BERTRANDITE AT HICKS DOME, HARDIN COUNTY, ILLINOIS

James W. Baxter and J.C. Bradbury
Illinois State Geological Survey
Urbana, Illinois 61801

ABSTRACT

Bertrandite, a berylium silicate, has been discovered in two occurences of intrusive breccia at Hicks Dome in the northwest corner of the Illinois-Kentucky Fluorspar District. Chemical analyses showed that the relatively high amounts of Be were present in breccia cuttings from an exploration drill hole near the center of the dome. Processing of the drill cuttings by HC1 leach, particle sizing, and heavy liquid separations at various gravities produced a Be concentration in which bertrandite was tentatively identified by optical measurements in oil immersions. This determination was confirmed by x-ray diffraction analyses of optically identical crystals concentrated from a breccia outcrop on the west flank of the dome.

INTRODUCTION

Abnormal amounts of berylium were detected in cutting of breccia from the Henry Hamp, Jr., No. 1 test well (Trace, 1960) on the apex of Hicks Dome, Hardin County, Illinois (NE¼ NW¼ SE¼ Sec. 30, T. 11 S., R. 8 E.). This prompted investigations in our laboratories that led to the tentative identification of the beryllium silicate, bertrandite, in selected samples of the well cuttings. Subsequent field mapping and sampling of surface exposures of breccia at Hicks Dome revealed additional beryllium mineralization in a shale breccia dike on the west flank of the dome. Petrographic and mineralogic investigations of the shale breccia revealed discrete crystals of bertrandite. Although the detection of bertrandite by x-ray diffraction of a sample of Hicks Dome breccia has been reported previously (Anon., 1977), we deemed it worthwhile to record the manner of occurrence of the bertrandite and its mineralogic characteristics in the Hicks Dome breccias.

HICKS DOME BRECCIAS AND MINERALIZATION

Geologic Setting

Hicks Dome is an oval structural and topographic high, located in the northwestern part of the Illinois-Kentucky Fluorspar District. Its long axis trends northwest-southeast (Weller *et al.*, 1920; Weller, Grogan, and Tippie, 1952; Baxter and Desborough, 1965; Baxter, Desborough, and Shaw, 1967), and it is superimposed on a highly faulted, broad, gentle arch (Heyl *et al.*, 1965) that extends to the southeast through the fluorspar district (Fig. 1). The central high at Hicks Dome exposes limestone and chert of Devonian age and is surrounded by a low belt of the Devonian New Albany Shale Group, which is in turn encircled by a ridge of chert, siltstone, and limestone of the Fort Payne Formation (Mississippian). A complex pattern of faulting, brecciation, mineralization, and intrusion by igneous rocks suggests that the dome was formed by an explosive release of gases (Brown, Emery, and Meyer, 1954; Heyl *et al.*, 1965; Bradbury and Baxter, in preparation).

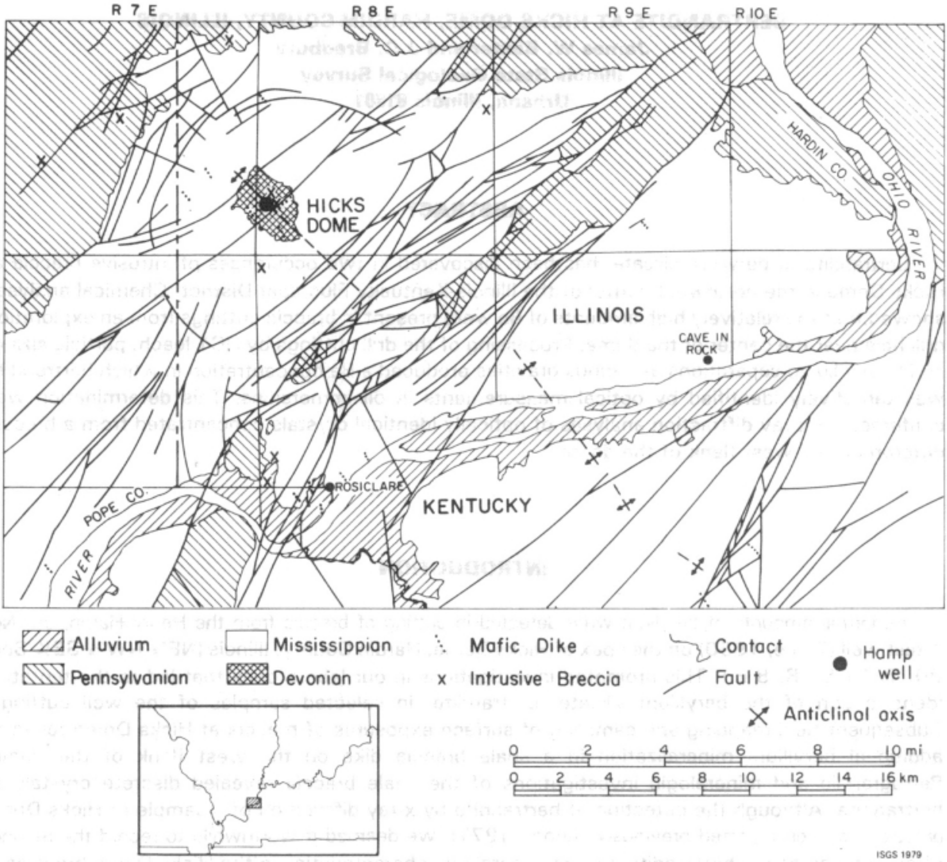


Figure 1. Geologic map of Hicks Dome and adjacent portions of the Illinois-Kentucky mining district (adapted from Grogan and Bradbury, 1968). Published with permission of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.

Hamp Well Subsurface Breccia

The mineralized subsurface breccia encountered in the Hamp Well (Fig.2) consisted of a mixture of broken and finely comminuted sedimentary rocks. Rock particles varied widely in lithology; they also showed evidence of mixing of materials from different formations and rock systems. Some samples were an ''agglomeration of sandstones, quartzites, limestones, dolomites, and shales'' (Brown, Emery, and Meyer, 1954). Megascopic mineralization consisted of fluorite, assaying as much as 11 percent on samples from 5-foot (1.5-m) intervals, and traces of sphalerite and galena. Radiometric analyses on 25-to 30-foot (7.6- to 9.1-m) composite samples showed up to four times the normal background values. These anomalous values appeared to be caused by the presence of thorium (Brown, Emery, and Meyer, 1954).

Beryllium content

Chemical and semiquantitative analyses of those samples from representative portions of the Hamp Well that showed the greatest radioactivity was reported by Trace (1960). He demonstrated that the radioactivity was related to thorium and associated with increases in beryllium, niobium, and rare earths. Three depth intervals were identified as having the greatest beryllium contents: 1725 to 1750 feet (526 to 533 m), 1785 to 1815 feet (544 to 553 m), and 2150 to 2175 feet (655 to 663 m). Samples from each interval were found to have 0.06 percent Be by semiquantitative spectrographic analysis (Trace, 1960, p. B64, table 30.2).

Surface Breccias

Most of the breccias that crop out on Hicks Dome consist of silicified fragments, essentially from the immediately enclosing rocks, in a matrix of finely comminuted rock and microcrystalline quartz. This contrasts with the lithologic admixture found at depth in the Hamp Well. The locally derived breccias include not only bodies in Devonian limestone in the central portion of the dome, but also a series of dikelike exposures showing an arrangement that is roughly radial to the center of the dome (Fig. 2). The geometry of the surface breccias and their relationship to country rock and to Hicks Dome suggest that these bodies are "burst" or "shatter" breccias formed by the rapid dilation of fractures upon the explosive release of gases (Bradbury and Baxter, in preparation).

Bradbury, Ostrom, and McVicker (1955) first described the breccia dikes as fault (?) breccias, but also suggested an alternative theory of formation involving explosive release of gases. Our subsequent field work revealed numerous additional occurrences which range from a few inches (cm) up to 10 feet (3 m) in width, are essentially vertical, and occur within the Fort Payne Formation and the New Albany Shale. Some can be seen extending 200 to 300 feet (60 to 90 m), but those enclosed by shale are poorly exposed, and known occurrences in shale are confined to creek beds. A strike diagram of 19 dikes shows clustering around two major directions of faulting in the Illinois Fluorspar District: north 50° to 60° east, and north 30° west (Fig. 2).

Known surface mineralization is mostly confined to breccias of the central area and the immediate surrounding belt of New Albany Shale. Fluorite and barite are most common, and an abandoned fluorite mine is located on the east flank of the dome at the edge of the central area. Other minerals previously recognized include minor amounts of sphalerite and galena and a single report of monazite and florencite (Trace, 1960).

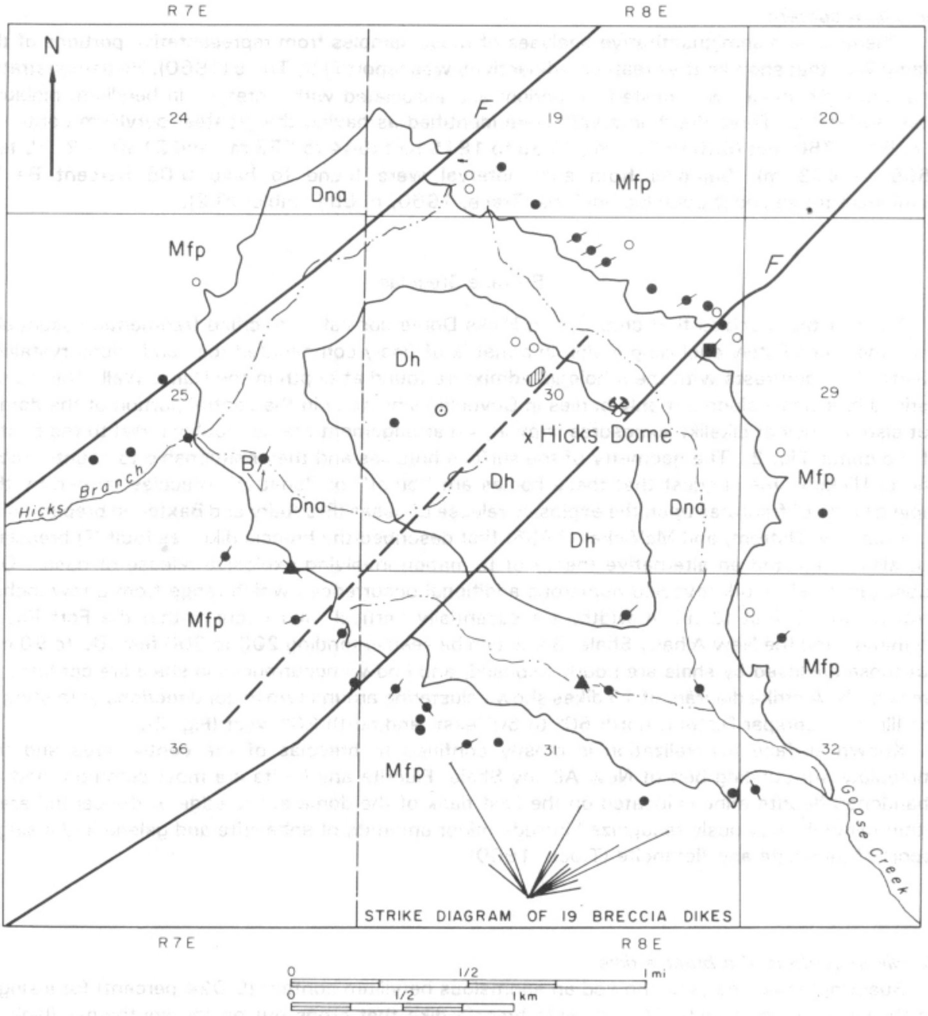
Beryllium content of a breccia dike

Spectrographic analyses showed an anomalous beryllium content (0.024 percent) for a single northeast-trending, 4-inch (10-cm) wide breccia dike that crops out on the southwest flank of Hicks Dome and is enclosed within the New Albany Shale (Bradbury and Baxter, in preparation). This breccia is composed of relatively unaltered, rotated fragments of laminated, carbonaceous, dolomitic, dark brown shale set in a cement that is mainly composed of calcite, with some dolomite, ankerite, quartz, and purple and lighter-colored fluorite (Plate 1, Fig. a).

MINERALOGIC INVESTIGATIONS

Hamp Well Breccia

Samples. A set of drilling samples, representing 5-foot sample intervals and submitted to the Illinois State Geological Survey by St. Joe Minerals Company, served as the basis of our investigations. Representative cuts of those samples that were richest in Be (Trace, 1960) were analyzed spectrographically. Samples from intervals of 1730-1735 feet, (527-529 m) and 1740-1745 feet, (530-532 m), containing 0.20 and 0.17 percent Be, respectively, were chosen for further investigation. These samples appeared to consist chiefly of broken and finely comminuted carbonate rock.



- Locally derived breccia, outcrop
- Sample, boulders
- Locally derived breccia dike, strike indicated
- Probably same, strike not determined
- Deep-seated breccia, strike indicated
- Lamprophyre, strike indicated
- Abandoned mine
- Hamp well
- B Bertrandite occurrence
- F Fault
- Mfp Fort Payne Formation and younger
- Dna Devonian New Albany Shale
- Dh Devonian Hunton Limestone Megagroup

ISGS 1979

Figure 2. Distribution of breccia exposures and orientation of breccia dikes.

Beryllium concentration procedures. Preliminary tests, monitored by spectrographic analysis, indicated that the beryllium minerals were insoluble in dilute HC1, were less than 270 mesh in particle size, and had a specific gravity between 2.5 and 2.6. Based on the results of these tests, we followed a concentration scheme consisting of: (1) an acid leach in 20 percent HC1; (2) grinding of the residue to pass 270 mesh; (3) separation and recovery of the $< 2\,\mu m$ fraction by settling in water and decantation; and (4) gravity separations of the $> 2 \mu m$ fractions in bromoform-acetone mixtures. This scheme recovered a $<$ 2.62 specific gravity product that contained 1.2 percent Be, representing a sevenfold concentration of beryllium. Table 1 shows the results of analysis of the gravity fractions and the $< 2 \mu m$ particle-size separate. The small amounts of Be in the other gravity fractions probably represent portions of the beryllium mineral not freed by the 270-mesh grind, particularly because the amount of Be decreases progressively with increasing specific gravity. The very small amount of Be in the $< 2 \mu m$ material indicates that little Be was lost to overgrinding.

TABLE 1. Be content of various fractions from insoluble residue of sample 1740-45.

Sample no.	Mesh size	Specific gravity	Weight of Sample (g)	Be (%)
H-38	$-270 + 2\ \mu m$	<2.62	0.41	1.20
H-39	$-270 + 2\ \mu m$	2.62 – 2.81	2.74	0.29
H-40	$-270 + 2\ \mu m$	>2.81	2.26	0.18
H-41	$-2\ \mu m$			0.07

Tentative identification of beryllium mineral. X-ray diffraction of the beryllium concentrate failed to produce any peaks identifiable with a beryllium mineral, suggesting that no specific mineral was present in an amount greater than about 5 percent. Microscopic examination of the concentrate in oil immersions disclosed about 5 percent (by visual estimate) of single, platy grains, and aggregates of platy grains that appeared to have refractive indices and other optical characteristics of bertrandite. Another heavy liquid separation, performed on the concentrate at 2.57 specific gravity, produced a float crop that generated x-ray diffraction peaks of low intensity coincident with the major peaks of bertrandite. A microscopic examination of the re-concentrate revealed examples of twinned crystals (Plate 1, Figs. b and c) like those subsequently recovered from the shale breccia dike exposure and identified as bertrandite.

Because the original concentrate had been assayed to have 1.2 percent Be, which calculates to about 8 percent bertrandite, we concluded that some beryllium was present in a form other than well crystallized bertrandite. The failure of the x-ray diffractogram to indicate bertrandite in the original concentrate could have been caused by either the presence of some beryllium in a mineral species other than bertrandite or poor crystallinity of some of the bertrandite (see section, "Comparisons with Other Bertrandites").

Shale Breccia Dike

Petrographic studies. Thin sections, cut from bulk samples of the mineralized shale breccia, revealed numerous, colorless, minute crystals, most of which were about 100 μm in maximum dimension (Plate 1, Fig. d), and were intimately associated with fluorite, quartz, and sparry calcite. The crystals showed moderate relief and birefringence and were biaxial negative. Favorably oriented crystals showed a tri-sector twinning (Plate 1, Fig. e). Similar twinning, with the twinning axis parallel to the acute bisectrix, has been described for a bertrandite from Cornwall, England (Phemister, 1940). These crystals, therefore, were tentatively identified as bertrandite and as the source of the Be values.

Recovery of bertrandite. Because calcite formed the bulk of the matrix material of the shale breccia, the other epigenetic minerals—fluorite, quartz, and bertrandite—were easily freed from hand specimens of the breccia by the simple expedient of acid digestion. No grinding of either the outcrop samples or the leach residue was done. Wet sieving of the residue through 10-, 35-, 65-, 200-, and 325-mesh screens eliminated rock fragments from the finer particle sizes.

Examination of the various-sized fractions with a binocular microscope revealed that tabular crystals of bertrandite were concentrated in the pan (minus 325-mesh) and on the 325-mesh screen (minus 200-mesh). Mineral aggregates, which were composed of the tabular crystals with fluorite or quartz, were retained on the 200-mesh screen (minus 65-mesh) and to a lesser extent on the 65-mesh screen (minus 35-mesh). The concentration achieved in the minus 325-mesh samples allowed the positive x-ray identification of bertrandite as the predominant component in a mixture of bertrandite, quartz, and fluorite. Scanning electron micrographs of a twinned crystal and an aggregate of crystals are shown on Plate 1, Figures f and g, respectively.

X-RAY IDENTITY OF TWINNED CRYSTAL

A single twinned crystal from a concentrate of the shale breccia dike was mounted in a Gandolfi powder camera for x-ray diffraction analyses. After a 3-hour run, eleven d-spacings characteristic of bertrandite were identified. The d-spacings and their corresponding degree of 2Θ and intensities are shown in Table 2. Low angle x-ray scattering obscured and probably prevented detection of the (111,021) line (dÅ = 3.94, intensity = 40). X-ray diffractograms of the Hicks Dome bertrandities, however, generally show low intensities for that line, although this may be related to crystal cleavage that often results in some degree of preferred orientation, even in finely ground samples.

TABLE 2. Single crystal of Hicks Dome bertrandite—3-hour Gandolfi camera run.

2Θ	d, A	I
20.3	4.37	10
28.0	3.19	10
35.4	2.54	8
39.2	2.30	2-5
40.5	2.23	3
45.5	1.99	2
53.9	1.70	1
55.3	1.66	1
59.2	1.56	2
63.0	1.478	1
72.0	1.31	3

HICKS DOME BERTRANDITES

Bertrandite at Hicks Dome occurs predominantly as minute, tabular, euhedral to subhedral crystals (Plate 1). They are mostly about 100 μm in maximum dimension and commonly twinned. In concentrates from the Hamp Well, untwinned crystals or crystal fragments are loaded with dark inclusions, but twinned crystals from both occurrences are largely free of inclusions. The optical properties of bertrandite from both occurrences are essentially identical to those given in Larsen and Berman (1934), and the refractive indices in index oils match values they cite: $\alpha = 1.591$, $\beta = 1.605$, $\gamma = 1.614$.

Twinned crystals are usually twinned on a brachydome (031) and tend to lie on the macropinacoids in immersion oils so that each portion of the twin displays a centered or slightly off-centered acute bisectrix figure—as was also observed in favorable orientations in thin sections cut from the shale breccia dike. Untwinned crystal fragments of bertrandite concentrated from the Hamp Well breccia, in samples ground to pass the 270-mesh screen, tend to give an obtuse bisectrix figure indicative of basal 001 cleavage. This cleavage has been described by Winchell (1933, p. 410) as being the best cleavage for bertrandite, and as being normal to the obtuse bisectrix. Dana and Ford (1955) cite perfect (110) and other cleavage directions for bertrandite.

The specific gravity of Hicks Dome bertrandite has not been accurately determined, but a minus 200-plus 325 mesh fraction from the shale breccia was upgraded by specific gravity separations using bromoform = acetone mixtures and crystals of quartz and orthoclase feldspar as indicators. In this manner, concentrations of fluorite with some quartz ($>\sim$2.66 sp gr), quartz and some bertrandite ($\sim$2.57-$\sim$2.66 sp gr), and bertrandite with little quartz plus one or more unidentified minerals ($\leqq$2.57 sp gr) were obtained (Fig. 3). These separations were designed primarily to obtain concentrations of the three major mineral components, but, when considered with similar evidence from concentrations achieved with samples from the Hamp Well breccia, they suggest a specific gravity between 2.5 and 2.57 for Hicks Dome bertrandite.

COMPARISON WITH OTHER BERTRANDITES

Bertrandite, $Be_4(OH)_2Si_2O_7$, is a beryllium dihydroxydisilicate of which both hydrated and anhydrous forms have been described. Occurrences accredited to the mineral species vary considerably in terms of water content, physical characteristics, optical properties, and x-ray diffraction data. A concentration of Hicks Dome bertrandite sufficient for accurate chemical analysis has not yet been obtained, nor has a thermogravimetric analysis (TGA) been made. Nevertheless, a comparison of the physical and optical properties of Hicks Dome bertrandite with those of other bertrandites indicates that the Illinois occurrence is more closely related to typical varieties than to hydrated forms such as those from Spor Mountain, Utah (Montoya, Havens, and Bridges, 1962) and gel bertrandite (Semenov, 1957) from the USSR (Table 3). Although the optical properties compare favorably with typical bertrandite (Dana and Ford, 1955, p. 632), our rough estimate of the specific gravity is lower than the range commonly cited for bertrandite (2.59 to 2.60).

TABLE 3. Physical and optical properties for several bertrandites

	Hicks Dome	Gerl bertrandite* (USSR)	Spor Mountain, Utah†	Mt. Isa, Queensland‡	Boomer Mine, Colorado §
Color	Colorless	Pale violet	?	Colorless	Pale pink
Crystallinity	Fine crystalline	Colloidal	Microcrystalline to cryptocrystalline	Crystalline	Crystalline
Cleavage	(001), other	—	—	(001) (010), other	?
Habit	Tabular	—	—	Tabular	?
Specific Gravity	2.50—2.57	2.176	2.3—2.4	2.60	?
Birefringence	.023	Isotropic	Weak	0.025	?
Refractive Index	α = 1.591 ±, β = 1.605 ±, γ = 1.614 ±	1.511—1.53	1.54—1.58	α = 1.589, β = 1.603, γ = 1.613	
Axial angle	∼75°	—	—	∼80°	?

*Source: Semenov, 1957; Montoya, Havens, and Bridges, 1962.
†Source: Montoya, Havens and Bridges, 1962.
‡Source: Vernon and Williams, 1960.
§Source: Sharp and Hawley, 1960.

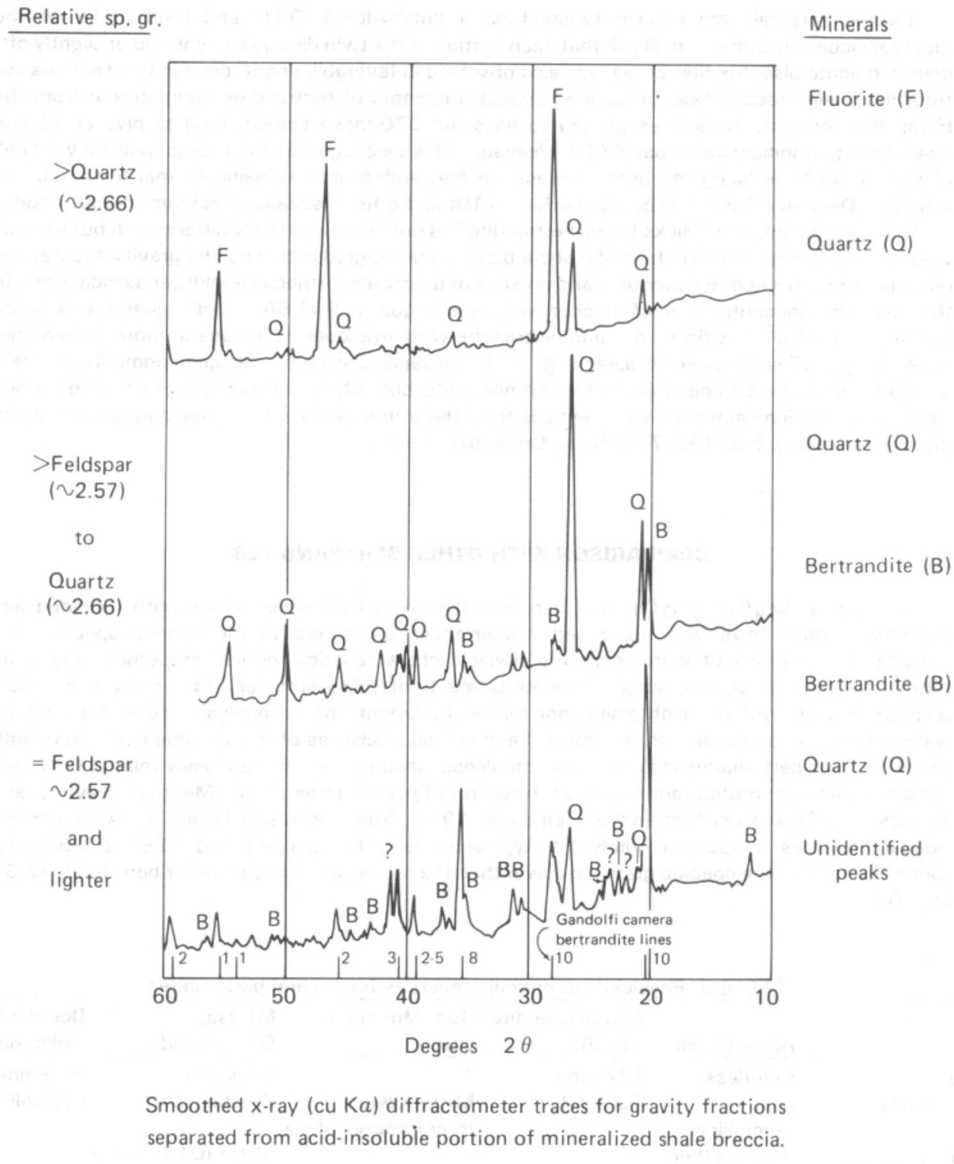


Figure 3. Smoothed x-ray (cu kα) diffractometer traces for gravity fractions separated from acid-insoluble portion of mineralized shale breccia (− 200 + 325 mesh).

Table 4. X-ray diffraction data for several betrandites

Hicks Dome, Illinois		Gel bertrandite (USSR)* †		Spor Mountain, Utah †		Mt. Isa, Queensland ‡		Boomer Mine, Colorado †	
d, A	I/I_o	d, A	I/I_o	d, A	I/I_o	d, A	I/I_o	d, A	I/I_o
7.56	10	-	-	7.62	7	7.56	10	7.76	6
-	-	4.81	10	-	-	-	-	-	-
4.37	100	4.31	100	4.39	100	4.38	100	4.44	100
3.93	12	-	-	3.98	43	3.94	40	3.97	31
3.80	12	-	-	3.86	23	3.80	8	3.86	31
3.20	30	3.15	100	3.21	100	3.19	90	3.21	54
3.16	35	-	-	-	-	-	-	3.06	2
2.93	13	-	-	2.95	15	1.93	10	2.95	7
2.87	16	-	-	2.89	13	2.88	10	2.90	10
2.55	17	-	-	-	-	-	-	2.57	36
2.53	60	2.53	100	2.54	65	2.54	80	2.55	40
2.43	10	-	-	2.44	10	2.42	6	2.44	7
2.29	20	2.31	80	2.30	55	2.28	60	2.30	47
2.21	30	-	-	2.23	52	2.22	60	2.24	23
-	-	2.20	80	2.19	21	2.18	2	2.19	5
2.11	6	-	-	2.12	5	2.10	4	2.12	2
2.03	5	-	-	2.03	11	2.02	6	2.04	4
1.98	15	1.998	40	1.98	25	1.983	20	1.99	12
-	-	-	-	-	-	-	-	1.97	3
-	-	-	-	1.92	5	1.923	6	1.92	5
1.78	6	-	-	1.79	5	1.787	6	1.80	3
-	-	-	-	-	-	-	-	1.77	2
1.74	4	-	-	-	-	-	-	1.74	1
1.70	6	1.714	20	1.70	14	1.698	16	1.71	13
-	-	-	-	-	-	-	-	1.67	4
1.65	12	1.651	20	1.66	11	1.650	10	1.65	9
1.63	6	-	-	1.63	5	1.628	<2	1.64	2
-	-	-	-	1.58	7	1.57	4	1.58	3
1.55	16	1.555	40	1.56	17	1.555	30	1.56	9
		-	-	-	-	-	-	1.53	1
		-	-	1.50	5	1.491	<2	1.50	2
		-	-	1.47	13	1.465	30	1.47	9
		1.454	6	-	-	-	-	1.46	3
		-	-	1.44	8	1.44	10	1.44	4
		-	-	1.42	2	-	-	1.41	1
		-	-	-	-	-	-	1.40	1
		-	-	1.38	3	-	-	1.38	1
		-	-	1.37	2	1.363	2	1.37	1
		-	-	1.35	4	1.338	4	1.34	1
		1.310	40	1.31	19	1.305	40	1.31	17

*Source: Semenov, 1957

†Source: Montoya, Havens, and Bridges, 1962.

‡Source: Vernon and Williams, 1960.

A diffraction scan through 60° 2Θ of the Hicks Dome bertrandite allowed comparison with diffraction data for other bertrandites. This comparison further confirmed our identification of bertrandite. The Hicks Dome material from the shale breccia dike has the same crystal structure as other examples (Table 4). The Hicks Dome bertrandite compares most favorably with diffraction data reported for an occurrence in the vicinity of Mica Creek near Mt. Isa, Queensland, Australia (Vernon and Williams, 1960). All major interplanar spacings for these bertrandites are recognized on diffraction scans of the Hicks Dome material. The apparent absence of some minor spacings can be explained by the incomplete nature of the mineral separations and perhaps, in part, by the degree of preferred orientation in the prepared samples.

Bertrandite is known to occur in association with both alkalic and acid igneous rocks, most commonly in pegmatitic and non-pegmatitic pneumatolytic-hydrothermal deposits (Mulligan, 1968). The geologic associations for Hicks Dome bertrandite and other occurrences, cited for comparison, are shown in Table 5. At least one lamprophyre dike and a few breccia bodies of deep-seated origin are known to occur in the immediate vicinity of Hicks Dome (Bradbury and Baxter, in preparation). The latter consist of igneous rock and mineral fragments, with varying amounts of sedimentary rock particles, in a carbonate matrix (calcite, dolomite, siderite). These are considered "carbonatitic" breccias formed by the upward streaming of CO_2-rich gases emanating from an alkaline magma. Other lamprophyres and similar breccias probably occur but are not exposed because they weather easily.

Table 5. Geologic associations of several bertrandites.

	Hicks Dome	Gel bertrandite USSR*	Spor Mountain, Utah†	Mt. Isa, Queensland ‡	Boomer Mine, Colorado §
Associated mineralization	Fluorite, calcite, quartz, Pb, Zn, Th, R.E.	Epidydimite berylite	Fluorite, saponite	Beryl, mica, quartz, albite	Quartz, topaz, fluorite, beryl,
Type of deposit	Breccia dike; massive breccia	Pegmatite	Disseminated	Pegmatite	Greisen-quartz-veinlike
Wall or host rock	Shale, limestone	Nepheline syenite	Rhyolite tuff	?	Schist, granite
Igneous affinities	Alkaline	Alkaline	Acid	?	Acid

*Source: Semenov, 1957.
†Source: Vernon and Williams, 1960.
‡ Source: Montoya et al., 1962.
§Source: Sharp and Hawley, 1960.

SUMMARY

The beryllium silicate, bertrandite, has been identified from a shale breccia dike that crops out on the southwest side of Hicks Dome, in Hardin County, Illinois. It compares more favorably to typical bertrandites than to hydrated forms reported from Spor Mountain, Utah. Optically similar crystals and mineral aggregates of bertrandite occur with low grade fluorspar at depth in the central portion of Hicks Dome. More detailed chemical, physical, and crystal structure investigations of these occurrences are planned.

ACKNOWLEDGMENTS

Colleagues at the Illinois State Geological Survey provided valuable assistance in various stages of our investigation of Hicks Dome bertrandite. Dr. Herbert D. Glass of the Stratigraphy and Areal

Geology Section ran some of the x-ray diffractometer analyses, advised on interpretation of diffraction patterns, and confirmed our identification of bertrandite. Ms. Suzanne J. Russell of the Coal Section provided Gandolfi camera diffraction data and scanning electron microscope views of bertrandite crystals.

REFERENCES

Anonymous, 1977, Geological Survey Research 1977: U.S. Geological Survey, Professional Paper 1050, p. 7

Baxter, J.W., G.A. Desborough, 1965, Areal geoglogy of the Illinois Fluorspar District. Part 2—Karbers Ridge and Rosiclare Quadrangles: Illinois State Geological Survey, Circular 385, 40 p.

Baxter, J.W., G.A. Desborough, and C.W. Shaw, 1967, Areal geology of the Illinois Fluorspar District. Part 3—Herod and Shetlerville Quadrangles: Illinois State Geological Survey, Circular 413.41p.

Bradbury, J.C., and J.W. Baxter, in preparation, Intrusive breccias at Hicks Dome, Hardin County, Illinois.

Bradbury, J.C., M.E. Ostrom, and L.D. McVicker, 1955, Preliminary report on uranium in Hardin County, Illinois: Illinois State Geological Survey, Circular 200, 21 p.

Browne, J.S., J.A. Emery, and P.A. Meyer, Jr., 1954, Explosion pipe in test well on Hicks Dome, Hardin County, Illinois Economic Geology, v. 49, no. 8, p. 891-902.

Dana, E.S., and W.E. Ford, 1955, A textbook of mineralogy, Fourth Edition, John Wiley and Sons, London, 851 p.

Grogan, R.M., and J.C. Bradbury, 1968, Fluorite-zinc-lead deposits of the Illinois-Kentucky mining district, *in* Ridge, J.D., [ed.], Ore deposits in the United States, 1933-1967, v. 1, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, p. 370-399.

Heyl, A.V., M.R. Brock, J.L. Jolly, and C.E. Wells, 1965, Regional structure of the southeast Missouri and Illinois-Kentucky mineral districts: U.S. Geological Survey Bulletin 1202-B, p. 9-12.

Larson, E.S., and H. Berman, 1934, The microscopic determination of the nonopaque minerals: United States Geological Survey Bulletin 848, 266 p.

Montoya, J.W., R. Havens, and D.W. Bridges, 1962, Beryllium-bearing tuff from Spor Mountain, Utah: Its chemical, mineralogical, and physical properties: U.S. Bureau of Mines Report of Investigations 6084, 15 p.

Mulligan, Robert, 1968, Geology of Canadian beryllium deposits: Geological Survey of Canada, Economic Geology Report no. 23, 105 p.

Phemister, J., 1940, Note on an occurrence of bertrandite and beryl at the South Crofty mine, Cornwall: The Mineralogical Magazine, v. XXV, no. 17, p. 573-578.

Semenov, E.I., 1957, New hydrous berylium silicates—gel bertrandite and sphero bertrandite: Trudy Instituta Mineralogii Geokhimii i Kristallokhimii redkikh Elementov, Vaprosy Mineral. Geokhim. i Genezesa Mist. Redkikh Elementov., Moscow, No. 1, p. 64-69 (in Russian).

Sharp, W.N., and C.C. Hawley, 1960, Bertrandite-bearing greisen, a new beryllium ore: U.S. Geological Survey Professional Paper 400 B, p. 73-74.

Trace, R.D., 1960, Significance of unusual mineral occurrence at Hicks Dome, Hardin County, Illinois, *in* U.S. Geological Survey Professional Paper 400 B, p. 63-64.

Vernon, R.H., and K.L. Williams, 1960, Bertrandite from Mica Creek, Queensland: American Mineralogist, v. 45, p. 1300-1303.

Weller, J.M., R.M. Grogan, and F.E. Tippie, 1952, Geology of the fluorspar deposits of Illinois: Illinois State Geological Survey, Bulletin 76, 147 p.

Weller, S., C. Butts, L.W. Currier, and R.D. Salisbury, 1920, The geology of Hardin County and the adjoining part of Pope County: Illinois State Geological Survey, Bulletin 41, 402 p.

Winchell, A.N., 1933, Elements of optical mineralogy—an introduction to microscopic petrography, Part II, Descriptions of minerals, New York, 439 p.

Plate 1. (Sh = shale, C = calcite, Q = quartz, f = fluorite, b = bertrandite)

Figure A. Photomicrograph of mineralized shale breccia dike showing character of brecciation.

Figure B. Photomicrograph of shale breccia dike showing relationship of bertrandite to other interstitial minerals.

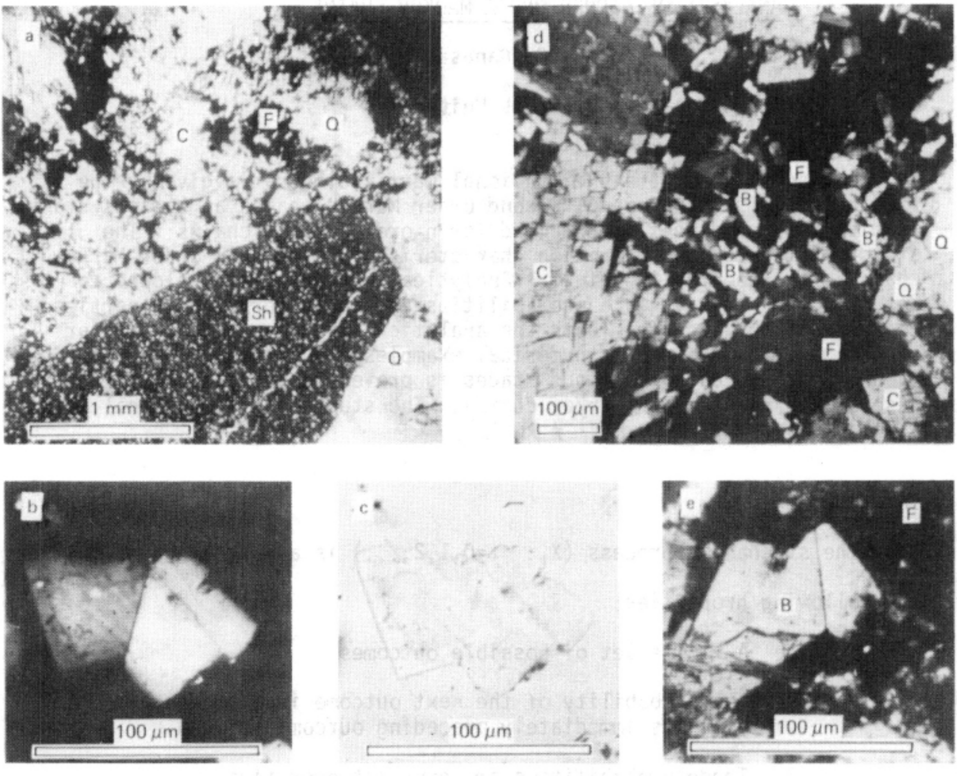
Figure C. Tri-sector twinning in Hicks Dome bertrandite, crossed nichols.

Figure D. Twinned crystal of bertrandite from core breccia, 1740 to 1745 feet, (530 to 532 m); – 2.57 gravity fraction, crossed nichols.

Figure E. Same as figure D, plane polarized light.

Figure F. Single twinned crystal of bertrandite, SEM view.

Figure G. Aggregate of bertrandite and fluorite, SEM view.


a
C
F
Q
Sh
Q
1 mm
d
F
B
B
B
Q
Q
C
F
C
100 µm
b
100 µm
c
100 µm
e
F
B
100 µm
f
50 µm
g
B
100 µm