies, Be}	{Alkalies, a }
Frank-Kamenetskii and Sosedko (1958)	{Alkalies, c }	{Alkalies, Be}	{Alkalies, a }
Schaller (1962)	{Alkalies, a }		{Alkalies, c }
Bakakin and Belov (1962)		{Alkalies, Be}	
Feklichev (1963)	{Alkalies, c }	{Alkalies, Be} {Mg, Al}	
Bakakin, Rylov and Belov (1967)		{Be, c }, {Al, a }	{Cs, a (or c)}, {Na, a (or c)}, {Ca, a (or c)}
This paper	{Fe, a }, {(Fe+Mn+Mg), a }, {Li, c }, {Na, a }	{Be, c }, {Be, Li}, {Al, a }, {Al, Fe}, {Al, (Fe+Mn+Mg)}	

{Fe+Mg+Mn} can be observed. Figures 1 and 2 have been inserted to get a better impression of the correlations between the pairs {(Fe+Mg+Mn), a } and {(Fe+Mg+Mn), Al}. The plot of Fe against a is not shown because it is very similar to that of Fig. 1. The same considerations hold for the plot of Fe against Al. This confirms the major role played by these elements within octahedral substitutions, and the importance of these substitutions in determining cell parameters.

2) A close positive correlation has been demonstrated between the pair {Li, c } and a negative one between the pairs {Be, Li} and {Be, c } (see also Figs. 3 and 4). This confirms that lithium is the most natural substitute for Be (Plyusnina, 1964; Vorma *et al.*, 1965) in beryls and that the degree of T' substitutions affects c parameters.

3) A correlation also exists between sodium and parameter a , as has already been claimed by several authors. In this context it should be remembered that Bakakin *et al.* (1967) affirmed that the existence of R impurities constituted by alkali elements is merely a consequence of O and T' -substitution and that therefore alkalis affect unit cell dimensions only indirectly.

Comparison with Previous Works and Conclusions

Correlations between chemical composition and lattice constants have been claimed very often in the past; some, though by no means all, have already been cited in the Introduction. Some recent reliable results are collected in Table 7, together with our deduction. Comparison of the results listed in Table 7 enables the follow-

ing conclusions to be drawn: The first seven papers cited insist on searching for a possible correlation between alkalis and some other lattice or chemical parameters, with apparently contradictory or at least inconclusive results. The reason for this failure was first pointed out by Bakakin *et al.* (1967) when they stressed that Li-cations enter the framework of beryl, while Na, K, Ca and Cs, being located within the channels of the framework, do not. They went on to propose some negative correlation, but they failed, as did all the other authors mentioned, to give a sound statistical basis for their claims. By contrast, the results of the present research have been obtained by means of proper statistical processing. Our research confirms that Li must be separated from (Na, K), and correlations thus found include the two proposed by Bakakin *et al.* (1967) and explain the uncertain influence of alkalis: an increasing content of Li, makes c larger, leaving a unchanged, while Na does the reverse; so, if the majority of one author's samples was Li-rich he found a positive correlation {Alkalis, c }, while if his samples were Na-rich he found a positive correlation {Alkalis, a }. The negative correlation {Alkalis, Be} proposed by many authors is in fact a {Li, Be} one, which constitutes further evidence for the presence of both elements in T' . The same holds for the negative correlation {Al, (Fe + Mn + Mg)}. As a scientific curiosity let us mention the paper on beryl by Radcliffe and Cambell (1966) which claims to have found some non-linear correlations on the basis of three measurements; later on Radcliffe (1969) subjected his three results to statistical analysis.

Acknowledgements. The authors wish to thank prof. Adelaide M. Santos for encouraging this research, prof. Robeiro R. de Azevedo for his help in collecting samples, and prof. Glauro Gottardi for his critical review of the manuscript. This work was supported in part by the Conselho Nacional de Pesquisas, Brazil; in part by the Banco Nacional de Desenvolvimento Economico, Brazil; and in part by the Consiglio Nazionale delle Ricerche, Italy.

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