(*Ia3d*), is nevertheless consistent with a garnet-type structure. The equivalence in atom positions is shown in Table 2. The precise nature of the crystal structure and formula of griphite can be determined only with additional methods of analysis, however. A crystal-structure analysis is now being undertaken to resolve the ambiguities remaining in the nature of the crystal structure and formula.

References

Ginzburg, A. J, (1952) Griphite in pegmatites of the Turkestan Range. *Dokl. Akad. Nauk S.S.S.R.* 84, 1045–1048.

Headden, W. P. (1891) A new phosphate from the Black Hills of South Dakota. *Amer. J. Sci.* 41, 415–417.

Jaffe, H. W. (1946) A new occurrence of griphite. *Amer. Mineral.* 31, 404–461.

McConnell, D. (1942) Griphite, a hydrophosphate garnetoid. *Amer. Mineral.* 27, 452–461.

Roberts, W. L., and G. Rapp (1965). *Mineralogy of the Black Hills.* Espe Printing Co., Rapid City, South Dakota.

BERYL FROM THE OXFORD MINE, TROUP COUNTY, GEORGIA

Dennis Radcliffe,[1] *Department of Geology, University of Georgia, Athens, Georgia*

AND

Arthur C. Bailey, Jr., *Department of Geology, The University of Tennessee, Knoxville, Tennessee*

Abstract

A survey of the literature indicates wide variation in chemistry and associated cell constants of common beryl. Computer refinement of selected crystals shows that the variation in cell constants are due at least in part to calculations based on non-unique X-ray reflections. Eighteen reflections of common beryl can be uniquely indexed. Least squares computations on the eighteen peaks leads to only slightly differing cell constants. These average $a = 9.216$ Å, $c = 9.197$ Å.

Beryl from the Oxford Mine shows distinct variations in crystal morphology including aquamarine exhibiting fractures filled with a second generation of beryl

[1] Present Address: C–E Minerals, 4020 Lexington Road, Athens, Ga. 30601.

growth, crystals elongated on *c* and crystals flattened parallel with *a*. The morphological variations of the Oxford pegmatite beryl could not be related to a systematic variation in cell dimension or chemistry.

INTRODUCTION

Most chemical analyses of natural beryl are characterized by two features. First, they invariably contain significant amounts of elements other than those required by the formula of beryl, $Be_3Al_2Si_6O_{18}$. For example Deer *et al.* (1962) gives 13 representative analyses of beryl in which the total of non-essential elements vary from 2.09 wt. percent to 10.24 wt. percent with an average of 4.70 wt. percent. Second, the analyses are always apparently deficient in beryllium relative to aluminum and silicon. Calculations on the data of Deer *et al.* (1962) show the percentage departure from the ideal BeO content varies from 1.6 percent to 24.6 percent with an average deficiency of 11.5 percent.

In view of these features several authors (*e.g.*, Folinsbee, 1941; Norrish, 1950; Ginzburg, 1955; Sosedko, 1957; Bakakin, 1962; Schaller, 1962; Grubb, 1964; Radcliffe, 1966; Nassau and Wood, 1968) have variously described the position of non-essential elements (mainly R_2O and R_2O_3) either in the channels of the beryl structure parallel to the *c* crystallographic axis or in the lattice proper where they probably substitute for beryllium. It would be expected that the lattice constants of beryl would be variable and reflect the chemical features described above. A survey of the literature suggests that the cell edge of beryl may vary from $a = 9.15$ to 9.41 Å and $c = 9.17$ to 9.23 Å, the $a{:}c$ ratio varying from 0.9799 to 1.0066. Presumably these data reflect variations in the structural chemistry of beryl?

The Oxford Brothers beryl pegmatite deposit has been described by Bailey (1969). The body lies in the southwestern part of the Georgia Piedmont close to the Alabama State Line. The pegmatite is a typical lensoidal graphic granite pegmatite separated from a rose quartz core by a narrow replacement zone characterized by A-type muscovite and beryl. Crystals of beryl weighing several hundreds of pounds are reported to have been collected from the property.

The beryl occurs in three distinct types: crystals elongated parallel to *c* (CB28), crystals flattened on the basal pinacoid (CB27), and masses of aquamarine up to 6 inches in dimension which are invariably fractured. This fracturing is of a regional nature and effects all minerals in the pegmatite. The fractures in the aquamarine are filled with small crystals (up to 1 mm) of transparent beryl (CB25) set in a friable matrix of white beryl (CB26). These latter probably represent a second generation of beryl emplaced in the original crystal

of aquamarine. This is the first reported occurrence of this phenomenon.

An investigation has been made to determine whether or not the different morphological shapes of the beryl reflect variations in the unit cell of beryl perhaps related to small variations in the chemistry.

Five crystals differing in habit (Table 1) were selected from the Oxford pegmatite to represent the variations in morphology and these are compared with 3 crystals (Table 1) analyzed in previous studies (Radcliffe and Campbell, 1966; Radcliffe 1969).

METHOD OF INVESTIGATION

Clean fractions of each crystal were crushed and screened. The 200–325 sized fraction was mixed with an internal standard of similar size and mass absorption (fused synthetic fluorite calibrated with silicon metal) and scanned at $1/2°/$minute on a Norelco Diffractometer using Ni filtered CuKα radiation.

The entire X-ray pattern was processed through a least squares progressive cycle computer program (Evans, Appleman, and Hardwerker, 1963) to obtain statistically precise and refined cell constants. Many ambiguous indices are possible for most of the relections of beryl, *e.g.*, 002 ≈ 110, 200 ≈ 102; this is due to the similarity of a and c. Thus slight variations of the input cell edges may cause a difference in the hkl value assigned by the program to the same line, even at low 2θ. This in turn leads to a statistically precise cell constant but probably an erroneous one. To obtain an accurate cell edge in the forward reflection region at least 10 reflections must be assigned fixed hkl values and be distributed throughout the X-ray pattern. To determine which reflections could be fixed all 8 beryl patterns were processed through the computer six times with varying a (9.19 — 9.13 Å) and c (9.18 — 9.24 Å) input dimensions. In each run 10 cycles of refinement were employed. Examination of the output data showed

Table 1. Description of Beryl Specimens

Number	Color	Genesis	Host Rock	Location
DR 522[*]	Yellow	Igneous	Narrow Pegmatite dyke	Birch Portage, Sask. Canada
DR 551	Green	Igneous	"　　　"　　　"	Birch Portage, Sask. Canada
DR 609	Aquamarine	Igneous	Granite	Mt. Antero, Colo.
CB 23	Aquamarine	Igneous	Zoned Pegmatite Body	Oxford Mine, Troup County, Ga.
CB 25	Transparent	Crystals in Fractures in Crystal of CB 23		Oxford Mine, Troup County, Ga.
CB 26	White	Friable Matrix for Crystals of CB 25		Oxford Mine, Troup County, Ga.
CB 27	Yellow	Replacement - flattened elongated on a in pegmatite		Oxford Mine, Troup County, Ga.
CB 28	White	Replacement - tapered, elongated on c in pegmatite		Oxford Mine, Troup County, Ga.

[*]DR 522, 551, 609. See Radcliffe and Campbell (1966); Radcliffe (1969).

Table 2. Lattice Constants of Beryl

Number	L*	aÅ	δ**	cÅ	δ	c/a	VÅ^3	δ
DR 522	19	9.2091	±.0006	9.1927	±.0015	.9982	675.17	±.12
DR 551	27	9.2232	±.0009	9.1905	±.0013	.9965	677.01	±.31
DR 609	17	9.2148	±.0021	9.1875	±.0031	.9970	675.62	± .1
CB 23	20	9.2181	±.0004	9.2052	±.0006	.9986	677.40	±.63
CB 25	22	9.2159	±.0008	9.1988	±.0011	.9981	676.61	±.10
CB 26	24	9.2168	±.0005	9.2029	±.0007	.9985	677.04	±.08
CB 27	15	9.2150	±.0028	9.1918	±.0037	.9975	675.96	±.37
CB 28	17	9.2171	±.0008	9.2043	±.0014	.9986	677.20	±.12
Average Value		9.216		9.192		.9979	676.7	

*Number of lines used in calculation of lattice constant.
**Standard Error of Estimate

that 18 lines on each pattern were indexed systematically with the same hkl value irrespective of the variable a and c input data. The Miller Indices and approximate d spacings are 100 (7.98) 002 (4.60) 102 (3.99) 112 (3.26) 202 (3.02) 211 (2.87) 300 (2.66) 212 (2.52) 004 (2.30) 104 (2.21) 311 (2.15) 204 (1.99) 320 (1.83) 313 (1.80) 411 (1.71) 224 (1.63) 413 (1.52) 324 (1.43). The above lines were assigned these fixed indices, the program assigning appropriate indices to the other lines of the pattern. Pertinent data for this procedure are given in Table 2.

DISCUSSION

The cell dimensions listed in Table 2 are very similar averaging $a = 9.216$ Å and $c = 9.197$ Å. These are only slightly different from these quoted by Berry and Mason (1959) as typical for beryl ($a = 9.215$ Å, $c = 9.192$ Å). The variation of previously reported dimensions emphasizes the difficulty of determining the lattice constants from powder diffraction data, when most reflections have possible non-unique indices. It is predicted that significant departure from the range of values given in Table 2 should occur only when a large atom substitutes in the structure, *e.g.*, Schaller (1962) describes beryl with $a = 9.30$ Å, $c = 9.20$ Å, $Cs_2O_3 = 6.32$ wt. percent.

Partial microprobe analyses (Table 3) were conducted on the Oxford Pegmatite beryl crystals using DR522, DR551, Al_2O_3, 3 feldspars, and 2 olivine crystals as standards. No systematic variations of chem-

Table 3. Partial Analyses by Microprobe of
Oxford Pegmatite beryl.

	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Σ	100 - Σ
CB 23	64.0	20.9	.3	1.1	86.3	13.7
CB 27	65.1	19.5	.2	1.0	85.8	14.2
CB 28	64.6	21.0	1.6	1.1	88.3	11.7

istry or slight variations in cell dimensions could be related to the morphological differences already noted in the Oxford Pegmatite beryl crystals.

REFERENCES

BAILEY, ARTHUR C. (1969) *Geology of Smith's Crossroads Area, Troup County, Georgia.* M.S. thesis, Univ. Ga. Athens.

BAKAKIN, V. V., AND N. V. BELOV (1962) Crystal chemistry of beryl. *Geokhimia* 5, 484–500.

DEER, W. A., R. A. HOWIE, AND J. ZUSSMAN (1962) *Rock Forming Minerals: Ortho- and Ring Silicates.* John Wiley and Sons, Inc., New York.

EVANS, H. T., JR., D. E. APPLEMAN, AND D. S. HANDWERKER (1963) The least square refinement of crystal unit cells with powder diffraction data by an automatic computer indexing method (abstr.) *Amer. Crystallogr. Assoc., Cambridge, Mass. Ann. Meet., Program,* 42–43.

FOLINSBEE, R. E. (1941) Optical properties of cordierite in relation to alkalis in the cordierite-beryl structure. *Amer. Mineral.* 26, 485–500.

GINZBURG, A. I. (1955) On the question of the composition of beryl. *Trans. Mineral. Muz. Akad. Sci. S.S.S.R.* 7, 56.

GRUBB, P. L. C. (1964) On beryl from Western Australia. *J. Roy. Soc. West. Australia* 47, 51–53.

NASSAU, K., AND D. L. WOOD (1968) An examination of red beryl from Utah. *Amer. Mineral.* 53, 801–806.

NORRISH, K. (1950) An X-ray study of beryl. *J. Roy. Soc. West. Australia* 34, 1–16.

RADCLIFFE, D. AND F. A. CAMPBELL (1966) Beryl from Birch Portage, Saskatchewan. *Can. Mineral.* 8, 493–505.

——— (1969) Cell Constants of Birch Portage Beryl, Saskatchewan. *Can. Mineral.* 10, 104–105.

SCHALLER, W. T., R. E. STEVENS, AND R. H. JAHNS (1962) An unusual beryl from Arizona. *Amer. Mineral.* 47, 672–699.

SOSEKDO, T. A. (1957) The change of structure and properties of beryls with increasing amounts of alkalis. *Zap. Vses. Mineral Obshch.* 86, 495–499.