

ideal formula is $\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12} \cdot 6\text{H}_2\text{O}$, but natural herschelite shows substitution of calcium and potassium for sodium. There is probably a composition gap between chabazite and herschelite which will be more closely defined by additional analyses, but for the present an arbitrary boundary, as shown by the dashed line on Fig. 1, from the potassium apex to the mid-point on the Ca-Na join, can be suggested. The relationship between chabazite and herschelite is exactly analogous to that between heulandite and clinoptilolite, as described by Mason and Sand (1960).

It should be noted that the composition of herschelite is very similar to that of gmelinite, and that these two species are not distinguishable on the basis of chemical analyses, although they are different structurally and in x-ray powder photographs. They may be dimorphs of $\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12} \cdot 6\text{H}_2\text{O}$, but the conditions favoring the formation of one or the other remain to be elucidated.

I am indebted to Mr. John Albanese for drawing my attention to this problem, and for providing me with specimens of herschelite from the original locality in Sicily.

REFERENCES

- LEVY, A. (1825). Descriptions of two new minerals. *Ann. Phil.*, **10**, 361-363.
MASON, B. and L. B. SAND (1960). Clinoptilolite from Patagonia; the relationship between clinoptilolite and heulandite. *Am. Mineral.*, **45**, 341-350.
STRUNZ, H. (1956). Die Zeolithe Gmelinite, Chabasit, Levyn (Phakolith, Herschelite, Seebachit, Offretit). *Neues Jahrb. Mineral., Monatsh.*, 250-259.
WALKER, G. P. L. (1951). The amygdale minerals in the Tertiary lavas of Iceland. I. The distribution of chabazite habits and zeolites in the Garron plateau area, County Antrim. *Mineral. Mag.*, **29**, 773-791.
WYART, J. (1933). Recherches sur les zeolites. *Bull. Soc. Franc. Mineral.*, **56**, 81-187.

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BAOTITE (PAO-T'OU-K'UANG) FROM RAVALLI COUNTY, MONTANA¹

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INTRODUCTION

The carbonatic RE-Nb deposits of southern Ravalli County, Montana, have been studied systematically by Crowley (1960) and by Heinrich and

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Levinson (1961). Near the southeastern corner of the area, in the upper reaches of Sheep Creek (Heinrich and Levinson, 1961, Fig. 1), in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 10, T. 4 S., R. 22 W., Crowley examined a carbonatic vein containing masses of a brown, striated, semi-metallic, highly radioactive mineral later identified as eschynite (Heinrich and Levinson, 1961). Microscopic examination of acid-insoluble residues from the eschynite-bearing carbonatite revealed small brilliant crystals of an unknown mineral first thought to represent a new species but subsequently demonstrated to be identical with baotite, a newly described niobium silicate from China. These crystals are the subject of this study. The deposit was reexamined in July 1961 by Crowley and Heinrich, but no additional eschynite-baotite rock was found.

The writers are indebted to R. A. Borup of Dow Chemical Company for the analysis, to E. B. Gross and S. H. Quon for technical assistance, and to Michael Fleischer for supplying a translation of one of the Russian references. The laboratory investigation was supported by Michigan Memorial Phoenix Project 204.

HISTORY OF BAOTITE

Pao-t'ou-k'uang was described by Peng (1959) from an unspecified locality. Later this name, transliterated from Chinese to Russian (and thence to English), was given as baotite by Semonov (1960), who presented the formula as $Ba_4(Ti,Nb)_8ClO_{16}(Si_4O_{22})$. Further studies by Semenov *et al.* (1961) established the composition as $Ba_4Ti_7NbSi_4O_{23}Cl$ and revealed that the mineral was found near the town of Baotou, Inner Mongolia, Chinese People's Republic.

Our material, first studied crystallographically, was found to have a combination of symmetry and cell dimensions not referable to any other species. Analysis established compositional similarity with baotite. With the availability of the Russian physical-property and x-ray data (Semenov *et al.*, 1961) for comparison with ours, we were able to confirm that the Montana mineral is indeed baotite.

GEOLOGY

The carbonatic vein is exposed in a bulldozer trench about 75 feet long, 15–20 feet wide, and 3–6 feet deep, which follows the vein along its strike. The vein, which strikes N. 60° W. and is vertical, ranges in thickness from less than an inch to nearly a foot. It is parallel with the foliation of the enclosing hornblende gneiss, a dark, strongly foliated rock that contains essential hornblende and labradorite and accessory quartz, augite, microcline, apatite and magnetite. The foliation of the gneisses strikes N. 22–

70° W. The gneiss has been intruded by sills of diabase and by small dikes and sills of pegmatite as much as $1\frac{1}{2}$ feet thick.

Below the northern end of the trench is an irregular small cut in which no carbonatite is exposed. The vein is asymmetrically banded and also shows variations in composition along the strike. Along its margins there are locally conspicuous exomorphic developments of sodic amphiboles and coarse-grained biotite. Bands, seams and lenses occur in which the following minerals are concentrated:

1. Calcite
2. Dolomite
3. Ancylyte
4. Monazite
5. Sodic amphiboles
6. Barite

One part of the vein contains a core of white pearly barite, about a foot long and 3 inches or less thick. The monazite grains are the largest found in the district, some reaching a diameter of 1 inch.

The complete list of minerals identified in the vein is: actinolite, allanite, ancylite, apatite, baotite, barite, biotite, calcite (two generations), chlorite, columbite, dolomite, eschynite, glaucophane, magnetite, monazite, muscovite and quartz.

DESCRIPTION OF BAOTITE

The baotite appears as grains and partly faced crystals 0.8–4 mm in size embedded in calcitic carbonatite associated chiefly with eschynite and monazite. All of the crystals positively identified as baotite have been found in a thin calcite crust on masses of eschynite. They have a very high luster, nearly semi-metallic, and are nearly black in reflected light. Table 1 compares the physical properties of baotite from Montana with those of baotite from Inner Mongolia.

The crystallography of baotite is summarized in Table 2. The forms are based on measurements of a single crystal, the most complex found (Fig. 1). Most crystals show more simple development with the forms $\{110\}$ and $\{011\}$ dominant.

The x-ray crystallography was derived from single-crystal rotation and layer line photographs, taken with an equi-inclination Weissenberg camera on both *a*- and *c*-axis orientations.

X-ray powder diffraction data for baotite are listed in Table 3. Semenov *et al.* (1961) describe the crystal structure as consisting of quadruple metasilicate rings of Si_4O_{12} and chains of Ti-Nb octahedra. The Cl ions are believed to occupy large structural gaps.

TABLE 1. PHYSICAL AND OPTICAL PROPERTIES OF BAOTITE

	Montana	Inner Mongolia
Fracture	Hackly	
Cleavage	(110) two directions at 90°	Two cleavages
H	6, brittle	6
G	4.71 ± .01	4.42
Luster	Vitreous	Vitreous
Color (reflected light)	Black	Light brown to black
Color (transmitted light)		Brownish green
Pleochroism	ω = brown ε = dark red brown to nearly black	ω = greenish yellow; colorless ε = greenish brown, dark brownish to light greenish yellow
Optical group and sign	Uniaxial (+)	Uniaxial (+)
Indices of refraction	ω = 1.944 ε > 2.00	ω = 1.94 ε = 2.16

TABLE 2. CRYSTALLOGRAPHY OF BAOTITE

Tetragonal; dipyramidal—4/m					
$a:c=1:0.3000^1$, $\rho:r=0.3000:1$					
Forms	ϕ	ρ	A	\bar{M}	M
a 010	00 00	90°00'	90°00'	45°00'	
m 110	45°00'	90 00	45 00	90 00	
d 120	26 34	90 00	73 26	71 34	
-d 120	-26 34	90 00	116 34		71°34'
i 011	00 00	16 42	90 00	78 16½	
k 031	00 00	41 59	90 00	61 46½	
n 051	00 00	56 18½	90 00	54 48½	
u' 132	18 26	25 22½	82 13	67 27½	
v' 121	26 34	33 51½	75 34½	58 06	
w' 231	33 41½	47 15	65 58	43 56½	
y' 341	36 52	56 18½	60 03	34 32½	
'v 211	63 26	33 51½	60 07	58 06	
'w 321	56 18½	47 15	52 38	43 56½	
'z 411	75 58	51 45	40 22½	47 40½	
'y 431	53 08	56 18½	48 16	34 32½	

Structure cell. Space group $I4_1/a$

$a=20.02 \pm 0.02 \text{ \AA}$, $c=6.006 \pm 0.004 \text{ \AA}$; $a:c=1:0.3000$

$a=19.68 \text{ \AA}$, $c=5.88 \text{ \AA}$ (Inner Mongolia)

¹ Axial ratio based on x-ray crystallography.

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR BAOTITE

Montana (Cu-Ni radiation)				Inner Mongolia (Cu radiation)	
dÅ		I	hkl	dÅ	I
meas.	calc.				
5.6850	5.7014	.2	101		
4.9954	5.0081	.1	400		
4.0234	4.0745	5	321		
3.7391	3.7782	.4	411		
3.5160	3.5002	9	440	3.55	9
3.2983	3.3329	7	431	3.34	3
3.1385	3.1627	10	521	3.17	6
2.9088	2.8892	.4	611	2.88	8
2.8543	2.8741	7	202-		
2.7520	2.7728	.5	222	2.77	5
2.6926	2.6735	3	631	2.69	3
2.5030	2.5046	3	800		
2.4631	2.9933	.3	422		
2.2335	2.2310	9	602	2.24	8
2.0908	2.0392	4	642	2.04	3
1.9818	1.9787	4	732	2.00	4
1.9440	1.9512	3.5	213	1.959	3
1.9131	1.9258	2	802		
1.8723	1.8832	2	323		
1.7917	1.7952	4.5	842	1.828	2
1.7628	1.7618	9.5	523	1.775	6
1.7048	1.7108	8.0	613	1.716	5
1.6647	1.6686	.5	862		
1.6321		.5			
1.5661		.1			
1.5494		3	743		
1.5086	1.5011	.3	004		
1.4878	1.4845	1	204		
1.4483	1.4718	5	763		
1.4221	1.4230	25	424		
1.3711	1.3690	8	604		
1.3514	1.3603	9	624	1.358	4
1.3346	1.3203	100	644	1.337	10
1.3099	1.3035	2	734		
1.2950	1.2872	8	804		
1.2711	1.2768	4	824		
1.2105		6			
				.980	5
				.937	4
				.833	5

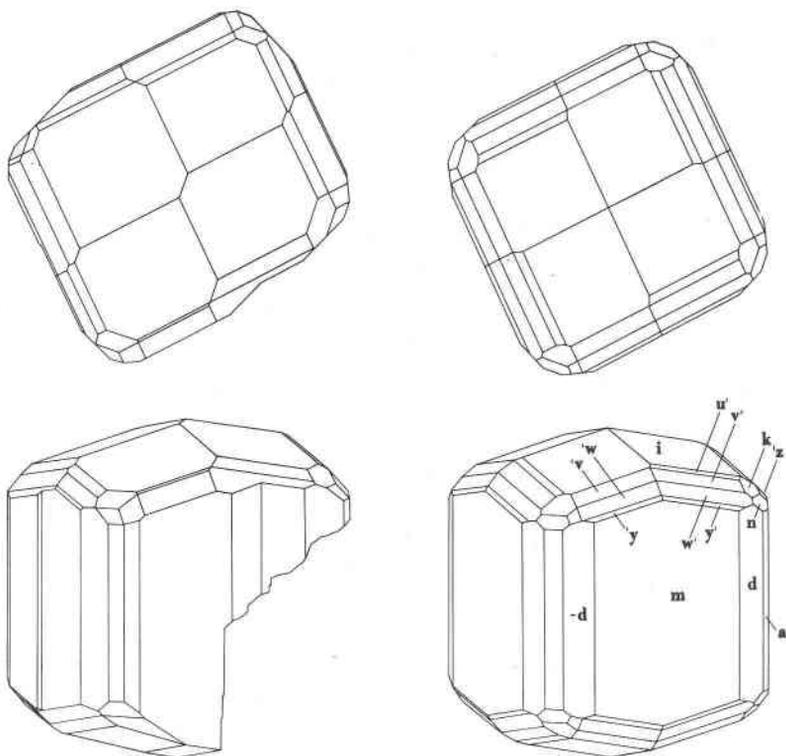


FIG. 1. Crystal of baotite from Ravalli County, Montana. *Left*: actual crystal; *right*: idealized, showing forms (see Table 2).

Three analyses of the Mongolian material have been published; one in Peng (1959) and two in Semenov (1961).

A complete analysis of the Montana mineral is planned. An *x*-ray fluorescence scan of our material by R. A. Borup shows Nb, Ba, Ti, and Fe are major constituents and traces of Sr and Ca are present. Mr. Borup also determined spectrographically: $\text{SiO}_2 = 12\%$, $\text{Cl} = 0.4\%$. Thus the Montana material contains all the major constituents of the Mongolian mineral, but has a much lower Cl content (0.4 vs. 2.01 and 2.17%).

PARAGENESIS

In both occurrences baotite is associated with alkalic rocks. The Montana mineral is a constituent of a carbonatic vein in Precambrian metamorphic rocks. The Mongolian mineral occurs in quartz veins with galena, pyrite, albite, aegirine, and alkali amphiboles. The veins cut Proterozoic quartzite near Hercynian alkali granite and syenite.

The Ravalli County carbonatic veins show an unusual development of

Nb species: columbite, niobian rutile, fersmite, eschynite and baotite. More typical carbonatites usually contain Nb principally as pyrochlore or as pyrochlore with greatly subordinate columbite.

REFERENCES

- CROWLEY, F. A. (1960), Columbium-rare earth deposits, southern Ravalli County, Montana. *Mont. Bur. Mines Geol., Bull.*, **18**.
- HEINRICH, E. WM. AND A. A. LEVINSON (1961), Carbonatic niobium-rare earth deposits, Ravalli County, Montana. *Am. Mineral.*, **46**, 1424-1447.
- PENG, CH'I-JUI (1959), The discovery of several new minerals of rare elements. *Ti-chih K'o-hsueh* 10 (in Chinese). Abs. in *Am. Mineral.*, **45**, 754, 1960.
- SEMENOV, E. I., KHUN VEN-SIN, AND T. A. KAPITONOVA (1961), Baotite, a new niobium mineral. *Dokl. Akad. Nauk U.S.S.R.*, **136**, 915-916 (in Russian). English Transl. by M. Fleischer (written comm.). Abs. in *Mineral. Abs.*, **15** (2), 135, 1961.
- SIMONOV, V. I. (1960), Baotite, a mineral with a metasilicate ring (Si_4O_{12}) *Kristallografiya*, **5**, 544-546 (in Russian). Abs. in *Am. Mineral.*, **46**, 466, 1961.

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AN X-RAY SPECTROGRAPHIC METHOD FOR MEASURING
BASE EXCHANGE CAPACITY

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Precise base exchange capacity measurements can be made by analyzing for exchanged strontium by x-ray spectrographic methods. Sample materials which had been used in A.P.I. project 49 and for which base exchange capacity values had been reported (Lewis, 1950) were used in this study. A good correlation ($r = .91$)¹ exists between the reported base exchange capacity values and the data provided by the x-ray fluorescent spectrograph for these samples as illustrated in Fig. 1.

The samples were prepared for this analysis according to a method previously described (Hinckley and Bates, 1960) consisting of exchanging Sr^{2+} onto the sample material by use of a SrCl_2 solution and by removing the excess strontium by a dialysis process. The method described by Bennett and Franklin (1954) was used in obtaining the precision values.

In the range from about 150 to 25 milliequivalents per 100 grams, the precision obtained at the .95 probability level is from ± 3.0 to ± 1.8 milliequivalents, respectively. At lower base exchange values, work on other samples, not plotted on Fig. 1, indicates that a precision in the order of $\pm 0.5\%$ of the base exchange capacity determined is obtained.

The sample underlined on Fig. 1 is a nontronite sample which did not

¹ Significant at least at 99% at $N = 56$ (Arkin and Colton, 1950, p. 140).