

OCCURRENCE AND AGE OF CHEVKINITE FROM THE
DEVIL'S SLIDE FAYALITE-QUARTZ SYENITE
NEAR STARK, NEW HAMPSHIRE*

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ABSTRACT

Chevkinite, a titano-silicate of the cerium earths, occurs as a well-crystallized accessory mineral in fayalite-quartz syenite of the Devil's Slide ring dike near Stark, New Hampshire. The mineral is monoclinic; space group $C2/m$, $C2$, or Cm ; $a=13.56 \text{ \AA}$, $b=5.82$, $c=11.21$, $\beta=100^{\circ}45'$. Crystals are black and prismatic, of splendent luster, irregular fracture, and are metamict. Cores of crystals are birefringent with strong pleochroism, n minimum = 1.97 (brown), n maximum = 2.05 (black), $2V$ variable from medium to large (-); rims of crystals are metamict, isotropic, and brown with n variable from 1.93-1.96. Density is variable, averaging 4.53. The x -ray powder diffraction pattern agrees with that for chevkinite from Bedford County, Va., and Mohave County, Ariz., but differs from that for chevkinite from Kobe-mura, Japan, and perrierite from Nettuno, Italy. The crystal symmetry and cell volume indicate a cell content of 48 oxygen atoms, but mutual substitution of ions such as Si, Ti, Al, Fe^{3+} , Y, Th, Nb, Ca, Fe^{2+} , Mg, Mn, and H is so extensive and complex that a structural formula cannot be established with certainty.

An age determination of the mineral by the lead-alpha activity method gave 207 million years compared with a maximum uncorrected age of 208 million years from total Pb, U, and Th analyses. The age of zircon from the same rock is 227 million years. Geologically the rock belongs to the White Mountain plutonic volcanic series (Mississippian?).

INTRODUCTION

Chevkinite, a titano-silicate of the cerium earths, occurs as a well-crystallized accessory mineral in fayalite-quartz syenite of the Devil's Slide ring dike just northwest of the village of Stark, New Hampshire. This is the third occurrence of chevkinite in this country; it has previously been reported by Eakins (1891) and Price (1888) from Bedford and Nelson Counties, Virginia, and by Kauffman and Jaffe (1946) from the Aquarius Mountains, Mohave County, Arizona. The most recent occurrence of chevkinite has been described by Takubo and Nishimura (1953) where it occurs at Kobe-mura, Japan, in its typical geological environment, pegmatite. Other foreign localities include the Ural Mountains, Russia (Rose, 1844; Hermann, 1866; Alimarin, 1935; and Boldireff, 1924, 1925); the Torendrika-Ifasina region of Madagascar (Lacroix, 1915, and Ungemach, 1916); the Kogendo region of Korea (Hata, 1940); Sabaragamuwa Province in Ceylon (Tschernik, 1913, 1914, and 1915), and the Salem district of Southern India (Damour, 1861). A mineral of similar composition found in the sands of Nettuno, Italy, has been described as a new mineral, perrierite, by Bonatti and Gottardi (1950 and 1954).

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Very little information on the field occurrence of chevkinite is given in the literature. Where the field data are reported, the only previously confirmed occurrences of chevkinite, other than as float, are in pegmatite. Lacroix (1915) suggests that in Madagascar the mineral originated in a pegmatitic phase of an alkalic aegirine granite. The New Hampshire occurrence in fayalite-quartz syenite represents the first time that chevkinite has been recognized as an accessory mineral in an igneous rock other than pegmatite.

PETROGRAPHY

The chevkinite described here occurs in the Devil's Slide syenite, one of the major rock components of the Devil's Slide ring dike which lies just northwest of the village of Stark, New Hampshire. Typically, the

TABLE 1. MODE OF THE DEVIL'S SLIDE QUARTZ SYENITE NEAR STARK, N. H.

Mineral	Volume per cent*
Microperthite	77.3
Plagioclase	2.7
Quartz	13.9
Hedenbergite	1.8
Hornblende	0.5
Fayalite	3.1
Chevkinite	0.2
Biotite	0.2
Apatite	0.1
Zircon	0.1
Magnetite, pyrite	0.1
Total	100.0

* Average of point count modes of 2 thin sections, determined by R. W. Chapman and H. W. Jaffe.

Devil's Slide syenite is rather coarse-grained and low in quartz, but the specimen from which the chevkinite comes is a medium-grained fayalite-quartz syenite with 12 to 15 per cent quartz. The following description applies to this specimen.

The quartz syenite is a tough, even-grained, subporphyritic rock composed essentially of greenish feldspar, quartz, and ferromagnesian minerals. The feldspar crystals are equidimensional to lathlike, with lengths ranging from 3 to 5 mm., and with widths of about 1 mm. The ferromagnesian minerals are smaller and more irregular. Carlsbad twins are common in the feldspar. Where fresh, the quartz syenite is greenish gray

or bluish gray, but on weathered surfaces it is white with brownish stains.

Microscopically the quartz syenite is hypidiomorphic granular and even-grained. An interdentated texture is common. Microperthite, quartz, hornblende, and fayalite ($\alpha = 1.815$, $\beta = 1.851$, $\gamma = 1.862$; $2V$ (calc.) = 57° , negative) are the principal minerals; and hedenbergite, plagioclase, chevkinite, biotite, apatite, zircon, magnetite, and pyrite are the accessories. Secondary minerals include yellow chlorite, sericite, epidote, and "leucocoxene." A mode of the quartz syenite, in volume per cent, is shown in Table 1.

MINERALOGY

Separation and purification

A 25-pound sample of the quartz syenite was crushed and screened to pass a 20-mesh sieve. The $-60+200$ mesh fraction was used for concentration of the chevkinite, at which size the mineral was free of attached impurities. Preliminary separations were made in bromoform to remove the quartz and feldspar which constituted most of the sample. Magnetite was removed with an Alnico hand magnet held above the grains. When the sample was brushed with the magnet, some of the fayalite was magnetic enough to be picked up. The magnetite-free fraction was then further concentrated in methylene iodide and the heavy fraction passed through the Frantz isodynamic magnetic separator at a pitch and tilt of 10° each. Most of the fayalite concentrated at an intensity of 0.1 ampere and all of it at 0.2 ampere. The magnetic concentrate at 0.3 ampere was almost pure chevkinite. Numerous repeated passes at 0.3 and 0.35 ampere finally yielded a 500-mg. concentrate of chevkinite of $99+\%$ purity. Under the binocular microscope, the mineral is black, with a splendid luster, not unlike that of ilmenite, and breaks with an irregular fracture. The concentrate yielded several well-developed prismatic crystals which were hand-picked for crystallographic study. These crystals were also used to determine the density of the mineral by means of the Berman balance. The results were found to vary considerably from sample to sample: 5.6 mg. sample, $d = 4.48$; 10.8 mg. sample, $d = 4.55$; 12.33 mg. sample, $d = 4.63$. The average value of these measurements was $d = 4.53$.

Optical properties

Chevkinite from New Hampshire is partly a metamict mineral; while it may form well-developed crystals, optical studies show that these are not all homogeneous. Within a single crystal, two phases, a fresh and a metamict zone, can be recognized. Commonly the cores of the small crystals are fresh and strongly pleochroic from brown to black, whereas the

outer metamict zones of the crystals are a light brown and isotropic with a lower index of refraction. Intermediate stages may also be present. The freshest material has a minimum index of refraction of 1.97 and a maximum of 2.05, $Z \wedge$ elongation is 6° – 9° , $2V$ is variable from medium to large, and the optic sign is negative. The isotropic metamict phase has an index of refraction ranging from 1.93 to 1.96. The presence of a metamict phase and the difficulties encountered in attempting to calculate a neutral formula for this and other occurrences of chevkinite suggest that the metamict phase may be amorphous and variable in composition, whereas the composition of the fresh mineral is not yet proved. This will be discussed further in the section on the chemistry of chevkinite.

CRYSTALLOGRAPHY

Single crystals about 0.3 mm. in size were mounted for x -ray crystallographic study by the Buerger precession method. The $(hk0)$ -lattice photo-

TABLE 2. UNIT CELL DATA FOR CHEVKINITE

	N. H. (unheated) (1)	N. H. (heated) (2)	Italy (3)	Russia (4)
a	13.56 Å	13.44	13.59	13.9
b	5.82	5.72	5.61	5.7
c	11.21	11.10	11.61	11.1
β	$100^\circ 45'$	$100^\circ 20'$	$113^\circ 28'$	$100^\circ 08'$

1. Measured by Buerger precession method.
2. Measured by least squares fit to powder diffraction data.
3. Measured by Weissenberg method on crystals of perrierite from Nettuno, Italy, by Bonatti and Gottardi (1950).
4. Inferred from morphological study on crystals from Mount Ilmen, Urals, by Boldireff (1924), with value for b assumed.

graph showed clearly the twinning on the (001) plane. Microscopic examination indicates that almost all crystals exhibit contact twinning on (001) in a manner strongly reminiscent of epidote. Upper level photographs indicate a centered cell and the space group is $C2$, Cm , or $C2/m$, most likely the last (C_{2h}^3). The dimensions, accurate to 0.5 per cent, are given in Table 2. It was noted that the precession patterns, made from untreated crystals, were somewhat diffuse, presumably because of their partly metamict character.

The crystals gave morphological measurements of poor quality, but the measurements were sufficiently accurate to identify the forms with certainty. Among those observed are the following:

<i>c</i>	001	<i>e</i>	021	<i>p</i>	112
<i>b</i>	010	<i>M</i>	101	<i>n</i>	111
<i>a</i>	100	<i>t</i>	201	<i>Q</i>	$\bar{1}12$
<i>m</i>	110	<i>r</i>	$\bar{1}01$	<i>o</i>	$\bar{1}11$
<i>d</i>	012	<i>κ</i>	$\bar{2}01$		

The crystals are commonly elongated parallel to the *b* axis, flattened on *a*, and twinned on *c*, as shown in Fig. 1*a*. Figure 1*b* is redrawn from Boldireff (1924) to show the similarity of habit between the crystals from New Hampshire and from the Urals. The predominance of the forms observed decreases in the order: *a*, *o*, *m*, *n*, *Q*, *t*, *M*, which is in accord with the *c* centered mode of the monoclinic lattice. The crystallographic elements, derived from the *x*-ray measurements, are as follows:

$$\begin{aligned}
 a:b:c &= 2.329:1:1.926 \\
 \beta &= 100^{\circ}45' \\
 x_0' &= 0.190 \\
 p_0' &= 0.842 \\
 q_0' &= 1.926
 \end{aligned}$$

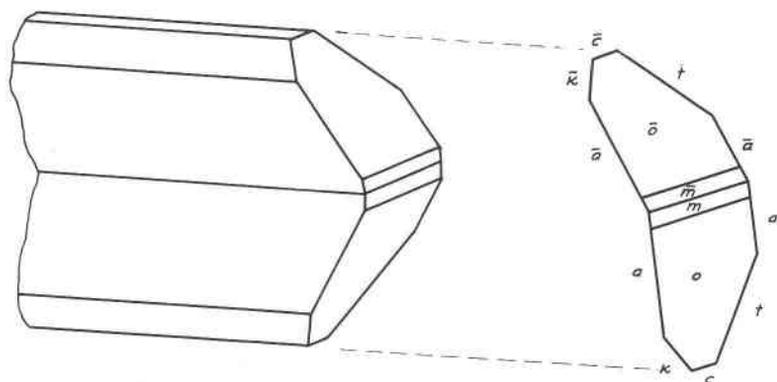
The similarity of crystals from the American and Russian localities is fully evident from the extensive crystallographic description given by Boldireff (1924) for the latter material. His morphological measurements give axial ratios which may be compared as follows:

$$\begin{aligned}
 a:b:c &= 2.426:1:1.955, \beta = 100^{\circ}45' \text{ (Russia)} \\
 a:b:c &= 2.329:1:1.926, \beta = 100^{\circ}45' \text{ (New Hampshire)}.
 \end{aligned}$$

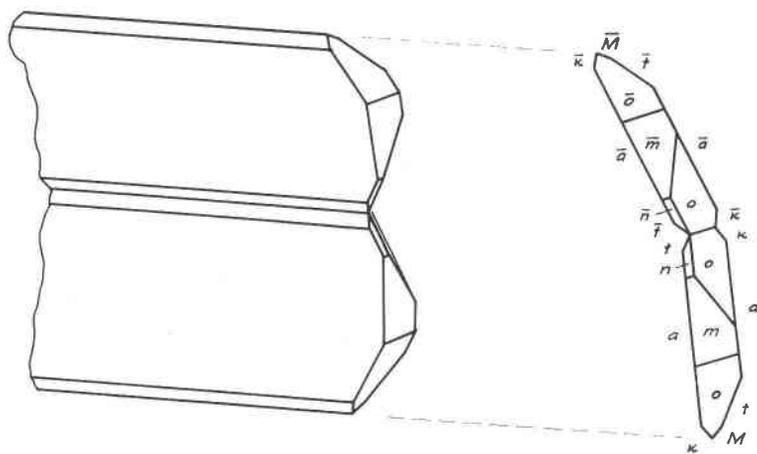
Although no *x*-ray study has been made of the Russian mineral, tentative cell constants are given in Table 2 based on Boldireff's axial ratio and an assumed value of *b*.

The comparison of the single-crystal data with those given for perrierite by Bonatti and Gottardi (1950) is not so clear. They claim the unit cell constants given in Table 2, as determined from sharp Weissenberg photographs. We have not been able to reconcile this unit cell with the morphological data as they are presented by these authors, in the form of stereograms and a limited number of interfacial angles. On the other hand, their arguments showing the close relationship between perrierite, Boldireff's chevkinite, and allanite (orthite) are convincing. In fact, especially in view of the chemical parallelism which will be shown later, there is a possibility that perrierite and chevkinite are the same mineral.

It is particularly apparent from the powder data that is available for chevkinite from several localities, that the unit cell of this mineral is capable of variation in size and shape of perhaps as much as 5 per cent, reflecting the great range of chemical substitution which it apparently can tolerate. This much variation in cell dimensions would readily account



a.



b.

FIG. 1. Crystal habits of chevkinite from (a) Stark, N.H., and (b) Ilmen Mt., Russia, (redrawn from Boldireff, 1924). Crystals are twinned on $c\{001\}$, and show the forms: $c\{001\}$, $a\{100\}$, $m\{110\}$, $M\{101\}$, $t\{201\}$, $\kappa\{201\}$, $n\{111\}$, $o\{\bar{1}11\}$.

for the dissimilarity of powder data obtained by us for New Hampshire chevkinite, by Takubo and Nishimura (1953) for Japanese chevkinite, and by Bonatti and Gottardi (1950) for the Italian perrierite. These data are given Table 3, together with expected d spacings as calculated from the unit cell constants for unheated chevkinite from New Hampshire given in Table 2. An attempt was made to index the x -ray pattern of the Italian material using the corresponding unit cell of Bonatti and Gottardi but without conclusive results. No attempt was made to index the Japanese pattern.

Chevkinite generally gives rather poor powder diffraction patterns because of its partial or nearly metamict character. Heating the mineral in air over a Bunsen burner for an hour was found to be effective in annealing the metamict mineral so that it gave greatly improved powder patterns. Except for sharpness, the patterns for heated and unheated material appear identical, but careful measurement indicates a slight shrinkage of the unit cell of about 1 per cent. The new cell, given in Table 2, was arrived at by a least squares refinement of the unheated cell to give the best fit to the sharpened powder data. The measurements of powder data for heat-treated samples from three American localities are given in Table 4, together with the calculated d spacings.

CHEMISTRY

A visual spectroscopic analysis (by H. W. Jaffe) of chevkinite from Stark, New Hampshire, gave the following results:

Major constituents (5%): Ti, Si, Ce, La, Fe

Minor constituents (0.5–5%): Ca, Nd, Al

Trace constituents (0.5%): Nb, Mg, F, Pb, Mn, Na, Y, Th.

A complete chemical analysis of the mineral is given in Table 5 and compared with selected published analyses of chevkinite from other localities. Additional analyses are tabulated by Kauffman and Jaffe (1946).

The analyses listed in Table 5 and others given in the literature do not readily yield a reasonable common formula for chevkinite, as determined by mol ratios. Several have been proposed; for example, $R^{2+}R_2^{3+}$ -(Si, Ti)₃O₁₀ (Boldireff, 1924), and $R_2^{3+}Ti_2Si_2O_{11}$ (Bonatti and Gottardi, 1954). None of these hypotheses is supported by any convincing evidence, nor do any of them have general applicability. The situation is certainly confused by complex substitutions of ions of different charges in particular crystal structure sites, but the chemistry is made even more uncertain by the presence of pronounced zoning in the single crystals and a widely varying density, as pointed out earlier.

The best approach to the problem of the constitution of chevkinite is

TABLE 3. POWDER DATA FOR UNTREATED CHEVKINITES

<i>hkl</i>	<i>d</i> (calc), Å.	N. H. (1)		Japan (2)		Italy (3)	
		<i>d</i> , Å.	<i>I</i>	<i>d</i> , Å.	<i>I</i>	<i>d</i> , Å.	<i>I</i>
001	11.014			5.399	2	3.85	43
200	6.656			5.195	3	3.50	37
201	6.235			4.834	1	2.92	100
002	5.506	5.50	W	4.104	2	2.81	46
110	5.332			3.566	4	2.67	40
201	5.277			3.462	4	2.50	41
111	4.947	4.92	MW	3.405	4	2.21	37
202	4.695			3.217	2	2.15	55
111	4.665	4.67	M	3.045	5	1.94	78
112	3.982			2.983	10	1.81	41
202	3.901			2.956	10	1.78	40
112	3.695			2.841	7	1.73	40
003	3.671	3.67	W	2.699	6	1.65	55
310	3.529			2.579	2	1.59	43
310	3.515	3.51	MW	2.513	3	1.45	43
203	3.497			2.458	4	1.40	51
401	3.364			2.247	2	1.34	55
400	3.328			2.231	2	1.24	47
311	3.224			2.176	5		
312	3.194	3.20	Sb	2.158	4		
113	3.135			2.108	2		
402	3.117	3.11	M	1.952	3		
411	3.033			1.723	2		
203	2.988	2.98	W	1.659	3		
113	2.924			1.612	3		
020	2.905	2.90	M	1.597	2		
021	2.813						
312	2.789	2.79	MW				
313	2.757						
004	2.754	2.74	VS				
403	2.732						
204	2.731						
220	2.666						
402	2.639						
221	2.637						
022	2.573	2.60	W				
221	2.548						
114	2.525						
		2.19	W				
		1.99	MW				

Intensity (*I*) symbols: VS=Very strong; S=Strong; M=Medium; MW=Medium weak; W=Weak; F=Faint; VF=Very faint; b=Broad.

(1) Measurements by Mary E. Mrose, +0.2%; rad. used, CuK α .

(2) From Takubo and Mishimura (1953).

(3) From Bonatti and Gottardi (1954).

TABLE 4. POWDER DATA FOR HEAT-TREATED CHEVKINITES, d IN $\text{\AA} \pm 0.2\%$ MEASURED BY DAPHNE D. RISKA; $\text{CuK}\alpha$ RADIATION

hkl	$d(\text{calc})$	N. H.		Ariz.		Va.		N. H.		Ariz.		Va.	
		d	I	d	I	d	I	d	I	d	I	d	I
001	10.920	11.1	F	11.1	F	11.1	F	2.24	VF	2.24	VF	2.24	F
200	6.611							2.17	M	2.17	M	2.16	M
201	6.167							2.08	VFb	2.08	VFb	2.08	VFb
002	5.460	5.44	F	5.47	F	5.44	F	2.00	VF	2.00	VF	2.00	VF
201	5.254							1.97	Mb	1.97	Mb	1.96	M
110	5.250											1.94	VF
111	4.869	4.86	W	4.85	W	4.86	W	1.82	VF	1.83	VF		
202	4.638							1.79	VF	1.79	F	1.79	F
111	4.606	4.60	W	4.60	W	4.60	W	1.74	VFb	1.74	F	1.74	Fb
112	3.927							1.70	VF	1.71	F	1.70	F
202	3.882			3.85	VF	3.84	VF	1.67	VFb	1.67	Fb	1.67	Fb
112	3.657							1.63	VFb	1.63	F	1.62	Fb
003	3.640	3.63	VF	3.65	VF	3.64	F					1.53	VF
310	3.491											1.50	VF
311	3.472	3.47	F	3.47	W	3.47	W					1.44	VF
203	3.462							1.43	VFb			1.43	VF
401	3.334	3.35	VF	3.35	F	3.34	VF	1.41	VFb			1.41	VF
400	3.306											1.37	VF
311	3.196	3.20	S	3.21	S	3.18	Sb					1.36	VF
312	3.152	3.15	S	3.15	S			1.34	VF			1.34	VF
113	3.096	3.08	W	3.10	W	3.09	W	1.29	VFb			1.29	VFb
402	3.083							1.27	VFb			1.26	VFb
401	3.017	3.00	F	3.01	W	3.00	W					1.20	VF
203	2.971											1.18	VF
113	2.896												
020	2.860	2.86	M	2.86	M	2.87	M						
312	2.768												
021	2.767	2.76	F	2.75	W	2.77	W						
004	2.730												
313	2.720												
403	2.700	2.71	S	2.71	S	2.71	S						
204	2.700												
402	2.626												
220	2.625	2.61	VF	2.61	F	2.61	F						
221	2.595												
022	2.534	2.53	F	2.52	F	2.53	F						
221	2.512												
114	2.496												
222	2.435	2.44	VF	2.44	VF	2.44	VF						
511	2.429												
510	2.400												
204	2.378												
313	2.358												
114	2.355												
512	2.342												
404	2.319	2.32	VFb	2.32	VFb	2.32	VFb						
314	2.316												
222	2.303												

Symbols as for Table 3.

TABLE 5. CHEMICAL ANALYSES OF CHEVKINITE AND PERRIERITE

	1	2	3	4	5	6	7
SiO ₂	20.15	12.04	20.21	17.66	19.35	19.31	19.22
TiO ₂	17.81	17.08	18.78	17.93	19.06	23.24	17.22
Al ₂ O ₃	2.08	0.93	3.60	0.23	6.13	0.67	3.86
Fe ₂ O ₃	1.22	9.56	1.88	8.81	1.33	1.26	4.56
Nb ₂ O ₅	0.05	—	0.08	0.63	0.23	—	—
FeO	11.11	7.76	6.91	9.95	6.19	4.05	7.24
MgO	0.35	0.74	0.55	0.31	0.20	0.81	—
MnO	0.28	0.50	—	tr.	0.70	—	1.34
CaO	3.20	3.35	4.05	2.12	4.71	4.11	3.34
Ce ₂ O ₃	20.74	25.29	20.05	14.21	19.02	31.80	18.58
La ₂ O ₃	11.6	18.35	19.72	24.09	18.51	6.83	22.70
Pr ₂ O ₃	1.6						
Nd ₂ O ₃	5.8						
Sm ₂ O ₃	0.7						
Gd ₂ O ₃	0.5						
Y ₂ O ₃	0.5	1.50	1.82	2.45	3.49	1.51	1.25
ThO ₂	1.0	0.82	0.85	0.67	0.59	4.05	0.80
P ₂ O ₅	—	0.38	—	—	—	—	—
(Na, K) ₂ O	—	—	0.06	—	—	1.05	0.37+0.42
SnO ₂	—	—	—	0.25	0.09	—	—
H ₂ O	0.90	1.50	0.94	—	0.46	0.61	0.67
Total	99.59	99.80	99.50	99.31	100.06	99.30	101.57

1. Stark, N. H., Glen Edgington, Analyst.
2. Mohave County, Arizona (Kauffman and Jaffe, 1946).
3. Bedford County, Virginia (Eakins, 1891).
4. Kōgendō, Korea (Hata, 1940).
5. Kobe-mura, Kyoto Pref., Japan (Takubo and Nishimura, 1953).
6. Nettuno, Italy, perrierite (Bonatti and Gottardi, 1954).
7. Ilmen Mt., Urals (Kauffman, 1924).

Notes:

- a. La, Nd, Pr, Sm, Gd, T, and Th were determined spectrographically in analysis 1 by H. J. Rose, Jr., on the rare-earth precipitate separated from chevkinite.
- b. U=0.0186 in analysis 1, determined fluorimetrically by A. M. Sherwood.
- c. Pb=0.0098 in analysis 1, determined spectrographically by C. L. Waring.

through a study of the limitations imposed by the size and symmetry of the unit cell as determined by the *x*-ray measurements. It is well known that most of the volume of a crystal unit cell of an oxide structure will be accounted for by the oxygen atoms alone. Neglecting all other atoms, the specific volume of oxygen in the related mineral epidote (whose structure has been established in detail by Ito, Morimoto, and Sadanaga, 1954) is 18.1 Å³. Two rare-earth minerals may be cited also to show that the moderate-sized rare-earth cations still do not influence the specific

volume of oxygen appreciably: in bastnaesite it is 17.6 \AA^3 , and in monazite it is 18.6 \AA^3 . Taking the value of the oxygen volume as 18.1 \AA^3 , as in epidote, the calculated number of oxygen atoms in chevkinite (unit cell volume 873 \AA^3) is 48.2. Since the space group $C2/m$ allows atoms in groups of 2, 4, 8 or 16, we may expect to find 48 oxygen atoms in the unit cell. On this assumption we can now count the average number of all the other atoms in the cell for each chemical analysis. The atom counts corresponding to 48 oxygen atoms for the seven analyses of Table 5 are given in Table 6, each from a different locality.

TABLE 6. UNIT CELL CONTENTS FOR CHEVKINITE FROM VARIOUS LOCALITIES

Atom	New Hampshire (1)	Arizona (2)	Virginia (3)	Korea (4)	Japan (5)	Italy (6)	Russia (7)
Ti	5.7 5.7	5.9 5.9	5.9 5.9	6.1 6.1	5.7 5.7	7.6 7.6	5.5 5.5
Si	8.6	5.5	8.4	7.9	7.6	8.3	8.1
Al	1.1 10.1	.5 9.3	1.8 10.8	.1 11.0	2.9 10.9	.3 9.0	1.9 11.5
Fe ³⁺	.4	3.3	.6	3.0	.4	.4	1.5
Ce	3.4	4.3	3.1	2.3	2.8	3.0	2.9
R.E.	3.3	3.1	3.0	4.0	2.7	1.1	3.5
Y	.1 6.9	.4 7.9	.4 6.6	.6 7.0	.7 6.3	.3 6.8	.3 6.9
Th	.1	.1	.1	.1	.1	.4	.2
Fe ²⁺	4.0	3.0	2.4	3.7	2.1	1.5	2.6
Ca	1.5 5.8	1.7 5.4	1.8 4.4	1.0 4.9	2.0 4.4	1.9 3.9	1.5 4.6
Mn	.1 28.5	.2 29.5	— 27.7	— 29.0	.2 27.3	— 27.3	.5 28.5
Mg	.2	.5	.2	.2	.1	.5	—
H	2.6	4.6	2.6	—	1.22	1.8	1.9
O	48.0	48.0	48.0	48.0	48.0	48.0	48.0
<i>d</i> (calc.)	4.94	5.24	4.76	—	—	4.86	—
<i>d</i> (obs.)	4.53(ave.)	4.67	—	—	4.38	4.53	4.45

Note: For analysis references, see Table 5.

The data contained in Table 6 still do not lead to an unambiguous formula for the mineral, but certain consistent patterns do appear. The number of titanium atoms in the unit cell does not vary far from 6 (average 6.05). Two kinds of titanium are implied, therefore, with one kind on a symmetry center, which is consistent with the probable octahedral coordination for this atom. Such a site is not possible for the tetrahedrally coordinated silicon, and thus there are most likely 8 of these atoms in the cell, since all of the 2-fold sites in the space group $C2/m$ correspond to symmetry centers. One possible formula could be written as follows: $R_3^{2+}R_3^{3+}AlSi_4Ti_3O_{22}(OH)_2$. However, Table 6 shows considerable variation from this ideal formula, suggesting a complex system of substitutions of the various cations for one another among the various cation sites (e.g., Al^{3+} and Fe^{3+} for Si^{4+} or Ti^{4+} , Ce^{3+} for Fe^{2+} , O^{2-} for OH^- , etc.). Also, it should be remembered that, in view of the chemical dis-

turbances resulting from the metamict state, an uncertainty of one atom more or less per group is to be expected. Consequently, it is impossible to predict of what type these sites will be in the actual structure.

When the number of atoms in the unit cell, and also the unit cell volume, are known, the density can be calculated, and these data where available are given in Table 6. The calculated densities are always considerably higher than the measured values, but this result is typical of a metamict mineral. For example, fresh zircon has a density of about 4.7, but densities of metamict zircon have been measured as low as 4.0.

Bonatti and Gottardi (1954) have described in detail the crystallographic and structural relations between chevkinite, allanite, and epidote. It seems likely that Ito's determination of the structure of epidote should aid in the solution of the chevkinite structure. The final answer to the question of the constitution of chevkinite must wait until the time when its structure is known, but until then, the above treatment probably provides the best understanding of the problem.

AGE DETERMINATION

The Devil's Slide fayalite-quartz syenite from which the chevkinite was obtained is one of the major components of the Devil's Slide ring dike near the village of Stark in the Percy Quadrangle, New Hampshire. The ring dike has been assigned by Chapman (1948) to the White Mountain plutonic volcanic series (Mississippian?). An age determination was recently made by the lead-alpha activity method (Larsen, Keevil, and Harrison, 1952) on zircon from the same rock containing the chevkinite. The zircon gave an age of 227 M.Y. confirming the age assigned by Chapman to the Devil's Slide syenite. Chevkinite from the same rock specimen was also determined and gave an age of 208 M.Y. using the approximate, uncorrected age formula of Keevil (1939) according to which

$$T = \frac{7.23 \text{ Pb}}{U + 0.322 \text{ Th}} \times 10^9$$

where Pb, U, and Th represent concentrations in percent.

The age formula of Larsen, Keevil, and Harrison (1952) is

$$T = \frac{c}{\alpha} \text{ Pb}$$

where Pb is the lead concentration in parts per million, α is the alpha count per milligram per hour, and c is a constant. c is taken equal to 2613 if all of the alpha activity is due to uranium and 1988 if all of the alpha activity is due to thorium. For zircon, c is assumed to be 2400 because previous analyses of the mineral have shown that the activity is due

equally to uranium and thorium. For chevkinite, the value for c is approximately 2100 based upon determinations of uranium and thorium in the mineral. The lead, uranium, thorium, alpha activities, and age calculations for zircon and chevkinite are given in Table 7.

If the chevkinite contained a large amount of original lead of crystallization, its age would not be expected to show any agreement with the zircon age. The reasonably good agreement between both ages and the geology suggests that chevkinite may have potential value as an age mineral where it occurs as an accessory constituent of igneous rocks from other localities.

TABLE 7. AGE DETERMINATIONS OF MINERALS FROM THE DEVIL'S SLIDE SYENITE, STARK, N. H.*

Mineral	U (%)	Th (%)	Alpha Count		Pb (ppm)	Age (M.Y.)
			$(\alpha/\text{mg/hr.})$			
			Calc.	Meas.		
Zircon	—	—	—	465	44	227
Chevkinite	0.0186	1.0	953	995	98	207

* Determinations by H. W. Jaffe.

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