BEHOITE, BETA-BE(OH)₂, FROM THE RODE RANCH PEGMATITE, LLANO COUNTY, TEXAS

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Abstract

Behoite, β-Be(OH)₂, is found in alteration zones around gadolinite occurring in the Rode Ranch pegmatite, Llano County, Texas.

It usually occurs as euhedral to subhedral, colorless crystals of psuedo-octedral habit, up to 1 mm diameter. Density 1.92 ± 0.01. Orthorhombic, $P2_12_12_1$. Axial ratio is $0.658 : 1 : 0.645$. Hardness about 4. Optically biaxial negative, $\alpha = 1.533$, $\beta = 1.544$, $\gamma = 1.548$, $2V = 82°$. Suggested orientation $\alpha = b$, $\beta = a$, $\gamma = c$, optical plane (100). The seven strongest X-ray lines are 3.88 (vs), 3.83 (vs), 2.95 (m), 2.79 (m), 2.39 (vs), 1.99 (m) and 1.96 (m). Infrared spectrum has major absorption maxima at 2.82, 2.85, 2.88, 9.30, 11.4, 12.8, 13.3 and 13.9-μm. DTA shows one strong exotherm at 310°C. Behoite is identical with synthetic β-Be(OH)₂ and isotypic with ϵ-Zn(OH)₂.

Introduction

The crystals of behoite were first observed by Joe Williams of San Saba, Texas in an examination of various samples from the Rode Ranch pegmatite. This pegmatite occurs in the Precambrian rocks of the Central Mineral Region of Texas and has a suite of rare earth minerals similar to the presently inundated Baringer Hill pegmatite (Hess, 1907). The Rode Ranch pegmatite contains the primary minerals allanite, gadolinite, crytolite and fergusonite in a matrix of red albitic plagioclase and microcline (Ehlmann *et al.*, 1964). The rare earth minerals were found at this locality during quarrying operations by the Texas Architectural Aggregate Company for milky quartz to be used in terrazo chips. The occurrence of β-Be(OH)₂ was reported at this locality by Ehlmann *et al.* (1964) on the basis of X-ray powder patterns but the mineral was not described in detail.

Montoya *et al.* (1964) slightly earlier reported an occurrence of β-Be(OH)₂ concentrated from altered volcanic tuff in the Honeycomb Hill, Juab County, Utah. Their material was extremely fine-grained and

was concentrated from the tuff matrix in the 1.85–2.02 specific gravity category by heavy liquids. The X-ray diffraction pattern matched synthetic β-BE(OH)$_2$ except for reflections which were attributed to montmorillonite, fluorite and calcite. In addition to these impurities, volcanic glass was assumed to be present.

The chemical compound, β-Be(OH)$_2$ was synthesized by Seitz *et al.* (1950) and its crystal structure and various properties were described. Of especial interest are the photographs of single crystals which are identical in habit to some of the natural crystals found in the Rode Ranch pegmatite.

The name behoite has not appeared previously in the literature; the name was given by Montoya (personal communication) who by virtue of a first identification of β-Be(OH)$_2$ in the literature (Montoya *et al.*, 1964) was given the privilege of naming the mineral. Behoite is taken from the chemical name beryllium hydroxide, and was approved by the Commission on New Minerals and Mineral Names of the International Mineral Association on the basis of data presented in the current study.

Crystals of behoite from the Rode Ranch pegmatite are preserved in the collection of the U. S. National Museum.

OCCURRENCE

The behoite crystals and aggregates occur in altered zones or rinds around masses of vitreous gadolinite. In general, the original gadolinite outlines are easy to delineate because they occur in a red, albite matrix which provides a distinctive border. A typical alteration rind, for example is approximately 2 cm thick on an ovaloid mass of gadolinite 5 by 8 cm (Ehlmann *et al.*, 1964).

The alteration zone between the fresh vitreous gadolinite in the interior and the enclosing pink albite contains a complicated mixture of several materials. Visual inspection indicates waxy, dull, lime-green to tan clay-like masses; vitreous to resinous, banded, brown to yellow veinlets and pearly white, flakey cross-cutting masses. X-ray diffraction analysis indicates the presence of bastnaesite, tengerite, nontronite and hematite. Bastnaesite appears to be most common, apparently occurring in several different forms and colors. The tengerite, in relatively pure form, occurs mainly as the white, flakey material. The vitreous brown to yellow layers are altered gadolinite and are amorphous; they show a hematite X-ray pattern on heating. Some hematite occurs as a loose, box-work pattern of veinlets and also serves as a host for euhedral behoite crystals.

Quarrying at depths below approximately five feet revealed gadolinite nodules with reddish-brown resinous altered rinds having no tengerite or behoite crystals. This material was completely amorphous. Apparently

the bastnaesite, tengerite and behoite are forming as near-surface alteration products of gadolinite through an intermediate amorphous material.

PROPERTIES

Physical. The behoite occurs as rounded crystal aggregates showing many triangular crystal faces, as anhedral layers, and as single pseudo-octahedral crystals up to 1 mm in size (Figure 1). Well-formed single euhedral
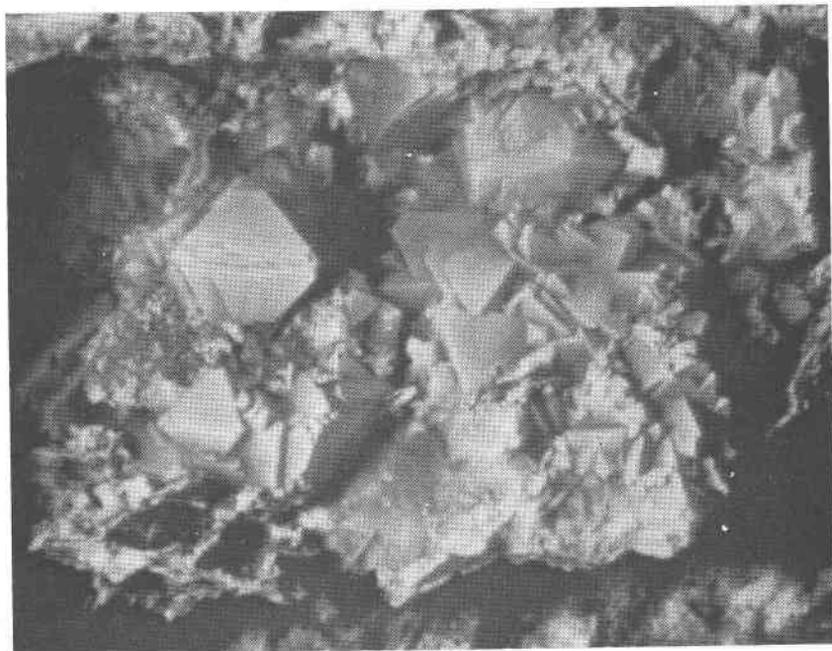

FIG. 1. Crystals of behoite in alteration rind around gadolinite. The crystals have been coated with ammonium chloride for photographing. The largest crystal is about 1 mm from point to point.

crystals occur rarely in small vugs. Most of the crystal faces show striations and etch pits. Behoite has a vitreous luster and is colorless although the matrix materials discolor some crystals to pastel shades of brown, red and yellow. The hardness could not be determined accurately on the small crystals but appears to be about 4. The mineral breaks with a conchoidal fracture and has no obvious cleavage.

The determination of the density was done by suspension in calibrated density liquids. The determination was made difficult by intermixed flakes of matrix but suspension of extremely small fragments of pure behoite indicated a density of 1.92 ± 0.01. A value of 1.924 g/cm^3 was

determined on synthetic β-Be(OH)$_2$ using the pycnometer method (Seitz *et al.*, 1950).

Chemical. Table 1 shows the results of the semiquantitative spectrographic analysis. The only major element present is beryllium. The other elements in trace and minor abundances cannot be considered necessary constituents of the behoite. Despite careful picking of behoite crystals under the binocular microscope, impurities were observed in crystals and particularly in crystal aggregates. An X-ray diffraction pattern of the spectrographic sample material showed minor clay impurities. The silicon

TABLE 1. SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF BEHOITE[a]

Element	Percent	Element	Percent
Be	Major	Cb	<0.006
Si	1–10	Cd	<0.004
Fe	0.3–3	Sn	<0.003
Ta	<0.1	Cr	<0.003
Bi	<0.03	Ca	<0.003
Sb	<0.02	Mg	<0.003
Zn	<0.02	Ti	<0.002
W	<0.02	Zr	<0.001
Sr	<0.02	Mo	<0.001
Na	<0.02	Co	<0.001
Pb	<0.01	Ba	<0.001
Cu	<0.01	V	<0.001
Ni	<0.01		

[a] Analysis by A. S. McCreath and Son, Inc., Harrisburg, Pennsylvania.

and iron present in Table 1, therefore may be assigned to impurities and not necessarily to the behoite.

Optical. Under cross nicols, crystals show extinction symmetrical to their outline. Crushed grains show a peculiar undulating extinction which varies from an equidimensional mosaic pattern to a "herringbone" pattern apparently formed by polysynthetic twinning. This twinning is subtle and does not show marked interference color alternations. Some grains appear to be fibrous and feathery aggregates. Many grains show anomalous blue and brown interference colors slightly on either side of extinction.

Optical data determined for behoite are:

Biaxial (−) $2V = 82°$

Colorless. $r < v$ strong

$$\alpha = 1.533 \pm 0.003$$
$$\beta = 1.544 \pm 0.003$$
$$\gamma = 1.548 \pm 0.003$$

birefringence $= 0.015$.

Because of the poor quality of the crystals and difficulty in differentiating between a and c, the writers did not obtain the optical orientation with certainty. By comparing their data with those of Megaw (1935) for isotypic ϵ-Zn(OH)$_2$, the following is suggested: $\alpha = b$, $\beta = a$, $\gamma = c$; acute bisectrix $= b$; optic plane $= (100)$.

Crystal Morphology. Goniometric studies of single crystals of behoite show an orthorhombic dome {011} combined with a prism {110} in such a way to simulate a pseudo-octahedral habit. Although the crystal faces give poor reflections, measurements were close to the following calculated values: a to $[110] = 33°21'$; b to $[110] = 56°39'$; b to $[011] = 57°10'$; c to $[011] = 32°50'$ (based on X-ray $a:b:c: = 0.658:1:0.645$). Because of the pseudotetragonal nature of the structure and poorly developed faces, it is difficult to differentiate between a and c. A pseudo-octahedral habit for synthetic β-Be(OH)$_2$ was reported by Fricke (1927) and Seitz *et al.* (1950). The observed habit conforms well with that of isotypic ϵ-Zn(OH)$_2$ reported by Groth (1906) on which {011} and {110} dominate. In a preliminary X-ray study of poorly developed behoite crystals Malcolm Ross (written communication, 1966) reported twinning involving a 90° rotation about the b axis in which the a and c axes of the twinned individuals coincide. The writers did not find evidence to confirm this twinning in the crystals they studied.

X-ray Crystallography. X-ray studies confirmed the orthorhombic nature of the mineral and showed that it has a structure identical to synthetic β-Be(OH)$_2$ (Seitz *et al.*, 1950) and isotypic to ϵ-Zn(OH)$_2$. Rotation and several levels of Weissenberg patterns were made in a camera of 5.73 cm diameter using copper radiation. The space group $P2_12_12_1$ (orthorhombic bisphenoidal class) was indicated by the characteristic extinct reflections: $(h00)$ when h is odd, $(0k0)$ when k is odd, and $(00l)$ when l is odd.

Initially the chemical nature of this new mineral was determined by its comparison with the X-ray powder data of β-Be(OH)$_2$ (XRDF data card 7-341 from Seitz *et al.*, 1950). A comparison of these data is given in Table 2. The measured data for behoite are the averaged values derived from four nearly identical films made in two cameras (11.46 cm diameter, CuKα radiation). The unit cell constants for behoite, determined from the indexed powder date of Table 2, are $a = 4.64 \pm 0.02$, $b = 7.05 \pm 0.02$, $c = 4.55 \pm 0.03$ Å; $a:b:c: = 0.658:1:0.645$. Using this unit cell, a molecular weight of 45.027, and a measured specific gravity of 1.92, Z was calcu-

TABLE 2. A COMPARISON OF X-RAY POWDER DATA FOR BEHOITE AND β-Be(OH)$_2$

Behoite from Texas		β-Be(OH)$_2$ (Seitz *et al.*, 1950)		
d(meas.)Å	I(obs.)	*hkl*	d(meas.)Å	I(obs.)
3.88	vs	110	3.93	s+
3.83	vs	011	3.80	s
2.95	m	111	2.94	m+
2.79	m	021	2.78	m
2.39	vs+	121	2.38	vs
2.32	vw	200	2.31	vw
2.28	w	002	2.27	mw
2.20	mw	210	2.19	m
2.17	vw	012	2.15	w
2.10	vw+	130, 031	2.08	w+
2.04	w	102	2.03	mw
1.99	m	211	1.97	m+
1.96	m	112	1.95	m
—	—	220	1.93	vvw
1.91	mw	022, 131	1.90	m—
1.78	vw	221	1.78	mw
1.77	vw	122, 040	1.76	w+
1.65	vw	230, 140, 041	1.64	w
1.64	vw	032	1.63	w
1.62	vw	202	1.62	w—
1.58	w	212	1.58	w
1.55	w	231	1.54	w+
1.54	w	132	1.53	w
—	—	310	1.50	vw
—	—	013	1.48	vw
1.43	vw	103, 311	1.43	w
1.41	vw	113, 240	1.40	w
1.40	vw	042	1.39	w
1.35	vvw	321	1.34	w—
1.33	mw	142, 123	1.33	mw—
1.29	vw	330	1.28	w
1.27	w	302, 033	1.27	mw
1.25	vw	312, 213	1.25	w
1.24	w	331	1.24	mw
1.21	vw	250	1.20	mw—
1.19	w	242, 223	1.19	mw

lated to be 4.00. X-ray powder data for behoite from Juab County, Utah (Montoya *et al.*, 1964) closely match the Texas behoite data.

Infrared Absorption. Figure 2 shows infrared absorption spectra of behoite and Sadtler Standard #Y419K, Be(OH)$_2$ (Sadtler, 1965). The behoite spectrum was taken on a Perkin Elmer Model 237 spectrophotometer
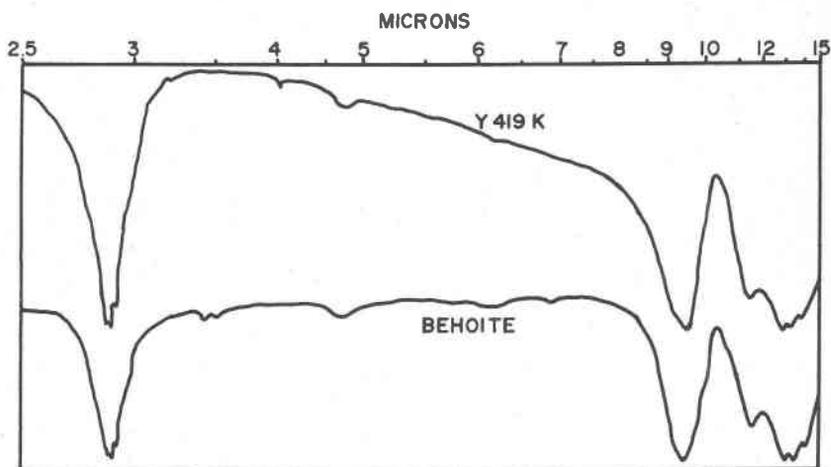
FIG. 2. Infrared absorption spectra of Be(OH)₂ (Sadtler Standard Y419K) and Behoite.

using the KBr pressed pellet technique. Except for a few small peaks, which probably are impurities, the spectra are identical.

The values of major absorption maxima on behoite shown in Figure 1 are: 2.82, 2.85, 2.88, 2.94 (shoulder), 4.74, 6.15, 6.85?, 9.30 (doublet ?), 11.4, 12.8, 13.3 and 13.9 μm.

DTA. Differential thermal analysis of the sample was done using a Dupont 900 instrument at a heating rate of 20° per minute in an air flow. The resulting pattern showed a two step endotherm, the first part beginning at about 265° and the second strong part beginning at about 290°C and peaking at 310°C. This endothermic reaction represents dehydroxylation of the behoite.

DISCUSSION OF ORIGIN

The element beryllium is considered by Rankama and Sahama (1950) to have a role similar to aluminum in the weathering cycle. The parallels are a result of similarity in ionic potential, 5.9 for beryllium and 5.4 for aluminum. The present study contributes to the concept of Rankama and Sahama in that the precipitation of beryllium hydroxide in the weathering zone is analagous to the role of aluminum, in the formation of gibbsite.

Under the pH conditions existing in the weathering environment, beryllium hydroxide is extremely insoluble. Gilbert and Garrett (1956) state the solubility in pure water is below 1×10^{-7} moles per 1000 grams of water and Kovalenko and Geiderovich (1959) give 1.71×10^{-9} moles

per liter. Kraynov (1968) discusses the migration of beryllium in natural waters and notes that in a survey of 400 analyses, the beryllium content in natural water is low at pH values about 7.5 to 8. He suggests that despite complexing, beryllium is removed from alkaline waters by hydrolysis thus forming the insoluble hydroxide. He further notes the presence of fluoride and carbonate ions in solution in natural occurring amounts does not markedly increase the concentration of beryllium.

It seems, therefore, that the rarity of the compound beryllium hydroxide in nature is a result of: (1) the dispersed nature and low abundance of beryllium in rocks; (2) the great stability of most beryllium minerals, such as beryl, chrysoberyl and phenacite, in surface weathering.

In those rare occurrences of unstable beryllium-bearing minerals in the weathering zone, such as epidymite and gadolinite, the alteration products are confusing. Alteration products reported occurring in leached cavities previously occupied by epidymite are the sorosilicates, helbertrandite, spherobertrandite and berylite (Beus, 1966). In the Baringer Hill pegmatite, similar to the Rode Ranch pegmatite in the present study, Hidden (1905) reported the occurrence of beryllium tengerite, a double basic carbonate of yttrium and beryllium. In that occurrence, one suspects the alteration products may well be tengerite and behoite mixed and not a single phase as reported.

In the present study the behoite is forming from gadolinite in leached encircling zones. Complete chemical analysis of the unweathered fresh gadolinite gives a BeO content of 9.25 percent. An estimation of behoite observed in the leached cavities at about 10 percent indicates little or no depletion of beryllium on weathering. It appears that as weathering progresses the fresh, green, vitreous, metamict gadolinite alters to a brown, resinous, metamict gadolinite which alters to a complex mixture containing the crystalline minerals, bastnaesite, tengerite and behoite.

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