The metamict character shown by much of the allanite in the Pikes Peak granite is probably entirely unrelated to the bastnaesite alteration, which may be assumed to have been completed at a time when the allanite was entirely crystalline. Supergene alteration, on the other hand, would be accelerated by metamictization through radiochemical effects and by the physical disruption of the allanite and the enclosing rock.

REFERENCES

Glass, J. J., and Smalley, R. G., 1945, Bastnäsite [Gallinas Mts., N. Mex.]: Am. Mineralogist, v. 30, p. 601-615.

Hutchinson, R. M., 1960, Structure and petrology of north end of Pikes Peak batholith, Colorado *in* Guide to the geology of Colorado: Geol. Soc. America, Rocky Mtn. Assoc. Geologists, Colo. Sci. Soc., p. 170-180.

Moore, G. E., Jr., 1959, Bedrock geology of the Carolina and Quonochontaug quadrangles, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ-117.

Olson, J. C., Shawe, D. R., Pray, L. C., and Sharp, W. N., 1954, Rare earth mineral deposits of the Mountain Pass District, San Bernardino County, California: U.S. Geol. Survey Prof. Paper 261, 75 p.

Silver, L. T., and Grunenfelder, Marc, 1957, Alteration of accessory allanite in granites of the Elberton area, Georgia: Geol. Soc. America Bull., v. 68, p. 1796.

Smith, W. L., and Cisney, E. A., 1956, Bastnaesite, an accessory mineral in the Redstone granite from Westerly, Rhode Island: Am. Mineralogist, v. 41, p. 76-81.

Sverdrup, T. L., Bryn, K. Ø., and Saebø, P. C., 1959, Bastnäsite a new mineral for Norway: Norsk geol. tidsskr., v. 39, p. 237-247.

Watson, T. L., 1917, Weathering of allanite: Geol. Soc. America Bull., v. 28, p. 463-500.

---

255. TUNELLITE, A NEW HYDROUS STRONTIUM BORATE FROM THE KRAMER BORATE DISTRICT, CALIFORNIA

By RICHARD C. ERD, VINCENT MORGAN, and JOAN R. CLARK,
Menlo Park, Calif.; U. S. Borax & Chemical Corporation, Boron, Calif.; and Washington, D. C.

Tunellite was first noted by Erd in some samples collected in 1957 from a ventilating shaft in the Jenifer mine, Kramer borate district, California, by Daniel M. Cooper of the U. S. Borax & Chemical Corporation. Initial mineralogical determinations showed that the optical properties of tunellite nearly matched those of hydroboracite, $MgO \cdot CaO \cdot 3B_2O_3 \cdot 6H_2O$, but its X-ray powder pattern could not be identified. Later Morgan analyzed material collected from the newly opened pit of the company and established the composition of tunellite, $SrO \cdot 3B_2O_3 \cdot 4H_2O$. In 1959 the mineral was discovered in the Furnace Creek borate area, Death Valley region, California, by James F. McAllister, U.S. Geological Survey, who kindly supplied material for comparison. Goniometric and X-ray crystallographic studies by Clark corroborated the chemical analysis and confirmed tunellite as a new species isostructural with nobleite (tables 255.1 and 255.2).

The name tunellite (pronounced tŭn nĕl′ īt) is in honor of Dr. George Tunell, Professor of Geology, University of California, Los Angeles.

The geology of the Kramer borate district has been described by Schaller (1930) and Gale (1946); more recent data are given by Smith (1960). In the western part of the deposit, where the initial open pit was excavated, a prominent fault has displaced the borate beds. Near this fault there is an angular discordance between the sodium borate ore and overlying borate-bearing mudstone beds; this discordance may have been the result of subsurface solution (Smith, 1960, p. 113). A 6-foot zone above the sodium borate-mudstone con-

TABLE 255.1.—*Crystallographic data for tunellite*, $SrO \cdot 3B_2O_3 \cdot 4H_2O$

	1 Space Group $P2_1/a-C_{2h}^5$	[1]2 Space Group $P2_1/n-C_{2h}^5$
a	14.36±0.05 A	13.75 A
b	8.19_8±0.02	8.19_8
c	9.93_0±0.02	9.93_0
a:*b*:*c*	1.752:1:1.211	1.677:1:1.211
β	113°55′±10′	107°23′
Cell volume		1068 A^3
Cell contents		$4[SrO \cdot 3B_2O_3 \cdot 4H_2O]$
Density (calculated)		$2.39_1 gcm^{-3}$
Specific gravity (measured, $D^{20}{}_4$)		[2] 2.40±0.01

[1] Transformation, $P2_1/a$ to $P2_1/n$: $\bar{1}0\bar{1}/010/001$.

[2] Determined using the sink-float method with a mixture of bromoform and carbon tetrachloride.

TABLE 255.2.—*Comparison of crystallographic, optical, and physical data for tunellite and nobleite*

	Tunellite	Nobleite [1]
Cell contents	$4[SrO{\cdot}3B_2O_3{\cdot}4H_2O]$	$4[CaO{\cdot}3B_2O_3{\cdot}4H_2O]$
Crystal system	Monoclinic	Monoclinic
Space group	$P2_1/a$	$P2_1/a$
a	14.36 ± 0.05A	14.56 ± 0.05A
b	$8.19_8 \pm 0.02$	$8.01_6 \pm 0.02$
c	$9.93_0 \pm 0.02$	$9.83_8 \pm 0.02$
β	$113°55' \pm 10'$	$111°45' \pm 10'$
Cell volume	1068 A^3	1066 A^3
Density (calculated)	2.39_1gcm^{-3}	2.09gcm^{-3}
Specific gravity (meas., D_4^{20})	2.40 ± 0.01	2.09 ± 0.01
Indices of refraction, sodium light:		
α	1.519 ± 0.003	1.500 ± 0.003
β	1.534 ± 0.002	1.520 ± 0.002
γ	1.569 ± 0.002	1.554 ± 0.002
2V (calculated)	68°	76°
Dispersion	$r > v$, weak	$r > v$, weak
Optical orientation	$X \wedge a = 29°$ $Y = b$ $Z \wedge c = -5°$	$X \wedge a = 29°$ $Y = b$ $Z \wedge c = -7°$
Cleavage	{100} perfect {001} distinct	{100} perfect {001} indistinct
Hardness	2½	3

[1] Data from Erd and others, 1961.

tact is disturbed and within this zone tunellite formed as a disseminated secondary mineral.

The first material found consisted of white compact fine-grained nodules associated with lenses of inderite and kurnakovite (the monoclinic and triclinic polymorphs of $2MgO{\cdot}3B_2O_3{\cdot}15H_2O$; Schaller and Mrose, 1960) and nodular ulexite in a greenish to black montmorillonitic clay. Subsequently individual long prismatic [001] and flat tabular {100} crystals of tunellite up to 1.5 cm in length were found in the clay. As the open pit was developed, Morgan discovered a large vuggy mass of hydroboracite lined with splendid equant crystals of tunellite up to 1 cm in diameter. Figure 255.1 shows idealized prismatic and equant habits, common forms, and optical orientation of the tunellite crystals from the open pit. Other minerals associated with tunellite in these occurrences are realgar, stibnite, several undescribed iron sulfides, adularia, and analcime.

Most of the physical and optical properties of tunellite are summarized in table 255.2. It is colorless, transparent, nonfluorescent, and has a subvitreous luster, except that the {100} and cleavage surfaces parallel to {100} are pearly. Thin crystals are flexible, inelastic, and sectile. Faces of the form {0kl} are striated parallel to [001], notably so in specimens from the Furnace Creek area. Faces of {100} are relatively smooth, lustrous, and soft, whereas {110} and {001} faces are rough, pitted, and hard. X-ray powder diffraction data for tunellite are given in table 255.3.

Determinations of SrO and B_2O_3 were made using separate 0.5-gram samples. The SrO sample was dissolved in dilute HCl, neutralized with NH_4OH, and combined with sufficient dilute H_2SO_4 to precipitate all of the strontium. An equal volume of methanol was added, the solution was mixed, and was allowed to stand overnight. The $SrSO_4$ precipitate was filtered into a dried and tared Gooch crucible and weighed after washing and drying. B_2O_3 was determined by titration with NaOH and manitol. Water was determined by loss on ignition of 1-gram samples. Redetermination of B_2O_3 on the residue proved that there was no loss of B_2O_3 due to volatilization during ignition. Calcium was not detected. The results of the analysis are given in table 255.4.

The synthetic $SrO{\cdot}3B_2O_3{\cdot}4H_2O$ was prepared by adding 3 g H_3BO_3 in 50 ml of water to a solution of 10 g recrystallized borax in 100 ml of water at 80° C. Three-fourths of a gram of $SrCO_3$ was added and the solution was stirred for one day. After six days, when most of the precipitate was found to be $SrCO_3$, 10 g more H_3BO_3 in 50 ml of water was added. An extremely fine-grained precipitate of $SrO{\cdot}3B_2O_3{\cdot}4H_2O$ had formed after two days, and rhomb- and octagonal-shaped plates 0.02 mm in diameter developed after standing for one month at room temperature. (See analysis, table 255.4.) We found no previous report

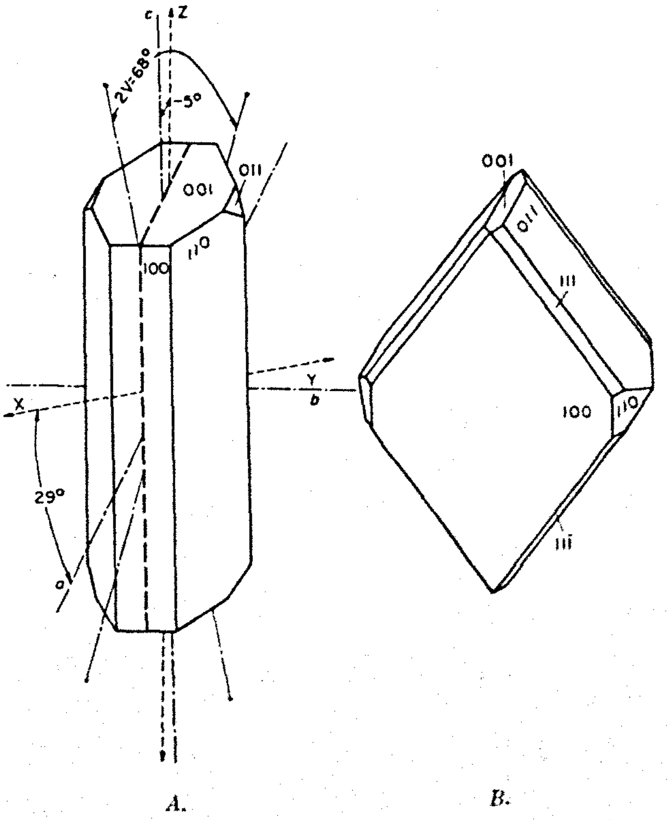

FIGURE 255.1.—Prismatic (*A*) and equant (*B*) habits and optical orientation of tunellite crystals from the Kramer borate district.

TABLE 255.3.—*X-ray diffraction data for tunellite*

Measured[1]						Calculated[2]	
Mineral[3]				Synthetic compound[4]		Indexing for space group $P2_1/a$ (table 255.1)	
Boron, Calif.		Death Valley region, California					
I	d_{hkl}	I	d_{hkl}	I	d_{hkl}	d_{hkl}	hkl
				1	9.10	9.078	001
3	6.97	4	6.97	24	6.97	6.954	110
4	6.79	7	6.78	11	6.79	6.783	$\bar{2}01$
100	6.58	100	6.57	100	6.57	6.564	200
2	6.22	3	6.21	15	6.21	6.200	$\bar{1}11$
						6.084	011
1	5.231	2	5.215	2	5.231	5.226	$\bar{2}11$
6	5.138	8	5.138	32	5.135	5.124	210
						5.024	111
1	4.750	1	4.745	11	4.750	4.738	$\bar{2}02$
6	4.531	11	4.525	18	4.529	4.539	002
						4.520	201
						4.240	$\bar{1}12$
						4.123	$\bar{3}11$
						4.102	$\bar{2}12$
<1	4.112	-----	-----	3	4.112	4.099	020
<1	3.972	<1	3.969	3	3.969	3.971	012
						3.958	211
1	3.924	1	3.914	8	3.922	3.913	120
7	3.872	9	3.867	21	3.867	3.860	310
						3.762	$\bar{1}21$
<1	3.741	<1	3.743	8	3.743	3.736	021
						3.656	$\bar{3}12$
4	3.597	8	3.592	9	3.596	3.586	$\bar{4}01$
1	3.513	1	3.513	17	3.517	3.508	$\bar{2}21$
2	3.486	2	3.484	16	3.484	3.477	220
						3.475	112
						3.445	121
1	3.399	1	3.399	3	3.399	3.391	$\bar{4}02$
						3.304	$\bar{2}03$
						3.285	$\bar{4}11$
2	3.290	5	3.286	2	3.288	3.282	400
2	3.175	2	3.175	8	3.175	3.179	202
				14	3.163	3.168	311
						3.158	$\bar{1}22$
						3.134	$\bar{4}12$
<1	3.110	<1	3.113	9	3.106	3.109	$\bar{3}21$
<1	3.100	<1	3.099			3.100	$\bar{2}22$
						3.064	$\bar{2}13$
4	3.052	7	3.045	19	3.046	3.047	410
						3.042	022
						3.036	221
2	3.028	5	3.028	18	3.025	3.026	003
						3.022	$\bar{1}13$
1	3.001	2	2.993	10	2.996	2.991	320
						2.964	212
1	2.955	1	2.954	7	2.952	2.948	$\bar{3}13$
1	2.898	1	2.898	9	2.898	2.893	$\bar{3}22$
1	2.889	1	2.887	11	2.887	2.882	$\bar{4}03$
1	2.841	1	2.840	11	2.840	2.839	013
<1	2.805	-----	-----	6	2.804	2.801	122
1	2.755	3	2.751	3	2.751	2.750	401
<1	2.724	-----	-----	4	2.722	2.719	$\bar{4}13$
3	2.700	4	2.696	8	2.697	2.699	$\bar{4}21$
						2.691	$\bar{5}11$
		<1	2.673	3	2.673	2.675	130
						2.668	$\bar{5}12$
						2.633	321
1	2.622	-----	-----	13	2.619	2.626	$\bar{1}31$
						2.617	031
						2.613	$\bar{4}22$
		1	2.609	-----	-----	2.607	411
						2.579	113
1	2.568	1	2.565	7	2.566	2.572	$\bar{2}23$
						2.562	420
						2.547	$\bar{1}23$
<1	2.536	<1	2.536	6	2.536	2.535	$\bar{2}31$
						2.528	312
						2.523	230
				6	2.514	2.512	222
						2.511	131
4	2.507	8	2.503	11	2.505	2.502	$\bar{3}23$
						2.500	510
<1	2.481	<1	2.479	4	2.479	-----	-----
<1	2.438	-----	-----	3	2.436	-----	-----
2	2.390	3	2.388	4	2.390	-----	-----
<1	2.378	-----	-----	3	2.375	-----	-----
2	2.362	5	2.359	5	2.361	-----	-----
1	2.322	-----	-----	6	2.320	-----	-----
4	2.268	6	2.266	13	2.266	-----	-----
3	2.207	7	2.202	8	2.204	-----	-----
<1	2.192	2	2.190	2	2.191	-----	-----
<1	2.178	-----	-----	4	2.176	-----	-----
1	2.145	<1	2.141	7	2.143	-----	-----
2	2.122	2	2.119	19	2.120	-----	-----
1	2.106	1	2.101	11	2.102	-----	-----
1	2.076	<1	2.071	11	2.073	-----	-----
1	2.053	2	2.051	11	2.051	-----	-----
1	2.032	2	2.024	13	2.026	-----	-----
<1	1.985	<1	1.981	4	1.983	-----	-----
2	1.949	4	1.948	7	1.948	-----	-----
1	1.936	2	1.931	6	1.931	-----	-----
1	1.904	2	1.903	6	1.896	-----	-----
<1	1.885	-----	-----	4	1.885	-----	-----
				1	1.858	-----	-----
<1	1.822	<1	1.819	3	1.821	-----	-----
1	1.805	1	1.802	4	1.804	-----	-----
				2	1.789	-----	-----
				1	1.772	-----	-----
<1	1.765	-----	-----	1	1.761	-----	-----
<1	1.748	1	1.744	3	1.745	-----	-----
<1	1.710	-----	-----	2	1.708	-----	-----
	←plus additional lines						
all with I≤1		all with I≤2		all with I≤3			

See footnotes at end of table.

---

[1] *X*-ray diffractometer data; Cu/Ni radiation, λ CuK_α=1.5418 A. Aluminum powder used as internal standard. Scanned at ¼° per minute from 8°–55°2*θ*; at 1° per minute from 55°–101°2*θ*.

[2] All calculated spacings listed for $d_{hkl} \geq 2.500$ A. Indexing assigned on basis of comparison with single-crystal precession photographs. Computation of the *d*-spacings by Daniel L. Appleman.

[3] Diffractometer charts X–1935 (Boron, Calif.) and X–1934 (Death Valley region, California) of the mineral show strong preferred orientation effects.

[4] Synthetic material prepared by R. C. Erd; analyzed by V. Morgan. Diffractometer chart X–1929.

TABLE 255.4.—*Chemical analyses of tunellite*

	Weight percent[1]		Molecular proportions		Ratios		Calculated composition for $SrO \cdot 3B_2O_3 \cdot 4H_2O$ (percent)
	Mineral[2]	Synthetic[3]	Mineral	Synthetic	Mineral	Synthetic	
SrO	27.71	27.02	0.2674	0.2607	1.023	0.988	26.94
B_2O_3	53.70	52.88	.7711	.7593	2.951	2.877	54.32
H_2O	18.71	20.04	1.0385	1.1123	3.974	4.214	18.74
Total	100.12	99.94	-----	-----	-----	-----	100.00

[1] Analyst, Vincent Morgan, U.S. Borax & Chemical Corporation.

[2] Material from U.S. Borax & Chemical Corporation open pit, Boron, Calif. Figure for SrO includes approx. 0.3 percent BaO determined using *X*-ray spectrochemical analysis.

[3] Material synthesized by R. C. Erd (Expt. 58–3).

of this compound, although the compound $SrO \cdot 3B_2O_3 \cdot 5H_2O$ was synthesized by Gode and Kesans (1953, p. 36).

Tunellite is soluble in cold dilute acid or strong alkaline solutions, but is unaffected by treatment with glycerol or methanol; a coating of $SrSO_4$ impedes further solution in H_2SO_4.

The differential thermal analysis curve of the mineral shows two endothermic troughs with initial temperatures of 200° C and 405° C and trough temperatures of 255° C and 430° C. An exothermic peak with initial temperature of 625° C and peak temperature of 670° C appeared near the end of the run which was discontinued at 700° C to prevent fusion of the sample in the block.

Heated in a closed tube tunellite exfoliates perpendicular to the cleavage, turns silvery white (resembling muscovite), then turns chalky white. Water driven off has a pH of 4 and probably indicates some loss of B_2O_3 due to rapid heating. On prolonged heating a clear glass forms from which an anhydrous strontium borate crystallizes. The melting point of tunellite has not been determined.

In late 1960, large crystals (some nearly 4 cm in length) were found in the open pit by M. L. Speckels, who kindly gave them to us for study. Some of these crystals have a specific gravity of 2.46 and contain up to 15.0 percent BaO. The presence of barium in tunellite suggests the possibility that $BaO{\cdot}3B_2O_3{\cdot}4H_2O$, synthesized by Gode and Kesans (1953, p. 36), may be isostructural with tunellite but data for this compound are not available. Tunellite is isostructural with nobleite (table 255.2) but the extent of any solid solution is unknown. There is no simple dehydration-hydration relation between tunellite, veatchite ($SrO{\cdot}3B_2O_3{\cdot}2H_2O$), and the $SrO{\cdot}3B_2O_3{\cdot}5H_2O$ of Gode and Kesans. Tunellite and veatchite have not been found as associated minerals, although both have been found in the Kramer area (Benda and others, 1960, p. 330).

REFERENCES

Benda, W. K., Erd, R. C., and Smith, W. C., 1960, Core logs from five test holes near Kramer, California: U.S. Geol. Survey Bull. 1045-F, p. 319-393.

Erd, R. C., McAllister, J. F., and Vlisidis, A. C., 1961, Nobleite, another new hydrous calcium borate from the Death Valley region, California: Am. Mineralogist, v. 46, p. 560-571.

Gale, H. S., 1946, Geology of the Kramer Borate District, Kern County, California: California Jour. Mines and Geology, v. 42, p. 325-378.

Gode, H. K., and Kesans, A. D., 1953, Sintezy boratov v vodnykh rastvorakh (Syntheses of borates in aqueous solutions), *in* Khimiia boratov (Chemistry of the borates): Akad. Nauk Latv. SSR, Izdatelstvo, p. 29-43, Riga.

Schaller, W. T., 1930, Borate minerals from the Kramer district, Mohave Desert, California: U.S. Geol. Survey Prof. Paper 158, p. 137-170.

Schaller, W. T., and Mrose, M. E., 1960, The naming of the hydrous magnesium borate minerals from Boron, California—a preliminary note: Am. Mineralogist, v. 45, p. 732-734.

Smith, W. C., 1960, Borax and borates, *in* Industrial minerals and rocks: New York, Am. Inst. Mining Metall. Petroleum Engineers, 3d ed., p. 103-122.

⚒

256. HYDROZIRCON FROM THE WIND RIVER FORMATION, WYOMING

By R. G. COLEMAN and R. C. ERD, Menlo Park, Calif.

Work done partly in cooperation with the U. S. Atomic Energy Commission

A high concentration of zirconium (1 to 5 weight percent) was discovered in a uranium-bearing arkose submitted for spectrographic analysis and uranium assay (table 256.1). This sample was collected as part of a geologic study of the Gas Hills uranium district in Wyoming (Zeller, 1957) and represented the mineralized zone within a nonproductive uranium prospect along the eastern border of the district (SW1/4SE1/4 SW1/4 sec. 15, T. 35 N., R. 89 W., Arminta SW quadrangle, Natrona County, Wyoming).

Zirconium-uranium mineralization is restricted to an area of less than 300 square yards within a small bench rising several feet above the nearly flat terrain and occurs below an iron gossan caprock within a coarse-grained arkose of the Wind River formation of early Eocene age. A series of samples was obtained in vertical sequence from the face of the prospect pit

TABLE 256.1.—*Chemical and spectrographic analyses of hydrozircon-bearing arkose, Wind River formation, Wyoming*

[Analysts: J. C. Hamilton (spectrographic); Lorraine M. Lee, E. J. Fennelly, G. T. Burrow (chemical)]

	ZW-120	ZW-121	$4929A_{28}$
	Chemical analyses (weight percent)		
U	0.16	0.11	0.25
As	0.052	0.12	Not determined
Se	0.0005	<0.0005	Not determined
	Semiquantitative spectrographic analyses (weight percent)		
>10	Si	Si	Si
5-10	Al	Al K	Al Na
1-5	K Na Zr	Na Fe Zr	Zr Fe K
0.5-1.0	Fe	------	Ca P
0.1-0.5	Ca Mg	As	As
0.05-0.1	Ti As Ba	Ca Mg Ba	Ba Mg
0.01-0.05	Mn Mo Sc	Ti	B Ti Mn Sr
0.005-0.01	Sr Cr Y	Mn Mo Sr Y	Pb La Ni Y
0.001-0.005	Ga B V La Cu Pb Yb	Ga Sc Cr V La Pb Yb	Ge Cr Mo Cu Ga Sc V
0.0005-0.001	------	Cu	Be Yb