OTS: 60-41,716 JPRS: 5979

1 November 1960

EMERALD MINES

(Of the Urals)

By K. A. Vlasov
and
Ye. I. Kutukova

- USSR -

Reproduced From
Best Available Copy

RETURN TO MAIN FILE

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20000821 162

Distributed by:

OFFICE OF TECHNICAL SERVICES
U. S. DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
1636 CONNECTICUT AVENUE, N. W.,
WASHINGTON 25, D. C.

DTIC QUALITY INSPECTED 4

JPRS: 5979

CSO: 5033-N

EMERALD MINES (OF THE URALS)

/Following is the translation of parts of the book by K. A. Vlasov and Ye. I. Kutukova entitled "Izumrudnyye Kopi" (English version above), Moscow, 1960, pages 3, 4, 8-12, 80-82, 111-154, 197-215./

INTRODUCTION

The emerald deposit of the Urals, well known in the world literature under the name Emerald Mines, has been studied by many investigators for nearly 130 years. The genesis of the emerald-bearing veins has provided the principal source of interest, especially in regard to genetic connections between the emeralds and certain intrusions.

The majority of investigators have associated the genesis of the emeralds with the Murzinka granite intrusion, while several of these have rather linked them with the vein derivative rocks of the diorite massif. The latter hypothesis has remained at present unconfirmed by factual material. The theory of a genetic connection between the emeralds and the granite massif has gotten an impetus to further development on the basis of the ample factual material gathered in the past few years.

The Emerald Mines of the Urals are of exceptional

interest as an example of those processes rarely encountered in the earth's crust of the interaction between the diverse derivatives of the granitic intrusion and the enclosing rocks of different compositions. In this deposit 80 minerals have recently been determined, whose content comprises about 60 elements in varying amounts. Especially interesting in the study of the Emerald Mines is finding out the chemical nature of the interactions which occur between the pneumatolytic pegmatite solution melts and the enclosing rocks, as well as the process of mineral formation and the geochemistry of the elements which participate in this process.

The vein complex of the Murzinka granite intrusion together with desiliconized pegmatites are represented by granitic pegmatites, and pneumatolytic-hydrothermal and hydrothermal formations. The interaction between the diverse derivatives of the granite intrusion and the enclosing rocks of different chemicomineralogical composition has produced highly interesting mineral-forming processes and unusual associations of chemical elements and minerals, especially in pegmatites at the contact line (the desiliconized pegmatites) where such rare minerals as emeralds, phenacite, chrysoberyl and alexandrite are encountered. The emeralds of the Urals have attained worldwide fame for their lovely green hue and purity.

An analysis of the great bulk of factual material gathered by the authors and found in the literature has made it possible to classify the vein complex, establish the link between its component parts and to discover the factors which underlie its diversity. All this has admitted a broadening of our concepts on the mineralogy, geochemisty and genesis of the deposit.

The Emerald Mines (of the Urals) are the classic, best studied example of emerald deposits in the world. New emerald deposits have been discovered in a number of foreign countries (India, and others) during the past decade. Attention is drawn to the common nature of the geological conditions found in the formation of these occurrences and the Emerald Mines of the Urals. A study of the Emerald Mines and an analysis of the factual material on foreign emerald deposits offer the possibility of undertaking exploration for similar deposits with a much more soundly established foundation.

Chemical, spectral, roentgenochemical, thermic and x-ray analyses made in this study were performed in the laboratories of the Institute of Mineralogy, Geochemistry and Crystallochemistry of Rare Elements and the Institute

of Geology of Ore Lodes, Petrography, Mineralogy and Geochemistry of the Academy of Sciences USSR. The larger part of the chemical analyses of minerals were done by M. Ye. Kazakova. Beryllium in low concentrations (<0.01 percent) was determined by the chemist, S. N. Fedorchuk.

The authors are grateful to N. V. Belov and Ye. A. Kuznetsov for having reviewed the manuscript and made a number of valuable comments. They also owe particular thanks to D. P. Serdyuchenko who generously assumed the task of scientifically editing the present work.

CHAPTER ONE

GEOLOGICO-PETROGRAPHIC SKETCH

Despite the considerable volume of geological studies of the Emerald Mines(of the Urals), the geology and petrography of the area still remain insufficiently investigated.

The Emerald Mines belong to the eastern wing of an anticlinorium, rendered complex by a series of secondary synclinal and anticlinal folds conformable with the general strike of the basic structure of the region. In regard to its geology and petrology the region of the Emerald Mines (Fig. 1) can be subdivided into three zones: eastern, western and central.

In the eastern zone the basic and ultrabasic rocks of the Asbestovskiy intrusion have evolved, represented by peridotites, dunites, pyroxenites and gabbro. In the central part of the region the Asbestovskiy intrusion borders on the small Eastern Massif of granodiorites, quartz diorites and diorites.

The western zone is made up of granites of the Murzinka intrusion. In relation to petrographic structure this granite massif is rather heterogeneous. Its central portion is composed of fine-and medium-grained biotite and two-mica granites which contain small fine-grained pegmatite bodies. In the endocontact zone there are muscovite pegmatoid granites, among which one finds sections of fine-and medium-grained granites, two-mica

and muscovite granites, as well as a considerable number of streak and veined pegma ite bodies and amphibolite xenoliths. The width of this zone is 0.5 - 0.7 km.

The central zone is composed of metamorphic rocks of the Paleozoic Era which follow along the contact of the granite intrusion for more than 25 kilometers. The width of the zone in which these rocks occur is 0.4 - 5 km. They are made up of serpentine, talc serpentine, talc, talcochlorite, talcophlogopite and tremolite rocks, amphibolites, amphibolic gneisses, quartzites and ampelites. Besides this, small lenticular bodies of peridotites and talc peridotites occur, ordinarily converted to serpentines. All of the above mentioned rocks are broken through by a large number of quartz diorite and diorite porphyrite dikes. The described metamorphic layer contains the emerald-bearing vein complex.

The general strike of the metamorphic rock is south-south-east, nearly meridional, dipping north-east at an angle of 50-85°, and it is only at the south of the area that the strike of the rocks changes to the north-west at 300-305°. The metamorphic rock zone extends up to five kilometers here and then, somewhat narrowing, it one again resumes the south-south-east direction and issues beyond the borders of the region. The contact between the granites and rocks of the metamorphic layer is extremely complex. In direct proximity to the contact an injection zone has developed (0.3 - 0.5 km thick), made up of amphibolites and amphibole gneisses and granites and pegmatites strongly injected into the jointing.

A description is given below of the rocks which compose the region of the Emerald Mines. In order to adumbrate the genetic connection between the rocks, their metamorphic differences are described after the rocks from which they are derived.

Sedimentary rocks:

carbonaceous shales
quartzites.

Effusive rocks:

plagioclase-porphyrites
hornblende porphyrites
amphiboles with porphyritic texture.

Ultrabasic and basic rocks, products of their metamorphism:

Dunites, peridotites,
serpentines and talc serpentines,
talc schists,
talcochlorite rocks,

talc-dolomitic rock,
tremolitic rock,
phlogopite-tremolitic schists,
tremolite-chlorite-talc schists, etc.

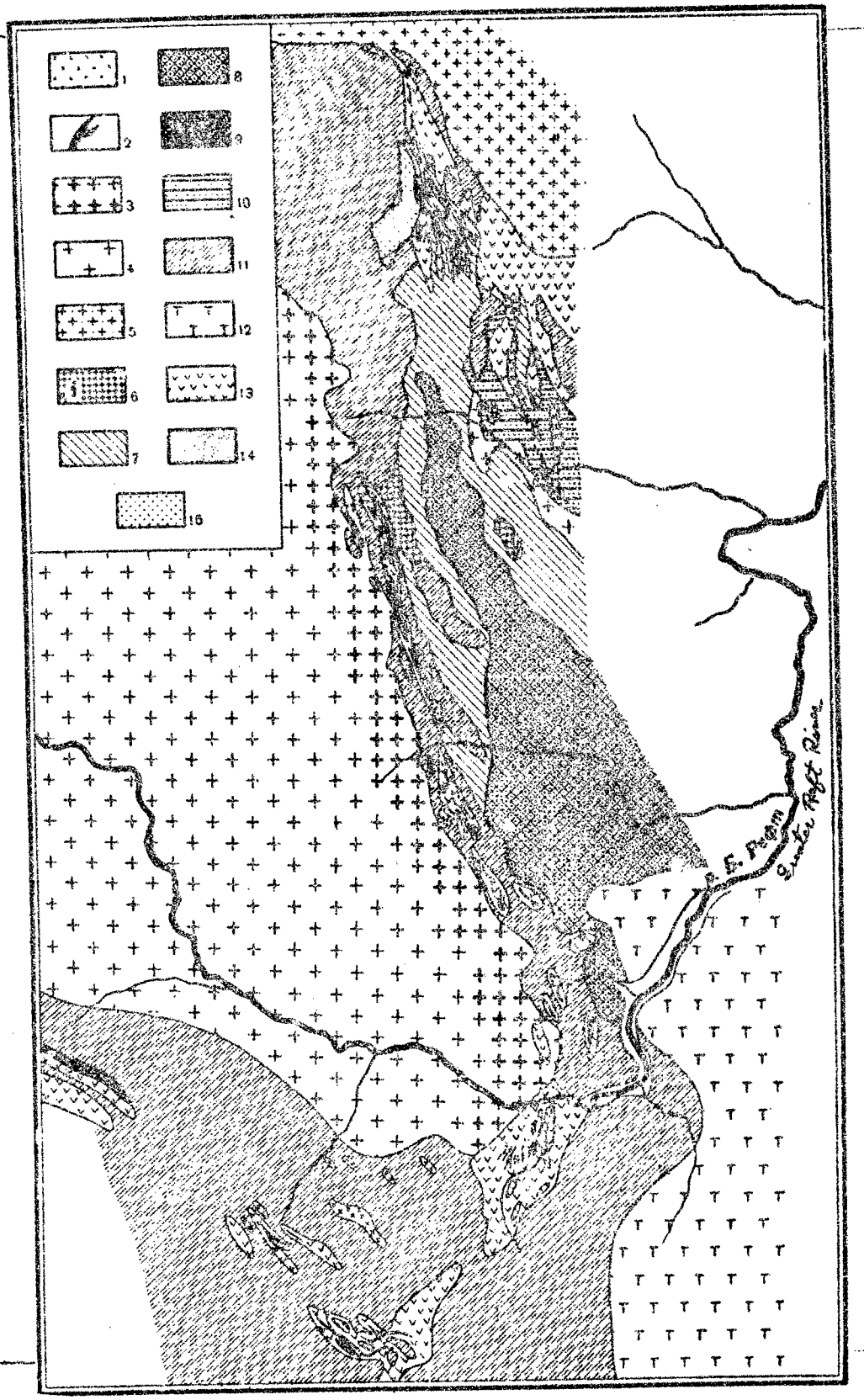
Metamorphosed pyroxenites:
amphiboles containing chromium.
Gabbro.

Eastern granodioritic massif:
diorites,
granodiorites,
amphibolic gneisses.
Vein rocks:
quartz diorites,
dioritic porphyrites.
Murzinka granite massif:
Granites:
fine- and medium-grained biotite, two-mica,
porphyroid two-mica,
pegmatoid muscovite.
Vein rocks:
pure strain pegmatites,
hybrid pegmatites (desiliconized pegmatites),
pneumatolytic-hydrothermal and hydrothermal formations.

SEDIMENTARY ROCK

The sedimentary rock, especially the Upper Devonianm takes up an insignificant area and is represented by carbonaceous shales and quartzites with thin seams of sandstones and chlorite-clay slates. They are widely distributed in the southern portion of the emerald-bearing zone. The sedimentary rock in the form of 0.5 to 0.75 km wide bands have been traced with gaps on occasion of 3.5 - 4 km. Their strike is ordinarily close to the meridion line, ranging from NW 345° to NE 45°, the dip is north-east and south-east at an angle of 45 to 60°, rarely greater.

Carbonaceous shales occur nearly everywhere in the form of sheet-like bodies with a thickness of up to 10 m;


1
2
3
4
5
6
7
8
9
10
11
12
13
14
16
E. Fork
Sucker Right River

[See previous page.]

Fig. 1. Schematic Geologic Map of the Emerald Mines (compiled by N. M. Uspenskiy, supplemented by L. A. Izergin).

1. aplites and pegmatites; 2. the emerald-bearing vein complex; 3. pegmatoid granite; 4. two-mica even-grained granite; 5. porphyroid granite; 6. granodiorites; 7. quartz diorites and diorite porphyrites; 8. diorites; 9. diorite gneisses; 10. talc-carbonate rocks; 11. amphiboles and amphibole gneisses; 12. gabbro; 13. ultrabasic metamorphic rocks; 14. sandstones; 15. quartzites.

they occur among the serpentines, amphiboles and diorites. Occasionally, unique carbonaceous magmatic breccia turns up in which strongly fragmented carbonaceous material has been cemented by ultrabasic rocks and diorite - porphyrites.

The ampelites which are fine-grained and show intensive schist formation consist of extremely tiny quartz grains with a large amount of carbonaceous substance and biotite flakes. The carbonaceous matter is ordinarily unevenly distributed. The rock is often crossed in various directions by streaks of quartz with a mosaic structure.

Spectral analysis has revealed in the carbonaceous schists, besides the chief components, (expressed in percentages): titanium, vanadium, chromium, nickel, cobalt (0.05), barium, zirconium (0.035), beryllium, strontium and copper (0.005). Germanium was not discovered. The B_2O_3 content came to 0.01 percent (chemical determination).

Gradual transitions are observed between the ampelites and diorites most of the time; the boundary between them is, as a rule, indistinct. At the contact the diorite is strongly altered, schistose, enriched with carbonaceous substance, biotite and chlorite. The carbonaceous substance in it is unevenly distributed, in accordance with the closeness to the carbonaceous shale its quantity becomes markedly increased. The thickness of the transition zone is 25 - 30 cm. Sometimes the border between the ampelite and diorites is even and sharp; in such cases a thin seam of chlorite can be present at the contact. According to N. M. Uspenskiy carbonaceous shales are the product of the metamorphosis of diorite-porphyrites, which is borne out, in his opinion, by the gradual transitions between these rocks, as well as by the relicts of plagioclase phenocrysts in the shales. We are inclined to regard the carbonaceous shales as metamorphosed remains of the roof of sedimentary rocks, which are most likely bituminous clay shales. The enrichment of the diorites with carbonaceous matter has taken place as a result of their assimilation of the carbonaceous shale, which sometimes masks the sharpness of the contact between these rocks. A. K. Podnogin considers the plagioclase phenocrysts seen in the ampelites as new formations, associated with the feldspathization of the carbonaceous matter under the influence of the diorite intrusion, which is fully possible.

Quartzites are the product of the metamorphism of sandstone. They occur as lenticular bodies and bands together with carbonaceous shales. Their contact with the latter is ordinarily smooth and distinct. The rock is fine-grained, massive, light gray in color, consisting basically of quartz (85 - 95 %) with small amounts of biotite. Apatite, zircon and magnetite are found as accesory minerals.

EFFUSIVE ROCKS

In the opinion of N. S. Simbirtsev, A. K. Podnogin and P. K. Olerskiy, effusive rock, presumably stemming from the Devonian Era, has been traced in the form of separate outcroppings in a meridional direction to the east of the emerald-bearing zone. This is commonly represented by strongly metamorphosed plagioclases and hornblende porphyrites. We have come upon effusive rock outcroppings (andesite-porphyrites and metamorphosed quartz albitophyres) east of Malyshev Settlement. Probably, the effusive rocks were also distributed in the emerald-bearing zone. Amphiboles with typical porphyritic texture which are quite widespread here~~abouts~~ have quite possibly been formed at the expense of hornblende porphyrites.

The plagioclase porphyrites are encountered in the form of sheet-like bodies or veins which occur conformably with the metamorphosed formation. The rock is strongly metamorphosed, greenish gray in color, with porphyritic texture. It is obvious under the microscope that its basic mass consists of plagioclase (No. 20 - 25), actinolite, epidote, chlorite and quartz. Accessory minerals are zircon and apatite. The porphyritic phenocrysts are represented by plagioclase (No. 25 - 40), twinned in accordance with the albite and pericline laws.

Hornblende-porphyrites are dark green in color, with porphyritic texture. The basic mass is made up of a fine aggregate of albite, quartz, epidote and chlorite. The porphyritic phenocrysts are of hornblende and more rarely plagioclase (No. 25 - 40).

The amphiboles are an intensively sheared dark green rock with characteristic porphyritic texture, thus distinguishing them from the chromium-bearing amphiboles. The matrix of the rock has a nematoblastic texture and consists of parallel hornblende and plagioclase crystals

with sparse quartz grains. Accessory minerals are sphene and pyrite. The porphyritic phenocrysts of oval, and less frequently roundish shape are of uralitic hornblende. Occasionally the hornblende of the phencrysts and matrix are changed to biotite.

8. FLUORITE

Fluorite is one of the principal fluorine-containing minerals in the Uralian Emerald Mines. It is usually found in separate grains, crystalline aggregates and large lenses up to 0.5 x 1.0 x 1.5 meters in size. Well developed crystals are seen more rarely, for the most part octahedrons or combinations of cubes with octahedrons. The size of the crystals varies from tenths of a millimeter to 2 x 3 cm. Fine fluorite cubes in druse form frequently grow on albite plates. The color is violet, rose, rose-violet, green, greenish-blue, pale yellow; colorless fluorite is found. Quite frequently the color in one and the same sample changes from colorless to violet-rose and violet. The dark-violet variety has a faint violet streak. The mineral ranges from translucent to transparent. The specific weight is 3.165 - 3.173. It is nearly colorless in section, sometimes faintly light violet hued. It is optically isotropic. N = 1.43.

Certain fluorite varieties were analyzed by the spectral method (Table 22).

The cause of the particular coloration in fluorite still remains rather obscure. Pieces of rose red fluorite become colorless when placed in sunlight for several days. The presence of small amounts of manganese (Table 23) in certain fluorite varieties allows one to surmise a connection between this element and the coloration. Such an assumption also explains the color change of fluorite in light, since manganese has a variable valency.

In pure strain pegmatites fluorite is found in the form of sparse fine grains (up to 0.3 cm) of violet color. They ordinarily fill up the spaces between grains of microcline and quartz and are formed in the last stage of the pegmatitic process.

TABLE 22

Findings of Spectral Analyses of Fluorite
(in percentages)

Elements	Varieties				
	Violet	rose	green	yellow	light violet
Silicon	0,001	0,01	0,0001	0,001	0,001
Titanium	0,05	0,05	0,05	0,05	0,05
Magnesium	0,005	0,05	0,005	0,05	0,05
Manganese	0,01	0,01	—	—	0,001
Strontium	0,005	0,005	0,0005	0,005	0,0005
Beryllium	0,0005	0,0005	0,0005	0,0005	—
Zirconium	—	0,005	—	—	—
Iron	—	0,01	—	—	—
Barium	—	—	0,0005	0,0005	—

TABLE 23

Chemical Analytical Findings of Manganese
and Chromium in Fluorite (in percentages)

Components	Varieties					
	Violet	rose	green	yellow	blue	colorless
MnO. . . .	0.0028	0.0035	not found	not found		0.0014
Cr_2O_3 . . .	not found	not found	" "	" "		not found
Sp. wt.	3.173	3.168	--	--	3.165	--
Analyst	L. B. Tumilovich					

In the desiliconized pegmatites the fluorite is more widely distributed and typified by different forms, size of segregations, as well as by different color. In desiliconized pegmatites with plagioclasite lenses, the basic part of the fluorite is found in the form of fine violet colored grains in the phlogopite zones. It is found in lesser quantity in the plagioclasite part of the veins. In the latter case fluorite forms larger grains, sometimes up to five to seven centimeters in cross section, usually colorless or various intensities of violet. Associated with fluorite, one observes topaz, beryl, apatite, corundophillite and plagioclase.

In the desiliconized pegmatites with muscovite-fluorite lenses, the fluorite appears as the main rock-forming mineral. It occurs in the form of large xenomorphic grains up to ten cm across and lenses 0.5 x 1.5 meters large. Occasionally well formed crystals are present. The colors are flesh-red, light blue, violet and white. It is associated with beryl, apatite and tourmaline, filling the spaces between them or lying in their fissures, thus indicating its later segregation. The fluorite sparsely found in the chlorite zone of the desiliconized pegmatites forms grains and grain aggregates (up to 3 x 7 cm) of yellow color. It is associated with chrysoberyl and phenacite.

In hollows of the desiliconized pegmatites one sometimes finds fine (0.1 - 0.3 mm) well formed colorless and faint violet crystals (octahedrons) of fluorite; they grow together with bavenite on flat-prismatic crystals of albite and spherulites of corundophillite. Fluorite separates earlier than the bavenite, which is attested to by the intergrowth of the latter on the fluorite.

In pneumatolytic-hydrothermal veins fluorite is found in the form of single grains in phlogopite or muscovite-albite fringes. The color is violet, of various intensities. The most characteristic association is with albite, muscovite, beryl, molybdenite, sphalerite and bornite.

Fluorite found in dolomite veins appears last. It forms xenomorphic grains (up to 2.5 cm in cross section) of greenish blue hue. It is associated with phenacite and scheelite.

Hence, fluorite has a large field through which it ranges. It occurs both in pegmatites and in pneumatolytic hydrothermal and hydrothermal formations. The most usual associations for fluorite are plagioclase, prochlorite,

corundophillite, chrysoberyl, phenacite, beryl, topaz, apatite, quartz, native bismuth and molybdenite. Fluorite frequently fills the crevisses in crystals of emerald, beryl, topaz. phenacite and apatite or contains fine inclusions of chrysoberyl, which testifies to its later segregation.

RARE-EARTH METAL MINERALS

BERYLLIUM MINERALS

23. Beryl

Beryl occurs in the form of columnar, short and long prismatic crystals, as well as in fine-grained aggregates. Occasionally, its long prismatic crystals form aggregates with divergent structure. The heads of crystals are rarely seen. The most usual forms are (Koksharov, 1852): $(\bar{1}010)$ and (0001), while $(11\bar{2}1)$ and $(11\bar{2}0)$ (Fig.58) are considerably rarer. Prismatic crystals have smooth lustrous faces on which well expressed vertical striations are found. The columnar crystals have uneven, ribbed faces. The usual size of the crystals is 1.2 x 1.5 x 6 cm, but larger ones are also encountered, reaching 6 x 7 x 20 cm. The crystals are often fissured, the cracks running chiefly parallel to the basal pinacoid. They are filled in with phlogopite (Fig. 59), quartz, plagioclase, fluorite, native bismuth and muscovite. Sometimes the beryl is discontinuous at several spots and separated (Fig. 60). The color of beryl is light green; greenish yellow, yellow and in broken varieties white; occasionally colorless crystals are found. Zonal coloration of the crystals is characteristic in the basal pinacoid, rarer in prisms (Fig. 61). Green and bluish green hues in beryls are caused by the presence of chromium and partially vanadium; yellow is probably connected with the presence of iron. S. V. Grum-Grzhimaylo and L. A. Pevneva (1956) are of the opinion that different hues in the beryls basically depends on the presence of some particular quantity of ferrous iron. The cleavage is imperfect. They range from transparent to translucent. In section it is colorless, the decayed varieties are brown, barely transparent. Optically monoaxiel, negative; sometimes anomalously biaxial. Certain physical and optical properties of beryl are shown in Table 48.

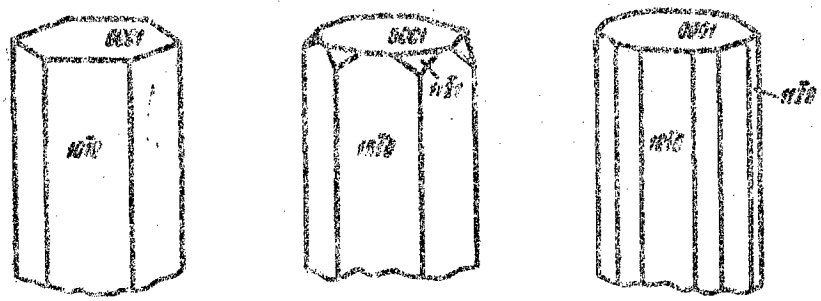


Fig. 58. Beryl Crystals

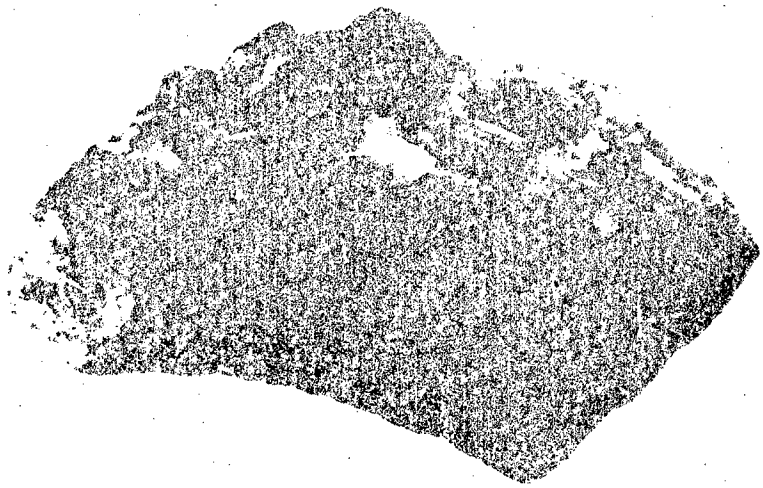


Fig. 59. Beryl Covered with Phlogopite.
Natural size.

The interplanar spaces of beryl and emerald are identical (Table 49). The material for an X-ray structural analysis was chosen from a zonal crystal of beryl (from the phlogopite zone of desiliconizaed pegmatites).

To ascertain the nature of the water content, the beryl was thermically analyzed. No thermal effects whatsoever were discovered on the heating curves, which is in all probability connected with a very slow release of the water (Fig. 62). According to N. A. Dilaktorskiy (1931) the basic bulk of the water from beryl is released within the range of 890° - 920°, while according to A. I. Ginzburg (1955) it is at a temperature from 890° - 920° to 1120° - 1180°.

The recalculations of the results of chemical analyses of beryl (Table 50) have produced the following formulas:

Analysis 1. $(Na_{0,11}K_{0,07}Ca_{0,06}Mg_{0,01})_{0,25}Be_{2,69}(Al_{2,03}Fe^{\cdots}_{0,03})_{2,06}[Si_{6,01}O_{18}]\cdot 0,16H_2O$

Analysis 2. $(Na_{0,19}Ca_{0,03}Mg_{0,02})_{0,24}Be_{3,00}Al_{2,0}[Si_{5,86}Al_{0,09}O_{18}]\cdot 0,38H_2O$

Analysis 3. $(Na_{0,20}Li_{0,11}Ca_{0,04})_{0,35}Be_{3,02}(Al_{1,97}Fe^{\cdots}_{0,02})_{1,99}[Si_{5,96}O_{18}]\cdot 0,27H_2O$

Fig. 60. Light green beryl crystal broken by fissures and separated toward the longitudinal axis. The fissures are filled with phlogopite. Nat. size.

Among the isomorphic admixtures in the beryl, sodium, lithium, calcium, iron and magnesium were observed, while in one case a considerable amount of potassium was discovered together with sodium in the beryl (Table 50, analysis 1).

Fig. 61. A Zonal Beryl Crystal

In beryl from a muscovite-fluorite lens (Table 50, analysis 2), chromium, manganese, copper, nickel and vanadium were established in addition by the spectral method.

Table 48

Physical and Optical Properties of Beryl

Locality where the sample was taken	Crystal form	Color	Spec. wt.	N_o	N_e	N_o-N_e
From pure strain pegmatites (see Table 50, anal.1)	Short columnar	light yellow	2.675	1.576	1.570	0.006
From the phlogopite zone of desiliconized pegmatites with muscovite-fluorite lenses	Long prisms	light green	2.70	1.580	1.574	0.006

Table 48 (continued)

Locality where the sample was taken	Crystal form	Color	Spec. wt.	No	Ne	No-Ne
(see Table 50, anal. 2)						
From plagioclase lenses in desiliconized pegmatites (kaolinized beryl)	Long prisms	greenish white	2.683	1.580	1.574	0.006
From the phlogopite zone of desiliconized pegmatites with plagioclase lenses	" "	light green	2.713	1.582	1.576	0.006
From pneumatolytic-hydrothermal veins (see Table 50, anal. 3)	Short prismatic	colorless	—	1.584	1.578	0.006

Four beryl samples were analyzed only by the spectral method; apart from the chief components, the elements listed in Table 51 were discovered.

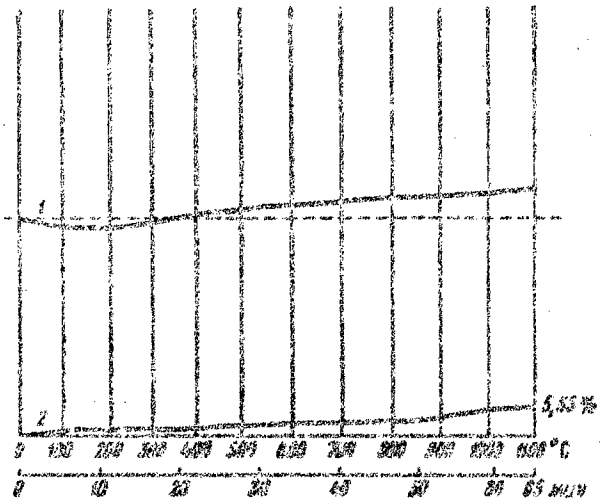


Fig.62. Curves of temperature (1) and weight loss (2) in beryl.

Table 49

Interplanar Spaces of Beryl and Emerald

(Cu - radiation 2R = 57,3 мм, d = 0,6 мм)

No. of lines	Beryl I	Beryl d	№ линий	Beryl I	Beryl d	№ линий	Emerald I	Emerald d	№ линий	Emerald I	Emerald d
1	—	—	36	2	1,082	1	7	8,77	36	1	1,081
2	—	—	37	2,5	1,069	2	5	7,98	37	1,5	1,071
3	—	—	38	—	—	3	1	4,85	38	1,5	1,064
4	3	4,63	39	3	1,047	4	3	4,60	39	2,5	1,046
5	—	—	40	—	—	5	2,5	3,97	40	1	1,027
6	2,5	3,68	41	2	1,014	6	—	—	41	1	1,012
7	6	3,49	42	3	0,997	7	3	3,99	42	2	0,995
8	10	3,26	43	—	—	8	8	3,24	43	1	0,965
9	—	—	44	2,5	0,959	9	2,5	3,03	44	1,5	0,957
10	10	2,86	45	1	0,929	10	10	2,86	45	1	0,930
11	—	—	46	2	0,919	11	1	2,59	46	1	0,919
12	4	2,53	47	5	0,913	12	3	2,51	47	2,5	0,913
13	1,5	2,31	48	—	—	13	3	2,29	48	2,5	0,891
14	3	2,14	49	—	—	14	3	2,15	49	1	0,879
15	4,5	1,988	50	2	0,854	15	3	1,988	50	1	0,833
16	-	—	51	1,5	0,847	16	2,5	1,818	51	1	0,849
17		—	52	4,5	0,834	17	3	1,790	52	2	0,836
18	5	1,740	53	—	—	18	5	1,734	53	1	0,833
19	3	1,707	54	—	—	19	1,5	1,709	54	1	0,826
20	5	1,625	55	3	0,814	20	3	1,621	55	1	0,815
21	3,5	1,593	56	—	—	21	2,5	1,593	56	1	0,812
22	3,5	1,569	57	6	0,806	22	2,5	1,565	57	2,5	0,806
23	—	—	58	2	0,798	23	2,5	1,529	58	1	0,798
24	5	1,511	59	—	—	24	5	1,508	59	1	0,786
25	3,5	1,454	60	—	—	25	3	1,449	60	1	0,784
26	4,5	1,427	61	—	—	26	3	1,428	61	1	0,781
27	4	1,369				27	2,5	1,363			
28	7,5	1,276				28	4	1,275			
29	7,5	1,260				29	5	1,259			
30	—	—				30	0,5	1,236			
31	6	1,205				31	3	1,202			
32	—	—				32	1	1,176			
33	2,5	1,150				33	1,5	1,146			
34	—	—				34	2	1,113			
35	2,5	1,102				35	1	1,101			

The greatest number of elements was discovered in the beryl from plagioclase lenses in desiliconized pegmatites, which clearly reflects the more complex chemical composition of these bodies in comparison with pure strain pegmatites.

Beryl undergoes all stages in its formation, beginning with high temperature pure strain pegmatites and winding up with low temperature quartz veins.

In the fine- and medium-grained pegmatites of the pure strain which occur in granites, beryl is found as an accessory mineral in the form of fine grains with a light yellow or light green tint principally associated with potash feldspar.

Beryl occurring in medium- and coarse-grained textured pegmatites embedded in amphiboles and diorites form fine-grained aggregates or prismatic crystals with light yellow or pale green, nearly white color. It is usually encountered with potash feldspar grains or with their contact with quartz. It is associated with apatite, fluorite, columbite, molybdenite and garnet.

In pegmatites with block structure beryl is most widespread in the southern part of the Emerald Mines. It ordinarily forms large short-prismatic and columnar crystals weakly tinted with light yellow and pale green, sometimes with uneven ribbed surfaces. Nearly white varieties are often found. The size of the individual crystals reaches 15 x 18 x 25 cm. Crystal concretions and pockets are found in large block sections of the veins and at the contact between the microcline zone and quartz core; more rarely, beryl is present in the microcline and quartz body.

The beryl in desiliconized pegmatites is encountered in the form of long prismatic crystals with a blue green color. Their matrix occurs in the phlogopite zone near the contact with plagioclase cores, and considerably less frequently with the cores themselves. The beryl crystals contained in the phlogopite zone are, as a rule, strongly corroded by the phlogopite, containing large quantitites of its scales in the form of inclusions, and are cracked. The cracks are filled with phlogopite and chlorite. The size of the crystals varies from quite tiny to 2.5 x 3.0 x 10 cm. In exceptional cases the crystals reach 20 cm in length. The color of the beryl is bluish green, rather intensive, sometimes unevenly distributed in spots. Often zonal coloration is found in the crystals with pinacoidal or prismatic form. The periphery of the crystals is light green,

Компоненты	1 Светло-желтый				2 Светло-желтый				3 Бесцветный			
	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на O_{18}	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на O_{18}	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на O_{18}
SiO_2	66,03	1,0994	2,1988	6,01	64,99	1,0824	2,1642	5,90	64,38	1,0710	2,1438	5,86
Al_2O_3	18,95	0,3718	0,5577	2,03	18,38	0,3606	0,5409	1,97	19,46	0,3322	0,5733	2,09
Cr_2O_3	—	—	—	—	0,06	—	—	—	—	—	—	—
Fe_2O_3	0,42	0,0052	0,0078	0,03	0,23	0,0028	0,0042	0,02	Сл.	—	—	—
BeO	12,33	0,4929	0,4929	2,69	13,83	0,5529	0,5529	3,02	13,72	0,5485	0,5485	3,00
MgO	0,21	0,0052	0,0052	0,03	—	—	—	—	0,11	0,0027	0,0027	0,02
CaO	0,73	0,0139	0,0139	0,08	0,40	0,0071	0,0071	0,04	0,30	0,0053	0,0053	0,03
Na_2O	0,65	0,0210	0,0105	0,11	1,16	0,0374	0,0187	0,20	1,10	0,0354	0,0177	0,19
K_2O	0,55	0,0116	0,0058	0,07	—	—	—	—	—	—	—	—
Li_2O	0,105	—	—	—	0,30	0,0200	0,0100	0,11	—	—	—	—
Cs_2O	0,095	—	—	—	—	—	—	—	—	—	—	—
H_2O^+	0,55	—	—	—	0,90	—	—	—	1,25	—	—	—
H_2O^-	—	—	—	—	0,00	—	—	—	—	—	—	—
11 Сумма	100,67		3,2026		100,25		3,3480		100,34		3,2913	
13 Аналитик и год исследования	14 И. Разина, 1957 г.				20 М. Е. Казакова, 1945 г.				21 В. С. Салтыкова, 1946 г.			

22 Примечание. Обр. 1 — из пегматита чистой линии с блоковой структурой; обр. 2 — из мусковит-флюоритовой линзы десилицированных пегматитов; обр. 3 — из альбит-кварцевой жилы.

[Key next page.]

Table 50

Table 50

Chemical Composition of Beryl

1. Light yellow 2. Light green 3. Colorless

4. components
5. weight %
6. atomic quantities of cations
7. atomic quantities of oxygen
8. atomic quantities of cations, computed for O_{18}
9. weight in percentage
10. atomic quantities of cations
11. atomic quantities of oxygen
12. atomic quantities of oxygen, computed for O_{18}
13. weight in percentage
14 atomic quantities of cations
15. atomic quantities of oxygen
16. atomic quantities of cations, computed for O_{18}
17. total sum
18. Analyst and year of research
19. I. Razina, 1957
20. M.Ye. Kazakova, 1945
21. V.S.Saltykova, 1946
22. Note. Sample 1. from pure strain pegmatite with block structure; sample 2. from a muscovite-fluorite lens in desiliconized pegmatites; sample 3. from an albite-quartz vein.

Table 51

Findings of Spectral Analyses of Beryl (in percentages)

Elements	1. Bluish green	2. Bluish green	3. Greenish white	4. Light green
Manganese	0,001	0,001	0,01	0,005
Bismuth	—	0,005	—	—
Vanadium	—	0,005	—	0,05
Zinc	—	—	—	0,005
Gallium	—	—	0,01	0,001
Copper	—	—	—	0,0005
Cobalt	—	—	—	0,001
Nickel	—	—	—	0,025
Lithium	—	—	—	0,5
Scandium	—	—	—	0,025
Titanium	0,01	0,01	0,01	0,005

Note. Sample 1. from a muscovite-fluorite lens;
sample 2.- 3. from a quartz lens;
sample 4. from a plagioclase lens in desiliconized pegmatite.

almost colorless, the center a rich green (emerald). The beryl crystals which tend to be located in the plagioclase part of the veins are characterized by good preservation, a small number of inclusions, less fissuring and fainter coloring. The dimensions of the crystals are 0.5 x 0.6 x x 4 cm, larger ones are rarely encountered. The cracks in the crystals are filled in with plagioclase and fluorite. The beryl's color is greenish blue, occasionally rather rich. It is associated with apatite, chrysoberyl, alexandrite, fluorite, plagioclase and beryl-containing

margarite.

The beryl in muscovite-fluorite lenses of desiliconized pegmatites is represented by macrocrystalline aggregates with a light green color. It is associated with fluorite, apatite, muscovite, topaz, quartz, molybdenite, native bismuth and corundophilite. It appears to have an earlier time of segregation than all the other minerals with the exception of apatite, whose isomorphic crystals are sometimes included in the macrocrystalline aggregates of beryl.

In hollows in the muscovite-fluorite lenses one finds very fine thin prismatic, nearly colorless crystals of beryl, directed toward the long side perpendicular to the faces of the macrocrystalline beryl aggregates, thus attesting to their later segregation.

In pneumatolytic-hydrothermal veins (albite-quartz muscovite-quartz and albite-quartz) beryl is found in the form of large long prismatic crystals, intergrowths and pockets (up to 10 x 20 cm) distributed along the contact between the albite or albite-muscovite zone and the quartz body. It is seen considerably less often in the quartz body itself or in the albite-muscovite zone. The crystals are weakly colored green and greenish-yellow, on occasion just about colorless. The fissures in them are filled with quartz, muscovite and albite. The size of individual crystals varies from 1.2 x 1.5 x 2.5 to 5.5 x 6.0 x 10.0 cm. The most typical association is with quartz, muscovite, albite, fluorite, sphalerite, molybdenite, bornite and chalcopyrite.

In all vein bodies crystallization of beryl began earlier than that of phlogopite, muscovite, fluorite, chrysoberyl, phenacite, topaz, while the emerald began to form first, followed by beryl.

The processes of alteration of beryl and its substitution with other minerals does not have a wide distribution, although in certain sections, especially in the pneumatolytic-hydrothermal veins, they do appear rather intensive.

The beryl in desiliconized pegmatites and pneumatolytic-hydrothermal veins is replaced at later stages in the hydrothermal process by bavenite (see Fig. 83), bertrandite and beryllium-containing microcline. In the hypergenetic zone the beryl is sometimes completely substituted by kaolin. In pure strain pegmatites the replacement process appears considerably weaker, and bertrandite is mainly developed in lieu of the beryl.

24. THE EMERALD

In color intensity and transparency the Uralian emeralds enjoy world renown. The crystals are long prismatic (Fig. 63), their size is 1 x 1x 3 or 1 x 1.5 x x 5 cm, sometimes up to 4 x 5 x 20 cm. Druses of the crystals are often found. The color is green, with varying intensity, ranging from bluish green to rich green. Zonal coloring of the crystals along the pinacoidal faces is characteristic of the emeralds; the periphery is most often nearly colorless, the central portion intensively colored bluish green, the opposite appearing more rarely. Zonal coloration is occasionally seen on the prism, whereupon the change in color intensity is shifted along the longitudinal axis of the crystal, several intermittent bands of varying intensity being present in certain crystals.

A large number of inclusions of phlogopite, talc, actinolite, tourmaline, cracks in the crystals and uneven distribution of color lessen the quality of the emeralds as precious stones. In certain instances the emerald crystals have been strongly corroded by phlogopite, muscovite and corundophillite, they are often split by cross fractures along which one part of the crystal can be turned in relation to another at a 30 - 40° angle around the L_6 axis. The cracks are ordinarily filled with plagioclase, quartz, phlogopite (Fig. 64), muscovite and fluorite. There are particularly many inclusions in emeralds embedded in phlogopite, whose flakes either gird the crystals (Fig. 65) or interlock with them. Sometimes the phlogite flakes nearly join the central part of the crystal, at the same time as the peripheral part is absolutely free of inclusions and almost transparent (Fig. 66). Crystals which are contained in plagioclase or quartz have less inclusions, their faces are smoother and more lustrous, although they are less brilliant in color. The refraction indices are: No = 1.586, Ne = 1.582, No - Ne = 0.004 (the emerald from talc schist). The remaining physical and optical properties are similar to beryl.

The heating and weight loss curves for the emerald (Fig. 67) are similar to those of beryl.

Recomputing the findings of the chemical analysis of the emerald (Table 52) leads to the formula:

$$(Na_{0,32}Ca_{0,08})_{0,40}Be_{2,97}(Al_{1,66}Cr_{0,02}Fe^{\cdots}_{0,02}\ Mg_{0,26})_{1,96}\ [Si_{5,99}O_{18}]\cdot 0,4H_2O,$$

i.e. the composition of the emerald is contained in the general formula of beryl. Only the lack of aluminum and presence of considerable amount of magnesium attract attention. The latter probably isomorphically replaces aluminum according to the scheme 2Al - 3Mg. The occurrence of considerable amounts of magnesium in the emerald also produces the scandium structure in it. Moreover, among the isomorphic admixtures in the emerald one finds calcium, iron and chromium. The presence of considerable amounts of sodium (1.80 percent Na_2O) with a large ionic radius in the beryl structure has been unexplained up to now. Bragg, in 1937, expressed the supposition that the sodium ions are arranged in channels intrinsic to the structure of the beryl.

Supplementary to chemical analyses of the emerald one has found by spectral investigation: lithium (0.1%), scandium (0.025%), vanadium (0.05%), nickel (0.025%), copper (0.0025%), gallium (0.001%), bismuth (0.0005%). Then spectroscopic analysis was made of the second zonal crystal of emerald, in which, aside from the basic components, the elements presented in Table 53 were discovered.

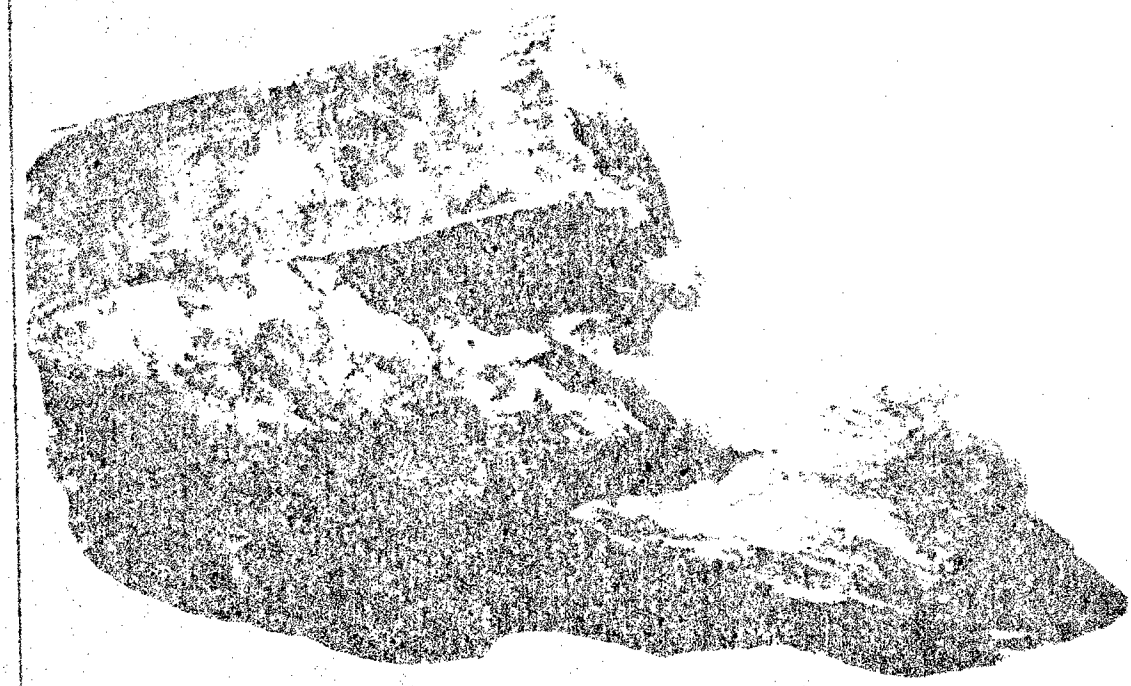


Fig.63. Emerald crystal in Phlogopite. Natural size.

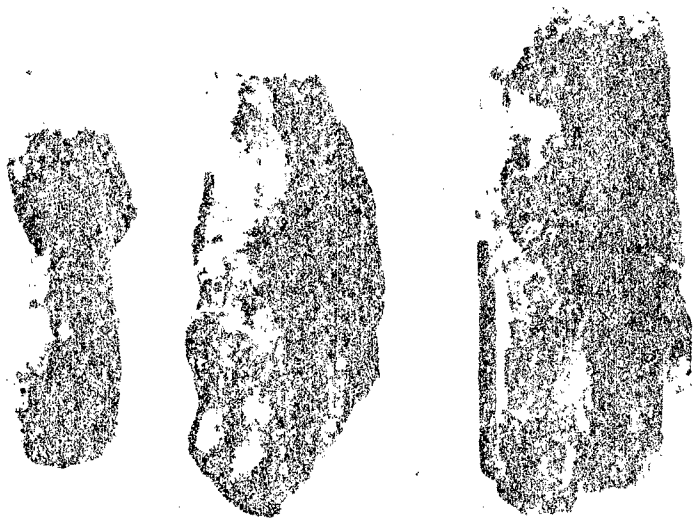


Fig. 64. Filling in of Fractures in Emerald with Phlogopite (ΦΛ). Natural size.

Fig. 65. Envelopment of Emerald Crystals with Phlogopite Flakes (ΦΛ). Natural size.

Comparison of the data from chemical and spectral analyses shows that the emerald is characterized by high chromic oxide content (0.25%) in releation to light green beryl of the same deposit (0.06%), as well as by the presence of scandium (0.025 - 0.03%) and vanadium (0.02 - 0.05%). Determination of the chromium content in the emerald from the Somerset deposits in South Africa, made

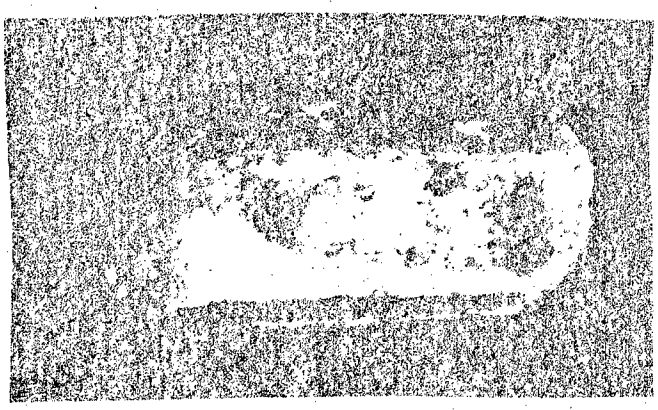


Fig. 66. Filling in of the Central Part of an Emerald Crystal with Phlogopite Flakes. Natural size.

at the chemical laboratories of the Institute of Mineralogy, Geochemistry and Crystallochemistry of Rare Elements of the Academy of Sciences USSR, has shown the same

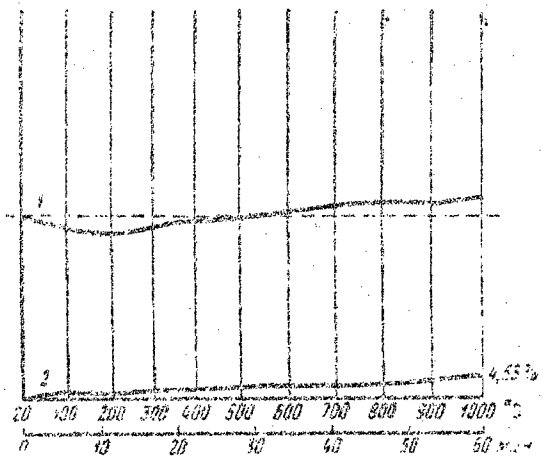


Fig.67. Heating (1) and Weight Loss (2) Curves of Emerald

content in this sample (0.29% Cr_2O_3) as in the emerald described (0.25% Cr_2O_3).

Emeralds are found only in desiliconized pegmatites. They tend to occur mainly in the phlogopite zone and at its contact with plagioclase bodies and cores. Emeralds are often present in the plagioclase itself. It is considerably rarer that the emerald crystals are observed in the phlogopite-talc zones in which the talc has formed with phlogopite. In isolated cases the fine emerald crystals occur in quartz separations in the plagioclase cores, as well as in actinolite lenses and phlogopite-tremolite zones.

Table 52

Chemical Composition of the Emerald

Components	Weight %	Atomic quantitites of cations	Atomic quantities of oxygen	Atomic quantities of cations calculated for O_{18}
SiO_2	64,69	1,0770	2,4540	5,99
TiO_2	Не обн.	—	—	—
Al_2O_3	15,16	0,2974	0,4461	1,66
Cr_2O_3	0,25	0,0032	0,0048	0,02
Fe_2O_3	0,35	0,0044	0,0066	0,02
BeO	13,37	0,5315	0,5315	2,97
MnO	Сл.	—	—	—
MgO	1,88	0,0469	0,0469	0,26
CaO	0,80	0,0143	0,0143	0,08
Na_2O	1,80	0,0580	0,0290	0,32
K_2O	Сл.	—	—	—
H_2O^+	1,29	—	—	—
H_2O^-	Не обн.	—	—	—
Sum	99,60		3,2362	

Analyst and year of investigation: M. Ye. Kazakova, 1957

Note: The analyzed emerald came from the center of zonal crystal.

As has already been mentioned above, the emeralds which lie in the phlogopite zone are well facetted, having a deep green color, sometimes unevenly distributed, are fractured and contain considerable amounts of inclusions. At one section of phlogopite shale a single transparent crystal of pure emerald was found, 6.5 x 8 x 12 cm in size and rich green in color. This sample is now kept at the Mineralogical Museum of the Academy of Sciences USSR.

Table 53

Findings of Spectral Analysis of Zonal Emerald (in %)

Elements	Peripheral Zone with rich green color	Central Zone with light blue color
Vanadium	0,5	—
Nickel	0,025	0,005
Gallium	0,005	0,005
Lithium	0,07	0,07
Scandium	0,63	—
Cobalt	0,004	—
Copper	0,0005	0,0005

Emeralds found at the phlogopite-talc zones also display an intensive green color, occasionally containing significant amounts of phlogopite, talc and actinolite inclusions (Fig. 68). Emeralds which occur in plagioclase, on the other hand, contain the least inclusions, are less corroded, although the intensity of color is considerably weaker. Well facetted crystals are seldom met with. The usual size of the crystals is 0.8 x 0.8 x 5.0 cm, sometimes somewhat larger. The closest associations characteristic of the emerald is with phlogopite, plagioclase, fluorite, topaz, apatite and beryl.

The color of emeralds, as has been mentioned above, is connected with chromium for the most part, which is gotten from the enclosing rock. Ultrabasic rocks (dunite

peridotite, pyroxenite) are favorable for the formation of emeralds, as are the products of their metamorphism, serpentine, and chromium-bearing amphiboles. In thick veins where the interaction processebetween the pegmatic solution melt and the enclosing rock took place most intensively, more chromium entered the melt solution and the emeralds have a richer color. In this instance they are ordinarily found at the phlogopite zones. When the reaction between the pegmatite solution melt and the enclosing rock proceeded less vigorously, less chromium got into the solution, the emeralds became colored with a fainter green and ordinarily tended to occur at the central part of the veins, at the plagioclase body or cores (Fig. 69).

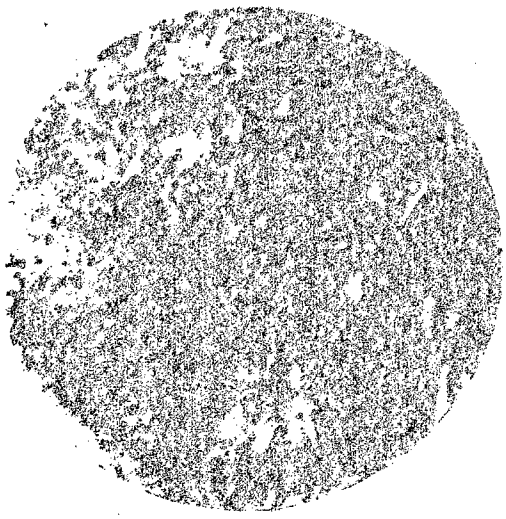


Fig. 68. Inclusions of Phlogopite (Ф), Actinolite (Ak), Talc (T) and Tourmaline (Tp) in Emerald. Magn. 20x. Nic. +

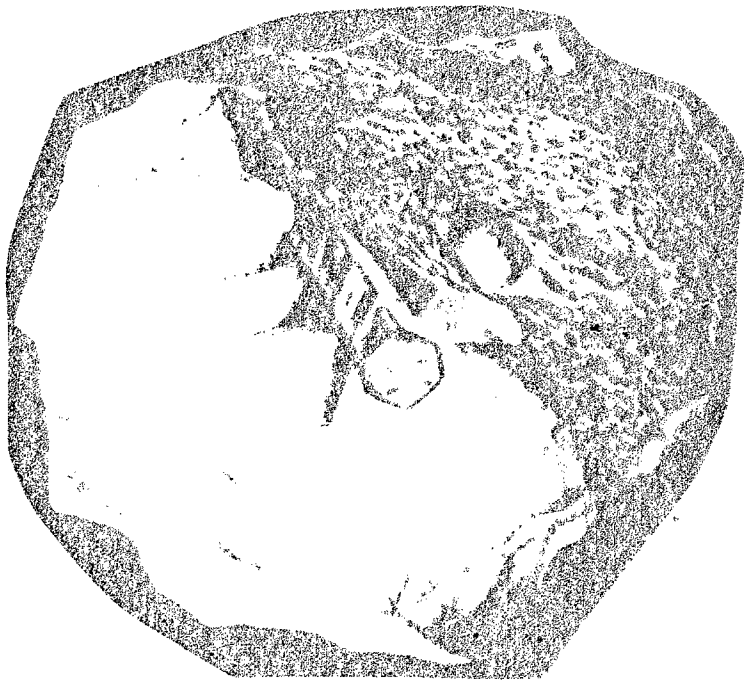


Fig. 69. Emerald in a Plagioclase Lens.
Nat. size.

25. PHENACITE

Phenacite is found as an accessory mineral in desiliconized pegmatites, clinchumites and dolomite apophyses which cut through serpentine. It is found in crystals, ranging from 1 x 1.1 x 1.2 to 4 x 5.5 x 6 cm in size, and in isolated cases going up to 8 x 9 x 10 cm. Occasionally crystal aggregates are seen with the dimensions 12 x 15 x 18 cm. The crystals are principally short prismatic (compressed along axis C) and rhombohedral, characterized by the development of the following forms (according to N. I. Koksharov): R (1011), a (1120), p (1123) (Fig. 70 a, b). More complex crystals are rarely found which assume the following shapes: R $(10\bar{1}1)$, a $(11\bar{2}0)$, p $(11\bar{2}3)$, d $(10\bar{1}2)$, g $(10\bar{1}0)$ (Fig. 70 c). The crystals

frequently have smoothed out faces, corroded by phlogopite. The cracks are filled with flakes of chlorite and phlogopite (Fig. 71). The phenacite is most often colorless, pellucid, less frequently wine-yellow and yellow. In some instances the color in one and the same crystal varies from colorless to wine-yellow. The wine-yellow variety loses its color when placed in sunlight for some time, becoming colorless. The cleavage in $(11\bar{2}0)$ is clear, in $(10\bar{1}1)$ incomplete. It has conchoidal fracture.

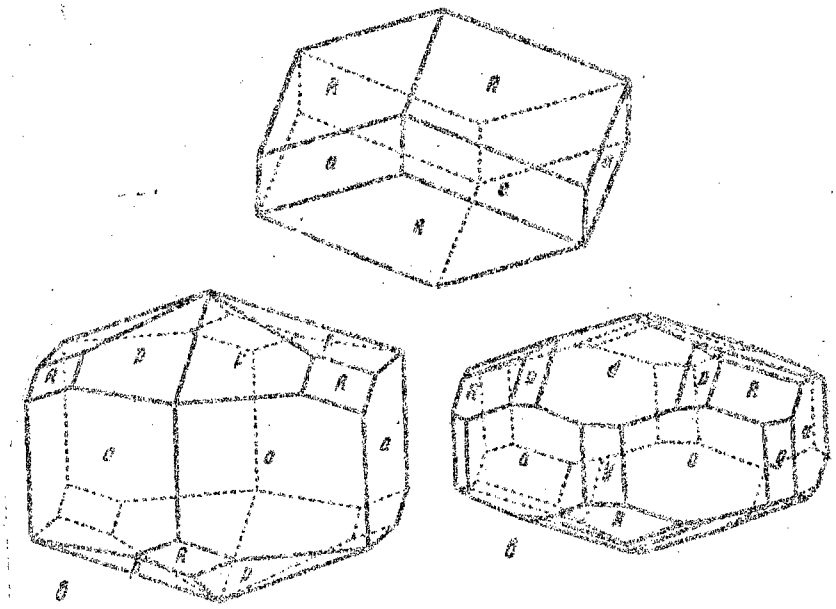


Fig. 70 (a, b, c). Phenacite crystals (according to N. I. Koksharov)

The glance is glassy, sometimes weakly adamantine. It is transparent to translucent. The broken variety is opaque. The specific weight is 2.938 - 3.001 (Table 54). It fluoresces light blue or yellow. Certain varieties phosphoresce with a rich green hue.

Phenacite sections are colorless. Its decayed kind displays a grayish brown color. It is optically monoaxial and positive. Refraction indices: Ne = 1.669, No = 1.654, Ne - No = 0.015.

Fig. 71. Phenacite Crystals Overlain by Phlogopite. Nat. size.

The interplanar spaces of phenacite measured with a debayegram are presented in Table 55. A calculation of the results of a chemical analysis (Table 56) boils down to the usual formula for phenacite Be_2SiO_4. Among the admixtures one finds slight amounts of sodium, potassium, calcium and magnesium. By spectral analysis the following were discovered to boot: chromium, titanium (0.005%), manganese (0.001%) and copper (0.0005%).

Phenacite is ordinarily found at the chlorite and phlogopite zones in desiliconized pegmatites or at the contact between them. It sometimes forms nests of huge crystals (up to 10 cm) located at the chlorite lenses or zones. The crystals are colorless, water-clear, wine-yellow, and yellow, often fractured. The cracks are filled in with chlorite and phlogopite. The decayed

phenacite variety is opaque. Phenacite is associated with fluorite, apatite, chrysoberyl, alexandrite, tourmaline, beryl-containing margarite, phlogopite and chlorite.

Table 54

Specific Weights of Phenacite Varieties

Variety	Spec. wt.	Investigator
Transparent	2.969	Nordenschild (1833)
Water-Clear	2.996	" "
" "	2.982	Koksharov (1857)
" "	3.001	Breithaupt
" "	2.938	Kutukova
Wine-Yellow	2.939	" "

Phenacite found in dolomite apophyses in association with scheelite, fluorite and pyrite is of hydrothermal origin, notwithstanding the fact that, if one can judge from the literature (Pough, 1938) its short prismatic form should be an indication of formation at a high temperature.

Phenacite has an earlier segregation time than apatite, fluorite, phlogopite, chlorite which fill in the spaces between its crystals. Phenacite and chrysoberyl commenced crystallization nearly simultaneously, the crystallization of chrysoberyl coming to an end somewhat later (see Fig. 72).

Veins with a strong development of chlorite and talc zones are most propitious to phenacite formation, since chlorite and talc are the main absorbants of oxides of aluminum and silicon, although the shortage of these oxides produces phenacite instead of beryl.

At certain sections in these instances where the

Table 55

Interplanar Spaces of Phenacite

(Cu-radiation, 2R = 57.3, d = 0.6 mm)

No. Lines	I	d	No. Lines	I	d
1	1	4,23	29	3,5	1,216
2	1	4,02	30	3,5	1,194
3	2	3,83	31	3,0	1,182
4	3,5	3,64	32	3	1,143
5	2	3,47	33	1	1,130
6	2	3,34	34	1	1,104
7	2,5	3,22	35	1	1,079
8	5	3,11	36	1	1,056
9	1	2,98	37	3	1,009
10	2	2,90	38	1,5	0,9878
11	6	2,51	39	1,5	0,9641
12	5	2,34	40	1	0,9478
13	3	2,26	41	3	0,9411
14	6,5	2,18	42	3	0,9090
15	4	2,114	43	1,5	0,9019
16	5	2,068	44	1	0,8949
17	1	2,020	45	1,5	0,8881
18	2,5	1,789	46	2	0,8756
19	4	1,720	47	1	0,8646
20	4	1,522	48	1	0,8521
21	2	1,490	49	1	0,8458
22	2	1,467	50	2,5	0,8366
23	3,5	1,438	51	2	0,8249
24	3	1,424	52	2	0,8197
25	1	1,368	53	1	0,8150
26	10	1,308	54	1	0,7904
27	3,5	1,265	55	2	0,7970
28	5	1,252	56	1	0,7952

chlorite zone is lacking or very thin, chrysoberyl and beryl-containing margarite crystallize jointly with the phenacite.

We did not see phenacite, chrysoberyl and beryl together; the association of phenacite with beryl is very rarely encountered.

Table 56

Chemical Composition of Colorless Phenacite from the Phlogopite Zone

Components	wt. %	Atomic quantities of cations	Atomic quantities of oxygen	Atomic quantities of cations, calculated for O_8
SiO_2	52,92	0,8811	1,7622	0,97
TiO_2	Не обн.	—	—	—
Al_2O_3	Сл.	—	—	—
Cr_2O_3	Не обн.	—	—	—
Fe_2O_3	» »	—	—	—
FeO	» »	—	—	—
BeO	45,82	1,8318	1,8318	2,02
MgO	0,13	0,0032	0,0032	—
CaO	0,20	0,0036	0,0036	0,00
Na_2O	0,63	0,0324	0,0162	0,04
K_2O	0,26	0,0056	0,0028	0,01
П. п. п.	0,21	—	—	—
Sum	100,17		3,6193	
Sp. wt.	2,928			
Analyst		M. Ye. Kazakova		

26. CHRYSOBERYL

Chrysoberyl is found in the form of short prismatic, flat crystals, plates and granular aggregates. Feather-like striae are characteristic of the plates. The crystals are often fissured and covered by flakes of

phlogopite and chlorite. The color is yellow, greenish yellow and in decayed varieties brownish yellow. It is transparent to semitransparent. The specific weight is 3.631. The section is colorless. The indices of refraction: Ng = 1.757, Np = 1.747, Ng - Np = 0.010; 2V = 52°.

Recalculation of the chemical analyses of chrysoberyl (Table 57) produces the following formulae:

Analysis 1.

$$(Be_{0,97}Si_{0,04})_{1,01}(Al_{1,91}Fe^{\cdots}_{0,01}Fe^{\cdot\cdot}_{0,02}Mg_{0,02}Ti_{0,01})_{1,97}O_4$$

Analysis 2.

$$Be_{0,98}(Al_{1,99}Fe^{\cdots}_{0,05}Mg_{0,01})_{2,05}O_4$$

In addition to the data of chemical analyses there were discovered spectroscopically: in one sample (Table 58, anal. 1) -- bismuth (0.05%), vanadium (0.02%), manganese and gallium (0.01%); in the second sample (anal. 2) -- tin (0.1%), gallium (0.01%) and vanadium (0.05%).

According to S. V. Grum-Grzhimaylo (1940, 1946) the color of chrysoberyl is produced by the presence of isomorphic admixtures of chromium (green) and iron (yellow) in it. The intensity of the color depends on the content of these elements.

The interplanar spaces in chrysoberyl and its variety - - alexandrite, measured with debayegrams were nearly identical (Talbe 57).

The segregations of chrysoberyl tend to occur c primarily in the reaction zones of desiliconized pegmatites: chlorite, phlogopite and alumobiotite. It is rarely present in the plagioclase part of the veins. Chrysoberyl is encountered in the largest quantity in the chlorite zones of the apical parts of desiliconized pegmatites in the form of tabular segregations, often with featherlike striae, grayish green and greenish yellow in color, in association with phenacine, fluorite or plagioclase and tourmaline. In the phlogopite and alumobiotite zones chrysoberyl is found rather often in the form of short prismatic crystals, plate-shaped isolations, less often granular accretions and apophyses up to 1.5 - 2 cm thick (Fig. 73). It is associated with phenacite (Fig.74), apatite, tourmaline and fluorite. In plagioclase chrysoberyl is seen in the form of large crystals, lettuce green in color and closely associated with beryl-containing margarite.

Chrysoberyl forms earlier than apatite, fluorite,

phlogopite, chlorite, beryl-containing margaite which frequently fill the spaces between its crystals. In relation to the emerald, beryl, tourmaline, chrysoberyl forms later. The crystallization of chrysoberyl and phenacite proceeded nearly simultaneously.

Along the system of random fissures, chrysoberyl is sometimes replaced by kaolin and due to the high pelitic content it becomes brownish gray (Fig.75) in thin sections.

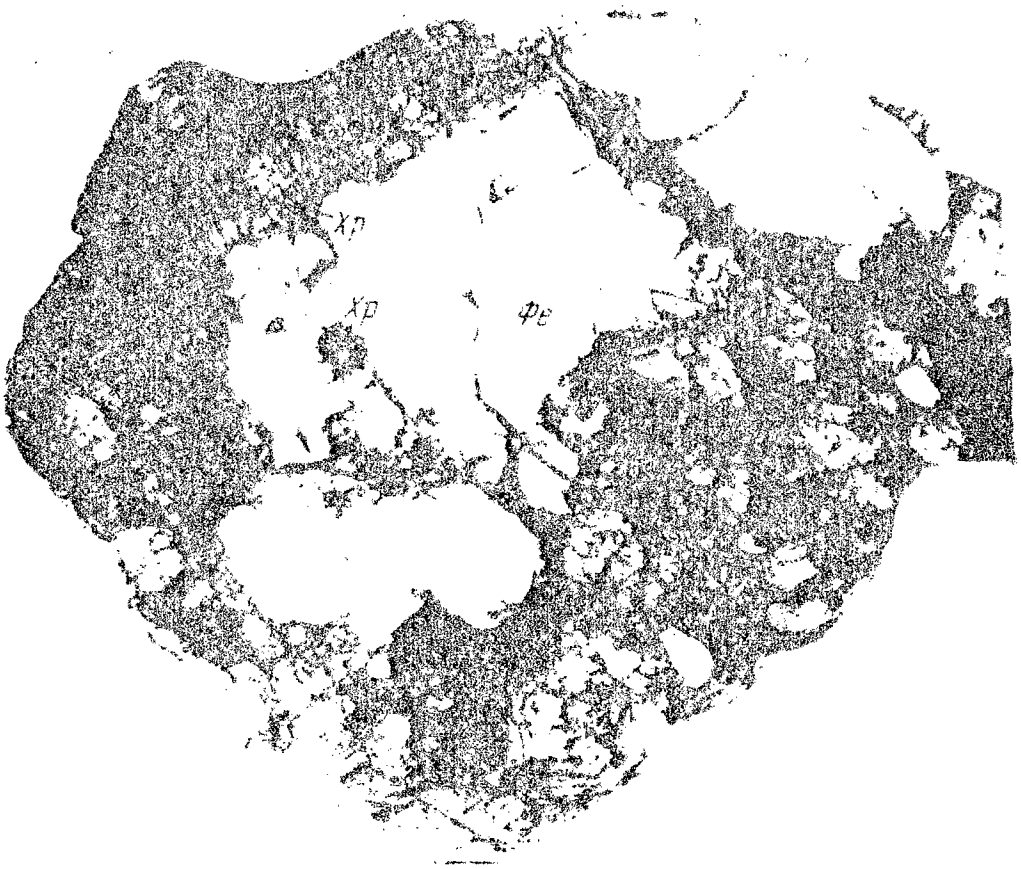


Fig. 72. Interrelation between phenacite (Фе) and chrysoberyl (Хр). The chrysoberyl granules are distributed around the segregation of phenacite and fill the cracks in it. Magn. 4 x. Without an analyzer.

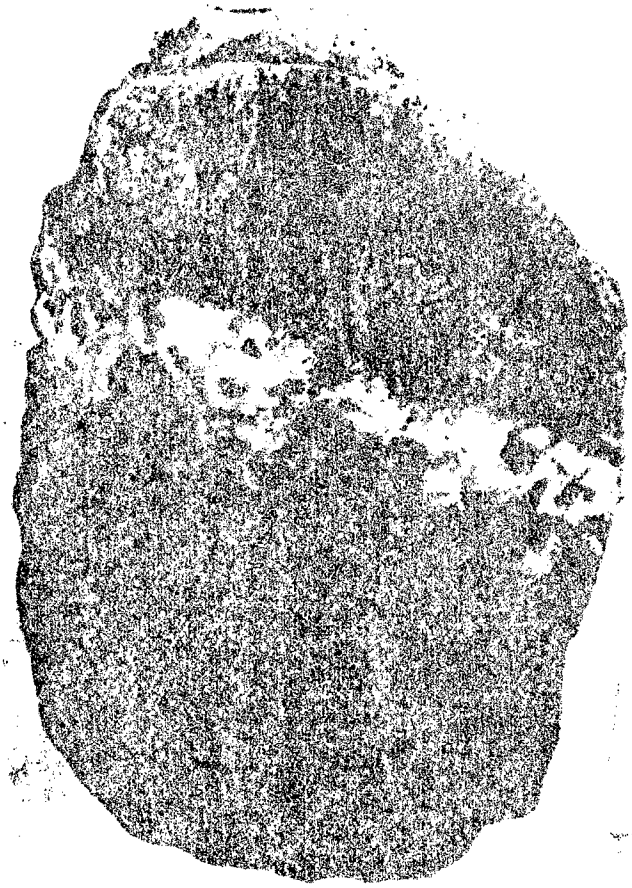


Fig. 73. Chrysoberyl Apophysis in the Phlogopite Zone. Nat. size.

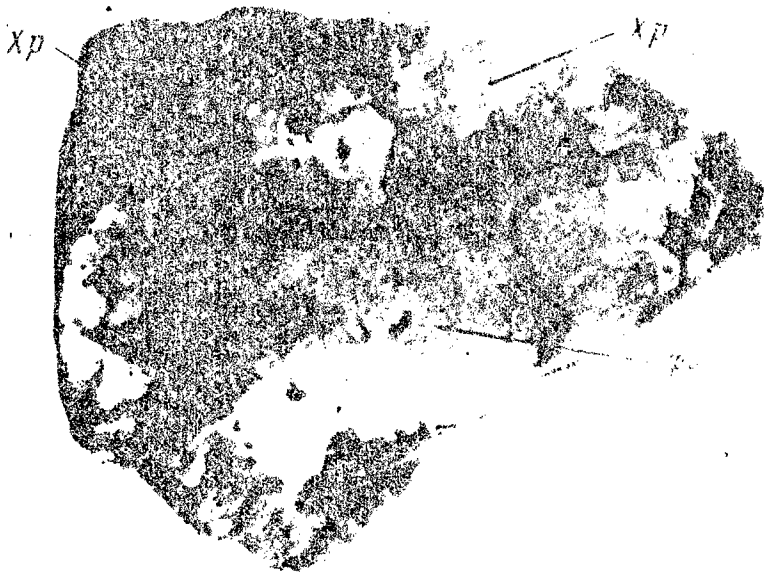


Fig. 74. Association of Chrysoberyl (Xp) with Phenacite (I e). Nat. size.

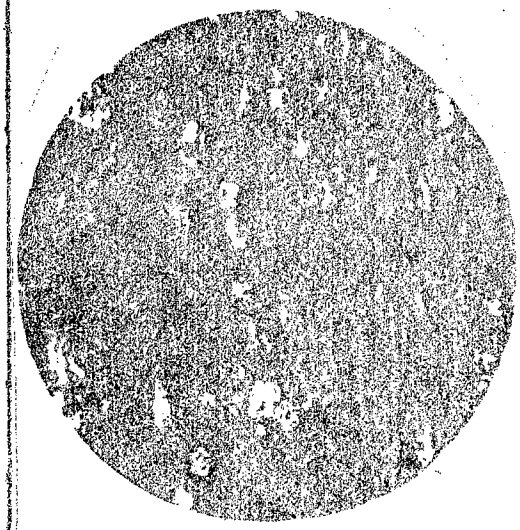


Fig. 75. Change in Chrysoberyl.
Magn. 45 X. Without analyzer.

Table 57

Interplanar Spaces in Chrysoberyl and Alexandrite
(Cu-radiation 2R = 57,3, d = 0,6 мм)

No. of lines	Alexandrite		Chrysoberyl		№ линий	Alexandrite		Chrysoberyl	
	I	d	I	d		I	d	I	d
1	1	4,38	—	—	28	1	1,134	1,5	1,137
2	1	4,22	—	—	29	1	1,102	2	1,105
3	1	3,99	1,5	4,04	30	1	1,074	2	1,078
4	1	3,47	—	—	31	1	1,064	1	1,064
5	3	3,33	5	3,35	32	1	1,053	—	—
6	4	3,22	3,5	3,22	33	3	1,040	2	1,041
7	1	2,90	—	—	34	1	1,033	—	—
8	1	2,70	—	—	35	1	1,017	1	1,020
9	5	2,54	6	2,56	36	1	0,999	1	1,004
10	2	2,35	—	—	37	—	—	1	0,978
11	4	2,31	—	—	38	3	0,951	3	0,953
12	3	2,25	4	2,26	39	—	—	1,5	0,936
13	2	2,12	—	—	40	2	0,929	—	—
14	10	2,07	9,5	2,08	41	—	—	1,5	0,904
15	1	1,86	—	—	42	1	0,893	1	0,89
16	10	1,61	10	1,61	43	4	0,856	4	0,859
17	2	1,54	3	1,54	44	1	0,838	1,5	0,840
18	—	—	4	1,51	45	2	0,829	1,5	0,831
19	1	1,48	—	—	46	2	0,827	1	0,828
20	3	1,46	4	1,46	47	—	—	1	0,825
21	1	1,38	—	—	48	1	0,814	1	0,815
22	3	1,36	6	1,37	49	1	0,807	—	—
23	5	1,35	3	1,30	50	1	0,803	—	—
24	1	1,290	3	1,281	51	1	0,788	1	0,790
25	3	1,251	3,0	1,252	52	1	0,786	—	—
26	3	1,246	—	—	53	1	0,782	—	—
27	1	1,202	2	1,203					

Table 58

3 Компоненты	1 Пластинчатая разность серовато-зеленого цвета				2 Кристаллы зеленовато-желтого цвета			
	4 вес. %	5 атомные количества катионов	6 атомные количества кислорода	7 атомные количества катионов, рассчитанные на O_4	8 вес. %	9 атомные количества катионов	10 атомные количества кислорода	11 атомные количества катионов, рассчитанные на O_4
SiO_2	1,90	0,0316	0,0632	0,04	—	—	—	—
TiO_2	0,34	0,0043	0,0086	0,01	—	—	—	—
SnO_2	0,12	0,0005	0,0010	0,00	—	—	—	—
Al_2O_3	76,00	1,4910	2,2365	1,91	78,88	1,5476	2,3214	1,99
Cr_2O_3	0,08	0,0010	0,0015	0,00	Сл.	—	—	—
Fe_2O_3	0,57	0,0072	0,0108	0,01	3,05	0,0382	0,0573	0,05
FeO	1,29	0,0193	0,0193	0,02	—	—	—	—
BeO	19,05	0,7616	0,7616	0,97	18,05	0,7216	0,7216	0,93
MnO	0,00	—	—	—	0,12	0,0016	0,0016	0,00
MgO	0,65	0,0161	0,0161	0,02	0,35	0,0087	0,0087	0,01
CaO	0,27	0,0048	0,0048	0,01	—	—	—	—
H_2O^+	0,00	—	—	—	—	—	—	—
H_2O^-	0,10	—	—	—	—	—	—	—
12 Сумма	100,47		3,1234		100,45		3,1138	
13 Аналитик		14 М. Е. Казакова				15 В. С. Салтыкова		

Table 58

Chemical Composition of Chrysoberyl

1. Platy variety with grayish green color
2. Crystals with greenish yellow color
3. Components
4. weight %
5. Atomic quantities of cations
6. Atomic quantities of oxygen
7. Atomic quantities of cations, calculated for O_4
8. weight %
9. Atomic quantities of cations
10. atomic quantities of oxygen
11. atomic quantities of cations, calculated for O_4
12. Sum
13. Analyst
14. M. Ye. Kazakova
15. V. S. Saltykova

In certain cases the chrysoberyl and phlogopite has, under the influence of carbonate solutions, been replaced by dolomite and the fine micaceous type of gilbertite. Beryllium is thereby apparently carried off in the form of bicarbonates.

27. ALEXANDRITE

Alexandrite is a chrysoberyl variety colored green by chromium (0.30% Cr_2O_3). It is a dichroic mineral and becomes cherry red in artifical illumination. The crystals are tabular along a(100), more rarely short and long prismatic. Measurements of the crystals were made by N. I. Koksharov. The principal forms of alexandrite are: o (111), B (100), a (010), i (011), s (120), and

n (121). They are in part trillings (Fig. 76), part twins. The trillings assume a six-sided, platy face and in the Urals have gotten the name "peshka" (pawns) (Fig. 77 a). Sometimes the trillings form pseudohexagonal crystals with incident angles (Fig. 77 b). Feathery striae are often seen in in twins (Fig. 77c). The crystal planes are lustrous and for the larger part smooth, only planes (010) and (100) tend to be covered with vertical streaks (Fig.77d). Trillings are often intergrown in groups consisting of four, five and more individuals. The size of the crystals is 0.7 x 1.5 x 1.5 up to 1.5 x 2 x 4 cm, rarely larger. The largest crystal concretion of alexandrite known today consists of 22 superbly formed trillings. The size of the concretion is 11 x 14 x 25 cm, individual trillings in it attaining 9 cm (Fig. 78). The crystals are often cracked, the splits filled in with flakes of phlogopite. The color is green, and grayish green. It is transparent to semi-transparent. The specific weight is 3.663. The interplanar spaces of alexandrite are presented in Table 57. In section it reveals well expressed pleochroism: Ng -- emerald green, Nm -- orange yellow, Np -- violet red. The remaining physical and optical properties are analogous with chrysoberyl.

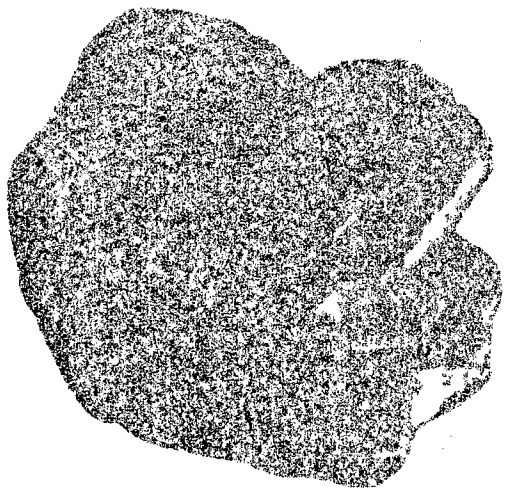


Fig.76 Alexandrite Trilling. Magn. 2 x .

The spectral method has revealed in addition to the data from chemical analysis (Table 59): gallium (0.1%), vanadium (0.5%), cobalt (0.001%), manganese (0.001%), magnesium and copper (0.0005%).

Chemical Composition of Alexandrite

Components	weight %	Atomic quantities of cations	Atomic quantities of oxygen	Atomic quantities of cations calculated for oxygen.
Компоненты	Вес. %	Атомные количества катионов	Атомные количества кислорода	Атомные количества катионов, рассчитанные на O_4
SiO_2	2,43	0,0405	0,0810	0,05
TiO_2	Сл.	—	—	—
SnO_2	0,04	0,0001	0,0002	0,00
Al_2O_3	75,26	1,4766	2,2149	1,90
Cr_2O_3	0,30	0,0040	0,0060	0,01
Fe_2O_3	0,31	0,0038	0,0057	0,01
FeO	1,41	0,0196	0,0196	0,03
BeO	18,74	0,7492	0,7492	0,96
MnO	Не обн.	—	—	—
MgO	» »	—	—	—
CaO	1,51	0,0269	0,0269	0,03
H_2O^+	0,10	0,0112	—	—
H_2O^-	Не обн.	—	—	—
Sum	100,10		3,1035	

Analyst M. Ye. Kazakova

Recalculation of the findings of the chemical analysis of alexandrite produces the formula:

The largest alexandrite aggregations are found in the phlogopite zones of desiliconized pegmatites or in association with beryl and emerald, or in the form of well formed crystals in association with

phenacite, chrysoberyl, apatite and tourmaline. In certain cases alexandrite tends to concentrate at the contact between the phlogopite zone and the plagioclase or to be located in the latter. Occasionally it is present in muscovite-fluorite lenses in desiliconized pegmatites as small crystals (up to 0.5 cm) embedded in the fluorite. The usual associations for alexandrite are with apatite, phenacite, fluorite, tourmaline, beryllium containing margarite, phlogopite, chlorite,

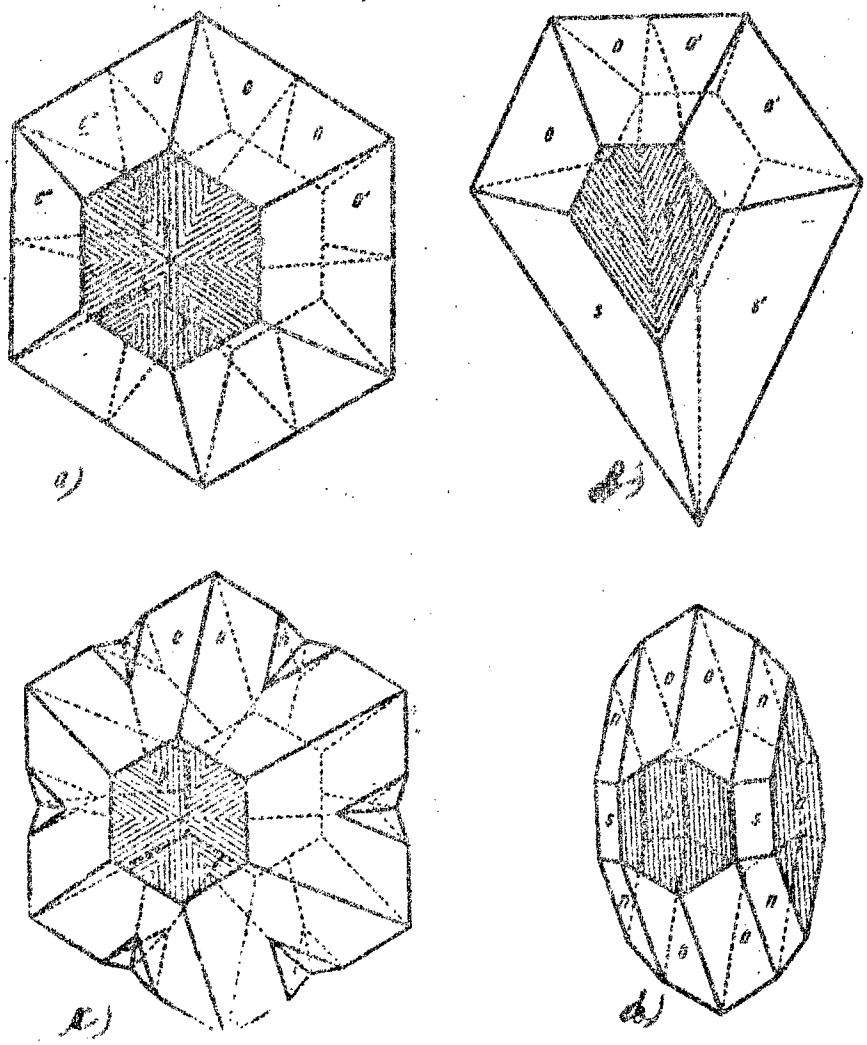


Fig. 77. Alexandrite Crystals (according to N. I. Koksharov).

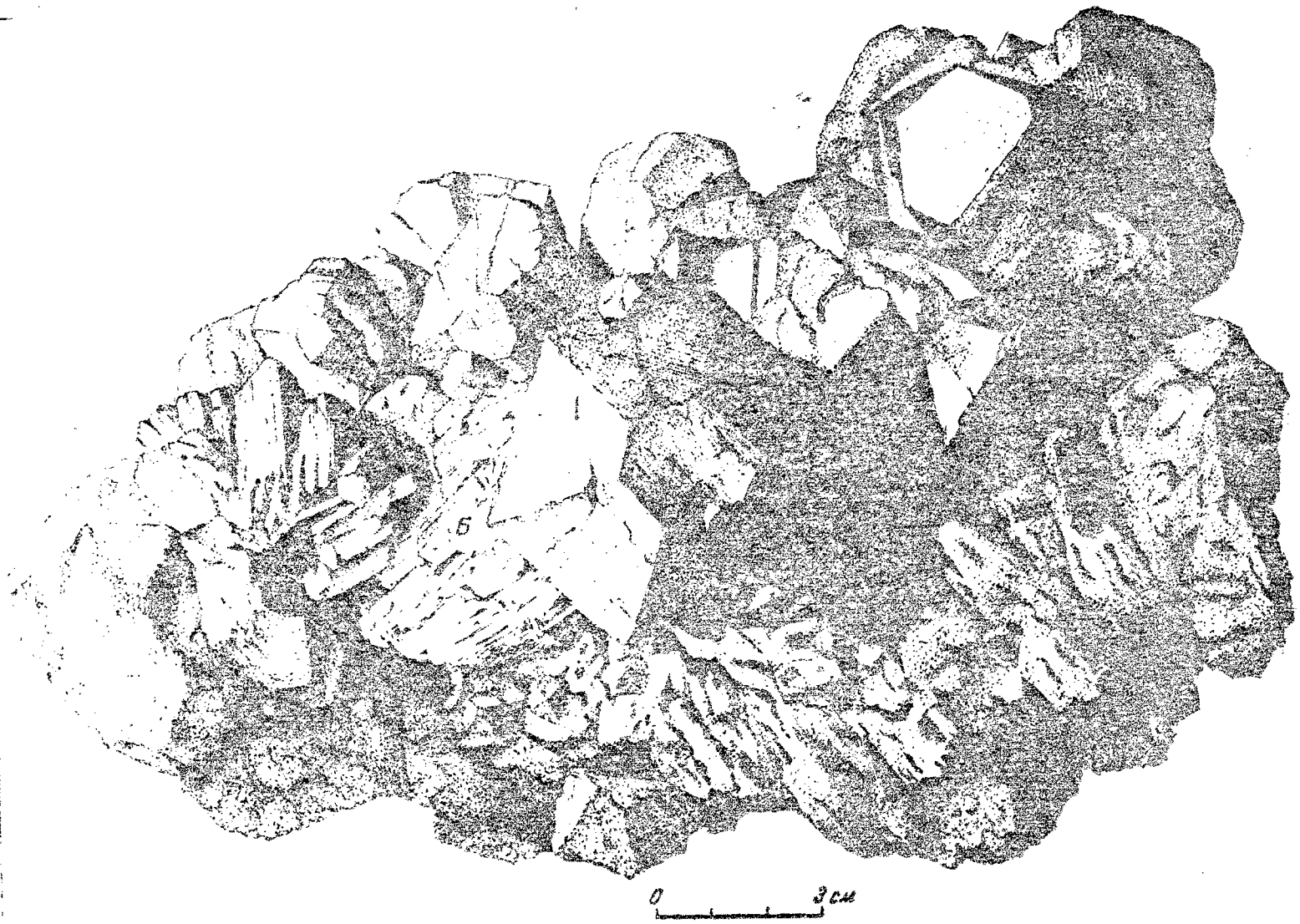


Fig. 78. Alexandrite Crystal Group. Б - beryl

plagioclase, and beryl. It segregates earlier in time than flucrite, beryllium-containing margarite, apatite, phlogopite, and chlorite, while later than beryl (Fig. 79) and tourmaline.

Chrysoberyl and alexandrite form under conditions of relative concentration of the molten alumina solution, as borne out by their close association with chlorite and beryllium-containing margarite.

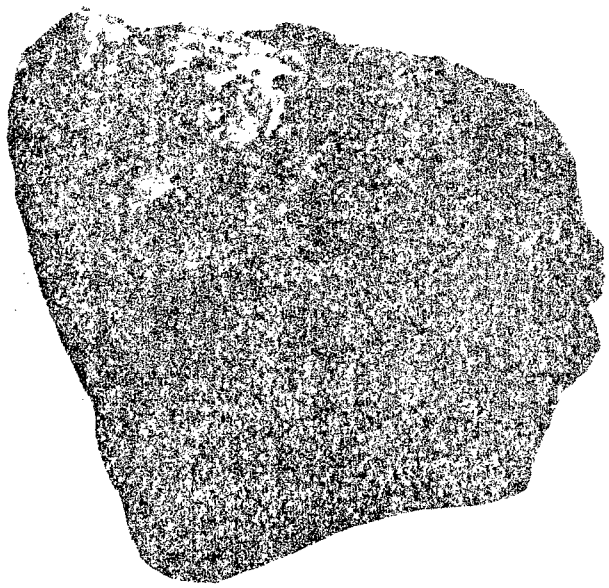


Fig. 79. Crystal of beryl (Б) in alexandrite (Ал). Magnified 2 times.

28. BAVENITE

A mineral was discovered at the Emerald Mines in 1939 by Ye. T. Kutukova (1946) which, although very closely related to bavenite in physical and optical properties and chemical composition, did nonetheless differ from Californian bavenite (Schaller, Fairchild, 1932) by a significantly greater beryllium oxide content (6.60% BeO instead of 2.67%). This particular discrepancy in beryllium oxide was explained by the complexity of separating beryllium and aluminum and the inaccuracy of previous methods, all the more so since the sum total of oxides of these elements in both analyses was nearly identical (see Table 62, analyses 1, 4). Rowledge and Hayton (1948), while studying this mineral from deposits in Londonderry (Western Australia) which is close in physical and optical properties to bavenite although contains an increased amount of beryllium oxide (7.14 - 7.72% BeO), presumed it to be a new mineral and called it duplexite. Fleischer and Switzer (1953), knowing from the literature that bavenite from the Emerald Mines contains 6.60% BeO, doubted the correctness of classifying this mineral as an independent species. They undertook repeated chemical investigations of bavenite samples from previously known deposits, as well as analyzing several samples from new sections. No great variations in beryllium oxide content were discovered and it seemed apparent that in the early analyses a part of the beryllium oxide had been taken for aluminum oxide. Thus, in bavenite from Mesa Grande (Schaller, Fairchild, 1932) which was analyzed by Fairchild (2.67% BeO) there was found to be 7.66% (see Table 62, anal.5). On the basis of these data they came to the conclusion that the mineral from the Londonerry deposit, described by Rowledge and Hayton as duplexite, should be classified as bavenite according to its physical and optical properties and beryllium oxide content, which was also indicated by comparison of X-ray plates of duplexite and bavenite.

Bavenite from the Emerald Mines is found in the form of radial columnar spherolites (Fig. 80), radiating segregations (Fig. 81) and rosettes consisting of bunches of felted parallel fine laminae . The size of the segregation usually varies from 0.4 x 0.6 to 1 x 1.2 cm, in rare instances going up to 3.5 x 4 cm. The color is white, sometimes with a faint greenish tint. The streak

is white. The luster is silky. Cleavage along (100) is good. It is brittle. The hardness is 5 - 6. Specific weight is 2.733. It is colorless in section, with well marked cleavage. It is optically biaxial and positive. Elongation is positive. The refraction indices and angle of optical axes in bavenite are presented in Table 60. The interplanar spaces measured with debayegrams in bavenite from the Emerald Mines and from Baveno (Italy)* are almost similar (Table 61).

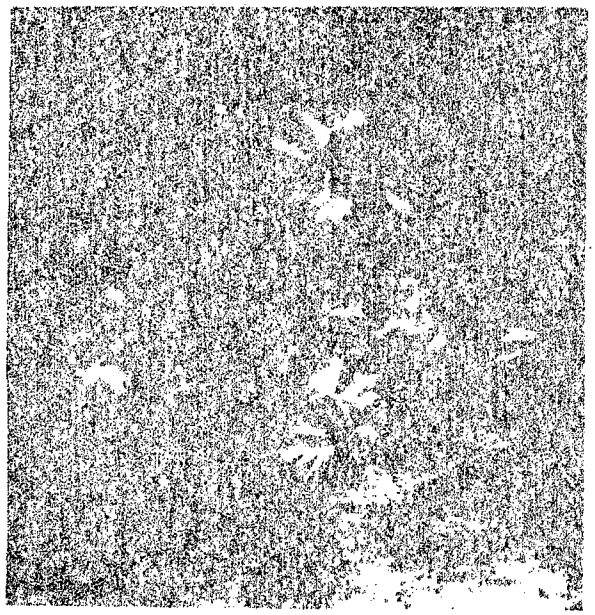


Fig. 80. Radial Columnar Spherolites of Bavenite (Бб). Magn. 2 x.

Table 60

Optical Properties of Bavenite

Place of origin	Ng	Nm	Np	Ng-Np	2V	Author
Emerald Mines	1,593	1,588	1,586	0,007	60	Ye.I.Kutukova (1946)
Baveno, Italy	—	1,589	—	—	47	Artinin (1901)
Mesa-Grande, Calif.	1,589	1,581	1,579	0,010	58	Schaller, Fairchild (1932)
Muotta Nera, Switz.	1,589	—	1,583	0,006	—	Claringbull (1940)
Londonderry, Western Australia	1,593	—	1,582	0,011	22	Rowledge and Hayton (1948)

* Materials from the collection of the Mineralogical Museum, Moscow Geological-Prospecting Institute.

The heating curves of bavenite attest to the fact that high temperature water is in it and is separated in the range of 890° - 950° (Fig. 82).

As a supplementary finding through spectral analysis of the bavenite one discovered: magnesium (0.05%), germanium (0.01%), gallium (0.001%), strontium (0.0025%) and copper (0.0005%). In one of the bavenite samples, S. N. Fedorchuk established 7.6% beryllium oxide content.

Fig. 81. Radial Segregations of Bavenite (Бβ). Magnified 2 x.

The first chemical formula for bavenite proposed by Artini (Table 62, anal. 3) has the following form: $6SiO_2 \cdot Al_2O_3 \cdot 3CaO \cdot H_2O$. Fairchild (anal.4), having discovered 2.67% BeO in the bavenite from California gave a new formula: $9SiO_2 \cdot Al_2O_3BeO \cdot 4CaO \cdot H_2O$.

Fleischer and Switzer's recalculation of the analysis of bavenite from California (Table 62, anal. 5) for O = 26 has led to the following formula $Ca_{4.11}Be_{2.95}Al_{1.22}Si_{9.22}O_{26} \cdot 1.90H_2O$.

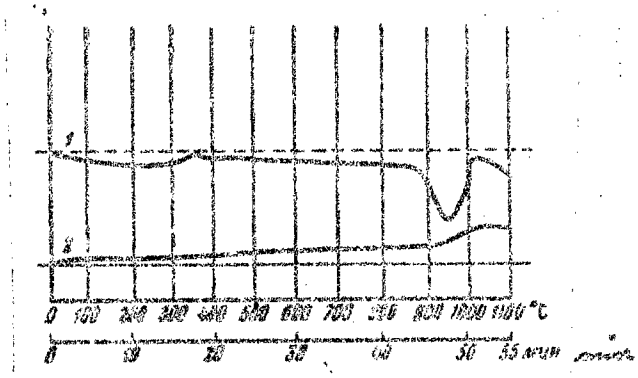


Fig. 82. Heating (1) and Weight Loss (2) Curves of Bavenite.

The bavenite from the Emerald Mines was analyzed twice, the material having been selected from one and the same sample. The findings (Table 62, anal.1 and 2) turned out to be very close. The aluminum and beryllium oxides precipitations were analyzed by the spectral method to check on the purity of the separation; the analysis showed good results.

Recomputations of the analyses of bavenite from the Uralian Emerald Mines produce the following formulas:

Analysis 1. $Ca_{4,0}Be_{2,44}Al_{1,74}Fe^{\cdot\cdot\cdot}_{0,01}[Si_{8,78}B_{0,08}O_{25,76}](OH)_{1,91}$

Analysis 2. $Ca_{4,0}Be_{2,38}Al_{1,79}Fe^{\cdot\cdot\cdot}_{0,01}[Si_{8,78}B_{0,08}O_{25,76}](OH)_{1,94}$

Bavenite tends to occur in the plagioclase part of the desiliconized pegmatites. It is formed as a result of hydrothermal changes in beryl. In this process a part of the beryllium becomes bound in bavenite and beryllium-containing microcline at the site of the

Table 61

Interplaner Spaces of Bavenite

(Cu = radiation 2R = 57,3, d = 0,6 мм)

No. of lines	Emerald Mines		Baveno, Italy	
	I	d	I	d
1	2	4,93	1	4,87
2	2	4,08	—	—
3	1	3,91	2	3,92
4	1	3,81	—	—
5	10	3,68	10	3,75
6	1	3,59	—	—
7	10	3,33	7	3,36
8	10	3,21	6	3,19
9	3	3,10	4	3,12
10	4	3,00	3	3,00
11	2	2,81	3	2,84
12	1	2,76	—	—
13	1	2,64	—	—
14	7	2,54	3	2,57
15	2	2,47	2,5	2,49
16	2	2,39	3	2,41
17	5	2,29	1,5	2,28
18	1	2,22	1,5	2,24
19	1	2,17	—	—
20	2	2,12	—	—
21	3	2,07	2,5	2,09
	3	2,05	—	—
22	1	2,00	4	1,98
23	4	1,96	4	1,94
24	6	1,92	—	—
25	4	1,86	3	1,87
26	3	1,82	3	1,82
27	1	1,79	3	1,77
	3	1,75		
28	9	1,73	5	1,73
29	1	1,68	1,5	1,68
30	1	1,67	—	—
31	9	1,65	2,5	1,65
32	1	1,64	1,5	1,62
33	1	1,60	1,5	1,59
	1	1,58	—	—
34	5	1,562	3	1,569
35	1	1,535	1	1,533
36	1	1,509	—	—

Emerald Mines **Beveno, Italy**

No. of lines

37	2	1,482	2	1,483
38	—	—	1	1,457
39	2	1,449	—	—
40	2	1,376	—	—
	3	1,373	—	—
41	1	1,345	1	1,349
42	8	1,319	3	1,321
43	5	1,300	2	1,301
44	2	1,285	—	—
45	2	1,270	—	—
46	4	1,247	3	1,249
47	1	1,207	—	—
	1	1,192		
48	4	1,178	1	1,182
49	—	—	1	1,163
50	3	1,152	1	1,155
51	1	1,141	—	—
52	1	1,130	—	—
53	1	1,108	1	1,111
54	5	1,086	1,5	1,090
55	5	0,071	1,5	1,074
56	6	1,050	1,5	1,053
57	1	1,033	—	—
58	3	1,021	1	1,023
59	1	1,010	—	—
60	4	1,000	1	1,001
61	3	0,983	1	0,985
62	—	—	1	0,976
63	4	0,963	1	0,969
64	1	0,949	—	—
65	2	0,940	—	—
66	3	0,932	1	0,930
67	1	0,916	1	0,915
68	2	0,901	1	0,902
69	3	0,887	—	—
70	2	0,838	—	—
71	2	0,834	—	—
72	2	0,829	1	0,837
73	2	0,823	—	—
74	—	—	0,5	0,817

reaction, while a considerable portion of it is carried off and deposited in the form of the same kinds of new formations in the crevices and hollows of beryl, plagioclase, muscovite in association with fluorite, tabular-prismatic albite and fine-scale mica. Moreover, the radial columnar precipitations of bavenite with epidote, sphene, ferruginous prochlorite (ripidolite) are found in thin plagioclase streaks which cut through amphiboles and serpentine.

Fig. 83. Replacement of Beryl (B) with Bavenite (B_B). Magnif. 20 x. Nic.+.

The most characteristic bavenite associations are with beryl, plagioclase (No.31), fluorite, corundophilite, muscovite, albite, beryllium-containing microcline. Bavenite is later in precipitation time than all the minerals associated with it, with the exception of ripidolite, later than albite and epidote which grow on the segregation of bavenite. Frequently, the bavenite crystallizes about spherolites of corundophilite

Компоненты (8)	Изумрудные Копи (1)								Италия, Баваро, вн. 3	Калифорния, Мета-Гранде	
	вн. 1 (4)				вн. 2 (5)					вн. 4 (6)	вн. 5 (7)
	вес. % (9)	атомные количества катионов (10)	атомные количества кислорода (11)	атомные количества катионов, рассчитанные на Ca_4 (12)	вес. % (13)	атомные количества катионов (14)	атомные количества кислорода (15)	атомные количества катионов, рассчитанные на Ca_4 (16)	вес. % (17)	вес. % (18)	вес. % (19)
SiO_2	57,11	0,9509	1,9018	8,78	57,26	0,9532	1,9064	8,78	56,83	58,40	57,64
TiO_2	—	—	—	—	0,00	—	—	—	—	—	—
Al_2O_3	9,60	0,1884	0,2826	1,74	9,89	0,1940	0,2910	1,79	15,42	12,15	9,46
Cr_2O_3	—	—	—	—	0,00	—	—	—	—	—	—
Fe_2O_3	0,11	0,0014	0,0021	0,01	0,10	0,0012	0,0018	0,01	—	0,10	—
FeO	—	—	—	—	0,07	—	—	—	—	—	—
BeO	6,00	0,2639	0,2639	2,44	6,33	0,2531	0,2531	2,33	—	2,67	7,08
MnO	—	—	—	—	Сл.	—	—	—	—	—	—
MgO	—	—	—	—	0,00	—	—	—	0,42	—	—
CaO	24,30	0,4333	0,4333	4,00	24,35	0,4342	0,4342	4,00	24,47	23,73	23,66
K_2O	—	—	—	—	0,00	—	—	—	—	—	—
Na_2O	—	—	—	—	0,00	—	—	—	0,29	—	—
B_2O_3	0,31*	0,0088	0,0132	0,08	0,31	0,0088	0,0132	0,08	—	—	—
H_2O^+	1,87		0,1038		1,00		0,1055		2,43	2,90	3,86***
Сумма (32)	99,90		3,0007		100,13		3,0052		99,73	99,93	99,60
Уд. вес (30)	2,733								2,73	(31)	(4)
Аналитик (32)	В. С. Салтыкова (33)				М. Е. Казакова					Фершейлд	Корнов
Литературный источник (34)	Е. И. Кутукова (1946) (28)								Artini (1901)	Schuller, Fairchild (1952)	Fleischer, Switzer (1953)

* Бор определялся из отдельной навески химиком М. Е. Казаковой. (29)
** Анализы 4 и 5 производились из одного образца.
*** Потеря при прокаливании и H_2O.

Table 67

Table 62

The Chemical Composition of Bavenite

1. The Emerald Mines
2. Baveno, Italy, analysis 3
3. Mesa Grande, California
4. Analysis 1
5. Analysis 2
6. Analysis 4 **
7. Analysis 5
8. Components
9. Weight %
10. Atomic quantities of cations
11. Atomic quantities of oxygen
12. Atomic quantities of cations, calculated for Ca_4
13. Weight%
14. Atomic quantities of cations
15. Atomic quantities of oxygen
16. Atomic quantities of cations, calculated for Ca_4
17. Weight %
18. Weight %
19. Weight %
20. Sum
21. Spec.wt.
22. Analyst
23. V. S. Saltykova
24. M. Ye. Kazakova
25. Fairchild
26. Carron
27. Literature source
28. Ye. I. Kutukova (1946)
29.

* Boron was determined from a separate sampling by the chemist, M. Ye. Kazakova.

** Analyses 4 and 5 were made from one sample.

*** Losses in roasting and H_2O.

in close association with fine (up to 1.5 m [mm ?] colorless or faintly violet crystals of fluorite and late transparent albite.

The replacement of beryl with bavenite and beryllium containing microclase proceeds along the system of irregular cracks; when the process has gotten far underway this network of fissures becomes concentrated, and the beryl is either completely replaced or sustained in the form of insignificant relicts amidst the bavenite (Fig. 8). Occasionally one sees the pseudomorphism of bavenite and beryllium-containing microcline after beryl. During later stages in the hydrothermal process bavenite is substituted by bertrandite.

29. BERTRANDITE

Bertrandite is found as an accessory mineral in gross line pegmatites and in pneumatolytic-hydrothermal veins. It is noted somewhat less often in pure line

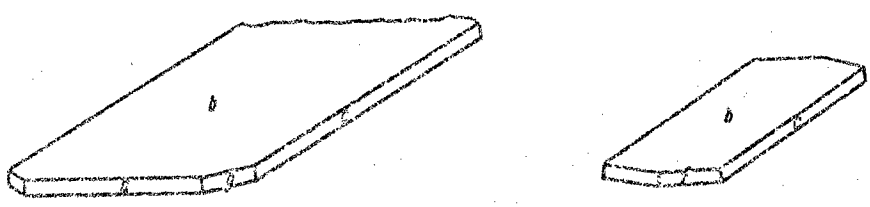


Fig. 84. Bertrandite Crystals

pegmatites. Bertrandite crystals are very tiny (0.5 x x 2.0 x 3.0 mm) and display a plate form. Sometimes prismatic crystals are discovered, forming aggregates 0.5 x 0.8 x 1.0 cm in size.

In view of the friability of the mineral, well preserved crystals are very rarely met with. Measuring the platy crystals, the following forms were discovered (Fig. 84; indices presented according to V. M. Goldschmidt): a(100), b(001), c(010), g(110) and f(130). The faces (010), (110), (130) are very narrow and

ordinarily produces poor signals. Face (001) is often dull and in certain sections strongly pitted.

The mineral is colorless, water-transparent, becoming milky white upon decaying. The luster is glassy, sometimes pearly. Cleavage along (001) is perfect, along (010) good. It is colorless in section. Optically biaxial, negative. Refraction indices: Ng = 1.614, Nm = 1.606, Np = 1.592, Ng - Np = 0.022; 2V = 74°. The sign of the principal zone is negative. Computation of the debayegram of bertrandite is presented in Table 63.

Table 63

Interplanar Spaces in Bertrandite

(Cu radiation, 2R = 57,3 мм, d = 0,6 мм)

No. of lines

№ линий	J	d	№ линий	J	d
1	1,5	5,177	26	3	1,170
2	1,5	4,881	27	1	1,145
3	4	4,655	28	3	1,120
4	7	4,375	29	1	1,105
5	3	3,934	30	1	1,090
6	1	3,828	31	2	1,075
7	2,5	3,510	32	1,5	1,055
8	5	3,321	33	1	1,039
9	10	3,174	34	1	1,014
10	5	2,600	35	1	1,003
11	6	2,527	36	0,6	0,939
12	5	2,285	37	1	0,898
13	7	2,220	38	2	0,858
14	2,5	2,028	39	1	0,842
15	4	1,981	40	2	0,836
16	2	1,790	41	1,5	0,827
17	2,5	1,699	42	1	0,819
18	2	1,652	43	1	0,8114
19	4	1,554	44	0,6	0,8094
20	5	1,463	45	3	0,802
21	1,5	1,362	46	1	0,798
22	2,5	1,341	47	0,6	0,791
23	7	1,305	48	1	0,788
24	2,5	1,250	49	0,6	0,782
25	3,5	1,218	50	1	0,77

A recomputation of the findings of chemical analysis of bertrandite (Table 64) boils down to the usual formula $Be_4[Si_2O_7][OH]_2$. Iron and calcium are present as admixtures in it.

The spectral method has determined in bertrandite, in addition to the findings of chemical analysis: germanium (0.005%), manganese (0.001%) and magnesium (0.0005%).

Partial chemical analysis of the transparent platy crystals of bertrandite from the kaolinized part of desiliconized pegmatites veins has shown the following results (in percentages): SiO_2 48.99, BeO 41.97, H_2O 8.07.

The water in bertrandite is, as shown by thermal investigation, of the high temperature type and separates within the range of 875 - 1000° (Fig. 85).

Bertrandite develops in the late hydrothermal stage after beryl and in certain instances after bavenite (Fig. 86). Bertrandite crystals ordinarily fill the hollows which form as a result of the leaching of beryl and bavenite in plagioclase cores in desiliconized pegmatites. In intensively kaolinized plagioclases one often observes pseudomorphs of bertrandite and beryllium-containing microcline after beryl. In these cases the

Table 64

Chemical Composition of Bertrandite from Muscovite-Fluorite Lenses in Desiliconized Pegmatites

Components	Weight %	Atomic quantities of cations	Atomic quantities of oxygen	Atomic quantities of cations, calculated for (O,OH)$_4$
SiO_2	50.93	0,8480	1,6960	2,03
TiO_2	0,00	—	—	—
Al_2O_3	Сл.	—	—	—
Fe_2O_3	0,14	0,0018	0,0027	0,00
FeO	0,00	—	—	—
BeO	40,83	1,6324	1,6324	3,91
MgO	0,00	—	—	—
CaO	0,68	0,0121	0,0121	0,03
H_2O^+	7,46	0,8282	0,4141	1,99
H_2O^-	0,14	—	—	—
Sum	100,18		3,7573	

Analyst and year of Research: M. Ye. Kazakova, 1957

beryl crystals embedded in the kaolin matrix have a milky white color and easily break with slight pressure.

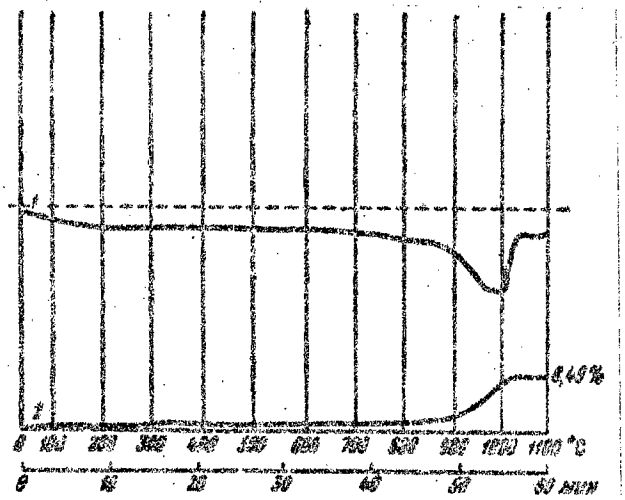


Fig. 85. Heating (1) and weight loss (2) curves of bertrandite.

Besides, bertrandite is seen in the kaolin matrix as well formed flat crystals which sometimes gather in paralel aggregates. In those cases, where the bertrandite has formed with bavenite, unique reticular segregations develop; when studied under the microscope it has been discovered that they consist of flakes of bertrandite and fine-scale mica.

Somewhat less often bertrandite is found in muscovite-fluorite lenses in desiliconized pegmatites, as well as in albite-quartz and muscovite-albite pneumatolytic-hydrothermal veins. It is represented by fine prismatic crystals or aggregates of crystals (up to 1.0 cm across) which have grown on the corroded faces of beryl or on the walls of hollows formed as a consequence of its having been leached.

In pure line pegmatites bertrandite develops rather less often on beryl.

The most usual bertrandite associations are with plagioclase (No. 28 - 38), beryl, bavenite, albite, fluorite and corundophilite. In relation to these minerals bert andite forms later.

The flat bertrandite crystals stemming from kaolinized plagioclase lenses in desiliconized pegmatites are sometimes somewhat altered, this being expressed in turbidity and the appearance of milky white color. These

alterations in the bertrandite are connected with their increased water content and the presence of a considerable amount of calcium, previously noted by P. P. Pilipenko at Tigeretskiye Belki deposits (1915) and F. V. Chukhrov and N. N. Smol'yanin at the North Koundradskiy deposit (1956).

Fig.86. Development of Bertrandite (Be) on Beryl (Б) and Bavenite (БВ). Magnif. 35 x. Without an analyzer.

30. BERYLLIUM-CONTAINING MARGARITE

Margarite (diphanite) has been described very briefly by A. Ye. Fersman(1925); this beryllium mineral was not mentioned in the chemical analyses presented. The beryllium oxide content (1.88 - 3.26%) in margarite from the Emerald Mines distinguishes it substantially from the other margarite varieties in deposits in the USSR (Afanas'yev and Aydin'yan, 1952; Ginzburg, 1955) and in foreign countries (Koch, 1934 - 1935). Nevertheless, A. I. Ginzburg did note that an increased amount of beryllium was contained in margarite from Postmasburg (South Africa) according to spectral analyses.

At the Emerald Mines margarite is found in cross-line pegmatites and in pneumatolytic-hydrothermal formations in the quality of an accessory mineral. It is seen as a finely scaled dense mass and mutually intersecting

flakes which form apophyses up to 5-6 cm and rosettes up to 1.5 x 1.8 cm. On occasion margarine is seen as tabular crystals 0.5 x 1 x 1.5 cm in size. The color is pearly white, grayish blue, bluish green and light brown. Cleavage is perfect along (001). It has a pearly luster at the base line, glassy at the fracture. It is transparent to semitransparent. The hardness is 4.0 - 4.5. Specific weight 3.037 - 3.07. It is colorless in section. It is biaxial, negative; 2V = 63°. The index of refraction : Ng = 1.646, Nm = 1.643, Ng = 1.632, Ng - Np = 0.014. Extinction in sections perpendicular to (010) inclining 6°.

The interplanar spaces in margarites with different colors (light brown, bluish green and pearly white) calculated from debayegrams were nearly identical (Table 65). The heating curves of these varieties of beryllium margarite were characterized by a single sharply expressed endothermic reaction in the 900-960° temperature range, connected with the removal of water (Fig.87).

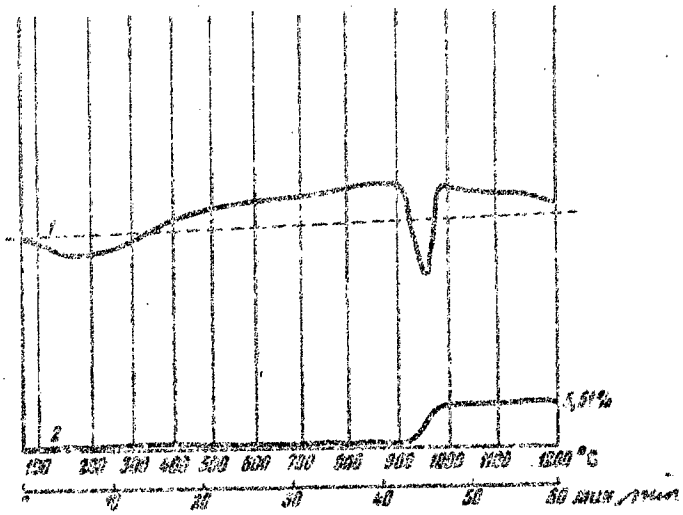


Fig. 87. Heating (1) and weight loss (2) curves of margarite.

Recalculation of the findings of chemical analyses of margarite (Table 66) produce the following formulas:

Analysis 1. $(Ca_{0,95}Na_{0,07}K_{0,02})_{1,04}(Li_{0,20}Mg_{0,06})_{0,26}(Al_{2,06}Fe^{\cdots}_{0,02})_{2,08}$
$[Al_{1,48}Be_{0,52}Si_{2,00}O_{10}][O_{0,93}OH_{1,77}F_{0,20}]_{2,0}$

Analysis 2. $(Ca_{0,94}Na_{0,14}K_{0,04})_{1,12}(Li_{0,19}Mg_{0,10})_{0,29}(Al_{1,89}Fe^{\cdots}_{0,01}Cr_{0,02})_{1,92}$
$[Al_{1,09}Be_{0,30}Si_{2,01}(O_{0,92}OH_{0,08})_{10}][OH_{1,63}F_{0,37}]_{2,0}$

Analysis 3. $(Ca_{0,98}Na_{0,08}K_{0,01})_{1,07}(Li_{0,09}Mg_{0,08})_{0,17}(Al_{2,06}Fe^{\cdots}_{0,01})_{2,07}$
$[Al_{1,54}Be_{0,42}Si_{2,04}O_{10}][O_{0,13}OH_{1,59}F_{0,28}]_{2,0}$

In contradistinction to ordinary margarite, the silicon in tetrahedrons of the margarite analyzed coming from the Uralian Emerald Mines was not only replaced by aluminum, but by beryllium as well; compensation in the valency is then achieved by the replacement of oxygen by fluorine or the hydroxyl group.

Precipitated beryllium oxide (Table 66, analysis 2, 3) was analysed by the spectral method which showed the presence of foreign substances totaling not more than 0.1%. Spectroscopic determination revealed in the margarite: strontium (0.005 - 0.05%), nickel (0.005 - 0.05%), titanium (0.05%), vanadium (0.005%), gallium (0.001 - 0.005%), copper (0.0005 - 0.0025%) and tin (0.001%). A comparison of the findings of chemical and spectral analyses of the different margarite varieties has shown that only insignificant variations are observed in their beryllium oxide content. Chromium (0.4%) and nickel (0.25%) are present in the bluish green margarite, which is apparently responsible for the green coloration.

In cross line pegmatites margarite occurs chiefly in the phlogopite zones and at their contacts with plagioclase bodies. It is not found in pure line pegmatites. In the phlogopite zone margarite is represented by tabular segregations (0.3 x 1 x 1.5 cm) of light brown and grayish blue color (Fig. 88), as well as by foliates of a pearly white hue which sometimes make up streaks (Fig. 89). It is associated with tourmaline, fluorite, apatite and chlorite. At the contact between plagioclase and the phlogopite zone, the pearly white margarite variety forms fringes up to 5 - 6 cm thick which are composed of finely scaled massive deposit or foliations (up to

Table 65

Interplanar Spaces in Different Margarite Varieties

(Cu irradiation, 2R = 2R = 57 3 мм, d = 0,6 мм)

No.of lines	Light brown		Bluish green		Pearly white	
	J	d	J	d	J	d
1	1	5,003	—	—	—	—
2	2	4,439	2,5	4,47	2,5	4,45
3	1,5	3,758	1,5	3,77	2	3,77
4	8	3,152	9	3,18	9	3,15
5	1	2,977	3,5	3,02	3,5	2,98
6	3	2,883	6	2,89	6	2,89
7	4	2,770	6	2,77	6	2,76
8	3	2,676	5	2,68	—	—
9	7	2,543	6	2,53	5	2,53
10	8	2,398	5	2,41	6	2,40
11	2,5	2,161	3	2,16	5	2,16
12	1,5	2,108	3	2,11	—	—
13	5	2,074	4,5	2,07	5	2,07
14	6	1,910	7,5	1,91	10	1,90
15	—	—	1,5	1,76	—	—
16	3	1,655	4	1,66	5	1,659
17	5	1,584	5	1,60	8	1,589
18	—	—	7,5	1,91	—	—
19	—	—	1,5	1,76	—	—
20	—	—	2,5	1,66	—	—
21	—	—	5	1,597	—	—
22	10	1,464	10	1,465	10	1,462
23	2	1,329	2	1,366	4	1,328
24	2,5	1,290	3	1,295	5	1,289
25	—	—	2,5	1,271	5	1,267
26	1	1,242	2,5	1,251	4	1,241
27	1,5	1,215	2,5	1,222	5	1,216
28	1	1,183	—	—	2	1,178
29	2	1,160	2	1,163	4	1,160
30	1	1,099	1	1,100	1,5	1,096
31	1	1,076	1,5	1,081	3	1,078
32	1,5	1,035	1,5	1,036	2	1,032
33	1,5	1,006	1,5	1,006	1	1,007
34	1	0,945	1	0,947	2	0,943
35	1	0,916	0,5	0,917	1	0,915
36	2	0,867	—	—	2,5	0,877
37	2,5	0,845	2	0,847	3	0,846
38	1	0,797	2	0,784	2	0,797

Компоненты	Светло-коричневый (обр. 1)*				Голубовато-зеленый (обр. 2)				Жемчужно-белый (обр. 3)			
	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на (O, OH)12	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на (O, OH)12	вес. %	атомные количества катионов	атомные количества кислорода	атомные количества катионов, рассчитанные на (O, OH)12
SiO_2	30,44	0,5068	1,0136	2,00	30,16	0,5021	1,0042	2,04	30,88	0,5141	1,0282	2,04
TiO_2	Сл.	—	—	—	Необн.	—	—	—	Сл.	—	—	—
Al_2O_3	45,58	0,8938	1,3407	3,54	45,59	0,8944	1,3416	3,56	46,22	0,9068	1,3602	3,60
Cr_2O_3	Необн.	—	—	—	0,40	0,0052	0,0078	0,02	—	—	—	—
Fe_2O_3	0,38	0,0048	0,0072	0,02	0,13	0,0016	0,0024	0,01	0,37	0,0046	0,0069	0,01
BeO**	3,26	0,1303	0,1303	0,52	1,88	0,0752	0,0752	0,30	2,67	0,1067	0,1067	0,42
MnO	Сл.	—	—	—	Сл.	—	—	—	—	—	—	—
MgO	0,67	0,0166	0,0166	0,06	1,06	0,0263	0,0263	0,10	0,87	0,0216	0,0216	0,08
CaO	13,43	0,2404	0,2404	0,95	13,18	0,2350	0,2350	0,94	13,90	0,2479	0,2479	0,98
BaO	0,04	0,0003	0,0003	0,00	Необн.	—	—	—	—	—	—	—
K_2O	0,25	0,0054	0,0027	0,02	0,52	0,0110	0,0055	0,04	0,21	0,0044	0,0022	0,01
Na_2O	0,57	0,0184	0,0092	0,07	1,08	0,0348	0,0174	0,14	0,70	0,0226	0,0113	0,08
Li_2O	0,78	0,522	0,0261	0,20	0,72	0,0482	0,0241	0,19	0,36	0,0241	0,0120	0,09
P_2O_5	Необн.	—	—	—	Необн.	—	—	—	—	—	—	—
S	0,11	—	—	—	» »	—	—	—	—	—	—	—
Cl	0,20	—	0,0028	—	0,13	—	0,0028	—	—	—	—	—
F	0,82	—	0,0216	—	1,64	—	0,0432	—	1,35	—	—	0,28
H_2O^+	3,98	—	0,2209	—	3,80		0,2109	—	3,40	—	—	1,59
H_2O^-	0,32	—	—	—	0,70	—	—	—	0,04	—	—	—
Сумма	100,86		3,0324		100,99		2,9954		100,97		3,0212	
$O = -F_2$	—0,35				—0,69				—0,55			
	100,51				100,30				100,42			
Уд. вес	3,057				3,077				3,057			
Аналитик	Л. Б. Тумилович								М. Е. Казакова			

* Обр. 1 и 3 взяты из флогопитовой зоны пегматитов линии скрещения, обр. 2 — из оторочки, развитой на контакте линз хромитовой и мусковит-флюоритовой залегающих в серпентинитах.

** Бериллий определен химиком С. Н. Федорчук (обр. 1) и М. Е. Казаковой (обр. 2).

***

****

Table 66

Table 66

Chemical Composition of Beryllium-Containing Margarite

1. Light brown (sample 1)*
2. Bluish green (sample 2)
3. Pearly white (sample 3)
4. Components
5. Weight %
6. Atomic quantities of cations
7. Atomic quantities of oxygen
8. Atomic quantities of cations, calculated for $(O, OH)_{12}$
9. Sum
10. Spec. wt.
11. Analyst
12. L. V. Tumilovich
13. M. Ye. Kazakova
14. * Samples 1 and 3 were taken from the phlogopite zone of cross line pegmatites, sample 2 from fringes which had developed at the contact between lenses of chromite and muscovite-fluorite embedded in serpentine.

    ** Beryllium was determined by the chemists, S. N. Fedorchuk (sample 1) and M. Ye. Kazakova (sample 2).

    *** Not found

    **** Trace

Fig. 88. Tabular Crystals of Margarite (Mp) in Phlogopite Schist

Fig. 89. Fringes of Finely Scaled Margarite (Mp) at the Contact between the Phlogopite Zone (ΦΛ) and Plagioclase (ΠΛ). Natural size.

0.8 x 1.0 cm) sometimes oriented along the cleavage foliation of the phlogopite zone, sometimes perpendicular to it. Occasionally pearly white margarite occurs in the plagioclase body and in the chlorite zones in association with apatite and platy bhrysoberyl. At one of the sections along the contact between chromite and muscovite-fluorite lenses a bluish green margarite variety was found, made up of thin (1 - 2 cm) fringes.

In pneumatolytic-hydrothermal veins margarite is encountered considerably less frequently. Two varieties occur here, the pearly white and light brown. Pearly white margarite forms thin fringes (1 - 2 cm) in albite quartz and muscovite albite veins at the contact between the albite zone and phlogopite. Its light brown variety is seen in the form of thin tabular precipitations (0.3 x x 0.4 cm) in the phlogopite zone of muscovite-albite veins together with fluorite. The most characteristic paragenesis of margarite: phlogopite, plagioclase, fluorite, apatite, chrysoberyl and tourmaline. Its precipitation time is later than the above listed minerals. Margarite is formed either during the late stages of the pegmatite process or at the pneumatolytic-hydrothermal stage and under conditions where the molten solution is enriched with aluminum and deprived of silicon dioxide and alkalis.

COLUMBIUM, TANTALUM, MOLYBDENUM, TITANIUM AND ZIRCONIUM MINERALS

31. Columbite

Columbite from the Uralian Emerald Mines appears as a secondary mineral. It is found in the form of tabular or short columnar crystals. According to A. Ye. Fersman (1925) the following forms occur among them (in a Bregger unit): (100), (010), (001), (111), (201) and narrow faces (110). The size of the crystals varies from very small to 1.2 x 1.5 x 3.5 cm, in individual case up to 3.5 x x 5.0 x 6.0 cm. Sometimes they are fissured and filled with albite and muscovite. Brownish yellow halos are ordinarily found around the columbite, thanks to which they are readily recognized in fine segregations amidst potash feldspar and albite. The specific weight is 6.06.

Recalculation of the results of chemical analyses of columbite (Table 67) have produced the following formulas:

Analysis 1. $(Fe^{\cdot\cdot}_{0,30}Mn_{0,53})_{1,01}(Nb_{1,31}Ta_{0,55}Ti_{0,01})_{2,03}O_6$

Analysis 2. $(Fe^{\cdot\cdot}_{0,12}Mn_{0,85}Mg_{0,01}Ca_{0,01})_{1,01}(Nb_{1,60}Ta_{0,22}Ti_{0,02}Al_{0,02})_{2,0}O_6$

Columbium, tantalum and titanium, as well as iron and manganese in the columbite are isomorphically replaced by one another. The same columbite samples underwent spectroscopic analysis (Table 68). The findings showed the identical composition of admixtures in both samples.

Columbite is a typical mineral of pure line pegmatites; its most significant accretions occur in perfectly differentiated and block pegmatites which occur in rocks of metamorphic strata.

In fully differentiated and block pegmatites, columbite is represented by large crystals up to

Table 67

1 Компоненты	Колумбит 2				Колумбит-танталит 3			
	4 вес. %	5 атомные количества катионов	6 атомные количества кислорода	7 атомные количества катионов, рассчитанные на O_6	4 вес. %	5 атомные количества катионов	6 атомные количества кислорода	7 атомные количества катионов, рассчитанные на O_6
Nb_2O_5	43,69	0,3288	0,8220	1,31	33,00	0,2482	0,6205	1,03
Ta_2O_5	37,47	0,1696	0,4240	0,68	49,00	0,2218	0,5545	0,92
SiO_2	Нет 8	—	—	—	0,05	0,0008	0,0016	—
TiO_2	0,29	0,0036	0,0072	0,01	0,36	0,0045	0,0090	0,02
Al_2O_3	—	—	—	—	0,35	0,0068	0,0102	0,03
FeO	10,42	0,1457	0,1457	0,58	2,92	0,0406	0,0406	0,17
BeO	—	—	—	—	0,0054	0,0002	0,0002	—
MnO	7,64	0,1073	0,1073	0,43	14,50	0,2044	0,2044	0,85
MgO	—	—	—	—	0,03	0,0015	0,0015	0,01
CaO	—	—	—	—	0,08	0,0014	0,0014	0,01
TR_2O_3	—	—	—	—	0,03	0,0002	0,0003	—
WO_3	Нет 8	—	—	—	—	—	—	—
Сумма 9	99,48		1,5002		100,36		1,4442	
Уд. вес 10	6,061							
Аналитик и год исследования 11	Т. А. Бурова, 1945 12				М. В. Кукарчик, 1956 13			

Примечание. Образец колумбита взят из среднезернистых пегматитов чистой линии, колумбит-танталита — из пегматитов полидифференцированного типа. 14

Chemical Composition of Columbite

1. Components
2. Columbite
3. Columbite-tantalite
4. Weight %
5. Atomic quantities of cations
6. Atomic quantities of oxygen
7. Atomic quantities of cations, calculated for O_6
8. Not discovered
9. Sum
10. Specific weight
11. Analyst and year of research
12. T.A. Burova, 1945
13. M.V. Kukharchik, 1956
14. Note: The columbite sample was taken from medium grained pure line pegmatites, the columbite-tantalite from the fully differentiated type pegmatite.

3.5 x 5 x 6.0 cm, tending to occur either at the contact between the intensively albitized microcline zone and the quartz core, or at the blocks of potash feldspar which are sometimes strongly albitized. In tantalum and columbium content (see Table 67) it belongs to the columbite-tantalite, rich in manganese. A predominance of tantalum over the columbium in the columbium-tantalates is generally characteristic of pegmatite veins having a complex structure and strongly developed substitution processes.

Table 68

Findings of Spectral Analysis of Columbite (in percentages)

Element	Columbite	Columbite-Tantalite
Beryllium	0,005	0,005
Scandium	0,005	0,005
Lead	0,005	0,005
Bismuth	0,0025	0,005
Copper	0,005	0,0025
Nickel	0,005	—
Rubidium	0,025	—

Columbite is often found in pegmatites with medium-grained texture. The crystals have considerably smaller size (up to 0.6 x 0.8 x 1.5 cm) and are rather un-uniformly distributed among segregations of potash feldspar or the albite which develops on it. The columbite coming from the medium-grained pegmatites (Table 67, analysis 1) are characterized by the prevalence of columbium over tantalum (in a 2:1 ratio) with nearly equal molecular contents of Fe and Mn.

Occasionally, columbite is found in pegmatites occurring in a granite massif and in albite-quartz veins. In the first instance fine columbite crystals (up to 0.1 x 0.15 x 0.3 cm) tend to occur at microcline granules, and in the second at albite fringes in the quartz veins.

The usual association for columbite is with microcline, garnet, quartz, molybdenite and fluorite. The basic part of the columbite was formed in the early stage of the pegmatite process, inasmuch as its crystals are as a rule embedded in microcline, sometimes in albite and garnet which developed along the microcline.

32. Microlite

Microlite is rarely encountered in the form of fine octahedral crystals and oval granules. Its color is light yellow and reddish brown. It occurs with potash feldspar in granitic pegmatites. The debayegram for microlite is typical of the given mineral.

33. Molybdenite

Molybdenite is found at the Emerald Mines as a secondary mineral. It is represented by fine scales and idiomorphic plates showing hexagonal forms, while crystals are rarely seen. The size of the plates ordinarily varies between 0.5 and 5 cm in diameter and goes up to 10 cm in isolated cases. It is grayish white in reflected light. It is strongly anisotropic.

Table 69 shows the chemical analyses of molybdeite from pure line pegmatites (analysis 1) and plagioclase lenses in desiliconized pegmatitites (analyses 2 and 3).

Table 69
Chemical Composition of Molybdenite

Components	Analysis 1 weight %	Analysis 1 Atomic quantities	Analysis 2 wt. %	Analysis 2 Atomic quantities	Analysis 3 wt. %	Analysis 3 Atomic quantities
Mo	59,67	0,6219	60,07	0,6261	60,08	0,6262
S	40,30	1,2570	40,24	1,2551	39,95	1,2461
Se	0,0032	—	0,0058	—	0,0072	—
Te	—	—	0,002	—	0,0023	—
Re	0,0008	—	0,0006	—	0,0055	—
Sum . . .	99,97		100,31		100,04	

The findings of spectral analyses of five molybdenite samples are presented in Table 70. The first three of these samples were also studied by the chemical method (1, 2, 3)

Molybdenite is found in pure line pegmatites occurring both in granites and in metamorphic strata, as well as in desiliconized pegmatites and in pneumatolytic-hydrothermal formations.

In pure line pegmatites molybdenite tends to occur at the microcline which is met with in the form of fine phenocrysts and sometimes platy segregations up to two centimeters in size. In the desiliconized pegmatites it forms fine (up to 0.5 cm) phenocrysts at the contact between the plagioclase bodies and phlogopite zone. Its large segregations (2-5 cm, sometimes up to 10 cm in diameter) are found at the plagioclase cores or at their contact with quartz inclusions. The most abundant impregnation deposit of molybdenite is noted in grayish green plagioclase, where it is closely associated with native bismuth. Besides, molybdenite is present in the phlogopite zone and sometimes is noted in actinolite lenses. In pneumatolytic-hydrothermal veins molybdenite is encountered in the form of fine flakes in quartz bodies and phlogopite zones; only at a single section near the contact between the quartz body and plagioclase does one see large (up to 5 cm) tabular precipitations of molybdenite.

In this manner molybdenite is present in all vein formations, beginning with high temperature pegmatites

Table 70

Findings of Spectral Analyses of Molybdenite
(in percentages)

Elements	From pure line pegmatites	From desiliconized pegmatites			
	1	2	3	4	5
Beryllium *	—	0,0033	0,02	0,0001	0,0003
Arsenic	—	—	—	—	0,01
Manganese	0,005	0,005	0,005	0,005	0,005
Lead	0,001	—	0,001	—	—
Tin	—	0,001	—	—	—
Magnesium	0,0025	0,35	0,020	0,095	0,005
Silicon	0,005	0,01	0,005	0,004	0,005
Germanium	—	—	—	—	0,005
Bismuth	0,005	0,035	0,020	—	—
Aluminum	0,01	0,04	0,04	0,01	0,01
Copper	0,005	0,020	0,005	0,005	0,005
Silver	0,0025	—	0,0025	—	—
Nickel	—	0,025	—	—	—
Calcium	0,01	0,04	0,05	0,1	0,05
Strontium	0,0005	—	—	0,0005	0,0005

* Beryllium was determined by quantitative Spectral Analysis

Fig. 90. Intergrowth of Molybdenite with Native Bismuth. Magn. 150 x

and ranging up to low temperature quartz viens. Its characteristic associations are with plagioclase, native bismuth, phlogopite and actinolite. Fine tabular molybdenite crystals are often covered with albite and calcite. The precipitation time of molybdenite in desiliconized pegmatites is close to that of native bismuth, with which it forms intimate intergrowths (Fig. 90).

Molybdenite from the Emerald Mines is often substituted at the oxidation zone by powellite, ferrimolybdite and molybdic ocher. It is frequently possible to see hollows with hexagonal or fissured form, covered with a coating of molybdic ocher having a yellow or bluish green color with still preserved, occasional remainders of molybdenite and powellite flakes.

During the process of formation of the Emerald Mines the greatest amount of molybdenum tended to concentrate at the mobile part of the molten pegmatite solutions enriched with volatile compounds. The latter was characterized from the very inception by increased molybdenum content; moreover, the relative concentration of these elements was heightened upon the interaction of the melt solution with the enclosing rock, when the other components of the melt left to form contact zone minerals. Increased molybdenum concentration is also noted in later pneumatolytic-hydrothermal solutions.

34. POWELLITE

Powellite is rather infrequently found at the Uralian Emerald Mines. It is seen in thin foliar aggregates (up to 1.5 - 2 cm across) having a yellowish gray and light brown color. Monoaxial, positive. The index of refraction is N = 2.02 ± 0.02. Powellite coming from the plagioclase zone in desiliconized pegmatites was analyzed spectroscopically (Table 71).

Powellite is ordinarily adapted to plagioclase in desiliconized pegmatites and is formed as the result of oxidation of molybdenite, from which only individual flakes are often left over. Powellite is substituted in its turn by molybdic ocher with a greenish blue hue.

Table 71

Findings of Spectral Analysis of Powellite

Elements	Weight %	Elements	Weight %
Beryllium	0,005	Iron	0,1
Manganese	0,005	Bismuth	0,0025
Lead	0,005	Aluminum	0,1
Tin	0,005	Copper	0,005
Magnesium	0,05	Strontium	0,035
Silicon	0,005	Barium	0,0025

35. FERRIMOLYBDITE

Ferrimolybdite, a product of the oxidation of molybdenite, has a limited occurrence. It is found at the plagioclase in desiliconized pegmatites where it has a large number of chink-like hollows whose walls it colors gray yellow or greenish yellow. The size of the hollows varies from 0.3 to 2 cm in diameter. Sometimes, in a powdery mass of ferrimolybdite there are preserved individual molybdenite flakes covered by a thin coating of this mineral.

Ferrimolybdite is associated with molybdenite, apatite, beryl, fluorite and native bismuth.

36. MOLYBDIC OCHER

Molybdic ocher is the end product of the oxidation of molybdenite. It is found in plagioclase cores in desiliconized pegmatites, where a large amount of chink-like hollows are seen, whose walls have kept sparse traces of greenish blue ocher with molybdenite flakes from being leached out.

37. ZIRCON

Zircon is found in the phlogopite zone as very fine (up to 0.01 mm) prismatic crystals, usually surrounded by pleochroic halos (Fig. 91). Spectral analysis of phlogopite with an extremely large number of inclusions of zircon shows traces of zirconium.

Fig.91.

Zircon Crystals with pleochroic halos. Magn. 400 x. Without an analyzer.

The greatest quantity of zircon was found in the raction zone at the contact between diorite and serpentine, composed of ferrophlogopite. Somewhat fewer zircon inclusions are contained in the phlogopite zones of desiliconized pegmatites.

38. SCHEELITE

Scheelite was discovered at the Emerald Mines in the form of granular aggregates (up to 0.3 - 0.5 cm in diameter) with greenish yellow color in dolomite streaks which transverse serpentine. It is associated with phenacite, fluorite, ilmenite, pyrrhotite and pyrite.

SECONDARY ELEMENTS

BERYLLIUM

The geochemical history of beryllium at the Emerald Mines of the Urals is extremely interesting. In order to discover the distribution of this element in the enclosing rock and different types of veins, as well as to discover the laws underlying its distribution, a number of chemical (Table 95) and quantitative spectral determinations were made.

The highest constant beryllium oxide content was characteristic of granite (0.0007 - 0.0025%) and its vein complex (0.0021 - 0.0037%). Increased beryllium oxide contents (0.0008 - 0.0022%) were noted for ultrabasic rock and its metamorphized varieties only in sections adjoining the contact with the granite of the Murzinka intrusions. With greater distance from this intrusion the beryllium content in ultrabasic rock diminished sharply. For example, east of the contact with the granite massif one noted only traces of beryllium in the ultrabasic rock, while in serpentinized peridotite from the Asbest deposit, beryllium was not discovered. It follows from this that the basic source of beryllium is the granite intrusion.

Table 95

Beryllium Oxide Content in Rocks

Rock	BeO Content,%	Number of determinations
Pegmatite . . .	0,0021 — 0,0037	6
Aplitic rock . . .	0,0018	1
Biotite granite . . .	0,0014 — 0,0014	2
Binary granite . . .	0,0007 — 0,0025	5
Porphyroid granite . . .	0,0028	1
Quartz diorite . . .	0,0007 — 0,0033	3
Diorite-porphyrite . . .	0,0014 — 0,0072	2
Amphibole gneiss . . .	0,0028	1
Chromium-containing . . .	0,0025 — 0,0051	2

Table 95 (Continued)

Rock	BeO Content,%	Number of determinations
amphibole		
Tremolite rock	0,0017	1
Pyroxene porphyrite	trace	2
Pyroxenite	0,0011	1
Peridotite	trace	1
Serpentinized	not found	1
peridotite	0,0008	1
Dunite	0,0018—0,0022	2
Serpentine	0,0064	1
Chlorite zone	0,0013	1
Talc zone		

The wide distribution of beryllium attests to its mobility in the mineral-formation process. It is in all probability introduced in the form of fluorine compounds together with water pairs and anhydrous hydrofluoric acid, which is borne out by the presence of clinohum te in association with phenacite in the serpentine. The serpentine is not only cut through in this case by clinohumite streaks, but is also heavily impregnated by the latter near these streaks.

Beryllium in some particular quantities is present in nearly all the minerals of the Uralian Emerald Mines with the exception of talc, calcite, dolomite and chromite. It occurs as the principal component in beryl (12.33 - 13.83% BeO), emerald (13.37%), phenacite (45.82%), chrysoberyl (18.05 - 19.05%), alexandrite (18.74%), bavenite (6.35 - 6.60%), and bertrandite (40.83%). In other minerals beryllium is found in the form of isomorphic admixtures.

The uneven distribution of beryllium in the vein complex should be noted (Table 96). In pure line pegmatites there occurs among the intrinsic beryllium minerals only beryl and very insignificant amounts bertrandite formed after the beryl. In the dispersed state beryllium is found in eight minerals: microcline, garnet, muscovite, columbite, columbite-tantalite, quartz, apatite and albite. Beryllium is contained in garnet and albite-cleavelandite from differentiated pegmatites in increased amounts in comparison with pegmatites having

undifferentiated structure.

In pneumatolytic-hydrothermal veins, just as in pure line pegmatites, beryllium is present as the chief component in the composition of beryl and bertrandite which develops after it. In the dispersed state it occurs in quartz, muscovite, bornite and albite, while it is found in the latter in somewhat greater amounts than in albite from pure line pegmatites.

Table 96

Content of Dispersed Beryllium in Pegmatite Minerals

Minerals	No. of determinations	Fluctuation in BeO content, %
PURE LINE PEGMATITES		
Microcline	5	0,0015 — 0,0018
Muscovite	2	0,0052 — 0,0054
Fine-grained albite	1	0,0026
Cleavelandite	2	0,0045 — 0,0072
Garnet	1	0,0025
DESILICONIZED PEGMATITES		
Plagioclase	4	0,0019 — 0,127
Prochlorite	3	0,008 — 0,1445
Corundophilite	1	0,0033
Phlogopite	5	0,0018 — 0,0067
Actinolite	1	0,0091
Hornblende	1	0,0014
Be-margarite	5	1,88 — 3,26
Prehnite	1	0,1084
Clinohumite	1	0,0036
Topaz	1	0,0014
Apatite	1	0,0007
Native Bismuth	1	0,0007
Fuchsite	1	0,0091

One finds in the desiliconized pegmatites, in distinction to pure line pegmatites and pneumatolytic-hydrothermal formations, all of the independent beryllium minerals known from the Uralian Emerald Mines: beryl, emerald, chrysoberyl, alexandrite, phenacite, bavenite, and bertrandite. Moreover, beryllium is present in increased quantities in margarite, plagioclase, prochlorite, prehnite, actinolite, where the content of this element exceeds the clarke by several times.

Silica deficiency in the mineral formation process of desiliconized pegmatites results in beryllium, which has an ionic radius close to that of silicon, starting to function as the latter in crystalline structures. This produces partial dispersion of the beryllium in the minerals of the contact zones, especially in prochlorite. Silica deficiency, together with relative excess of aluminum, produce the characteristic associations of beryllium minerals: beryl + chrysoberyl, phenacite + chrysoberyl which tend to occur mainly with chlorite.

In conditions where there is a shortage of silicon dioxide which enters into the formation of aluminosilicates of magnesium, iron, calcium, i.e. elements which have more basic properties than beryllium, beryl cannot be formed in a number of instances and instead of it there arise: beryllium aluminate --chrysoberyl and beryllium silicate --phenacite. The process follows the following scheme:

$$Be_3Al_2Si_6O_{18} \rightarrow 5SiO_2 + Be_2SiO_4 + BeAl_2O_4$$

As Goldschmidt has pointed out (1938) the association of beryl, phenacite, chrysoberyl and quartz cannot be formed under the same temperature and pressure conditions. He does nevertheless assume the association of phenacite with quartz. This assumption is true, apparently for granitic pure-line pegmatites, where no alumina excess is perceived. In the desiliconized pegmatites of the Emerald Mines such a paragenetic association is hardly probable due to the relatively high alumina concentration in this process.

Silicon is principally isomorphically replaced in beryllium minerals. This process has appeared most clearly in beryllium-containing margarite. In this mineral the amount of aluminum is reduced in conformity with an increase of beryllium in it. This regularity,

it would seem, points to the fact that beryllium replaces the aluminum; however, inasmuch as silica tetranedrons lie at the basis of the silicates, while the alumino-silicates are minerals in which a part of the silica tetrahedrons has been replaced by the aluminum oxides, it is more correct to consider the beryllium in margarite replaced not by aluminum, but rather by silicon, since aluminum itself replaces silicon in this mineral in half of the silica tetrahedrons. Inasmuch as bivalent beryllium takes the place of tetravalent silicon, two negative valences are freed by each atom, which can be compensated for either by the entry into the crystal structure of minerals of elements with high positive valency, or by the substitution of oxygen by fluorine or the hydroxyl group. Fluoride and OH enter in the composition of beryllium-containing margarite in significant amounts. Alumina and beryllium oxide tetrahedrons, in contrast to those of silica, permit the substitution of oxygen by fluorine and hydroxyl, and the entry of beryllium into margarite can be realized according to the following scheme:

$$Be^{2+} + 2(OH, F)^{1-} \rightarrow Si^{4+} + 2O^{2-}$$

Because of silica deficiency during the desilication process, beryllium probably plays a similar role as well in beryllium-containing plagioclases, prehnite and prochlorite.

The geochemistry of beryllium is of interest in the late hydrothermal stage of the process when the dissociation of the early beryllium minerals, chiefly beryl, takes place. Beryllium which is then liberated enters into reaction with calcium and forms an independent mineral, bavenite, as well as entering in the form of small admixtures into late albite, closely associated with bavenite.

The geochemical history of beryllium during the hypergenic process has remained in general scarcely studied up to now. It is natural to assume that it can migrate in the form of haloids, hydroxides, carbonates, bicarbonates and other soluble compounds.

ZINC

Among the independent zinc minerals found at the Emerald Mines only sphalerite is known. Zinc is present in 17 minerals in the form of isomorphic additions. It is seen in pure line pegmatites in muscovite (0.005 - 0.025%), garnet (0.005 - 0.05%) and in pneumatolytic-hydrothermal veins in bornite (0.05%) and in muscovite (0.005 - 0.025%). Desiliconized pegmatites are characterized by a considerably large amount of minerals (tourmaline, prochlorite, corundophilite, actinolite, prehnite, phlogopite, etc.), in the composition of which zinc is included (see Table 94).

The presence of sphalerite in pneumatolytic-hydrothermal veins and zinc in dispersion in pure line pegmatite minerals suggests that its main source is to be found in derivatives of the granite intrusion. The closeness in size of zinc's ionic radii to those of magnesium and bivalent iron and the high content of the latter in the vein complex have produced the strong scattering of zinc in ferro-magnesium minerals.

BORON

Boron is relatively widespread throughout the Uralian Emerald Mines. It is found in granites, their vein derivatives, as well as in the enclosing rocks (Table 97). Boron has probably been introduced into their metamorphosis by early emanations of granitic intrusions in the form of volatile fluorine compounds, in particular BF_3. The main mass of boron apparently was introduced at the vein stage in the formation of the deposits by pegmatite-pneumatolytic molten solutions.

Table 97

Boron Content in the Enclosing Rocks*

Rock	B_2O_3 Content, in %
Metamorphized dunite	0,018
Serpentine	0,014
Carbonaceous shale	0,01
Talc schist	0,005

Table 97 (Continued)

Rock	B_2O_3 Content, in %
Amphibole gneiss	0,004
Binary granite	0,021

* Boron was determined by chemical analysis

Only tourmaline occurs among independent boron minerals in pure line pegmatites. Boron is present as sparse additions in these pegmatites in muscovite (0.014 - 0.026% B_2O_3). In desiliconized pegmatites, besides tourmaline, boron enters in slight amounts in phlogopite (traces to 0.006% B_2O_3) and prochlorite (0.008 - 0.059%). The high boron content in bavenite (0.31% B_2O_3) should be mentioned, which forms at the late stage in the hydrothermal process in desiliconized pegmatites. Boron's ability to substitute silicon produces its widespread dispersion in chlorite, phlogopite and muscovite. It is interesting to note that a considerable silicon deficit in bavenite is compensated by boron.

Boron is a widely distributed element in the emerald deposits in other countries. In all cases its chief amounts are connected with tourmaline in desiliconized pegmatites, in which this mineral occurs more rarely. It is only natural that boron is fixed in tourmaline, since the molten solutions which form the desiliconized pegmatites hit the enclosing rock which is rich in Mg and Fe^{++}. The presence of significant quantities of boron in desiliconized pegmatites bears evidence to support their formation during the pneumatolytic stage.

Emerald-bearing bands disclose an increased boron content in contrast to fluorine running in the direction from north to south. This is evidently connected with the heterogeneity of the initial composition of the pegmatite pneumatolytic melt solutions which form in various parts of the intrusion and besides this, more deep-seated parts of the pegmatite bodies have been discovered in the southern part of the emerald-bearing zone, where boron in significant quantity is bound in tourmaline with the assimilation of iron from enclosing rocks.

CARBON

Carbon does not play a substantial part in endogenic processes at the Emerald Mines. In the late hydrothermal stage it enters into the composition of calcite, dolomite and rhodochrosite. The possibility does indeed exist that the formation of these minerals is connected with the decomposition if ultrabasic and basic rocks by late carbonate fractions of the granite intrusion and the calcium and magnesium derived from them. The carbon of carbonaceous shales did not participate in mineral formation, for the fractions of the granite intrusion did not react on the carbonaceous slates.

During the hypergenic stage considerable amounts of carbonic acid reacted with the ultrabasic rocks, dissociated the ferro-magnesian silicates with the formation of dolomite, displacing silica which crystallized in the form of opal and chalcedony. At this same stage malachite, azurite and bismuthite were formed.

TITANIUM

Among the independent titanium minerals found at the Emerald Mines there were rutile, sphene,(grothine) and ilmenite which are adapted to the chlorite zones of desiliconized pegmatitics. In the dispersed state titanium oxide forms a whole series of minerals: biotite, phlogopite, muscovite, fuchsite, tourmaline, etc.(see Table 94). The distribution of titanium in the indicated minerals and its crystallochemical properties allow one to suppose that it isomorphically replaces Fe^{***} in biotite and phlogopite, Al in tourmaline, Nb and Ta im columbite, which thus produces its intensive dispersion through a large number of minerals.

The main source of titanium in desiliconized pegmatites of the Emerald Mines is the enclosing rocks.

ZIRCONIUM

The Murzinka granite intrusion and the pegmatites associated with it are characterized by an exceptionally

low zirconium content. It is present in thousandths and ten thousandths of a fraction in amphiboles, amphibole gneisses, and diorite-porphyrites. In pure line pegmatites it is contained in 0.005% quantity in garnet, albite, columbite and apatite. The zirconium content in quartz attains 0.0025%. In desiliconized pegmatites zirconium is found both in dispersed state and in the form of zircon. The latter is found in extremely fine crystals, contained in phlogopite. Besides this, zirconium is contained in tourmaline and actinolite in quantities of 0.05%.

PHOSPHORUS

Phosphorus was established by chemical analysis in serpentine, chromium-containing amphibole and amphibole gneiss (see Table 94). In the mineral-formation process at the Emerald Mines it plays a considerable part. Among the independent phosphorus minerals only apatite is known which is present in nearly all the above mentioned rocks, as well as in pure line pegmatites, desiliconized pegmatites and pneumatolytic-hydrothermal formations. The source of phosophorus is probably both in derivatives of granite intrusion and the enclosing rock.

Phosphorus is found in the dispersed state as well. It has been determined in phlogopite (0.23 - 0.25 percent P_2O_5) by chemical analysis, and spectrally in native bismuth, ilmenite and plagioclase. Because of the closely related sizes of the ionic radii, phosphorus replaces silicon in apatite and garnet. It is not out of the question that in phlogopites, for example, silicon is also partially substituted by phosphorus, the symmetry of the PO_4 and SiO_4 making such an isomorphism possible. This is all the more probable, for the formation of the Uralian Emerald Mines proceeded with a lack of silica.

NIOBIUM AND TANTALUM

Columbium and tantalum have sparse occurrence at the Emerald Mines. Their independent minerals, columbite and tantalite, are found in pure line pegmatites as accessory minerals. These minerals have not been discovered in desiliconized pegmatites, which is well

explained, together with the low columbium and tantalum content in derivative granitic magma, by the dispersion of these elements in minerals rich in iron and which contain titanium: phlogopite, chlorite, where they isomorphically replace iron and titanium.

The slight columbium and tantalum contents do not permit their detection by the chemical method from ordinary samples. From large samples, columbium has been determined in binary granite (0.002 Nb_2O_5), in pegmatite (0.008 Nb_2O_5); in phlogopite from desiliconized pegmatites one has established Nb_2O_5 0.017% and Ta_2O_5 0.002%. Columbium has been established in kaolinite (0.01%) using the spectral method.

BISMUTH

Bismuth is found in granite and tremolite rock (0.0005%). In pure line pegmatites it is present in dispersion in tantalite, molybdenite, apatite, garnet, columbite and muscovite. In pneumatolytic hydrothermal veins bismuth is encountered in bornite, sphalerite and muscovite. In desiliconized pegmatites, it forms independent minerals: native bismuth and tetradymite, and is present also in dispersion in molybdenite, chrysoberyl, ilmenite, chromite, magnetite, phlogopite, fuchsite, apatite, beryllium-containing margarite and other minerals (see Table 94).

The granite intrusion and its different fractions are the source of bismuth. The relative dearth of sulfur in the granite intrusion has led to the dispersion of bismuth through a number of minerals and rocks and caused the formation of native bismuth. The presence of bismuth in tremolite rocks evidently attests to the introduction of this element to the roof of the intrusion at a very early stage in its interaction with the enclosing rock.

SULFUR

Sulfur has played an insignificant role in the process of mineral formation at the Emerald Mines. A part of it was brought in by fractions of the granite intrusion, as evidenced by the presence of sulfides in pure line pegmatites and pneumatolytic-hydrothermal

formations, while another part was assimilated from the enclosing rock (Table 98).

Table 98

Sulfur Content in the Enclosing Rock

Rock	Sulfur Content in %
Dunite	Не обн.
Serpentine	0,31
Tremolite Rock	Не обн.
Amphibole, containing chromium	0,07 — 0,08
Amphibole gneisses	0,14 — 0,18
Quartz diorite	0,11 — 0,12
Metamorphized quartz diorite	0,12

In pure line pegmatites, sulfur is found in only one mineral, molybdenite. In pneumatolytic-hydrothermal veins it is present, together with molybdenite, in sphalerite, pyrite, chalcopyrite and bornite. In desiliconized pegmatites, aside from the independent sulfur minerals, molybdenite and tetradymite, a part of the sulfur proceeds through dispersion, combining in beryllium-containing margarite (0.11%) and in a number of cases in phlogopite (0.03 - 0.15%).

The occurrence of native bismuth in cross line pegmatites and pneumatolytic-hydrothermal veins attests to sulfur insufficiency in the veins of derivatives of the granitic magma. This is also indirectly borne out by presence of tetradymite granules in native bismuth, in which, quite possibly, the role of sulfur is filled by tellurium. Only part of the elements which have an exceptionally strong resemblance to sulfur, as , for instance, zinc, molybdenium are found in the form of sulfides with a shortage of sulfur.

CHROMIUM

The presence of chromium in mineral formation at the Emerald Mines is basically required for the green

color of the emeralds. Chromium is contained in largest quantity in ultrabasic and basic rocks and their metamorphosed varieties, serpentines, amphiboles; it is not found in diorites and amphibole gneisses (Table 99).

Table 99

Chromium Content in Enclosing Rock
(Data of Chemical Analysis)

Rock	Cr_2O_3, %	Number of determinations
Metamorphosized dunites	0,39	1
Serpentines	0,15	1
Talc serpentines	0,28	1
Metamorphosized pyroxenites	0,11—0,15	2
Amphiboles	0,08—0,24	6
Tremolite rocks	0,08	1
Diorites	not found	3
Biotitic diorites	» »	2
Amphibole gneisses	» »	2

In ultrabasic rocks chromium is present in the form of chromite, as well as in isomorphic additions to ferromagnesian silicates. The chromium which is contained in pure line pegmatites in thousandths of a percent was most likely assimilated by the granite intrusion from rocks on the roof. In dross line pegmatites chromium enters in the form of additions to 19 minerals: epidote (1.05%), fuchsite (0.6%), beryllium-containing margarite (0.4%), alexandrite (0.30%), phlogopite (0.23%), chrysoberyl (0.08%), beryl (0.03 - 0.06%), emerald (0.13 - 0.25%) and others. It was discovered by spectral analysis in tourmaline (0.25%), biotite (0.025%), phenacite (0.005%), topaz (0.025%). The entrance of chromium into epidote, fuchsite, beryllium-containing margarite and phlogopite produces reduced intensity in the coloration of late beryl which ordinarily has a greenish white hue.

Under the effect of pegmatite and pneumatolytic-hydrothermal solutions on the ultrabasic rocks, chromium passes over into solution, from whence it enters the structure of the beryl, isomorphically replacing the Al in it and lending it a green color.

MOLYBDENUM

Molybdenum is encountered at the Emerald Mines in all vein bodies of the granite intrusion. In insignificant amounts it has been determined by spectral analysis in albite, muscovite, apatite (from pure line pegmatites), in sphalerite and bornite (from pneumatolytic-hydrothermal veins), in phlogopite, prochlorite, corundophilite, fuchsite, beryllium-containing margarite and native bismuth (from desiliconized pegmatites; see Table 94). The form by which it enters minerals in the dispersed state is unclear; it is possible that it is also partially present here in the form of finely dispersed molybdenite. Derivatives of the granite intrusion act as the source of molybdenum.

SELENIUM AND TELLURIUM

Selenium has been discovered by chemical analysis in molybdenite from pure line pegmatites in the quantity of 0.0032% and in molybdenite from desiliconized pegmatites ranging from 0.0058 to 0.0072%.

Tellurium forms an independent mineral, tetradymite, found in the form of fine granules in native bismuth, tending to concentrate at desiliconized pegmatites. Tellurium was determined by the chemical method, just like selenium, in molybdenite from desiliconized pegmatites in amounts of 0.002 - 0.0023%.

TUNGSTEN

Tungsten enters the chemical composition of scheelite found in dolomite streaks. In other minerals, it has not been determined by either chemical nor spectral methods.

It should be noted that together with the lack of tungsten in fractions of the granite intrusion, a small tungsten deposit is connected with this intrusion at several tens of kilometers from the Emerald Mines. It is true that the tungsten in this case is adapted to later quartz veins than the derivatives of the granite

intrusion which form the Emerald Mines. The occurrence of tungsten mineralization at single sections of the intrusion and the practical absence in others is evidence of diverse physicochemical conditions in their formation. Part of the tungsten in desiliconized pegmatites are, naturally, in a dispersed state and without considerable concentration are not detected by the spectral method used.

MANGANESE

Manganese, which forms part of the composition of more than thirty minerals found at the Uralian Emerald Mines, is partially brought in by derivatives of the granitic magma and partially assimilated from the enclosing rocks (see Table 94). In the quality of principal component, it enters the composition of garnet, tantalite and columbite, and in the form of isomorphic additions it is present in biotite, ilmenite, apatite, clinohumite, phlogopite, actinolite, sphalerite and other minerals.

Due to the proximity of dimensions of the ionic radii, manganese can isomorphically replace magnesium, iron, calcium, zinc and aluminum. The presence of considerable quantities of these elements in the mineral-formation process at the Emerald Mines produces the segregation of their independent minerals and the dispersion of manganese in them. The isomorphic substitution of ferrous iron by manganese has been most widespread in columbite, tantalite, garnet, ilmenite, phlogopite, etc. Less prevalent is the isomorphism between manganese and magnesium which occur in minerals of the chlorite, actinolite, tourmaline and clinohumite groups. Manganese replacement of calcium and zinc (in apatite, calcite and sphalerite) is noted considerably less frequently.

COPPER

Copper plays a minor role in mineral formation at the Uralian Emerald Mines. Its source has most likely been both derivatives of the granite intrusion and the enclosing rock containing from 0.0005 to 0.005% CuO. Spectral analyses show that copper is present in all vein bodies of the Emerald Mines in more than 30 minerals

(see Table 94). The content of dispersed copper in the minerals is measured principally in thousandths and ten thousandths of a fraction of a percent, and only in five minerals, namely garnet, sphalerite, molybdenite, fuchsite and prehnite, does it occasionally attain 0.02 - 0.5%. Copper enters as the main component into chalcopyrite, bornite, chalcosite, covellite, malachite and azurite. Sometimes native copper is found. The form of entry into other minerals is not fully known for copper. For example, a small amount of sulfur is present in phlogopite together with copper, and it is consequently uncertain whether bivalent copper substitutes $Fe^{\cdot\cdot}$ and Mg which have close ionic radii with it, or is it present in these minerals as a mechanical addition in the form of copper sulfide.

At the hypergenetic zone solutions containing copper sulfate enter into reaction with the non-decomposed sulfides, which brings about the formation of native copper and other secondary minerals (covellite, chalcosine). At the oxidation zone copper is precipitated in the form of carbonates -- as malachite and azurite.

DISPERSION ELEMENTS

LITHIUM

Lithium has been identified in both rocks and minerals of the vein complex. The spectral method has disclosed it in the rocks: granite (0.05%), diorite and amphibole gneiss (0.075%). No independent lithium minerals are found at the Uralian Emerald Mines. It can be assumed that the roots of the pegmatite veins have been uncovered here by erosion, although the preserved upper parts of the pegmatites are surrounded by ultrabasic rock where spodumene and lepidolite could not have formed as the result of reactions between the pegmatite and pneumatolytic-hydrothermal molten solutions and the enclosing rocks which contain large amounts of magnesium.

Through chemical analyses lithium was discovered in desiliconized pegmatites in phlogopite (Li_2O 0.12-0.49%), beryllium-containing margarite (0.36 - 0.78%), beryl (0.024 - 0.30%), fuchsite (0.25%) and plagioclase

(0.015%). In pure line pegmatites it is found in beryl (LiO_2 0.105 - 0.475 %), cleavelandite and microcline Li_2O 0.004%). The lithium oxide content in beryl from pneumatolytic-hydrothermal veins varies from 0.0475 to 0.46%. Lithium was determined by the spectral method in muscovite (0.05 - 0.7%), prochlorite (0.05%), precious talc (0.05%) and tourmaline (0.05 - 10%).

The relatively high lithium content in a whole group of minerals occurring in desiliconized pegmatites bears witness to the considerable condentration of this element in the pegmatite melt solutions intruded into ultrabasic rocks. Nevertheless the closely related crystallochemical properties of lithium and magnesium and the considerable content of the latter do not permit lithium to form independent minerals, and it has been distributed by means of dispersion, isomorphically replacing magnesium and phlogopite, fuchsite and other minerals.

RUBIDIUM

Rubidium has been determined by chemical and spectral quantitative analyses in a large number of minerals from different vein bodies. It was discovered by chemical means in cleaveleandite (0.005%), albite (0.006%), plagioclase (0.009 - 0.047%), potash feldspar (0.09%), beryl (0.006 - 0.01%), finely lamellar muscovite (0.218%) and in fuchsite (0.054%). By the spectral method it was found in quartz (0.02%), columbite (0.025%), garnet (0.011%), in phlogopite (0.18 - 0.3%), actinolite (0.01%), tourmaline (0.014%). It is evident from the data presented that rubidium is contained in the largest quantity in muscovite and phlogopite where it isomorphically replaces potassium.

CESIUM

Cesium was determined by chemical analysis in potash feldspar (0.001%), plagioclase (0.001%) and in beryl (ranging from 0.014 to 0.046%, made in eight determinations). The greatest amount of cesium was discovered in beryl (0.046%) which came from pneumatolytic-hydrothermal veins.

SILVER

This element was not established by spectral analyses in the rocks. Silver is present in small amounts in the minerals from different vein bodies. In pure line pegmatites it has been determined in molybdenite (0.0025%), apatite (0.0005%) and garnet (0.0005%). In pneumatolytic-hydrothermal veins silver is contained in sulfides: bornite, sphalerite, and chalcopyrite (see Table 94). It is interesting to note the presence of silver in molybdenite which also came from desiliconized pegmatites in the very same quantity as in molybdenite stemming from pure line pegmatites. Moreover, silver is contained in native bismuth (0.05%), as well as in ilmenite, fuchsite and phacolith in amounts of 0.0005%).

The most significant silver content is found in sulfides formed during the late stage of vein body formation. The chalcophylic nature of silver produces its association with such elements as zinc and copper.

STRONTIUM

Strontium has been determined by spectral analyses in both rocks and in the minerals of the vein complex. The presence of strontium in granite (0.005 - 0.05%) and in pure line pegmatites (0.005%) attests to the fact that the basic source of this element is vein derivatives of the granite intrusion.

The maximum strontium content tends to occur with diorite-porphyrites and amphibole gneisses (0.35 - 0.5%). Strontium has been established in pyroxenite (0.05%), chromium-containing amphibole (0.05%), tremolite rock (0.005%). It is not found in dunites and serpentines. In pure line pegmatites strontium is present in microcline, albite, apatite, molybdenite and muscovite. In pneumatolytic-hydrothermal veins it is found in albite, muscovite and sphalerite. In desiliconized pegmatites it composes apatites, fluorites, fuchsite, beryllium-containing margarite, plagioclase, phlogopite and other minerals (see Table 94) in rather significant quantities. In apatite, fluorite, and beryllium-containing margarite strontium isomorphically replaces calcium, while in phlogopite, muscovite and microcline only partially potassium.

It has been proven by a number of investigators

(Ahrens, 1948; Hahn and Walling, 1938) that in magmatic rocks a part of the strontium is a product of the radioactive conversion of rubidium. It is possible that the strontium at the Uralian Emerald Mines is also partially of radiogenic origin.

CADMIUM

By spectral analysis cadmium has been detected only in albite (0.025%) stemming from pure line pegmatites and in sphalerite (0.35 - 0.5%) from pneumatolytic-hydrothermal veins. It has not been found in rocks. In view of the relatedness of the geochemical properties of cadmium and zinc and the predominance of the latter, cadmium substitutes zinc in sphalerite in the form of an isomorphic addition.

BARIUM

Barium, just like strontium, is contained in maximum quantities in amphibole gneisses (0.35 - 0.5%), quartz diorites (0.0005 - 0.35%), diorite porphyrites (0.05%), granites (0.05 - 0.5%) and pure line pegmatites (0.02%). It is not found in ultrabasic rocks. Barium has been determined by spectral analysis in 11 minerals. It occurs in pure as well as cross line pegmatites.

In pure line pegmatites barium is present in muscovite, microcline, garnet and albite. In pneumatolytic-hydrothermal veins it is discovered only in muscovite and phlogopite. In desiliconized pegmatites barium enters into the composition of phlogopite, fuchsite, prehnite and other minerals (see Table 94). Barium, just like strontium, principally came from fractions of the granite intrusion.

The closeness between the barium and potassium ionic radii and the former's slight content in fractions of the granite intrusion determine the principal lines of behavior of this element which produce its dispersion in potassium minerals.

SCANDIUM

Scandium has not been established by spectral analysis in rocks. It was discovered by spectrochemical analysis of 10 gram samples in a number of rocks (Table 100). In the vein complex scandium is present in limited numbers of minerals. In pure line pegmatites it forms a part of the composition of tantalite and columbite in amounts of 0.005%.

Table 100

Scandium Content in Enclosing Rocks

Rock	Sc Content, %
Granite	0,0007
Porphyroid granite	0,0003
Diorite	0,0019
Diorite-porphyrite	0,0010
Amphibole gneiss	0,001
Pyroxene porphyrite	0,0010
Serpentine	0,0007
Chlorite zone	0,0006
Talc zone	0,0007

The highest scandium content is seen in actinolite (0.05%) from the reaction zone at the contact between diorite and serpentines and in minerals from desiliconized pegmatites, in the emerald (0.025% by chemical analysis) and beryl (0.025%). It is present in thousandths of a percent in phlogopite and ilmenite (0.005%).

In the emerald scandium apparently replaces aluminum. The presence of 1.89% magn sium in this mineral supports the contention of Rankama and Sahama(1952) that scandium can replace aluminum in aluminum minerals under the condition of simultaneous substitution of aluminum by magnesium.

The presence of scandium in columbite coming from pure line pegmatites speaks for a part of it apparently being brought in by derivatives of the granitic intrusion.

GALLIUM

The close relation of a number of geochemical properties of gallium to aluminum and its completely insignificant contents have determined the strong dispersion of this element throughout the rocks and minerals of the Uralian Emerald Mines.

Gallium has been determined by spectral analysis in dunite, talc schist, tremolite rock (0.001%), pyroxene, amphibole, diorite-porphyrite, quartz diorite (0.005%) and granite (0.005 - 0.01%). In slight quantities it is present in all of the vein bodies found at the Emerald Mines. In pure line pegmatites it occurs in hundredths and thousandths of a percent in the composition of muscovite, microcline, albite, garnet and quartz. In desiliconized pegmatites the most significant gallium content is characteristic of: alexandrite, prochlorite, plagioclase, phlogopite (see Table 94). It is interesting to note that in the molybdenites of the Emerald Mines gallium has not been disclosed by the spectral method; it was established in sphalerite in the amount of 0.001%.

The data presented on the distribution of gallium and the quantitative dependence between gallium and aluminum content (the greater the amount of aluminum, the greater that of gallium also) testify to the isomorphic replacement of aluminum by gallium in aluminum and aluminum-containing minerals.

INDIUM

Indium has been discovered by spectral analyses solely in sphalerite from albite-quartz veins in the amount of 0.001%, where it isomorphically replaces zinc.

THE RARE EARTHS

The minerals of the veins complex of the Uralian Emerald Mines are characterized by an insignificant content of rare earths. They have been detected by chemical analyses only in apatite (0.20 - 0.50% TR_2O_3) and in columbite-tantalite (0.04%), while by spectral methods

in native bismuth, prochlorite (0.01%), fluorite (0.001%). Yttrium was discovered in rutile (0.04%) and prochlorite (0.01%). The findings of X-ray spectrographic analyses of the rare earths taken from apaties of pure-line and desiliconized pegmatites have demonstrated that elements of the cerium group sharply predominate in their composition, whereupon cerium, lanthanum and neodymium are foremost (see Table 94). The quantitative and qualitative similarity between the elements of the rare-earth group and apatites from pure line pegmatites and desiliconized pegmatites, together with other factors, points indirectly to their close genetic connection. The elements of the rare-earth group in apatite and fluorite isomorphically replace calcium.

THALLIUM

Thallium was determined by spectral analyses in four minerals, muscovite (0.001 - 0.005%), microcline (0.001%), phlogopite (0.001 - 0.005%) and fuchsite (0.005%). The first two are characteristic of pure line pegmatites. The second two of desiliconized pegmatites. The finding of thallium in potassium minerals and its absence in iron-magnesium (chlorite, talc) and calcium (plagioclase, epidote) minerals once again indicates its closeness of its properties to potassium.

GERMANIUM

Germanium has been determined by spectral analysis in seven minerals: garnet (0.001 - 0.04%), topaz (0.04%), actinolite (0.05%), prehnite (0.001%), bavenite (0.01%), bertrandite (0.005%) and molybdenite (0.005%). Among the these, only garnet prevails with pure line pegmatites, the remaining minerals being connected with desiliconized pegmatites and particularly with the hydrothermal stage in their formation. Germanium is not found in the carbonaceous shales from the Emerald Mines.

Considering the closeness of the geochemical properties in germanium and silicon, it can be assumed that germanium replaces silicon in the above mentioned minerals.

TIN

Tin has been discovered by spectral analysis in 19 minerals from various vein bodies of the Emerald Mines. In pure line pegmatites it is present in muscovite (0.001 to 0.005%), garnet (0.005 - 0.01%), apatite (0.005%); in pneumatolytic-hydrothermal veins it enters into the compositions of sphalerite (0.001%) and bornite (0.005%). The number of minerals which contain tin is considerably higher in desiliconized pegmatites. It has been discovered by chemical analyses in chrysoberyl (0.12%) and alexandrite (0.04%), by spectral analysis-- in phlogopite, prochlorite, corundophilite (0.001%), tourmaline (0.001 to 0.005%). beryllium-containing margarite (0.001%) and other minerals (see Table 94). In view of the insignificant tin content in minerals it is very difficult to determine its crystallochemical role. High concentrations of this element in chrysoberyl (0.12%) which contains 0.34% TiO_2 attest to the isomorphic replacement of titanium by tin. It is possible that the dispersion of tin in other minerals is closely connected with titanium.

LEAD

Lead is found in amphibole gneiss (0.005%), quartz diorite and granite (0.001%). At the vein complex of the Emerald Mines it enters into the composition of 19 minerals. In pure line pegmatites in amounts of 0.001%, lead is noted in muscovite, albite, apatite, and solely in microcline, columbite, and tantalite does its content jump up to 0.005%. It is present in the albite-muscovite-quartz veins in sulfides: sphalerite (0.001%), bornite (0.005%), as well as forming part of the composition of albite (0.001%) and muscovite (0.001-0.005%). In thousandths of a percent lead is discovered in minerals of the desiliconized pegmatites: phlogopite, prochlorite, plagioclase, tourmaline. apatite, fluorite (0.001%), native bismuth (0.01%).and other minerals (see Table 94). The closeness of the dimensions of the ionic radii in lead and potassium, probably have produced their isomorphic replacement and the dispersion of lead.

VANADIUM

Vanadium has been established by spectral analyses in all rocks with the exception of granite, although in pure line pegmatites it is present in muscovite (0.005 to 0.02%) and albite (0.005%). The highest content of this element is noted in tremolite rocks, pyroxenites and chromium-containing amphiboles (0.05%). In dunite and serpentine vanadium is seen in significantly smaller quantities --0.005%. The mentioned regularities are generally characteristic of the geochemistry of vanadium.

In desiliconized pegmatites vanadium in the form of insignificant additions is found in tourmaline, rutile, alexandrite (0.5%), chrysoberyl (0.02-0.05%), emerald (0.05%), beryl (0.05-0.005%), beryllium-containing margarite (0.025-0.005%). Vanadium was determined by the chemical method in the emerald (0.02%) in beryl (0.004%). In hydrothermal streaks of epidote-calcite composition, it concentrates in the epidote (up to 0.20%).

The distribution of vanadium in the minerals of the vein complex confirms the deductions of a number of investigators (Goldschmidt, 1954; Rankama and Sahama, 1952) to the effect that this element during the magmatic process is closely connected with trivalent iron and aluminum which have similar ionic radii. It is interesting to note the occurrence of slight amounts of vanadium in the emerald. Inasmuch as the color of emeralds from certain deposits (Muzo, Columbia) is related to vanadium to a considerable extent, it may be assumed that the hue of Uralian emeralds is produced not only by chromium, but by vanadium as well. Vanadium , just like chromium, isomorphically substitutes the aluminum.

ARSENIC AND ANTIMONY

These elements are encountered very infrequently at the Emerald Mines. Arsenic has been determined by spectral analysis in two minerals from the desiliconized pegmatites, molybdenum and rutile, in quantities of 0.01%. Antimony was discovered by the spectral method in native bismuth (around 0.1%) and talc (0.01%).

CHLORINE

The function of chlorine in the process of mineral formation at the Emerald Mines is entirely insignificant. Its source is apparently partly the enclosing rock and partly derivatives of the granitic magma. In the enclosing rocks the chlorine content, determined by chemical analysis, varies from traces to 0.06%. In metamorphic dunites abd tremolite rock chlorine has not been detected. Chemical analysis of the minerals from pure line pegmatites has determined chlorine traces in muscovite and microcline. In desiliconized pegmatites chlorine is present in slight quantities (traces) in phlogopite, prochlorite, corundophillite, plagioclase and only in beryllium-containing margarite does its content reach 0.13 - 0.20%.

The crystallochemical similarity between chlorine and fluorine and the hydroxyl group, as well as the presence of a considerable number of minerals containing OH and F have produced the dispersion of chlorine in the structures of these minerals. It is possible that part of the chlorine occurs in gaseous-liquid inclusions.

RHENIUM

Rhenium was discovered by the chemical method in molybdenite from pure line pegmatites (0.0008%) and desiliconized pegmatites (0.0006 - 0.0055%). Its highest content (0.0055%) occurs in molybdenites which are associated with native bismuth and tetradymite in the plagioclase of desiliconized pegmatites.

COBALT

Cobalt was determined by spectral analysis in all ultrabasic and basic rocks and their metamorphic products (up to 0.01%). The least quantity is present in amphibole gneiss and quartz diorite (0.005%). In andanalyzed sample of granite cobalt was not discovered. It occurs in the vein complex principally in minerals of desiliconized pegmatites: phlogopite, prochlorite,

talc, actinolite and other minerals (see Table 94). As the list of these minerals shows, cobalt in desiliconized pegmatites is dispersed in ferro-magnesian and aluminum silicates.

NICKEL

Nickel, just like cobalt, has been determined by spectral analyses in all ultrabasic and basic rocks and their metamorphic products (0.2 - 0.35%). The lowest nickel content is seen in diorite-porphyrite (0.05%), amphibole gneiss and quartz diorite (0.005%). An analysis of a single sample of biotite granite showed the nickel content to be 0.05%, which apparently can be explained by the assimilation of surrounding rock by the granitic magma.

To check on the spectral data the nickel in dunite and serpentine was determined by the chemical method, its content totaling respectively 0.25 and 0.33%.

Minerals of pure line pegmatites and pneumatolytic-hydrothermal veins (microcline, quartz and albite) ordinarily contain thousandths of a percent of nickel. Nickel was determined by chemical analysis in native bismuth in the quantity of 0.87%.

The spectral method showed the nickel in cross line pegmatites to amount to more than in thirty minerals, while it is present in the largest quantity in phlogopite (0.085 - 0.1%), prochlorite (0.005 - 0.25%), corundophilite (0.02%), talc (0.1-0.2%), fuchsite, tourmaline (0.05 - 0.1%), magnetite (0.1%), chromite (0.05%), ilmenite (0.025%) and other minerals. In all of the listed minerals nickel isomorphically replaces magnesium and bivalent iron, which thus explains its wide dispersion in the minerals of desiliconized pegmatites which form during the assimilation of considerable amounts of magnesium and iron from the enclosing rocks.

Extreme interest in the geochemistry of the Emerald Mines (of the Urals) is aroused by the unusual quantitative and qualitative combination, during the formation of desiliconized pegmatites, of the elements found, on the one hand, in the granite intrusion and its vein derivatives, and on the other, in the enclosing ultrabasic rocks. Such unusual combinations of elements is not encountered

in the normal evolutionary development of magmatic rock. In this respect, the process of formation of desiliconized pegmatites must be regarded as a natural experiment which makes it possible to broaden our views on the isomorphism of elements involved in still other processes of mineral formation, rather than merely those restricted to this particular process.

During the formation of the desiliconized pegmatites, just as in general in any mineral formation process, the geochemistry of each element is fundamentally determined by the concentration and physicochemical properties of both the given element and the other elements which accompany it, i.e. by the law of mass action.

A change in the concentration of elements during the formation of desiliconized pegmatites in time and space, together with a heterogeneous initial composition of the molten pegmatite pneumatolytic solutions and enclosing rocks is determined by such factors as different volatility in the compounds, a different degree of assimilation of the enclosing rock and the discharge of elements at the late stage in the form of water-soluble salts. Thus, the presence of volatile compounds, particularly water pairs, fluorine compounds and hydroxides produced higher concentrations in the upper parts of beryllium, F and H_2O. The assimilation of large quantities of magnesium and iron determined the unique crystallochemical structure of the minerals, which in its turn produced other mineralogico-geochemical and, especially, isomorphic interrelations between the elements participating in the process. At later stages in the process alkali elements were carried off in the form of water soluble, principally fluorine compounds, which also resulted in a change in the concentration of elements participating in the process, in the formation of new minerals and the substitution of certain elements by others.

Together with the indicated factors which determine the geochemical characteristics of the formation of desiliconized pegmatites, including the phenomenon of isomorphism, it is necessary to point out a more general law which was in principle expressed by Le Châtelier to the effect that every modification in factors determined by chemical equilibrium causes processes in the system of development which counteract this change. An illustraion of this principle can be found in any element particpating in the formation of the Uralian Emerald Mines. Thus, for example, where there is a reduced SiO_2 concentration due to the assimilation

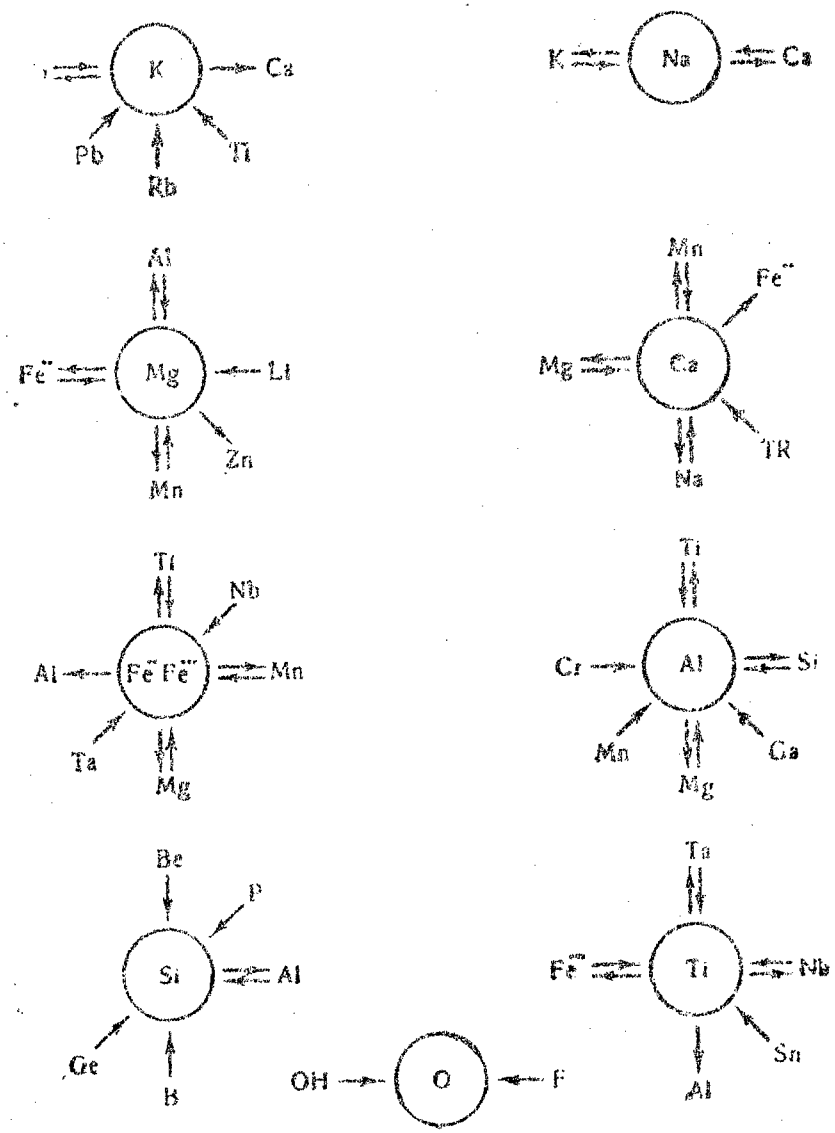


Fig. Diagram of Isomorphic Associations of Chemical Elements.

of the enclosing rock which is poor in silica, the process shifts to the side just as if there were an increased silicon concentration in connection with its substitution by aluminum and beryllium, thus producing such Al rich and correspondingly silica poor minerals as beryllium-containing margarite, corundophilite, etc. The same may be shown for potassium, whose lowered concentration in this process results in its replacement in considerable amounts by sodium, for example in phlogopite.

In the geochemical process under consideration complex isomorphic substitutions are seen, both within each of the three distinguished groups of elements, and between elements which enter different groups (fig. 106). In the first place, naturally, such elements pairs which are related on the basis of physico-chemical properties intermix, as: Mg and Al, Mg and Fe^{++}, Al and Si, as well as O and F. Isomorphism between the primary and secondary elements can be represented by such combinations as Be and Si, Mn and Fe, Cr and Al, Mn and Mg. Isomorphism between the dispersed elements and the primaries may be illustrated by the combinations of Li - Mg, Ga - Al, etc.

In studying isomorphism one should bear in mind that each element capable of replacing another in mineral-formation processes can in general be substituted by this element. Nevertheless, this process does in a number of cases seem to be unilateral, this depending primarily on the concentration of the reacting elements, i.e. on the law of mass action. Occasionally, the elements cannot form independent minerals due to small concentraion, and only primary or secondary elements will be replaced during the process of mineral formation.

THE END

Reproduced From
Best Available Copy

1471

FOR REASONS OF SPEED AND ECONOMY

THIS REPORT HAS BEEN REPRODUCED

ELECTRONICALLY DIRECTLY FROM OUR

CONTRACTOR'S TYPESCRIPT

THIS PUBLICATION WAS PREPARED UNDER CONTRACT TO THE
UNITED STATES JOINT PUBLICATIONS RESEARCH SERVICE
A FEDERAL GOVERNMENT ORGANIZATION ESTABLISHED
TO SERVICE THE TRANSLATION AND RESEARCH NEEDS
OF THE VARIOUS GOVERNMENT DEPARTMENTS