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DEPOSITS OF RADIOACTIVE CERITE NEAR JAMESTOWN, COLORADO*

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ABSTRACT

Cerite, a rare silicate of the cerium metals, occurs in small deposits in the pre-Cambrian rocks of the Front Range near Jamestown, Colorado. They are near the north border of a stock of Silver Plume granite, to which they are genetically related. Numerous lenticular schist masses in the granite suggest proximity to the roof.

The cerite rock containing about 75 per cent of cerite occurs as irregular lenses, one-fourth of an inch to 15 inches wide, in narrow aplite-pegmatite zones along the borders of small schist areas. Narrow veinlets of black allanite border the cerite rock and minute grains of uraninite (pitchblende) and pyrite are locally present.

Microscopic examination of the cerite rock shows it to be finely intergrown with

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varying amounts of allanite, brown epidote, törnebohmite, fluorite, bastnäsite, monazite, uraninite, and quartz. An analysis of the purer cerite rock showed 56 per cent of rare-earth oxides. A gray variety consisting chiefly of cerite, fluorite, and a brown epidote was found to show mild radioactivity on a photographic plate. An analysis of this material showed 0.513 per cent U_3O_8, 0.28 per cent ThO_2, 0.07 per cent PbO, and gave an age determination of 940,000,000 years.

Introduction

Cerite, a silicate of the cerium metals, is a rare mineral. Only four occurrences have been recorded, two in Sweden, and one each in Russia and in Canada. The deposits near Jamestown, Colorado, are thus the fifth known occurrence and the first in the United States. The mineral is commonly massive and finely granular, highly modified crystals of short prismatic habit being known only from Sweden. The color varies from gray to clove-brown or cherry-red, and the luster is dull adamantine. The hardness is about 5.5 and the specific gravity of the mineral is high, being nearly 5 (4.86, 4.91).

Several deposits of this little known mineral were discovered a few years ago by Charles Mohr, an old prospector, of Jamestown, Colorado, in the pre-Cambrian complex of the Front Range, 2 miles northeast of Jamestown, and 33 miles northwest of Denver (Fig. 1). The massive

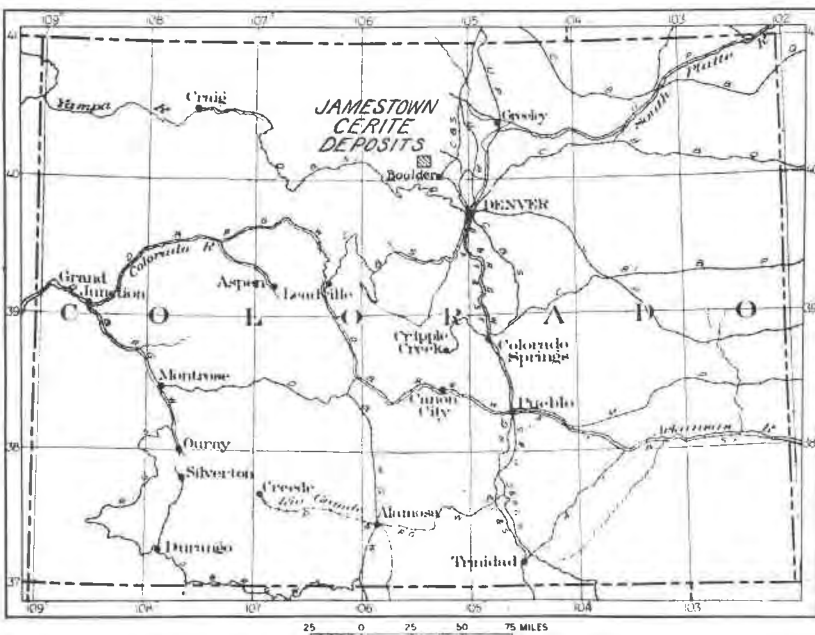


Fig. 1. Index map of Colorado showing the location of the Jamestown cerite deposits.

nondescript character of the material and its drab gray color give no indication of its unusual chemical composition, but its high specific gravity (4.65) would at once attract attention.

Several other rare-earth minerals are associated with the cerite, and the presence of radioactive materials makes possible a geologic age determination bearing a significant relationship to the widespread Silver Plume granite.

A comparison of the genetic and paragenetic relations of these deposits in Colorado to the other occurrences of cerite in the world are given in a later section of this paper.

The writers wish to acknowledge deep indebtedness to J. G. Fairchild and Charles Milton, of the U. S. Geological Survey Chemical Laboratory, for chemical analyses of some of the rare-earth minerals; to K. E. Lohman, of the U. S. Geological Survey, for making the photomicrographs; and to W. T. Schaller especially for many helpful suggestions during the preparation of this paper and for his analytical interpretation of the chemical data.

Geologic Occurrence

The pre-Cambrian rocks of the region consist of biotite schist and hornblende gneiss, which have been intruded by the Boulder Creek and Silver Plume granites and their associated pegmatites. These older rocks have been intruded by stocks and dikes of early Eocene (?) granodiorite and quartz monzonite. The chief rock in the vicinity of the cerite deposits is Silver Plume granite, the latest of the pre-Cambrian intrusives, which forms a large, irregular stock-like mass about 3 miles in diameter (Fig. 2). This mass is bordered on the north and southeast by schist and on the west by intrusive rocks of probable early Eocene age. Lenses and stringers of schist from 30 feet to half a mile long are scattered through the central part of the granite mass. In these inclusions, and in the bordering schist, the schistosity trends northeastward and dips steeply to the southeast. Dikes and lenses of pegmatite occur in the granite near the schist inclusions and in the bordering schist.

The cerite deposits appear to be near the central part of a granite stock, but detailed study of flow lines[1] in the granite (Fig. 2) seems to indicate that this granite body is composite, consisting of two separate stocks, and that the cerite deposits are actually near the border of a stock. The northern stock has a narrow rectangular outline, and is almost entirely free from schist inclusions. Its feeding channel was apparently

[1] Balk, Robert, Structural behavior of igneous rocks: *Geol. Soc. Am., Memoir* **5**, 7–25 (July 1937).

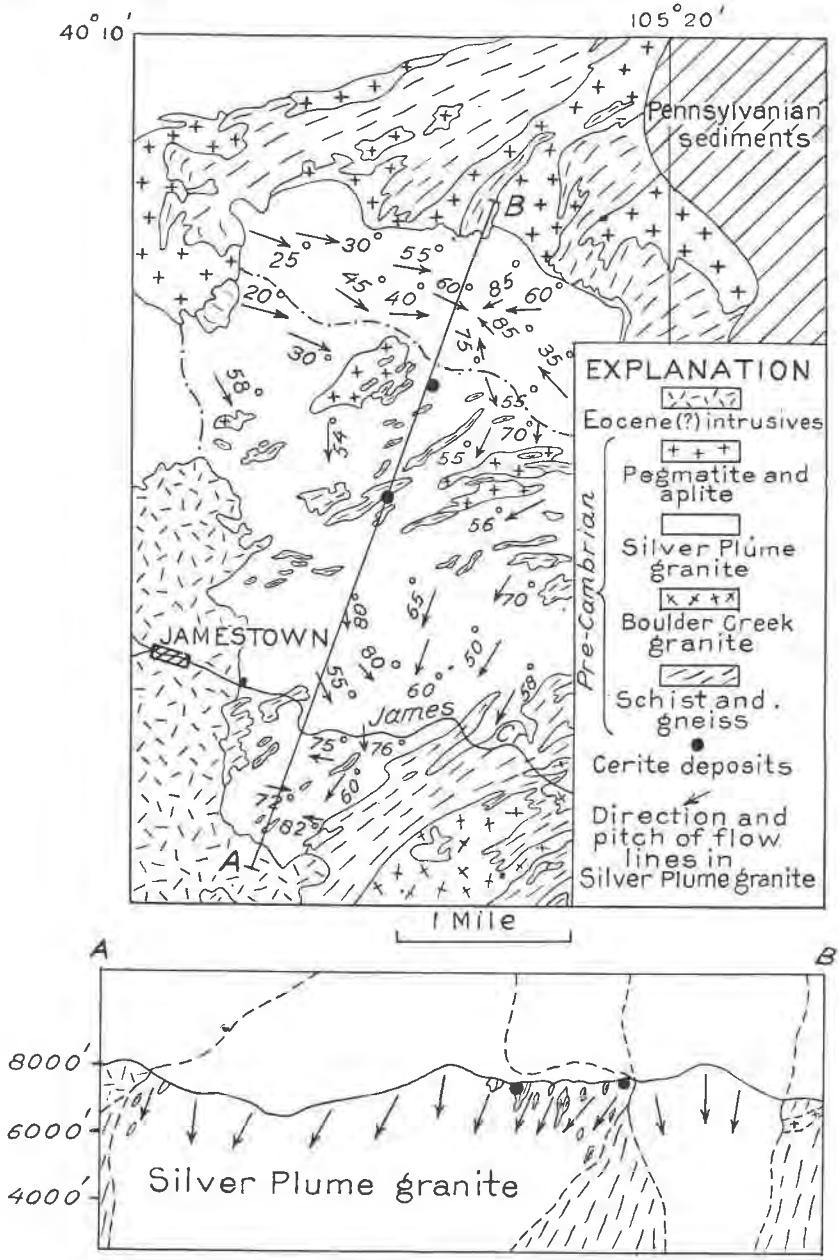


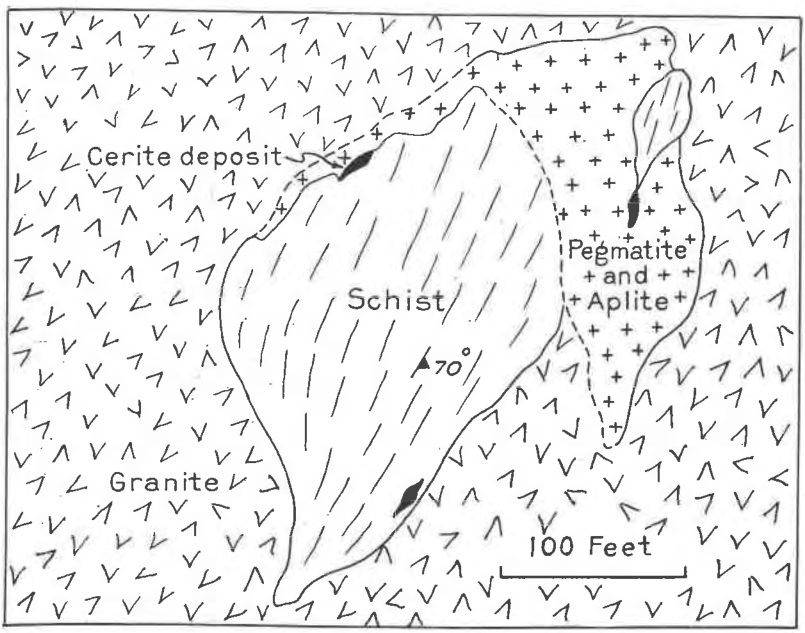
FIG. 2. Geologic plan and cross section of a part of the Jamestown district, showing the geologic setting of the cerite deposits.

beneath its center. The southern stock is roughly triangular in outline and contains abundant schist inclusions in its northern part. The magma appears to have come up from beneath the southern corner of the triangle and to have fanned out northward. If this interpretation is correct, the cerite deposits are near the north border of the southern stock, on the side away from the source of intrusion. The abundance of schist inclusions in the northern part of this stock, and their relative scarcity elsewhere, suggests that the present surface is closer to the roof in this locality than elsewhere. The supposed shape of the roof is shown in the cross section of Fig. 2.

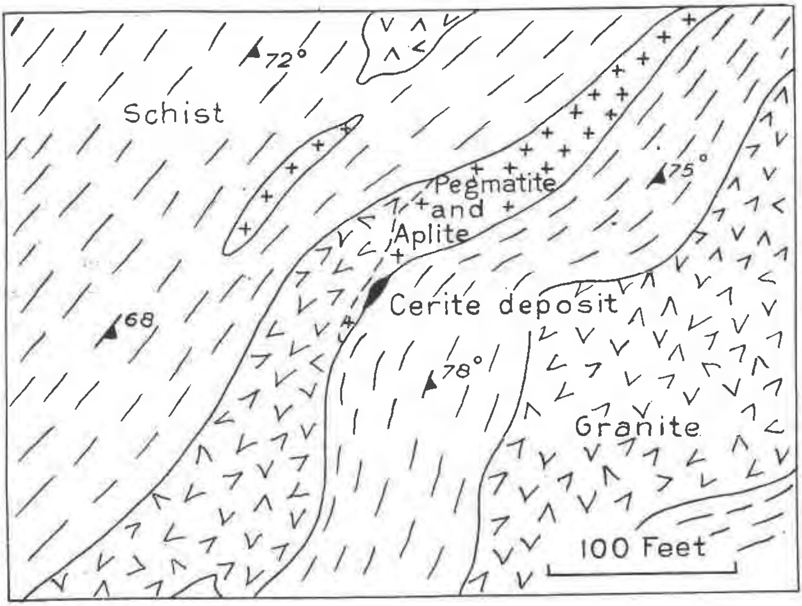
Mineralogy

Occurrence

Four separate deposits of cerite have been found in this region. Three (represented by a single dot in Fig. 2) form a small group near the north border of the granite stock and the fourth is about 3,600 feet to the south. The deposits are in pegmatite and aplite along the contact of the granite with schist inclusions. The northern three (Fig. 3) are grouped around a small schist lens about 300 feet long, and the southern one borders a long narrow tongue of granite which cuts a large schist mass



A



B

FIG. 3. Detailed geologic maps of the cerite localities showing the relation of the cerite deposits to the pre-Cambrian rocks. *A*. Northern group of cerite deposits. *B*. Southern cerite deposit.

about 3,000 feet long. The cerite and associated minerals, referred to as "cerite rock," occur in irregular lenses and stringers in aplite (Fig. 4) close to, or at, the schist border. The aplite grades into pegmatite, which in turn grades into granite within a few feet. The lenses of cerite rock range from a fraction of an inch to 15 inches in width, and from a few inches to several feet in length. Black allanite forms irregular replacement borders and locally cuts the cerite in veinlets as shown in Fig. 5. Minute grains of uraninite and of pyrite are sparingly scattered in both cerite and allanite, and chalcopyrite is locally associated with the pyrite.

Northern Group.—The cerite rocks in the northern group contain the same suite of minerals, but the minerals vary considerably in color and texture. The material in the northeastern deposit has a dense gray appearance, and microscopic examination of thin sections shows that it is made up of a fine-grained mosaic of cerite, deep violet fluorite,[2] allanite, brown epidote, quartz, and minor amounts of bastnäsite, uraninite and

[2] In a previously published abstract (*Am. Mineral.*, **21**, p. 199, March 1936), the writers identified the deep violet mineral as yttrocerite, but further work has shown it to be fluorite.

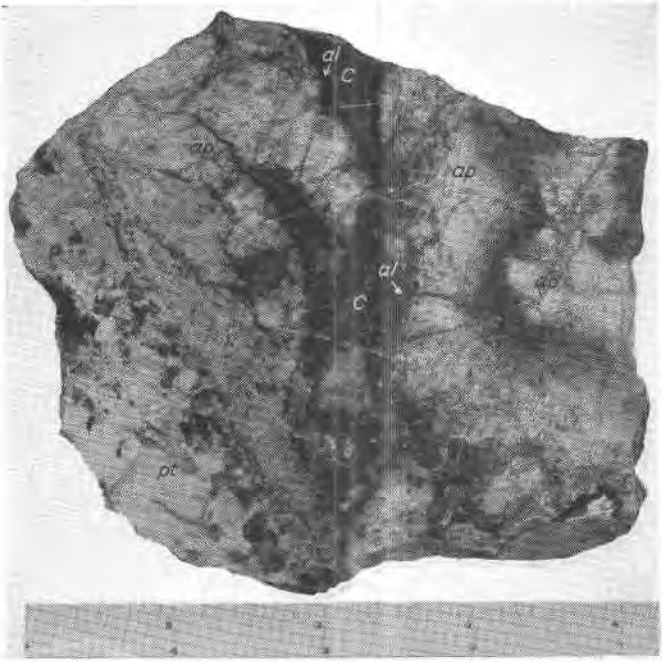


FIG. 4. (Scale in inches) Photograph of cerite specimen from northwestern deposit of northern group showing irregular veinlets of cerite rock (c) cutting aplite (ap) which grades into pegmatite (pt). A narrow band of allanite (al) borders the cerite, but is inconspicuous in places.

pyrite (Fig. 6). The grains are sub-angular to rounded and the grain size ranges from .01 to .11 millimeters, but averages about .03. The distribution of the minerals in this mosaic is very irregular. Cerite everywhere makes up more than 50 per cent of the material, but the fluorite content ranges from 10 to 25 per cent from place to place, the brown epidote from 10 to 20 per cent, and the quartz from 1 to 5 per cent.

Bands of black allanite border the cerite rock and are commonly one-half to 2 millimeters wide. The allanite has also replaced aplite on the other side of the black band, for euhedral crystals project into the aplite and are scattered through it for a distance of several inches from the allanite band. Quartz and orthoclase seem to have been equally susceptible to replacement. The allanite close to the cerite border is usually brown, whereas that farther away shows the green colors. This brown zone is absent, however, on the aplite side of the allanite band. Small to minute grains of pyrite and uraninite are sparingly scattered along the contact between cerite and allanite, and a few grains are found within the cerite.

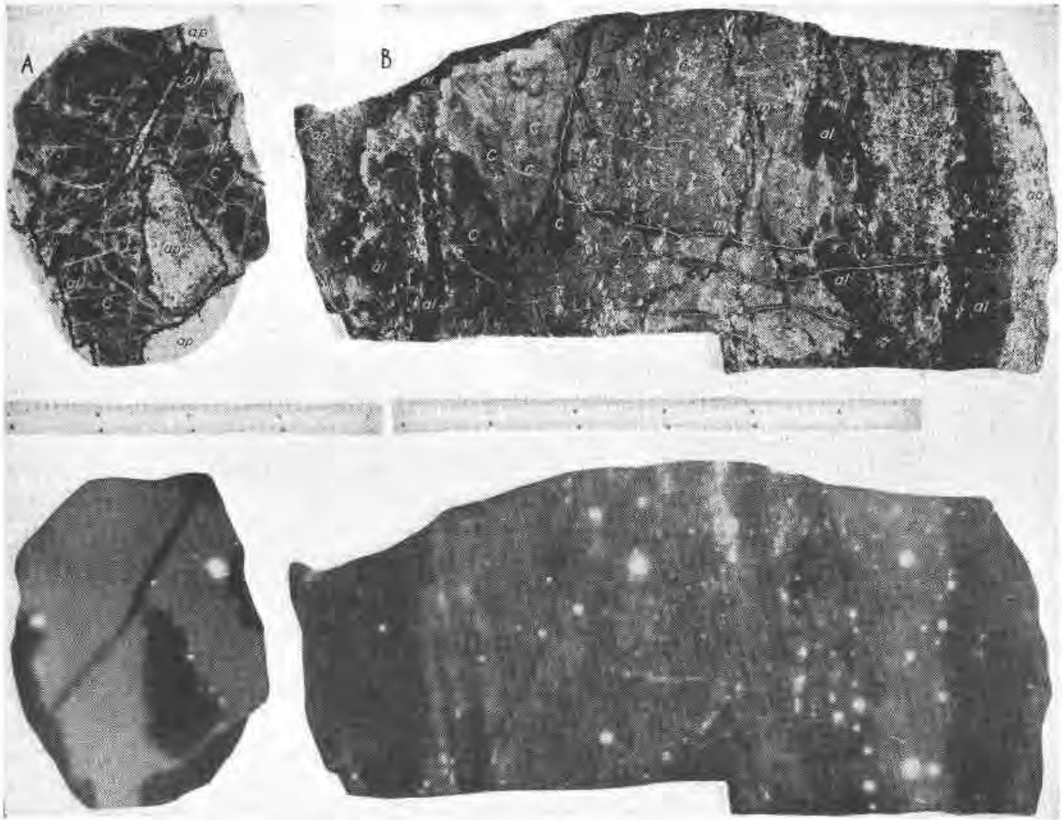


FIGURE 5. Photographs and radiographs of cerite specimens.

A. Specimen from northwestern deposit of northern group showing irregular veinlets of cerite rock (c) cutting aplite (ap) and bordered by irregular bands of allanite (al). Veinlet of allanite contains some quartz (q). Arrows point to grains of uraninite which produce large white spots in the radiograph.

B. Specimen from the southern deposit showing the full width of the vein and the complex mixture of rare-earth minerals: cerite (c); törnebohmite (t); monazite (m); brown epidote (e); allanite (al); bounded by aplite (ap). In the radiograph the white spots are due to uraninite.

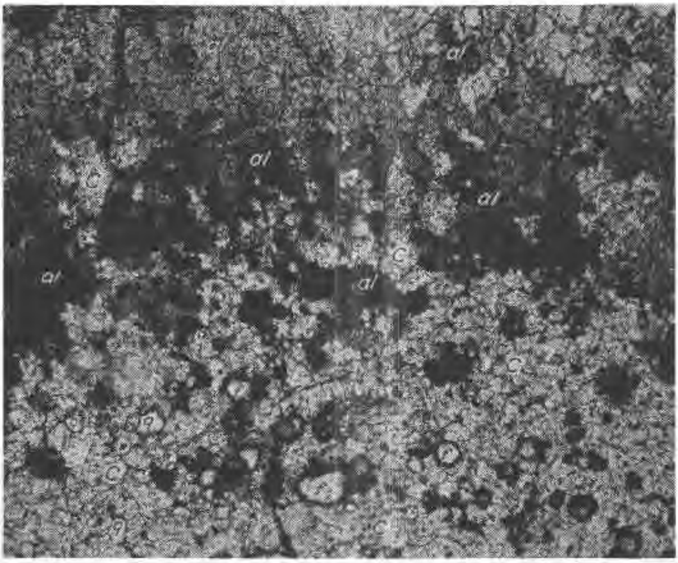


FIG. 6. (125×) Photomicrograph of cerite rock from northeastern deposit of northern group, showing the very irregular contact of the cerite material with allanite, which grades from brown at the border to green in the interior. Mixture of cerite and brown epidote (c); purple fluorite (f); quartz (q); allanite (al).

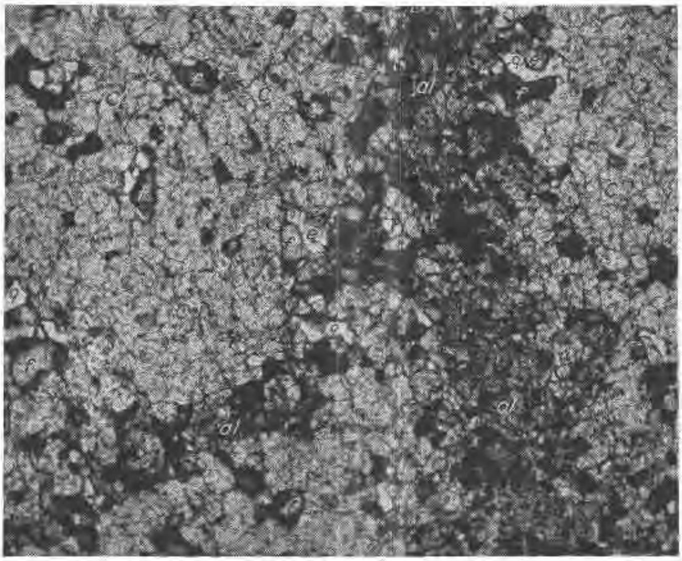


FIG. 7. (125×) Photomicrograph of cerite rock from northwestern deposit of northern group, showing veinlets of allanite (al) cutting the cerite material. Rounded grains of purple fluorite (f), brown epidote (e), and quartz (q) are scattered through the cerite (c).

In the northwestern deposit of the northern group the minerals are similar to those just described, but the cerite rock has a brownish cast, and the lenticular masses tend to be more irregular. Microscopic examination shows that much of the brown epidote, fluorite, and quartz is segregated into small rounded groups, surrounded by cerite (Fig. 7), but some of the grains of fluorite are concentrated along fractures in the cerite, like beads on a string, and some of the brown epidote occurs in

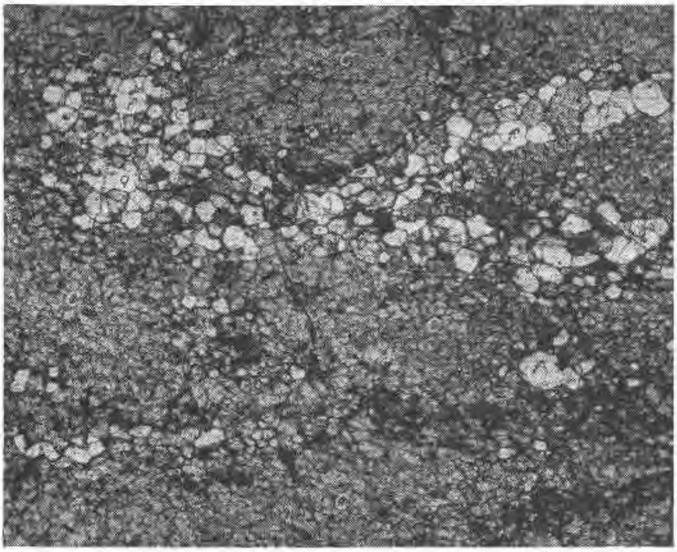


FIG. 8. (35×) Photomicrograph of cerite rock from southern deposit of northern group showing the schistose structure which suggests replacement of schist by the cerite. Mixture of cerite and brown epidote (c); purple fluorite (f); quartz (q).

irregular bands that seem to be replacing the cerite. Relatively straight veinlets of allanite cut the cerite rock in places. The larger ones, as shown in Fig. 5, contain a central seam of quartz.

The southern deposit of the northern group is in the schist a few feet from its contact with the Silver Plume granite, and the lenses of cerite rock are parallel to the foliation of the schist. The cerite and brown epidote are rather evenly distributed, but the fluorite is entirely absent in places and abundant in others. In one lens of cerite rock the grains tend to be elongated parallel to the foliation of the enclosing schist, and the fluorite and some of the coarser brown epidote grains are concentrated in irregular bands (Fig. 8). This structure gives the material a schistose appearance and suggests a replacement of the schist by the cerite.

Southern Group.—The most varied mineral assemblage is found in the southern deposit, 3,600 feet south of the northern group (Figs. 2 and 3). The lenticular vein here is about 8 inches wide and is bordered by aplite on one side and by aplite grading into schist on the other. As shown in Fig. 5, the vein consists of a rather complex mixture of rare-earth minerals bordered by irregular bands of allanite one-half to one inch wide. These minerals were apparently deposited in a definite sequence, each irregularly replacing parts of the earlier minerals. Lavender colored

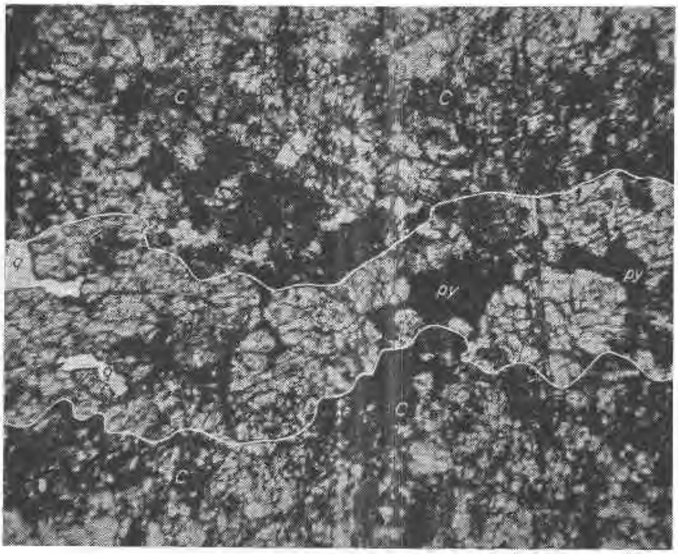


Fig. 9. (66×) Photomicrograph of cerite specimen from southern deposit showing irregular seam of törnebohmite (t), with some quartz (q) and pyrite (py) cutting cerite (c).

cerite was apparently the first mineral to be deposited. Cerite may have originally occupied the whole vein, but it is now confined to a band 1 inch to $1\frac{1}{2}$ inches wide on the western side of the vein (Fig. 5).

The cerite has been extensively replaced by greenish-gray törnebohmite, which now occupies most of the vein. This mineral is scattered through the cerite in irregular veinlets and masses, as shown in Fig. 9. The veinlets and the long direction of the crystals are roughly parallel to the walls of the vein as shown in Fig. 5.

Following the monazite, jet-black allanite extensively replaced törnebohmite, cerite and the aplite on either side of the vein as shown in Fig. 5. These bands of allanite are made up of large irregular grains 2 to 4 millimeters in diameter. Near the western side of the vein, a fairly regular veinlet of allanite and quartz 1 to 2 millimeters wide cuts through the cerite and törnebohmite. Figure 10 shows a photomicrograph of the

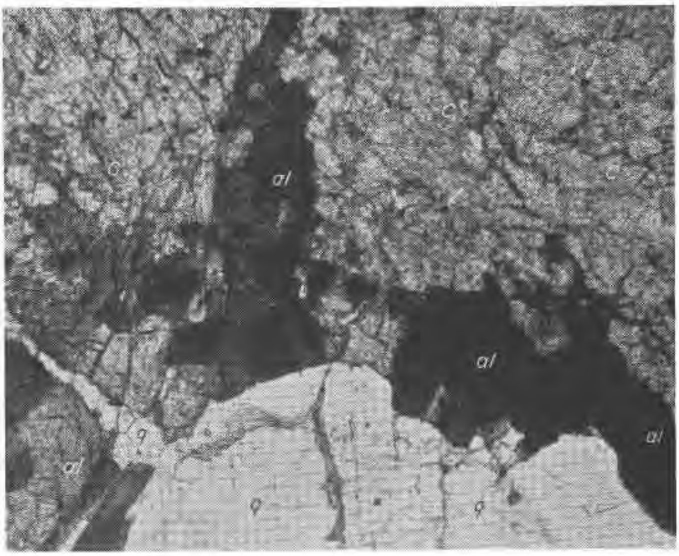


FIG. 10. (125×) Photomicrograph of cerite specimen from southern deposit, showing the border of a large veinlet of allanite (al), and quartz (q) that cuts through the cerite (c). Arrows point to minute spots of uraninite.

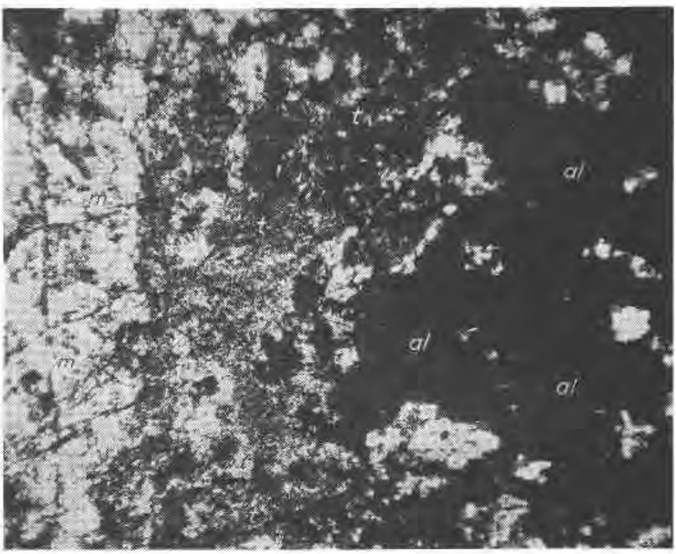


FIG. 11. (125×) Photomicrograph of cerite specimen from southern deposit showing allanite (al) irregularly replacing törnebohmite (t), and a seam of monazite (m) cutting the törnebohmite.

contact of this seam with the cerite, and illustrates how the allanite crystals finger out into the cerite. Most of the quartz appears to be contemporaneous with the allanite, but in one place a veinlet of quartz cuts the allanite (Fig. 10). In other places, masses of allanite irregularly replace cerite and törnebohmite as shown in Fig. 11.

Near the center of the vein the törnebohmite is cut by jagged veinlets of reddish-brown monazite. Although the veinlets are very irregular, the contact with the törnebohmite as seen in thin section is sharp (Fig. 11). A brown epidote which is scattered throughout the vein in small irregular discontinuous veinlets and lenses is later than the black allanite (Fig. 5). In places it cuts across veinlets and masses of the black allanite. It seems to be identical with the brown epidote of the northern group of deposits, but there the epidote is earlier than the allanite.

List of Minerals

The minerals of cerium and other rare-earths present in the Jamestown deposits are cerite, allanite, brown epidote, törnebohmite, bastnäsite, and monazite. The distribution of these and associated minerals in the two areas is as follows:

Northern deposit	*Southern deposit*
Cerite	Cerite
Allanite	Allanite
Brown epidote	Brown epidote
—	Törnebohmite
Fluorite	—
Bastnäsite	Bastnäsite
—	Monazite
Uraninite	Uraninite
Pyrite	Pyrite
—	Chalcopyrite
Quartz	Quartz

In addition to the mineralogical associations discussed under the section on occurrence, a more detailed mineralogical description is given on the following pages.

Cerite

The cerite occurs as small grains (about .2 mm.), gray to pinkish brown, some grayish lavender in color, in the aggregate already described. Under the microscope cerite shows faint pleochroism, colorless to pale pink. The birefringence is low. The character is positive, $2V=0°$ to $8°$. The indices of refraction are, $\alpha=1.815$, $\beta=1.815$, $\gamma=1.820$. The cerite grains in plain transmitted light resemble the brown epidote, but under crossed nicols the latter show high interference colors.

The cerite rock analyzed (Table 1) consisted of about three-fourths

TABLE 1. CHEMICAL ANALYSIS OF GRAY CERITE ROCK, A FINE-GRAINED MIXTURE OF CERITE, BROWN EPIDOTE, FLUORITE, BASTNÄSITE, AND SOME QUARTZ, FROM EASTERN DEPOSIT OF NORTHERN GROUP, NEAR JAMESTOWN, COLORADO.

[J. G. Fairchild, analyst]

	Per cent
SiO_2	18.78
Al_2O_3, TiO_2	0.24
FeO	1.17
U_3O_8	0.51 (U = .44)
Ce_2O_3	28.85
$(La, Tb)_2O_3$, etc.*	27.20
Y_2O_3, etc.	2.94
ThO_2	0.28 (Th = .25)
MnO	0.17
ZnO	None
CaO	12.55
MgO	0.16
PbO	0.07 (Pb = .07)
H_2O	0.96
CO_2	1.00
P_2O_5	None
F	5.94
Cl	None
B_2O_3, BeO	None
	100.82
Less O=F	2.52
	98.30

Sp. Gr. = 4.653
Pb: (U plus .36 Th) = .132 ± 1/5
Age = 940 million years ± 1/5 by logarithmic formula

* Neodymium and praseodymium were identified by absorption spectra.

cerite, with smaller quantities of fluorite, quartz, uraninite, and bastnäsite. Relegating the CO_2 to bastnäsite with the formula $(CeF)CO_3$, the remaining fluorine to fluorite, the $U_3O_8+ThO_2+PbO$ to uraninite, and assuming 5 per cent of quartz, the sample analyzed had the following mineral composition:

Cerite	76.1
Fluorite	11.3
Bastnäsite	5.0
Quartz	5.0
Uraninite	0.9
	98.3
All others	1.7
	100.0

Under "all others" are grouped the small quantities of Al_2O_3, TiO_2, FeO, MnO, and MgO. The assumption of 5 per cent of quartz is not based on any determination other than a rough estimate of grains in thin section. The calculation of the formula of cerite as shown in Table 2 suggests that this figure may be too high.

When the associated minerals are deducted and the remainder calculated to 100 per cent, the composition of the cerite is as shown in the last column of Table 2.

TABLE 2. CALCULATED ANALYSIS OF PURE CERITE

Analysis		Interpretation					Cerite Recalculated to 100 Per cent
		0.86% uraninite	5.00% bastnäsite	5.00% quartz	11.32% fluorite	76.14% cerite	
SiO_2	18.78	—	—	5.00	—	13.78	18.10
Al_2O_3, TiO_2	0.24	—	—	—	—	0.24	0.32
FeO	1.17	—	—	—	—	1.17	1.54
U_3O_8	0.51	0.51	—	—	—	—	—
Ce_2O_3	28.85	—	3.75	—	—	25.10	32.97
La_2O_3[a]	27.20	—	—	—	—	27.20	35.72
Y_2O_3	2.94	—	—	—	—	2.94	3.86
ThO_2	0.28	0.28	—	—	—	—	—
MnO	0.17	—	—	—	—	0.17	0.22
CaO	12.55	—	—	—	8.13	4.42	5.80
MgO	0.16	—	—	—	—	0.16	0.21
PbO	0.07	0.07	—	—	—	—	—
H_2O	0.96	—	—	—	—	0.96	1.26
CO_2	1.00	—	1.00	—	—	—	—
F	5.94	—	0.43	—	5.51	—	—
	100.82						100.00
	−2.52						
	98.30						

[a] Molecular weight taken is 331.

The recalculated analysis of the mineral cerite agrees closely with the published analyses. Small quantities of FeO (maximum 4.98 per cent), Al_2O_3 (maximum 2.64 per cent), and other constituents, are given in the analyses of cerite from Sweden. These older analyses report several per cent of water (maximum 8.10 per cent), and the formula of the mineral is generally written with considerable H_2O. The analysis of cerite from Colorado, with only about one per cent of H_2O, suggests, however, that the much greater content of water in the older analyses is due to alteration and is not inherent in the mineral. This conclusion is verified by Silberminz's[3] analysis of cerite from the Urals with only 1.29 per cent H_2O+ and 0.19 per cent H_2O-.

The content of CaO in ten analyses[4] of cerite varies considerably from none reported in two analyses from Sweden to a maximum of nearly 6 per cent in the cerite from Colorado. The figures reported are: 1.23, 1.27 (Urals); 1.31 (given as 1.35 by Dana), 1.65, 1.69, 3.56, 4.35, 5.80 (Colorado). The new mineral, lessingite, described by Silberminz, has 11.71 per cent CaO.

The recalculated analysis of the cerite from Colorado gives the following ratios:

SiO_2	.301 or 3
R_2O_3	.229 or 2
CaO	.103 or 1
H_2O	.070 or 1

yielding approximately the formula $CaO.2R_2O_3.3SiO_2.H_2O$. The mineral from Colorado is halfway between a calcium-free cerite and lessingite in composition, based on the content of CaO.

If the formula of calcium-free cerite is written $2R_2O_3.3SiO_2.H_2O$ (assuming that most of the water reported in the old analyses is due to alteration), then an apparent series exists:

CaO-free cerite	$2R_2O_3.3SiO_2.H_2O$
Cerite from Colorado	$CaO.2R_2O_3.3SiO_2.H_2O$
Lessingite	$2CaO.2R_2O_3.3SiO_2.H_2O$

Geijer[5] writes the formula of cerite as $2(Ca,Fe)O.3Ce_2O_3.6SiO_2.3H_2O$ which, when divided by two, becomes $(Ca,Fe)O.1\frac{1}{2}Ce_2O_3.3SiO_2.1\frac{1}{2}H_2O$, which is close to the formula of the cerite from Colorado.

In discussing the formula of allanite, Machatschki[6] groups the Ca and Ce together in his X-group and the varying content of CaO in analyses of cerite suggests that perhaps the CaO should not be separately considered but should be placed with the cerium and other rare earths.

The atomic ratios calculated from the recalculated analysis of the cerite from Colorado are:

[3] Silberminz, V., *Comp. Rend. Acad. Sci., U. S. S. R.*, A, No. **2,** 55, (1929); *N. Jahrb. Min.*, **1,** 123 (1930).

[4] Eight analyses of cerite from Sweden listed in Doelter's *Handbuch der Mineralchemie*, **2,** pt. 2, 166–167 (1915), the one from the Urals by Silberminz, and the one from Colorado.

[5] Geijer, Per, The cerium minerals of Bastnäs at Riddarhyttan: *Sveriges Geol. Undersökning*, Arsbok, **14** (1920), no. 6, 15 (1921).

[6] Machatschki, Felix, Die kristallochemischen Beziehungen zwischen Epidot-Zoisit und Orthit-Allanit: *Centralbl. Min., Geol., u. Pal.*, Abth. A, 89–96; 154–158 (**1930**).

Si	301	z = 301 = 1 × 301
Ce	208	
La	216	
Y	34	
Ca	103	590 X = 590 = 2 × 295
Fe	21	
Mn	3	
Mg	5	
O	1421	
(OH)	140	1561 = 5 × 312

The formula of cerite may then be written $X_2Y_0z_1(O,OH)_5$, with X = rare earths, Ca, Fe, Mn, Mg; or, for a calcium and water-free cerite, Ce_2SiO_5 or $Ce_2O_3 . SiO_2$.

The cerite from Colorado agrees with the cerite from Sweden in its optical properties. Lessingite apparently has different optical properties. While the cerite from Colorado is apparently the calcium-richest cerite and thus approaches lessingite in composition, the optical properties place it with cerite rather than lessingite as shown in Table 3.

TABLE 3. COMPARISON OF OPTICAL PROPERTIES OF CERITE

Cerite Colorado Glass	Cerite Sweden		Cerite Urals Silberminz	Lessingite Urals Silberminz
	Geijer	Larsen		
α=1.815	1.81	1.817	1.810	—
β=1.815		1.818	—	—
γ=1.820		1.821	1.825	1.785
B= .005	.002	.004	.015	.006
Sign +	+	+	+	−
2V=0° to 8°	0° to very small	25°	11°	44°

Allanite

Allanite, a rare-earth epidote, sometimes called orthite, is one of the more common minerals in the cerite assemblage, and apparently replaces the cerite. Allanite, in the veins of the southern deposit, occurs in bladed or tabular crystals up to 2 millimeters wide and 5 millimeters long. A few crystals of megascopic size have been observed in the northern deposit. The allanite is jet black and brittle with no distinct cleavage.

Under the microscope, however, the optical properties of allanite from the two localities are different. That from the southern deposit shows much stronger pleochroism and higher indices of refraction than that from the northern deposit. The pleochroism is: X, yellowish green, Y and Z, pinkish to reddish brown. Absorption strong, Y and Z>X. Indices of refraction: Allanite, northern deposit, $\alpha=1.758$, $\beta=1.765$, $\gamma=1.785$; positive; axial angle small, $2V=30°$. Allanite, southern deposit, $\alpha=1.788$, $\beta=1.810$, $\gamma=1.820$; negative; $2V=25°$ to $30°$.

The allanite from the southern deposit, which has unusually high indices of refraction and shows unusually strong pleochroism for this mineral, was analyzed by Charles Milton of the Geological Survey. The results given in Table 4 are comparable to the analyses of allanite given

TABLE 4.—CHEMICAL ANALYSIS OF ALLANITE FROM SOUTHERN CERITE DEPOSIT, NEAR JAMESTOWN, COLORADO.

[Charles Milton, analyst]

	per cent
SiO_2	30.40
Al_2O_3	10.25
Fe_2O_3	10.33
FeO	10.29
MgO	1.44
CaO	7.47
Na_2O	0.02
K_2O	0.16
H_2O	1.95
TiO_2	1.46
MnO	0.66
Ce_2O_3	14.61
Other rare earths	10.32
ThO_2	none
PbO	none
	99.36

by Dana,[6a] except for the presence of titanium, a low aluminum content, and high ferric iron and cerium contents. Of the 40 analyses given by Dana, none show any titanium, only 3 show less than 10.25 per cent Al_2O_3, and the alumina content of most of them ranges from 13 to 17 per cent. Only two of the analyses listed by Dana have a higher ferric iron oxide content than 10.33 per cent, and the majority range from 3 to 6 per cent. Only two of the listed analyses show more than 14.61 per cent Ce_2O_3, and most of them show a range of from 4 to 7 per cent. The 10.32 per cent of "other rare earths" in Milton's analysis is probably made up mostly of didymium and lanthanum. The listed analyses show from 2.71 to 23.98 per cent Di_2O_3 and from 0 to 8.10 per cent La_2O_3, whereas the Y_2O_3 and Er_2O_3 contents range only from 0 to 2.92 per cent and from 0 to 2.00 per cent, respectively. Milton's analysis also serves to check the

[6a] Dana, E. S., *System of Mineralogy*, 6th Ed., 524 (1909).

radiographs in showing that neither thorium nor lead is present, although about half of the listed analyses show the presence of thorium, ranging from 0.18 to 3.48 per cent ThO_2.

Treating the analysis as was done by Machatschki[7] for other allanites (Table 5), the analysis agrees fairly well with his formula $X_2Y_3z_3(O, OH,F)_{13}$ where

X = Ca, Ce, and other rare earths, Mn, K, Na
Y = Al, Fe''', Fe'', Mg, Ti
z = Si

TABLE 5. ATOMIC RATIOS OF ANALYSIS OF ALLANITE

Si	506		z = 506 = 3×169
Al	201		
Fe'''	129		
Fe''	143	527	Y = 527 = 3×176
Mg	36		
Ti	18		
K+Na	4		
Ca	133		
Mn	9	298	X = 298 = 2×149
Ce	89		
R.E.[a]	63		
(OH)	216	2,311	2,311 = 13×178
O	2,095		

[a] Molecular weight of (Rare earths)$_2$O$_3$ taken as 330.
Machatschki's formula = $X_2Y_3z_3(O, OH, F)_{13}$
Formula from Milton's analysis = $X_{1.79}Y_{3.17}z_{3.04}(O,OH)_{13.88}$

Brown epidote

Brown epidote is a common constituent of the cerite rock in both the northern and southern deposits. It occurs as disseminated grains and as individual bladed crystals, some of which are 0.15 to 0.35 millimeter in size.

In thin section the brown epidote is pale yellowish-brown and shows brilliant interference colors. It is optically positive, 2V variable, small to medium. Pleochroic colors, yellow and brown. The indices of refraction are: $\alpha = 1.748$, $\beta = 1.753$, $\gamma = 1.765$.

[7] Machatschki, Felix, Die kristallochemischen Beziehungen zwischen Epidot-Zoisit und Orthit-Allanit: *Centralbl. Mineral, Geol., u. Pal.*, Abth. A, 89–96; 154–158 (**1930**).

Törnebohmite

Törnebohmite, a monoclinic hydro-fluo-silicate of the cerium metals and aluminum, occurs as roughly rectangular grains about .16 by .48 mm., replacing cerite. In thin section törnebohmite shows distinct pleochroism, pink or yellow to blue-green. Both the refringence and birefringence are high. Optically positive, $2V=20°$ to $30°$. Dispersion distinct, $r<v$. Indices of refraction are: $\alpha=1.808$, $\beta=1.812$, $\gamma=1.838$.

Fluorite

The widespread deep violet fluorite was first thought to be yttrocerite[8] as the determined index of refraction (1.435) agrees with the index of 1.434 given by Larsen and Berman[9] for yttrocerite. The specific gravity of this fluorite seemed greater than 3.3, and hence apparently too high for fluorite. This apparent greater specific gravity, however, is more probably due to the minute inclusions of uraninite and cerite. A consideration of the index values given for the fluoride of the rare earths (fluocerite—or better, tysonite) with those of calcium fluorides containing rare-earth fluorides, indicates that the index of refraction given by Larsen and Berman for yttrocerite cannot be correct and that the material on which the determination was made must have been wrongly labelled and was fluorite and not yttrocerite.

The mean index of tysonite, rare-earth fluoride, is about 1.61. Hence the introduction of a small quantity of rare-earth fluorides into fluorite, with index of 1.434, raises the index considerably, as for example, in yttrofluorite whose index is given as $1.457\pm$. Therefore the Jamestown mineral with an index of 1.435 must be fluorite.

[8] The names yttrocerite and fluocerite are very misleading. Neither mineral is cerite with yttrium or fluorine respectively, as the name would indicate. Yttrocalcite similarly is not calcite containing yttrium. As Winchell (*Elements of Optical Mineralogy*, 3d ed., **1933**, p. 35) states: "Fluorite can take into crystal solution up to 50 per cent YF_3 and the mix-crystals are called *yttrofluorite.* It can take into crystal solution up to 55 per cent CeF_3 and the mix-crystals are called *cerfluorite* (unknown in nature). Mix-crystals of yttrofluorite and cerfluorite are known in nature; they are called yttrocerite." The name yttrocerite should be discarded as misleading. Depending on whether yttrium or the cerium metals are dominant, the so-called yttrocerite should be named either yttrofluorite or cerfluorite. Geijer (On fluocerite and tysonite: *Geolog. Förening. Förhandl.*, **43** (no. 344), 19–23, 1922) shows that "the fluocerite and the tysonite are one and the same mineral species with the formula (Ce, La, Di)F_3," and on the basis of priority prefers fluocerite. As this name is so misleading, it seems preferable to use the name tysonite.

[9] Larsen, E. S., and Berman, Harry, The Microscopic Determination of the Nonopaque Minerals: *U. S. Geol. Survey, Bull.* **848,** 47, (1934).

Bastnäsite

Bastnäsite, a fluocarbonate of cerium, with the formula $(CeF)CO_3$, was identified in a few of the coarser cerite specimens from Colorado, but it probably is present in all of the specimens. As Geijer[10] states for the cerite from Sweden, "There is, in fact, hardly one thin section with any notable percentage of cerite that does not also contain bastnäsite, often making up one third or more of the cerite ore." The powdered cerite rock effervesces slightly when treated with HCl, nearly every grain of material slowly evolving bubbles of CO_2 so that large aggregates of the powder, covered and permeated with minute bubbles, will float for some time in the acid. The effervescence is very different from that given by calcite, as shown by tests on material to which a little calcite was added. No calcite or analogous carbonate was seen in thin sections in any of the cerite rock from Colorado. In the interpretation of the analysis of the cerite rock, the CO_2 is allocated to bastnäsite.

A few isolated grains of bastnäsite gave the following optical properties: Uniaxial positive; $\omega=1.716$, $\epsilon=1.817$. The color is reddish brown, and the grains resemble monazite.

Monazite

Veinlets of reddish-brown monazite are found near the center of the veins of törnebohmite, and lenticular areas and grains of monazite are scattered through other parts of the vein.

Monazite is a monoclinic phosphate of the cerium metals. In thin section it is pale reddish-brown and shows high interference colors. The monazite is optically positive, $2V=10°$ to $15°$. Dispersion moderate, $r>v$. The indices of refraction are, $\alpha=1.790$, $\beta=1.791$, $\gamma=1.840$.

Uraninite

Small rounded grains of uraninite, identified by their radioactivity, are scattered throughout the veins, and appear to be later than all the other rare-earth minerals, as they are localized in places along late fractures. These grains show a dull black, faintly metallic luster as compared with the glossy, jet-black color of the allanite. Their distribution is shown in the radioactive photographs of Fig. 5. Some of the grains are as much as 1.5 millimeters in diameter, but most of them are of microscopic size (Fig. 10). These grains were identified as uraninite by comparing the intensity of their radioactivity with that of specimens of known uraninite.

[10] Geijer, Per, *Loc. cit.*

Sulphides

Pyrite and minor amounts of chalcopyrite are scattered throughout the vein in small grains and irregular veinlets, and appear to be the latest minerals deposited. They range in size from microscopic grains to masses and veinlets 2 millimeters wide. The veinlets cut through all the rare-earth minerals including the uraninite.

Comparisons with Other Deposits of Cerite

In central Sweden the two known deposits of cerite are about 30 km. apart. At the original locality[11] at Bastnäs in the Riddarhyttan district, province of Västmanland, where cerium was discovered in 1804, cerite has been identified at two mines. It occurs in leptites and mica schists with subordinate limestone-dolomite bands. The cerium minerals form narrow bands in the silicate zones (skarn) of quartz-banded hematite. These narrow bands are fine-grained aggregates of cerite, fluocerite, allanite, törnebohmite, and other minerals.

In the Östanmossa mine,[12] Norberg, N.E. of the Riddarhyttan district, cerite occurs with allanite, a magnesium allanite, and other non-cerium minerals, in a silicate skarn in granular magnetite replacing dolomite near a granitic contact. While present in some abundance, the cerite usually is only in microscopic grains.

In Russia, in the Kyshtymsk district in the Urals,[13] cerite with törnebohmite, lessingite, and bastnäsite, was found in pebbles in auriferous alluvials, derived from a contact zone of alkali granites.

Cerite is mentioned,[14] without description, as having been identified in the pegmatite in which the well known Villeneuve mine is situated, in Papineau County, Quebec, Canada. This pegmatite contains microcline, albite, muscovite, lepidolite, uraninite, monazite, purple fluorite, and many of the usual accessory pegmatite minerals. The occurrence in Colorado—in pegmatite and aplite—along the contact of granite and schist inclusions seems to be more closely related to the type of occurrence in Canada than the European occurrences, though here too contact metamorphism has played a role.

[11] Geijer, Per, The cerium minerals of Bastnäs at Riddarhyttan: *Severiges Geol. Undersokning*, **1921**, Arsbok 14 (for 1920), No. 6, 24 pp., Abs. in *Mineral. Abs.*, **1**, 251 (1921).

[12] Geijer, Per, Some mineral associations from the Norberg district: *Sveriges Geol. Undersökning*, **1927**, Arsbok 20 (for 1926), No. **4**, 32 pp., Abs. in *Mineral. Abs.*, **3**, 273–274 (1927).

[13] Silberminz, V., Sur le gisement de cerite, de bastnäsite et d'un mineral nouveau, la lessingite, dans le district minier de Kychtym (Oural): Abs. in *Mineral. Abs.*, **4**, 150–151 (1929).

[14] Ellsworth, H. V., Rare element minerals of Canada: *Canada Geol. Survey, Econ. Geol. Survey*, No. **11**, 241 (1932).

The mineral associations in these five occurrences are listed in Table 6.

TABLE 6. MINERALS ASSOCIATED WITH CERITE

Sweden		Russia	Canada	Colorado
Bastnäs	Norberg			
Cerite	Cerite	Cerite	Cerite	Cerite
—	—	Lessingite	—	—
Allanite	Allanite	—	—	Allanite
—	Mg-Allanite	—	—	Brown epidote
Törnebohmite	—	Törnebohmite	—	Törnebohmite
Fluocerite (Tysonite)	—	—	Fluorite	Fluorite
Bastnäsite	—	Bastnäsite	—	Bastnäsite
—	—	—	Monazite	Monazite
—	—	—	Uraninite Gummite	Uraninite
Lanthanite	—	—	—	—
Actinolite	Actinolite Tremolite	—	Common pegmatite minerals	Common pegmatite minerals
—	Diopside	—	—	—
—	Chondrodite Norbergite	—	—	—
—	Garnet	—	Garnet	—
Quartz	—	—	Quartz	Quartz
—	—	—	Tourmaline	—
—	—	—	Beryl	—
—	—	—	Apatite	—
—	—	—	Zircon	—
Magnetite (rare)	—	—	—	—
Chalcopyrite	—	—	—	Pyrite Chalcopyrite
Bismuthinite	—	—	—	—
Molybdenite	—	—	—	—
Linnaeite (rare)	—	—	—	—

RADIOACTIVITY

Specimens from each of the deposits were sawed in two and placed for 6 days on photographic plates, with black paper between. The results show that in the northern group of deposits the gray and brownish-gray mixture of cerite, brown epidote, and purple fluorite shows weak but distinct radioactivity, but the spots of strongly active uraninite stand out in prominent contrast (Fig. 5). The clove-brown cerite material is only very slightly radioactive and the allanite shows little or no radioactivity on short-period exposure.

In the large specimen from the southern deposit, it is difficult to interpret the results because the uraninite is so intimately and finely disseminated through the vein that it is impossible to tell how much of the radioactivity is due to the other rare-earth minerals present. However, it appears that the törnebohmite, brown epidote, and the monazite all show a weak radioactive response, the lavender cerite shows very weak activity, and the black allanite shows practically none. The larger grains of uraninite show up prominently against the background of the other minerals.

Age Determination

On the basis of its lead-uranium ratio, the calculated age of the gray cerite material is 940,000,000 years. However, owing to the small percentages of uranium and lead present, the range of probable error is large and is estimated by A. C. Lane[15] to be about 20 per cent. In spite of this large range, the analysis serves to place the cerite deposits and the Silver Plume granite to which they are related in the middle pre-Cambrian, and makes them younger than the Pikes Peak granite, whose determined age is one billion years.[16] This relation is substantiated by the field evidence, for throughout the Front Range the Silver Plume granite is found to be younger than the Pikes Peak granite.[17]

[15] Lane, A. C., Report of the Committee on the Measurement of Geologic Time, Division of Geology and Geography, *National Research Council*, 69, (**1935**).

[16] Physics of the Earth, vol. **4,** Age of the Earth, *Bull. Nat. Res. Council,* **90,** 338 (1931).

[17] Spurr, J. E., Garrey, George H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colorado: *U. S. Geol. Survey, Prof. Paper* **63,** 59–60 (1908).