PERRIERITE, CHEVKINITE, AND ALLANITE IN UPPER CENOZOIC ASH BEDS IN THE WESTERN UNITED STATES[1]

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ABSTRACT

Small primary crystals of perrierite, chevkinite and allanite occur in Cenozoic airfall ash beds at several localities in the western United States. The nometamict crystallinity of all three minerals gave definitive X-ray and optical data on unheated material.

INTRODUCTION

Small primary crystals of perrierite, chevkinite, and allanite occur in trace amounts in glassy airfall volcanic ash beds interlayered with terrestrial sedimentary rocks of late Cenozoic age in the western United States. The three minerals are rare-earth silicates that strongly resemble each other under reflected or transmitted light, and distinction between them requires care. The minerals were found during study of a large number of samples of volcanic ash beds to determine what petrographic properties can be used to correlate individual ash beds over wide areas (compare Wilcox, 1965). Several writers have reported on the occurrence of phenocrysts of chevkinite in volcanic ash beds, but to the writers' knowledge perrierite has not been previously reported in airfall ash beds in North America. Phenocrysts of allanite have only rarely been reported in airfall ash beds.

Samples of the ash were cleaned ultrasonically before and after the minerals were separated with heavy liquids from the volcanic glass shards. Commonly only a small amount of nonmagnetic heavy minerals (G.$>$2.86) and light minerals (G.$<$2.86$>$2.40) is obtained from a large amount of ash, and special care must be used during mineral separations.

The perrierite, chevkinite, and allanite crystals that are either enclosed in glass or have glass adhering were handpicked from clean heavy-mineral concentrates under a stereomicroscope, were mounted on spindles, and identified using optical spindle-stage techniques described by Wilcox (1959). Powder X-ray films were made to supplement optical identifications. Rounded detrital minerals and those minerals that do not have glass adhering were excluded from study because of possible detrital origin.

A few of the many ash beds that contain perrierite, chevkinite, or allanite are listed in Table 1, along with stratigraphic, locality, and certain petrographic information to show the general character of these ash

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beds. The glass shards, which form the bulk of the ash, are hydrated and probably contain several percent water. The index of refraction of the glass shards is shown in Table 1. Most of the primary minerals (phenocrysts) of the ash samples are silicates commonly found in silicic igneous rocks. Most of the ash samples studied have either perrierite, chevkinite, or allanite as a minor constituent, but a few ash samples contain both chevkinite and allanite. Allanite is an accessory in most of the biotite-bearing ashes studied, and chevkinite is characteristically present in many of the nonbiotitic ashes.

The writers acknowledge the help of several colleagues of the U. S. Geological Survey who collected ash samples and provided stratigraphic information (Table 1). W. N. Sharp aided in preparation of a few of the minerals prior to X-ray study, and J. W. Adams provided samples of perrierite from Virginia and heat-treated the perrierite for comparative X-ray study.

Perrierite

Perrierite, a rare-earth titanosilicate, is easily confused with chevkinite, and some doubt was expressed by Jaffe, Evans, and Chapman (1956) whether perrierite is a valid species. Additional work since 1956, however, indicates that perrierite and chevkinite are separate but related species (Bonatti, 1959; Gottardi, 1960; Lima de Faria, 1962, 1964; Mitchell, 1966; Ito, 1967).

Perrierite was identified in silicic ash beds of earliest Miocene age from along Goshen Hole Rim in southeastern Wyoming (Table 1) and from near Chimney Rock in southwestern Nebraska (locality 1, Tables 1, 3); the perrierite-bearing ash beds occur near the base of the Arikaree Formation of early Miocene age.

The ash beds that contain the perrierite have glass of similar refractive index, similar primary crystals, and similar optical properties of the primary crystals, including the hornblendes (Table 1).

The perrierite occurs as rare lustrous euhedral dark-reddish-brown to nearly opaque crystals and crystal fragments about 0.1 to 0.3 mm long, many of which have glass adhering. The crystals break with a conchoidal fracture and are dominantly elongate, slightly flattened prisms that commonly contain inclusions of a mineral (Fig. 1), probably apatite.

Optical properties of the Miocene perrierite are difficult to determine owing to dispersion and strong absorption, but some are listed in Table 2. With care the perrierite crystals can be distinguished from crystals of chevkinite by perrierite's lower refractive index and its lack of a position of complete absorption in plane polarized light during rotation about the *b*-axis (elongation).

TABLE 1. OCCURRENCE OF PERRIERITE, CHEVKINITE, AND ALLANITE; LOCATION, STRATIGRAPHIC, AND SELECTED PETROGRAPHIC INFORMATION

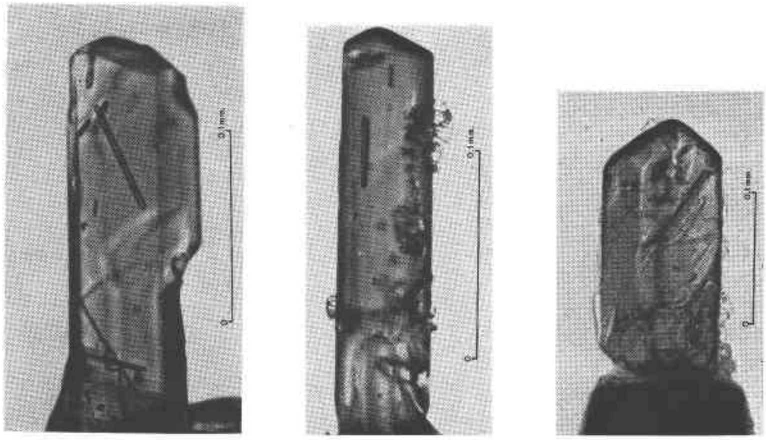
Spec. No.	Formation and age	Location	Petrography	
			Refractive index of glass	Primary crystals (glass adhering)
71	Lower part of the Arikaree Group (Gering Sandstone), early Miocene (compare Evernden and others, 1964, p. 186, KA-981).	South of Chimney Rock on main butte, SW¼SW¼ Sec. 17, T. 20 N., R. 52 W., South Bayard quad., Morrill County, Nebr.	Range: 1.495–1.514 Mode: 1.496	*q*, *sa*, *o*, *b*, *h* (10 measured; α=1.639–1.642), *m*, *il*, *sp*, *z*, *a*, *perrierite*.
DW5-23	Lower part of the Arikaree Formation; early Miocene.	Along Goshen Hole Rim, SE¼NW¼ Sec. 4, T. 21 N., R. 64 W., YBO Canyon quad., Goshen County, Wyo.	Range: 1.496–1.514 Mode: 1.496	*q*, *sa*, *o*, *b*, *h* (9 measured; α=1.639–1.643), *il*, *m*, *z*, *sp*, *a*, *perrierite*.
66W39	Pearlette Ash Member of Crooked Creek Formation of Hibbard (1949); late Kansan (Borchers fauna of Hibbard, 1941, 1958).	NW¼NE¼ Sec. 21, T. 33 S., R. 28 W., Irish Flats NE quad., Meade County, Kans.	Range: 1.499–1.501 Mode: 1.500	*q*, *sa*, *o*, *m*, *z* (colorless and pink), *f* looked for but not seen, *chevkinite*, *allanite*.
50-61A	Middle member of Harpole Mesa Formation; Quaternary (Pleistocene) (Richmond, 1962, p. 34).	Headwaters of Onion Creek, SE¼NE¼ Sec. 26, T. 24 S., R. 24 E.,[a] Polar Mesa quad., Grand County, Utah.	Range: 1.499–1.501 Mode: 1.500	*q*, *sa*, *o*, *f* (α=1.730), *h* (5 measured; α=1.688–1.690), *z* (colorless), *m*, *chevkinite* (Young and Powers, 1960).

TABLE 1. *(Continued)*

Spec. No.	Formation and age	Location	Petrography	
			Refractive index of glass	Primary crystals (glass adhering)
65W11 65W129	Pumice airfall from the ba of the Tshirege Member of Bandelier Tuff; Quaternary (Pleistocene) (K-Ar age 1.0 m.y., Smith and Bailey, 1966).	65W129: west side Pueblo Mesa, about 1½ miles south of Cañones, Cañones quad., Arriba County, N. Mex.	Range: 1.497–8	*q*, *sa*, *p* (extremely sparse), *f* (α=1.730), *h* (2 measured; α=1.660–1.662), *fa*, *m*, *z*, *br* (α=1.684), *chevkinite*.
65W130	Guaje Pumice Bed from base of Otowi Member of Bandelier Tuff; Quaternary (Pleistocene) (K-Ar age 1.4 m.y., Smith and Bailey, 1966).	West side Pueblo Mesa, same locality as 65W129.	Range: 1.497–1.499 Mode: 1.498	*q*, *sa*, *p* (extremely sparse), *f* (α=1.728–1.730), *m*, *br* (α=1.674–1.686), *fa*, *z*, *chevkinite*, *allanite*.
66G36	Lower part of Troublesome Formation; Miocene.	SW¼ Sec. 24, T. 1 N., R. 80 W., Kremmling quad., Grand County, Colo.	Range: 1.496–8 Mode: 1.497	*q*, *sa*, *o*, *b*, *h* (10 measured, α=1.654–1.659), *m*, *il*, *sp*, *z*, *a*, *allanite*.

[a] Location erroneously given as NW¼NW¼ Sec. 23 in Richmond (1962).

[Mineral abbreviations: *a*, apatite; *b*, biotite; *br*, bronzite; *ch*, chevkinite; *f*, ferroaugite; *fa*, fayalite; *h*, hornblende; *il*, ilmenite; *m*, magnetite; *o*, oligoclase; *p*, plagioclase; *q*, quartz; *sa*, sanidine; *sp*, sphene; *z*, zircon.]



A B C

FIG. 1. Photomicrographs of perrierite, chevkinite, and allanite; crystals contain needle-like inclusions of apatite?; mounted on tip of spindle. A, perrierite crystal (Spec. No. 71) from lower Miocene ash in lower part of Arikaree Formation near Chimney Rock, Nebr. B, chevkinite crystal (Spec. No. 66W39) from Pearlette Ash Member, Borchers locality, Meade County, Kans.; glass adhering to edges of crystal. C, allanite (Spec. No. 66G36) from Miocene ash in lower part of Troublesome Formation, Grand County, Colo.; glass adhering to edge of crystal. Photographs by R. B. Taylor and Sandra Brennan.

Powder-film data for perrierite from the Miocene ash beds is given in Table 3 for comparison with data by Bonatti (1959) of the Italian perrierite. Perrierite is easily separated from chevkinite or allanite by its distinctive powder-film lines (Table 3). The perrierite was identified only after routine X-ray study of material previously regarded as chevkinite. The Miocene perrierite is nonmetamict and gives excellent powder-film data distinct from chevkinite and allanite (Table 3). Using the unit-cell data presented by Bonatti (1959) and a U. S. Geological Survey least-squares refinement computer program written by H. T. Evans, D. E. Appleman, and D. Handwerker, the following approximate unit-cell values for the Miocene perrierite were obtained: $a=13.59\pm.007$ Å. $b=5.62\pm.002$ Å, $c=11.73\pm.004$ Å, and $\beta=113°57'\pm3'$. Some of the indices for the Miocene perrierite shown in Table 3 were assigned from the computer data using the space group assignment reported by Bonatti (1959, p. 136) as $C2/m$ and by analogy with the indices given by Bonatti.

CHEVKINITE

Chevkinite, a rare-earth titanosilicate, was reported by Powers, Young, and Barnett (1958) and Young and Powers (1960) as occurring

TABLE 2. SOME OPTICAL PROPERTIES OF PERRIERITE, CHEVKINITE, AND ALLANITE OF TABLE 1

	Perrierite	Chevkinite	Allanite
α	1.924–1.930	1.967–1.973	1.780–1.785
Optic angle	$2V_x$, large	Large (−) ?	$2V_x$, low to moderate
Pleochroism			
α_x	Colorless to light-brownish-yellow in thin slivers; medium-reddish-brown in thick grains	Dark-reddish-brown (yellow-brown in thin slivers)	Pale-olive-green
β	Very dark reddish brown	Opaque (even in thin slivers)	Dark-brown
γ_x	Opaque	Opaque	Dark-reddish-brown
Absorption	Strong in one direction	Strong in two directions	Strong in one direction
Dispersion	Strong	Strong	Strong
Habit	Mostly flattened elongate prisms and pencil-shaped prisms; a few short stubby prisms	Mostly slender pencil-shaped prisms; a few short stubby prisms	Mostly tabular stubby prisms
Optic plane	Parallel to elongation	Parallel to elongation	Parallel to elongation

in trace amounts in many silicic ash beds interbedded with terrestrial rocks that range in age from Eocene to Quaternary.

Chevkinite was found in pumice fragments and airfall ash associated with large ash-flow sheets from several areas of Cenozoic volcanism in the western United States including Yellowstone Park, Wyoming, Jemez Mountains area, New Mexico, and southern and central Nevada. Several ash beds contain both chevkinite and allanite, but where they occur together chevkinite is generally much more abundant than the allanite. In the rocks and pumice fragments examined by the writers the chevkinite generally occurs as lustrous dark-reddish-brown pencil-shaped euhedral crystals (Fig. 1B) about 0.1 to 0.5 mm long, indistinguishable from perrierite crystals under the stereomicroscope and distinguishable only with difficulty under the petrographic microscope. Optical and X-ray powder data of chevkinite from the Pearlette Ash Member is given in Tables 1 and 3. The chevkinite is geologically young, nonmetamict, and gives excellent powder film data from unheated material. The powder data is slightly different than data previously reported from partly

TABLE 3. SELECTED POWDER PHOTOGRAPH DATA FOR PERRIERITE, CHEVKINITE, AND ALLANITE OF TABLE 1
[Ni filtered Cu Kα radiation using 11.5 cm camera]

Perrierite — Chimney Rock, Morrill Co., Nebr. (71)

hkl	*d*(obs), Å	*d*(calc), Å	*I*
001	10.8	10.7	2
002	5.36	5.36	3
110	5.13	5.12	3
$\bar{1}11$	4.96	4.96	1
$\bar{1}12$	4.06	4.06	4
003	3.55	3.57	4b
—	—	—	—
112, 202	3.44	3.43, 3.43	2
$\bar{1}13$	3.19	3.19	1
103, 400	3.12	3.11, 3.11	2
$\bar{4}03$, 013	3.03	3.03, 3.02	2
$\bar{3}13$	2.97	2.97	10
$\bar{2}04$, 212, 311	2.93	2.93, 2.93, 2.92	10
020	2.82	2.81	5
113, 021	2.72	2.72, 2.72	1
004	2.68	2.68	5
$\bar{4}04$	2.61	2.62	1
220	2.56	2.56	1
022	2.50	2.49	4
	2.22	2.23	1b
	2.15	2.16	5
	—	—	—
	—	—	—
	—	—	—
	1.943	1.943	6
	1.835	1.832	1
	1.788	1.787	1b
	1.745	1.748	1b
	1.719	1.720	1
	—	—	—
	1.653	1.652	3
	1.602	1.601	2
	—	—	—
	1.410	1.412	1
	1.249	1.249	1b

Perrierite — Nettuno, Italy (Bonatti, 1959)

hkl	*d*, Å	*I*
—	—	—
002	5.34	65
110	5.13	25
—	—	—
—	4.06	20
003	3.56	20
$31\bar{1}$	3.53	15
—	3.43	20
—	—	—
400	3.15	15
—	3.03	20
$31\bar{3}$	2.96	100
311	2.93	55
020	2.82	65
113	2.73	15
004	2.675	20
—	—	—
220	2.550	15
022	2.488	15
—	2.229	50
—	2.166	25
—	2.156	25
—	2.095	15
600	2.088	15
024	1.941	50
	—	—
	1.779	15
	—	—
	1.719	10
	1.658	10
	1.649	10
	—	—
	1.585	15
	—	—
	—	—

Chevkinite — Meade Co., Kans. (66W39)

hkl	*d*(obs) Å	*d*(calc) Å	*I*
200	6.6	6.6	1
002, 201	5.43	5.48, 5.23	2
$\bar{1}11$	4.85	4.85	3
111	4.58	4.58	4
$\bar{2}12$	3.61	3.61	3
310	3.46	3.46	4
311	3.17	3.17	10
$\bar{3}03$, $\bar{3}12$	3.14	3.13, 3.15	10
013, $\bar{4}02$	3.07	3.09, 3.09	3
401, 203, $\bar{2}13$	2.99	2.99, 2.99, 2.99	3
$\bar{4}11$	2.86	2.86	4
$\bar{2}04$, 021, $\bar{3}13$	2.74	2.74, 2.74, 2.74	2
$\bar{4}12$, 121	2.71	2.71, 2.71	10
402, 104	2.61	2.62, 2.61	1
$\bar{1}14$	2.52	2.52	1
	2.23	2.23	3
	2.16	2.15	5
	1.961	1.961	5
	1.815	1.816	1
	1.783	1.784	1
	1.695	1.696	1b
	1.665	1.665	2
	1.627	1.627	1
	1.546	1.646	1
	1.512	1.515	1
	1.495	1.495	1
	1.430	1.429	1
	1.263	1.263	1
	1.204	1.204	1

Allanite — Cañones, N. Mex (65W130)

hkl	*d*(obs), Å	*d*(calc), Å	*I*
001	9.2	9.2	4
$\bar{1}01$	8.0	8.0	4
101	5.11	5.11	2
$\bar{1}02$	5.01	5.01	1
110	4.72	4.71	2
002	4.60	4.60	1
$\bar{1}12$	3.78	3.79	1
012	3.60	3.60	1
$\bar{2}11$	3.53	3.53	5
210	3.32	3.32	2
201	3.23	3.24	2
$11\bar{3}$	2.92	2.92	10
211	2.83	2.83	1
013	2.71	2.71	6b
$\bar{3}11$	2.63	2.63	5
202	2.56	2.55	2
$\bar{1}04$	2.51	2.51	1
	2.45	2.45	1
	2.41	2.41	1
	2.34	2.34	1
	2.30	2.30	1
	2.18	2.18	2
	2.16	2.16	2
	2.14	2.14	2
	2.10	2.11	1
	2.06	2.06	1
	1.916	1.916	2
	1.893	1.894	2
	1.772	1.773	1b
	1.742	1.741	1
	1.706	1.707	1
	1.677	1.677	1
	1.639	1.638	5
	1.617	1.617	1
	1.588	1.588	1
	1.559	1.560	1
	1.448	1.446	1
	1.416	1.416	1

metamict chevkinites (Jaffe and others, 1956). Using unit-cell data presented by Jaffe, Evans, and Chapman (1956, p. 477) and a U. S. Geological Survey computer program, the following unit-cell values for the three chevkinites of Table 1 were obtained:

	a	*b*	*c*	*β*
Pearlette Ash Member	13.37±0.003 Å	5.66±0.002 Å	11.28±0.003 Å	100°52′±2′
Middle member, Harpole Mesa Formation	13.37±0.002 Å	5.67±0.001 Å	11.24±0.004 Å	100°43′±2′
Tshirege Member, Bandelier Tuff	13.32±0.002 Å	5.68±0.005 Å	11.31±0.009 Å	100°43′±5′

The indices for the chevkinite from the Pearlette Ash Member were assigned from the least-squares computer refinement and by analogy with the data given by Jaffe, Evans, and Chapman (1956).

Allanite

Allanite, a rare-earth calcium aluminosilicate, was found in more than 20 silicic ash beds of Miocene age, in several ash beds of Oligocene age, and in several ash beds of Pleistocene age in Colorado, Kansas, Nebraska, New Mexico, Wyoming, and California. It was found in several silicic biotite-bearing ash beds in the lower part of the White River Group (Chadron Formation) of Oligocene age at Lone Tree Gulch, Natrona County, Wyoming. The mineral occurs in silicic biotite-bearing ash beds at the following localities: Harrison Sandstone near Agate, Nebraska (the K-Ar locality of Evernden and others, 1964, p. 178, KA 481); Arikaree Formation at Split Rock, Wyoming (the Split Rock local fauna locality of Love, 1961, p. 19, unit 2); North Park Formation in the North Park syncline, Colorado (at the measured section of Hail, 1965, p. 79); and in at least eight separate ash beds in the Troublesome Formation of Miocene age in Middle Park, Colorado. Allanite was found by the writers in airfall pumice of the Guaje Pumice Bed at the base of the Otowi Member of the Bandelier Tuff of Pleistocene age of New Mexico (Griggs, 1964; Smith and Bailey, 1966), in the Bishop Tuff in California, in the Yellowstone Tuff in Yellowstone Park, and in the Pearlette Ash Member at the Borchers fauna locality in Kansas. Trace amounts of allanite were found in airfall ash at the base of the Bivouac Formation of late Pliocene or Pleistocene age in northwestern Wyoming.

Allanite has been reported from upper Miocene welded ash-flow tuffs at the Nevada Test Site (F. M. Byers, oral commun., 1967), from lower Miocene tuffs in central Nevada (E. B. Ekren, written commun., 1966), in a Pleistocene ash in Nebraska (Miller and others, 1964, p. 25), and in rhyodacitic welded tuffs in Australia (Brand, 1966).

The fact that euhedral glass-mantled allanite occurs in fresh glassy airfall ash (as in Fig. 1C) and in ash-flow tuffs clearly indicates that it can be a product of primary magmatic crystallization and contradicts a recent statement that allanite is always to be ascribed to the autopneumatolitic residual stage (Tröger, 1967, p. 313).

The optical properties of the Miocene allanite are given in Table 2. The lower refractive index of the nonmetamict allanites studied is in the uppermost part of the range reported (Deer and others, 1962, p. 211). The optic plane is parallel rather than perpendicular to the elongation and has a smaller optic angle than generally reported (Deer and others, 1962, p. 211). The orientation of the optic plane of the allanite studied is difficult to determine owing to extreme axial dispersion and strong absorption when viewed along the acute bisectrix. By mounting the crystal parallel to the spindle axis, however, as in figure 1C, it can be rotated about the spindle axis 20° or 30° from the acute bisectrix, where the lateral rather than the pivotal motion of the isogyre indicates that the optic plane cannot lie transverse to the elongation (see, for instance, Becke, 1905).

Powder-film data from one of the allanites studied is shown in Table 3. The allanite gives excellent data from unheated material, and using unit-cell data given by Bonatti (1959) and a U. S. Geological Survey computer program, the following approximate unit-cell values for two allanites of Table 1 (Nos. 6, 7) were obtained: Troublesome Formation allanite, $a=9.03\pm0.004$ Å, $b=5.66\pm.002$ Å, $c=10.26\pm.005$ Å, and $\beta=115°35'\pm2'$; Guaje Pumice Bed allanite, $a=8.92\pm.002$ Å, $b=5.79\pm.002$ Å, $c=10.14\pm.002$ Å, and $\beta=114°51'\pm1'$. Some indices for the allanite from the Guaje Pumice Bed from the computer data are given in Table 3.

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