ACCESSORY ZIRCON FROM GRANITOID ROCKS OF THE MOUNT WHEELER MINE AREA, NEVADA

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Abstract.—Twenty-five accessory zircon fractions recovered from granitoid rocks exposed just north of the Mount Wheeler mine area, Nevada, have been studied. Minor-element contents are listed for all; physical properties and radiometric age data are given for a few. Results support the conclusion reached from previous work on other minerals and indicate that the large compositional range and systematic chemical gradients found in the intrusive rocks result more from assimilation of sedimentary rocks than from differentiation of magma. Uranium-thorium-lead isotope ages given by one zircon concentrate date the time of crystallization as Middle Jurassic, Pb/α determinations on three zircon fractions recovered from small xenoliths gave mid-Tertiary ages, and these low ages appear to result from loss of lead.

The Mount Wheeler mine area is in the southern part of the Snake Range, about 50 miles southeast of Ely, Nev. The granitoid rocks studied intrude lower Paleozoic sedimentary rocks and are exposed in a westward-trending band 1–3 miles wide (Drewes, 1958; Whitebread and others, 1962). Within an outcrop area of about 20 square miles, the intrusive rock ranges in composition from granodiorite with a CaO content of 4.5 percent to quartz monzonite with a CaO content of 0.5 percent. The higher CaO values are found where the igneous rock is in contact with Middle Cambrian Pole Canyon Limestone, the lower CaO values where it is in contact with Lower Cambrian Prospect Mountain Quartzite, indicating that CaO values reflect assimilation of the country rock.

Mineralogical differences that are related to variations in composition of the intrusive rock include variations in types of accessory minerals (Lee and Dodge, 1964) and in rare-earth contents of accessory allanite and monazite (Lee and Bastron, 1967). This paper describes the zircon types present in the intrusive rock. Minor-element contents have been determined for 25 zircon fractions, physical properties and lead-alpha age

data for a few, and isotopic ages for one. Variations in some of these properties can be related to CaO content of the intrusive rock.

ACCESSORY ZIRCON

After the preliminary concentration according to the method described by Lee and Dodge (1964), the zircon fractions were purified by centrifuging in methylene iodide and by use of the Frantz isodynamic separator. Clerici solution was not used. As the final step in the cleaning, each zircon fraction was subjected to ultrasonic vibration in distilled water for about an hour.

As noted by Lee and Dodge (1964, fig. 4), the zircon content of the intrusive rocks shows a fairly regular increase with an increase of CaO. The present study shows (fig. 1) that the zircon content of the more CaO-
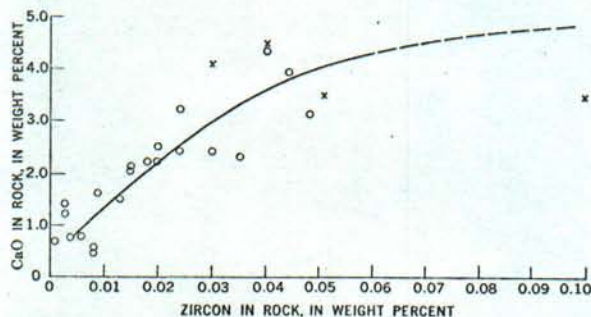

FIGURE 1.—Relation between amounts of CaO and zircon in 25 rocks on which this study is based. o, sample from main intrusive phase; x, xenolith.

rich rocks is 5–50 times as great as that of the CaO-poor rocks. Recovery of more than about 25 milligrams of clean zircon from rocks with a CaO content of less than about 1.5 percent was difficult, and so in general less information was obtained on the physical properties of zircons from such rocks.

Physical properties

The granitoid rocks in the Mount Wheeler mine area, Nevada, contain zircons having a rather wide range in size and elongation ratio (figs. 2, 3). The CaO-rich rocks contain acicular zircons, with elongation ratios in some grains reaching the extreme value of 20. The elongation ratios of the zircons show a rather large range; nevertheless, zircons recovered from the more mafic (CaO-rich) rocks are very similar in appearance from grain to grain, largely because of the simplicity of crystal habits and the clean, well-defined appearance of the grains (fig. 2). Many of the acicular zircons are completely free of inclusions. What inclusions are
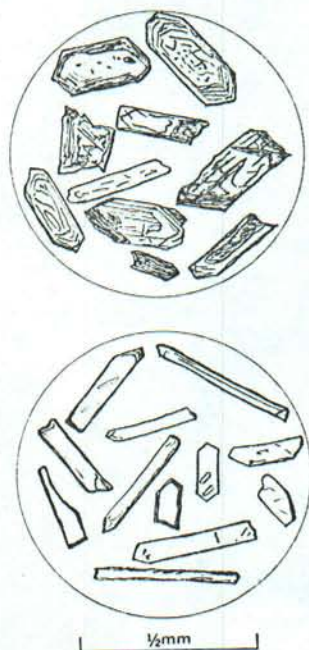

FIGURE 2.—Representative zircon concentrates recovered during this study. Top, zircons recovered from sample 63–MW–60, part of the main intrusive phase having a CaO content of 0.55 percent. Note the relatively clean grain near the center of the field. The number and clarity of those grains increase gradually with CaO content of the rock until an assemblage like the one below results. Bottom, zircons recovered from sample 40B–MW–60, a xenolith with a CaO content of 3.5 percent. This assemblage is typical of those recovered from rocks with a CaO content of 2.2 percent or more.

present are nearly always colorless, have indices of refraction much smaller than those of zircon, and are likely to be systematically oriented. Some of these inclusions may be apatite. The acicular zircons are almost devoid of zoning. Zoning, where present, is concentric, and indicates that the first-formed portions of the crystals also were elongated. This zoning is not pronounced; the difference between indices of refraction of adjacent zones is estimated to be less than 0.003 where observed. The outer zones may have either a higher or a lower index of refraction than the interior ones.

Zircons from CaO-poor rocks rarely have an elongation ratio greater than 6. The grains differ much more in appearance. Most grains contain many tiny inclusions that have haphazard orientation. Repeated zoning is common, with indices of refraction of adjacent zones estimated to differ by 0.005 or more.

According to the findings by Poldervaart (1956), such differences are not usually evident in zircons from a single pluton. The acicular zircon from the CaO-rich rocks of the Mount Wheeler mine area is much like the mineral described by Wyatt (1954), who studied the Monadhliath granite in Scotland and concluded (1954, p. 988) that "* * * the evidence indicates that very elongated zircon is produced only in granite which has been contaminated * * *." Taubeneck (1957) and Huang (1958) emphasized the greater elongation ratio of zircon from hybrid rocks. In the Mount Wheeler mine area the greatly elongated zircon is found where the country rock is limestone or shale; that contamination occurred is indicated both by the increased CaO content of the intrusive and by the presence of many xenoliths of Pioche Shale (Lee and Bastron, 1962, p. 1328).

Though differing in abundance, size, and elongation, the zircons from CaO-poor and CaO-rich rocks do not differ appreciably in optical properties (table 1). Indices of refraction of zircons recovered from a single hand specimen show about as great a range as do those from CaO-rich to CaO-poor rocks. Values are in the upper part of the range expectable for zircon, indicating relatively fresh, nonmetamict material (Deer and others, 1962, p. 59–66).

Unit-cell parameters (table 1) were calculated for several of the zircons by least-squares refinement of powder diffractometer data, using an internal standard of CaF_2 and a self-indexing computer program developed by Evans, Appleman, and Handwerker (1963). Results agree rather closely and these, too, typify relatively fresh, nonmetamict material (Deer and others, 1962, p. 59–66). Compared to the other zircons listed in table 1, however, samples 49–DL–61 and 63–MW–60 appear to have undergone incipient metamictization, as is indicated by their slightly expanded cell parameters and their less sharp diffractometer patterns.
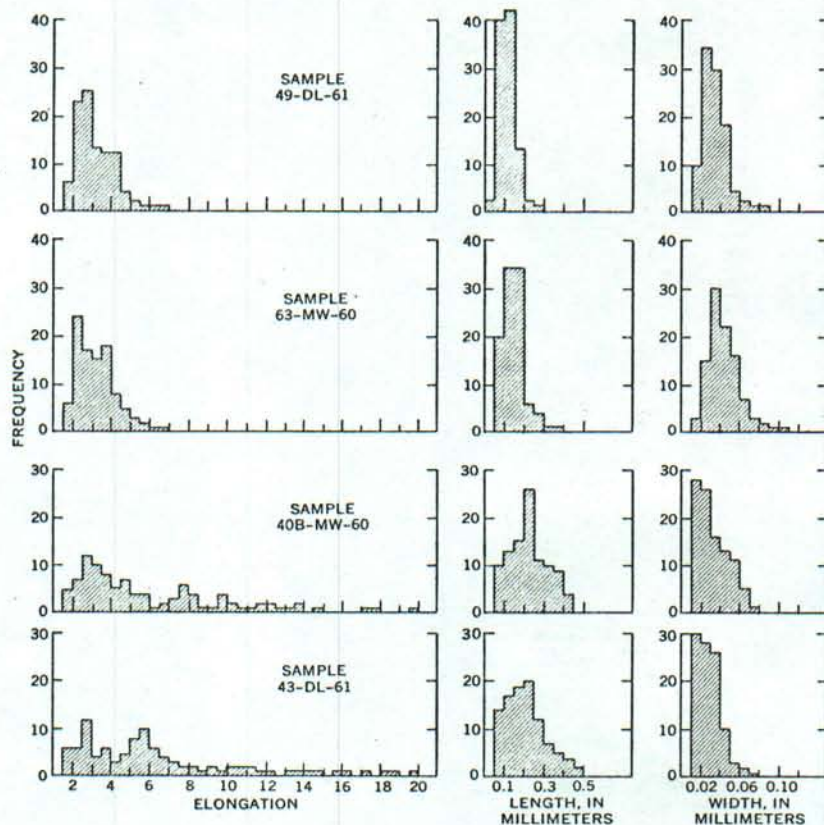
FIGURE 3.—Elongation- and size-frequency histograms of four representative zircon fractions
(table 1). Upper two samples are from CaO-poor rocks, lower two samples from CaO-rich
rocks. Note that size scales for length- and width-frequency histograms are not the same.
Plots are based on counts of 200 zircons from each rock.

Spectrographic analyses

Semiquantitative spectrographic analyses of the zircons are listed in table 1. Amounts of elements like Ca and Ti probably are a measure of contamination by such closely associated minerals as sphene and apatite. The contamination may have resulted from inclusions or compound grains. Some of the CaO-poor rocks contain tiny amounts of blue anatase, and because of its high specific gravity and low paramagnetic susceptibility this mineral was especially difficult to separate quantitatively from the zircon.

If it is correct that the uranium content of the granitoid rocks is nearly uniform throughout the area under study and that the uranium in these rocks is mostly in the zircon lattice, then the trend shown in figure 4 could be attributed to the sparsity of zircons in the CaO-poor rocks (fig. 1); the sparsely distributed zircons in the CaO-poor rocks contain more uranium in

their crystal lattices than do the more abundant zircons in the CaO-rich rocks.

From the standpoint of igneous processes, one of the most studied and interesting aspects of accessory zircon is its content of hafnium. It has been shown (Lyakhovich and Shevaleyevskii, 1962; Gottfried and Waring, 1964) that hafnium content is higher in zircon from early-formed gabbroic rocks than in zircon from late siliceous differentiates. Hevesy (1925), Hevesy and Jantzen (1923), Fleischer (1955), and several more recent investigators have shown that accessory zircon from alkalic rocks is characterized by low hafnium content. Hafnium-poor zircon also has been described from hybrid granites, and this is of particular interest to us here. Lyakovich and Shevaleyevskii (1962, p. 522) stated, "A higher than average ZrO_2/HfO_2 ratio would indicate that assimilation must have occurred on a large scale during emplacement of the igneous body." The

TABLE 1.—*Analytical data and physical properties for*

[Samples arranged in order of increasing CaO content.
CaO analyses by Paul Elmore, Samuel Botts, H. Smith, and Gillison Chloe.
Indices of refraction determined in sodium light by the immersion method.
Cell parameters were obtained by least-squares refinement of powder diffractometer data, using a self-indexing computer program developed by Evans, Appleman, and Handwerker (1963). The internal standard was CaF_2. Margin of error for both a and c is ±0.001A, except as noted.

Sample No.	49-DL-61	63-MW-60	229-MW-61	230-MW-61	238-MW-61	190-MW-61	205-MW-61	147-MW-61	234-MW-61	190-DL-62	71-MW-60	14-MW-60
CaO in rock (weight percent)	0.47	0.55	0.68	0.75	0.78	1.2	1.4	1.5	1.6	2.0	2.1	2.2
Indices of refraction												
1 ϵ±0.005		1.977–1.985 1.981 (avg)				1.978–1.987 1.983 (avg)				1.980–1.990 1.985 (avg)		1.987–1.990 1.989 (avg)
2 ω±0.005		1.922–1.930 1.926 (avg)				1.922–1.928 1.925 (avg)				1.920–1.930 1.925 (avg)		1.928–1.931 1.930 (avg)
3 $\epsilon-\omega$		0.055				0.058				0.060		0.059
Cell parameters												
4 a (A)	6.624 (±.004)	6.621					6.605			6.607	6.605	
5 c (A)	6.015 (±.009)	6.002 (±.003)					5.988			5.989	5.984	
6 c/a	.9082	.9065					.9066			.9064	.9068	
7 Volume (A³)	263.92 (±.35)	263.15 (±.11)					261.27 (±.06)			261.44 (±.05)	261.09 (±.07)	
Semiquantitative spectrographic analyses (weight percent)												
8 Al	0.2	0.15	0.3	0.1	0.07	0.7	0.15	0.15	0.015	1.5	3	0.05
9 Fe	.1	.02	.1	.15	.02	.07	.07	.015	.05	.05	.1	.0015
10 Mg	.005	.002	.003	.01	.0015	.005	.007	.015	.1	.1	.002	.1
11 Ca	.15	.07	.3	.15	.03	.5	.7	.7	.03	1.5	3	.015
12 Ti	.2	.3	.03	.02	1.5	.03	.3	.1	.002	.01	.02	0
13 Mn	.003	.0007	.003	.003	.001	.003	.007	.007	0	.003	.007	0
14 B	.005	0	.001	.003	.001	0	.003	.0015	.5	.15	.15	.5
15 Hf	.5	.5	.3	.5	.3	.5	.7	.2	.5	.003		.003
16 Nb	.01	.005	.003	.005	.015	.003	.007	.007	.003	0	0	0
17 Ni	0	0	.0015	.001	.0007	0	.02	.01	0	.005	(?)	0
18 Pb	.007	.015	.007	.005	.007	.003	0	0	0	0	0	.03
19 Sb	.07	0	0	.015	.015	.05	.07	.03	.05	.02	.015	.03
20 Sc	.07	.07	.07	.1	.07	.003	.07	.03	.01	.007	0	0
21 Sn	.1	.003	.1	.15	.0015	.003	0	.002	0	.007	.05	.05
22 Sr	0	0	.0015	0	.07	.07	.07	.07	.1	0	0	.15
23 Th	.1	.15	.1	.1	.5	.5	.5	.3	.3	0	0	.003
24 U	.5	.5	.3	.7	0	0	0	0	.003	0	.002	.3
25 V	0	.003	.2	.7	.7	.5	.3	.7	.5	.3	.2	.05
26 Y	.5	.1	.1	.1	.1	.1	.15	.1	.1	.05	.05	.05
27 Yb	.15	0	.02	.05	.02	.02	.015	.02	.05	0	0	0
28 Gd	.03	0	.03	.05	.05	.03	.03	.05	.02	0	0	0
29 Dy	.05											
30 Other	None	(Be) .0005	(W) .02	(Hg)¹	None	None	None	None	(La) .02	None	None	None
Lead-alpha age determinations												
31 α/mg-hr											647	
32 Pb ppm											57.5	
33 Pb/α age, m.y.											220±25	

¹ Xenolith.
² See quantitative lead value below.

hafnium values (0.15–0.7 percent) listed in table 1 are even lower than the results given in the papers just cited, and thus agree with the idea that assimilation has been important in the history of these rocks. The small range in hafnium values shows no obvious correlation with the geology.

Zircons from the CaO-poor rocks tend to contain more thorium than those from CaO-rich rocks (fig. 4B), but the thorium trend is not as steep as for uranium (fig. 4A), and the reason for the trend is probably different. Study of monazite from these same rocks (Lee and Bastron, 1967) showed that there is a relative dearth of thorium where CaO is abundant. The relation shown in figure 4B is consistent with this observation. Regarding the thorium contents of these zircons, about 100 micrograms of a green mineral identified as metamict thorite or huttonite was recovered from 1,000 grams of sample 126–MW–61. This mineral has a specific gravity above 3.32 and is optically isotropic with an index of refraction near 1.80; the small fraction analyzed spectrographically showed lines only for silicon and thorium. The thorium content of the zircon coexisting with this mineral is 0.07 percent, not notably high.

The allanites and monazites that coexist with these 25 zircons show an appreciable range of composition in terms of the rare-earth elements (Lee and Bastron,

accessory zircons from the Mount Wheeler mine area, Nevada

Semiquantitative spectrographic analyses by R. E. Mays. Results are based on their identity with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth, and are reported arbitrarily as midpoints of these brackets, 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, respectively. The precision of a reported value is approximately plus or minus one bracket at 68-percent, or two brackets at 95-percent confidence. 0, below limit of detection; leaders, (....), not determined. Age values determined by T. W. Stern from lead determinations by Harold Westley. All lead values are averages of duplicate determinations. Basis of calculations given in table 3]

36-DL-61	8-DL-61	31-DL-60	38-MW-61	40A-MW-60	25-DL-61	152-MW-61	40B-MW-60 [3]	126-MW-61 [3]	43-DL-61	27-DL-61 [3]	16-MW-60	98-DL-62 [3]
2.2	2.3	2.4	2.4	2.4	3.1	3.2	3.5	3.5	3.9	4.1	4.3	4.5

Indices of refraction—Continued

36-DL-61	8-DL-61	31-DL-60	38-MW-61	40A-MW-60	25-DL-61	152-MW-61	40B-MW-60	126-MW-61	43-DL-61	27-DL-61	16-MW-60	98-DL-62	No.
....	....	1.980-1.983	....	1.985-1.993	1.982-1.990	1.989-1.991	1.983-1.990	1.985-1.992	....	....	....	1.989-1.991	1
		1.982 (avg)		1.989 (avg)	1.986 (avg)	1.990 (avg)	1.987 (avg)	1.989 (avg)				1.990 (avg)	
....	....	1.920-1.924	....	1.921-1.930	1.923-1.930	1.929-1.931	1.922-1.928	1.925-1.930	....	....	....	1.929-1.932	2
		1.922 (avg)		1.926 (avg)	1.927 (avg)	1.930 (avg)	1.925 (avg)	1.928 (avg)				1.931 (avg)	
....	....	0.060	....	0.063	0.059	0.060	0.062	0.061	....	....	....	0.059	3

Cell parameters—Continued

36-DL-61	8-DL-61	31-DL-60	38-MW-61	40A-MW-60	25-DL-61	152-MW-61	40B-MW-60	126-MW-61	43-DL-61	27-DL-61	16-MW-60	98-DL-62	No.
....	....	....	6.604	6.605	....	....	6.608	....	....	....	....	6.603	4
....	....	....	5.984	5.986	....	....	5.984	....	....	....	....	5.980	5
....	....	....	.9061	.9063	....	....	.9056	....	....	....	....	.9056	6
....	....	....	261.01 (±.05)	261.13 (±.04)	....	....	261.25 (±.05)	....	....	....	....	260.75 (±.04)	7

Semiquantitative spectrographic analyses (weight percent)—Continued

36-DL-61	8-DL-61	31-DL-60	38-MW-61	40A-MW-60	25-DL-61	152-MW-61	40B-MW-60	126-MW-61	43-DL-61	27-DL-61	16-MW-60	98-DL-62	No.
0.03	0.07	0.05	0.05	1.5	0.3	0.05	0.1	0.1	0.05	0.05	0.02	0.15	8
.05	.07	.03	.1	.2	.07	.015	.05	.05	.015	.07	.03	.15	9
.005	.005	.005	.01	.005	.005	.0007	.005	.01	.0007	.005	.1	.02	10
.15	.3	.2	.15	1	1	.2	.2	.2	.05	.05	.015	.2	11
.015	.1	.07	.07	1.5	1.5	.1	.015	.015	.02	.02	.07	.015	12
.0005	.001	.0002	.005	.007	.003	0	.0015	.0015	0	.0015	0	.0015	13
0	0	0	0	0	0	0	0	0	0	0	0	0	14
.5	.3	.3	.7	.5	.15	.5	.5	.5	.3	.3	.5	.5	15
.005	.005	0	0	0	.005	0	0	0	0	0	0	0	16
0	0	0	0	(?)	0	0	(?)	(?)	0	(?)	(?)	(?)	17
(?)	.005	0	.015	0	.005	0	0	0	0	0	0	0	18
0	0	0	0	0	0	0	0	0	0	0	0	.015	19
.03	.03	.03	.03	.02	.015	.03	.02	.02	.02	.03	.03	0	20
0	0	0	0	0	.007	.02	0	0	0	0	0	0	21
0	0	0	0	.01	.003	0	0	0	0	0	0	.07	22
.05	.05	.05	.07	.1	0	.05	.07	.07	0	.05	0	0	23
.05	0	.05	.3	0	0	.05	0	0	0	0	0	0	24
.003	0	0	0	.0015	.003	0	.0015	.0015	.3	.002	.002	.1	25
.3	.3	.3	.15	.15	.3	.3	.15	.15	.05	.3	.2	.05	26
.05	.05	.05	.07	.07	.05	.05	.07	.07	0	.05	.05	0	27
0	0	0	0	0	0	0	0	0	0	0	0	0	28
0	0	0	0	0	0	0	0	0	0	0	0	0	29
None	None	None	None	None	None	None	None	None	None	None	(Au) .003 (W) .02 (Hg)[4]	None	30

Lead-alpha age determinations—Continued

36-DL-61	8-DL-61	31-DL-60	38-MW-61	40A-MW-60	25-DL-61	152-MW-61	40B-MW-60	126-MW-61	43-DL-61	27-DL-61	16-MW-60	98-DL-62	No.
584	....	....	....	....	....	283	443	....	428	302	405		31
43.0	....	....	....	....	....	2.0	6.8	....	29.0	20.5	6.7		32
180±20	....	....	....	....	....	20±10	40±10	....	170±30	170±20	40±10		33

[3] Lead value for 40A-MW-60 given in table 2.
[4] Present in less than measurable amount.

1967). Yttrium and the heavier lanthanides are present in largest amounts in minerals from the more felsic rocks, whereas the lighter or more basic lanthanides increase in abundance directly with CaO content of the rocks. Though rare-earth contents of the 25 zircons are much smaller, the same trend is apparent from the higher amounts of Y in zircons from the rocks poor in CaO (fig. 4C) and also from the fact that detectable amounts of Gd and Dy are found only in these same zircons (table 1). Scandium shows a trend (fig. 4D) very similar to that of Y, with which it is closely related chemically.

Small amounts of Nb, Sn, Sb, and B are present in some of the zircons from the rocks low in CaO (table 1). Deer, Howie, and Zussman (1962, p. 61) stated that such elements are more probably present as inclusions in zircon than in the zircon lattice; and this is a likely explanation for the small amounts of Nb, Sn, Sb, and B shown in table 1, for the same zircons contain the greatest number and variety of inclusions.

As shown in table 1, small amounts of other elements such as Hg, W, and Au were detected in some samples, and are present either as inclusions or as part of the zircon lattice.
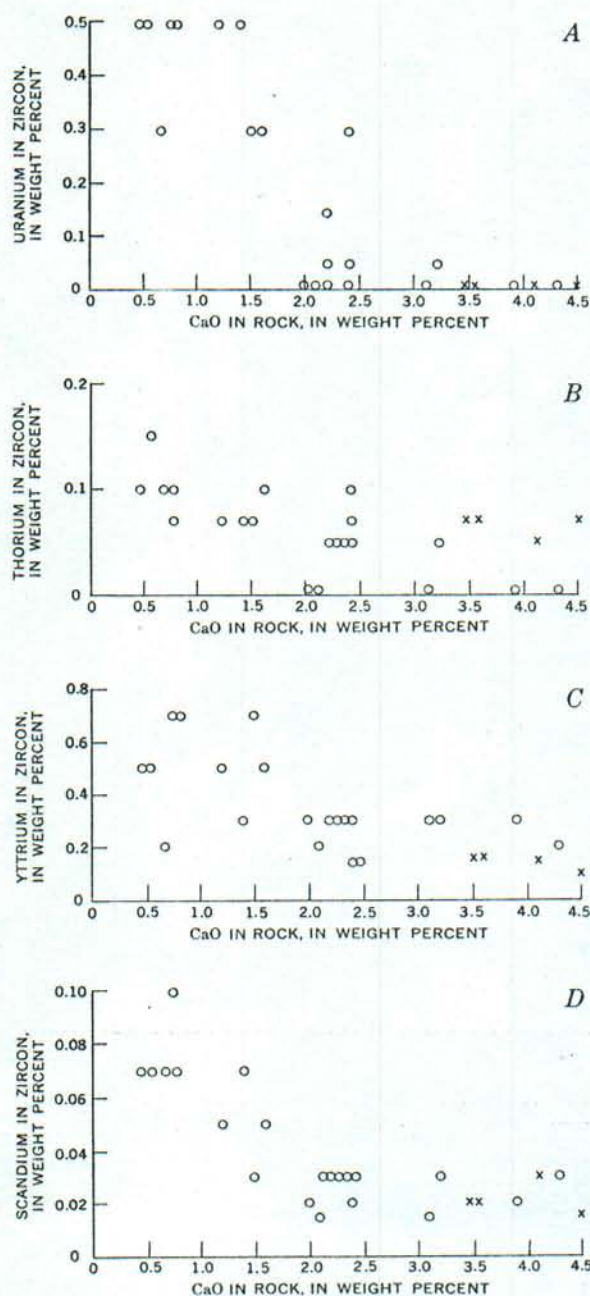
FIGURE 4.—Weight percentage of CaO in rock versus weight percentage of uranium (A), thorium (B), yttrium (C), and scandium (D) in constituent zircon. o, sample from main intrusive phase; x, xenolith.

Radiometric age determinations

Pb/α ages were determined for seven of the zircon fractions (table 1). Four of the ages are in the range 170 ± 20–220 ± 25 million years and three are in the range 20 ± 10–40 ± 10 m.y. Each of the three lower ages was determined on zircons recovered from a xenolith about the size and shape of a coconut. Ordinarily one would expect xenolithic zircons to show an age older, not younger, than zircons from the host intrusive phase, and so we were very surprised by the three young ages listed in table 1.

There is a general decrease in radioactivity (α/mg-hr) of the zircons as the CaO content of the rocks decreases, as one would expect from the uranium and thorium values already discussed. The most striking aspect of these age data, however, is the very small amounts of lead found in the three zircon fractions recovered from small xenoliths. Probably there has been loss of lead from these zircons through diffusion, but it is obvious that this explanation meets with difficulties, for two reasons. First, as already described, the zircons recovered from these small xenoliths are fresh and so would not be as readily susceptible to diffusion as the Precambrian, somewhat metamict zircon described by Tilton and others (1964). Second, in the case of our zircons there is a relatively short period of time ($180\pm$ m.y.) available for diffusion of lead to take place.

Table 2 presents uranium-thorium-lead isotope ages for zircon 40A–MW–60; the data show that the age of this zircon is Middle Jurassic. The processes that resulted in the very low lead values and consequent mid-Tertiary Pb/α ages may be related in some way to assimilation of the xenolithic masses from which the zircons in question were recovered. Whatever the nature of these processes, it is clear that sharply lowered Pb/α ages are not always found in zircons from similar environments. For comparative purposes, table 3 gives Pb/α ages for two zircon fractions recovered from rocks collected in the House Range, Millard County, Utah. Zircon 298–DL–64 is from the main intrusive phase, a porphyritic quartz monzonite (Gehman, 1958), whereas 299–DL–64 is from a coconut-size xenolith about 10 feet away. The Pb/α ages determined from these two zircon fractions are about the same, although the zircon from the xenolith actually has a higher lead content.

SUMMARY AND CONCLUSIONS

The results of this study support the idea that assimilation of country rock has played a significant role

TABLE 2.—*Uranium-thorium-lead isotopic ages of sample 40A–MW–60 zircon from Mount Wheeler mine area, Nevada*

[T. W. Stern and M. F. Newell, analysts]

Concentration (ppm)			Atom percent abundance				Ages (m.y.)		
U	Th	Pb	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}	$\dfrac{Pb^{206}}{U^{238}}$	$\dfrac{Pb^{207}}{U^{235}}$	$\dfrac{Pb^{208}}{Th^{232}}$
411.5	203.9	12.84	0.215	73.82	7.10	18.86	162	175	153

Decay constants: $U^{238} = 1.54 \times 10^{-10}$ yr^{-1}
$U^{235} = 9.72 \times 10^{-10}$ yr^{-1}
$Th^{232} = 4.88 \times 10^{-11}$ yr^{-1}

Atomic ratios: $U^{238}/U^{235} = 137.7$
$Pb^{204}, Pb^{206}, Pb^{207}, Pb^{208}$
$= 1.000, 18.51, 15.72, 38.44$

TABLE 3.—*Lead-alpha ages of two zircons from the House Range, Millard County, Utah*

[T. W. Stern, analyst. See text for exact locations and descriptions of samples]

Sample No.	Alpha/mg-hr	Pb (ppm)[1]	Age (m.y.)[2]
298–DL–64	854	69	200±40
299–DL–64	1,510	111.5	180±20

[1] Lead determination by Harold Westley. Single determination made for 298–DL–64; value for 299–DL–64 is average of two determinations.
[2] Ages were calculated using the following equations:
(a) $t = c$ lead/alpha, and
(b) $t_a = t - \frac{1}{2}Kt^2$,
where c = constant (based upon an assured Th/U ratio of 1) equal to 2,485,
K = constant equal to 1.56×10^{-4},
t = approximate age in millions of years,
t_a = age in millions of years, corrected for decay of parents,
lead = lead content in parts per million, and
alpha = alpha activity in alpha/mg-hr.

in the history of these granitoid rocks of the Mount Wheeler mine area, Nevada. These results include:

1. The crystal morphology of zircons from the CaO-rich rocks is almost identical to that of zircons taken from hybrid rocks in other areas. Distinctive features include large elongation ratios and rather simple crystal habits.

2. The very low Hf content of these zircons is consistent with the idea that assimilation has taken place.

3. Zircons from the more CaO-poor rocks tend to concentrate more of the heavier, less basic rare earths. Though not as well defined as the evidence provided by the allanites and monazites described previously, this still agrees with that evidence and favors assimilation over differentiation as an explanation for the chemical gradients observed.

Uranium-thorium-lead isotope ages date the crystallization of these rocks as Middle Jurassic. Mid-Tertiary Pb/α ages for three zircon fractions recovered from rather small xenoliths alert us to the apparent loss of lead, which may have resulted from diffusion in the solid state. Speculation on possible defects in the crystal structure of these zircons must await single-crystal study.

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1967

Fractionation of rare-earth elements in allanite and monazite as related to geology of the Mt. Wheeler mine area, Nevada*

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Abstract—Rare-earth contents of 20 allanites and 13 monazites, accessory minerals from a restricted outcrop area of intrusive granitic rocks, are reported. A quantity called sigma (Σ), which is the sum of the atomic percentages of La, Ce and Pr, is used as an index of composition with respect to the rare-earth elements. Values of sigma vary from 61·3 to 80·9 at.% for these allanites and monazites, representing an appreciable range of composition in terms of the rare-earth elements.

Degree of fractionation of rare earths varies directly with CaO content of the granitic rocks, which in turn depends largely on proximity of limestone. Four xenoliths included in the study suggest that spotty mosaic equilibria are superimposed on the regional gradients and that locally the degree of fractionation of rare earths responds to whole rock composition over distances of a few yards or less.

The chemistry of the granitic rocks under study appears to be similar in some respects to that of alkalic rocks and carbonatites. Allanites from the most calcium-rich rocks show a pronounced concentration of the most basic rare earths, and whole-rock concentrations of such rare constituents as total cerium earths, Zr, P, Ti, Ba and Sr increase sympathetically with whole-rock calcium.

The explanation for the concentration gradients observed in this chemical system must involve assimilation more than magmatic differentiation.

INTRODUCTION

In a study of the total range of variation in the composition of monazite with respect to the rare-earth elements Murata *et al.* (1953) sought to denote the composition of each sample by means of a single number. They proposed the quantity $\Sigma La + Ce + Pr$ in at.% of total rare-earth elements as a numerical index of the composition and of the stage of fractionation attained by the rare-earth elements. Later studies (see especially Murata *et al.*, 1957) confirm that this quantity ($\Sigma La + Ce + Pr$) is meaningful in discussion and comparison of cerium-earth mineral analyses, so it is used here. *This quantity will be referred to below simply as sigma or Σ.*

The sigma values for more than 80 monazite and 20 other cerium-earth minerals representing many geologic environments in different parts of the world vary between 51 and 92 at.% (Murata *et al.*, 1957, 1958; Heinrich *et al.*, 1960), giving a fair indication of the range in Σ expectable for monazites and allanites from different geologic settings. Murata *et al.* (1957) show that values of sigma in excess of 80 at.% represent considerable enrichment of the lighter, more basic

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rare-earth elements and (except for bastnaesite) usually are found only in minerals from alkalic rocks or from carbonatites associated with alkalic rocks. A similar result was obtained by GERASIMOVSKII and TURANSKAYA (1957).

The present study reports 20 allanite and 13 monazite analyses with sigma values from 61·3 to 80·9 at.%, representing an appreciable range of composition in terms of the rare-earth elements. These allanites and monazites are present as accessory minerals in granitic-type intrusive rocks that are exposed over about 20 square miles in the Mt. Wheeler mine area, White Pine County, Nevada. The degree of fractionation of the rare-earth elements in these accessory minerals is related to the geology in a way that provides a special clue to the history of the intrusive rocks.

TECHNIQUES OF STUDY

The general procedure for recovery of accessory minerals from the Mt. Wheeler granitic rocks is outlined by LEE and DODGE (1964). Final purification of -150 mesh allanite and monazite fractions was effected by use of the Frantz isodynamic separator and by centrifuging in Clerici (thallium malonate–formate) solution. Ultrasonic vibration was used to assist in washing the minerals after exposure to Clerici solution, and was found to be especially useful in the final stage of purification of the monazites. After all discrete grains of impurity had been removed by centrifuging and by use of the Frantz isodynamic separator, some individual grains of monazite were seen to be compound with an unidentified dark-coloured material when viewed in unfiltered ultraviolet light of the long-wavelength mercury vapor lamp (see MURATA and BASTRON, 1956). By the same test the monazite fractions were found to be practically free of contamination after about 30 min. of ultrasonic cleaning.

GEOLOGIC SETTING

Granitic rocks of the Mt. Wheeler area intrude lower Paleozoic sediments, are exposed in a westward-trending band 1–3 miles wide, and have a total outcrop area of about 20 square miles (see the maps of DREWES, 1958; WHITEBREAD et al., 1962). The highly variable mineralogy and texture of the intruding rocks suggested to LEE and BASTRON (1962) the possibility of more than one intrusive phase. More recently LEE and DODGE (1964) show that mineralogical differences in the intrusive rocks are controlled primarily by variations in the composition of the host rock. They list analytical results and plot molecular norms for 16 rock samples that range in composition from quartz monzonite (host rock, Lower Cambrian Prospect Mountain Quartzite) to granodiorite (host rock, Middle Cambrian Pole Canyon Limestone). They found, too, that bulk composition of the intrusive rocks, especially CaO content, has a striking relationship to the accessory minerals present. Allanite, apatite, sphene, zircon, epidote and magnetite tend to increase with CaO and are present in largest amounts in granodiorite with a CaO content of more than 4·0%. In quartz monzonite, on the other hand, where CaO may be as low as 0·5%, monazite, ilmenite, and garnet are the typical accessory minerals.

The abundances of accessory allanite and monazite in these intrusive rocks (Fig. 1) are especially relevant here. Allanite is present to the exclusion of monazite in rocks that contain more than about 2·0 wt.% CaO, but only monazite is present

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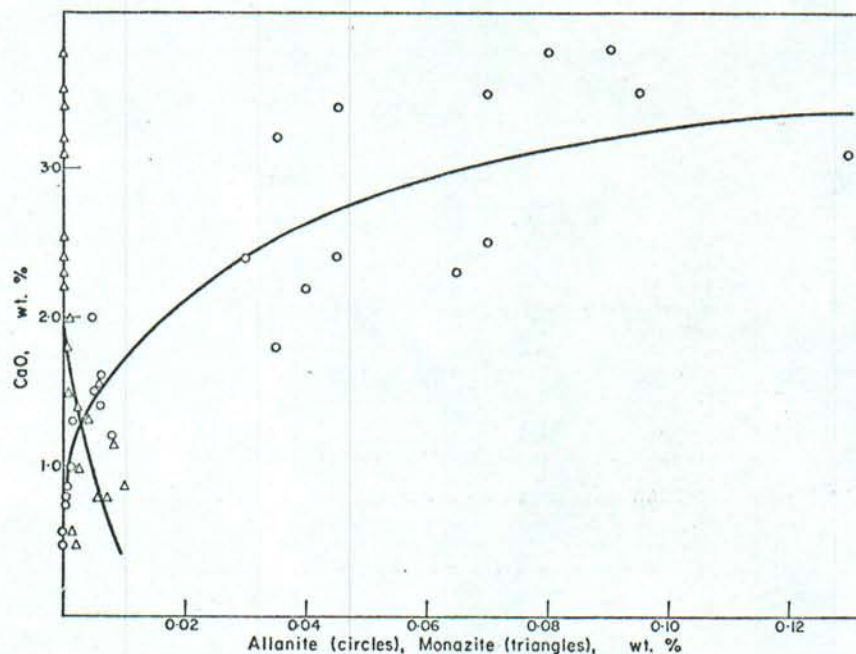
Fig. 1. Relation between amounts of CaO and allanite and monazite in Mt. Wheeler intrusive rocks. From LEE and DODGE (1964) with increased point coverage from present study.

in rocks that contain less than about 0·7% CaO. Both allanite and monazite are present at intermediate CaO values.

ALLANITE AND MONAZITE ANALYSES

Table 1 lists, in order of increasing value of Σ, 20 new allanite analyses along with one previously reported by LEE and BASTRON (1962). The main purpose of the 1962 study was to determine the beryllium content of allanite 38-MW-60 in order to test the idea that the nonpegmatite beryllium mineralization in the area may be genetically related to the intrusive rock containing this allanite as an accessory mineral. A quantitative spectrographic analysis of allanite 38-MW-60 showed no beryllium. Moreover, the element was not detected in any of the other allanites listed in Table 1 except 205-MW-61, which was found to contain 3 ppm beryllium. Thus, with this single exception, if beryllium occurs in any of these 21 allanites, it probably is present in amounts of less than 2 ppm. In view of the fact that allanite sometimes contains significant amounts (as much as 5·5%) of BeO (see for example BEUS, 1956; WARNER *et al.*, 1959), the present results support our 1962 finding and argue against a genetic relationship between the beryllium mineralization and the igneous rocks from which these accessory allanites were recovered. As seen below, however, four of the 13 monazites analyzed do contain detectable beryllium, and thus tend to contradict the allanite evidence on this point.

The twinning and lack of zoning and of metamictization described earlier for 38-MW-60 (LEE and BASTRON, 1962) are all typical of the other allanites listed in

Table 1. Rare earth and thoria contents and specific gravities of accessory

allanites from the M...

	Sample number	190-MW-61	120-MW-60	205-MW-61[1]	234-MW-61	71-MW-60	151-MW-61	147-MW-61	14-MW-60	25-DL-61	126-MW-61	31-DL-61	152-MW-61	8-
Weight per cent	Y₂O₃	1·00	1·35	0·70	0·86	0·51	0·44	0·46	0·16	0·20	0·24	0·13	0·15	0
	La₂O₃	5·86	3·98	5·86	6·45	3·64	6·10	5·63	5·75	6·68	5·51	6·45	5·51	7
	CeO₂	8·10	6·96	8·47	8·72	5·53	9·33	7·86	9·33	9·70	8·10	8·35	8·84	9
	Pr₆O₁₁	1·45	1·28	1·69	1·81	1·93	1·81	1·81	1·57	1·94	1·81	1·57	1·45	1
	Nd₂O₃	4·90	3·19	4·90	4·66	2·33	3·85	3·03	3·50	4·08	3·03	3·50	3·38	3
	Sm₂O₃	1·97	0·87	1·51	1·62	1·01	0·95	1·00	0·95	0·77	0·70	0·61	0·56	0
	Eu₂O₃	0·032	0·079	0·029	0·049	0·039	0·038	0·039	0·042	0·039	0·028	0·026	0·038	0
	Gd₂O₃	0·71	0·48	0·55	0·66	0·23	0·26	0·30	0·21	0·23	0·24	0·22	0·16	0
	Tb₄O₇	0·12	0·087	0·076	0·067	0	0	0	0	0	0·11	0	0	0
	Dy₂O₃	0·44	0·37	0·32	0·33	0·18	0·13	0·14	0·13	0·13	0·032	0·10	0·092	0
	Ho₂O₃	0·085	0·064	0·064	0·066	0·047	0·038	0·040	0·047	0·040	0·032	0·030	0·038	0
	Er₂O₃	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tm₂O₃	0·018	0·023	0	0·011	0·014	0·0080	0·0091	0	0	0·0074	0	0	0
	Yb₂O₃	0·050	0·077	0·023	0·028	0·0039	0·025	0·016	0·0056	0·0062	0	0·0050	0·0047	0
	Lu₂O₃	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total R. E. oxides	24·7	18·8	24·2	25·3	15·5	23·0	20·3	21·7	23·8	19·8	21·0	20·2	23
	ThO₂	2·05	1·24	2·50	1·36	0·91	1·25	1·48	1·25	1·36	1·36	0·91	1·08	0
	R. E. oxides + thoria	26·3	20·0	26·7	26·7	16·4	24·2	21·8	23·0	25·2	21·2	21·9	21·3	24
Atomic per cent of total rare-earth elements	Y	5·97	10·39	4·26	5·03	4·85	2·87	3·33	1·13	1·27	1·80	0·89	1·12	0
	La	24·20	21·28	24·85	26·02	24·07	27·27	28·42	27·40	28·93	28·67	31·72	28·16	31
	Ce	31·65	35·27	33·97	33·28	34·62	39·48	37·54	42·11	39·79	39·89	38·86	42·74	40
	Pr	5·72	6·56	6·85	6·99	12·24	7·75	8·75	7·16	8·04	9·02	7·38	7·08	6
	Nd	19·57	16·56	20·09	13·22	14·94	16·66	14·82	16·14	17·14	15·27	16·65	16·73	17
	Sm	7·60	4·35	5·96	6·12	6·23	3·97	4·70	4·23	3·10	3·38	2·82	2·65	2
	Eu	0·12	0·39	0·11	0·18	0·23	0·16	0·18	0·19	0·14	0·13	0·11	0·18	0
	Gd	2·66	2·34	2·11	2·38	1·37	1·07	1·36	0·89	0·92	1·13	0·97	0·74	0
	Tb	0·42	0·40	0·28	0·24	0	0	0	0	0	0	0	0	0
	Dy	1·57	1·72	1·19	1·17	1·05	0·49	0·61	0·53	0·49	0·52	0·44	0·41	0
	Ho	0·30	0·30	0·23	0·23	0·25	0·14	0·17	0·19	0·14	0·14	0·13	0·17	0
	Tm	0·06	0·10	0	0·04	0·07	0·03	0·04	0	0	0	0	0	0
	Yb	0·17	0·34	0·08	0·09	0·02	0·09	0·06	0·02	0·02	0·03	0·02	0·02	0
	Σ (La + Ce + Pr)	61·6	63·1	65·7	66·3	70·9	74·5	74·7	76·7	76·8	77·5	78·0	78·0	78
	Ce/(Nd + Y)	1·24	1·31	1·40	1·43	1·75	2·02	2·07	2·44	2·16	2·34	2·21	2·39	2
	Ce/(La + Nd)	0·72	0·93	0·76	0·75	0·89	0·90	0·87	0·97	0·86	0·91	0·80	0·95	2
	Ce/Nd	1·62	2·13	1·69	1·83	2·32	2·37	2·53	2·61	2·32	2·61	2·33	2·55	2
	(SpGr)[3]	3·72–4·05	>3·32	3·83–4·03	3·91 ± 0·02	3·84–4·07	>3·77	3·89 ± 0·02	3·84–4·07	3·72–4·00	3·77–4·01	3·87–4·03	3·93 ± 0·02	3

[1] Sample 205-MW-61 contains 3 ppm beryllium. Beryllium looked for but not detected in any of the other allanites listed here.

[2] Data for sample 38-MW-60 from LEE and BASTRON (1962).

[3] Specific gravity; see text for explanation and discussion.

Table 1. We have not systematically determined optical constants for these minerals, but in checking for impurities during mineral separation work we observed each of the allanite fractions several times in oil with an index of refraction near the β-index of the mineral. Allanite 38-MW-60 has $\beta = 1\cdot782 \pm 0\cdot005$; probably the others in Table 1 all have $\beta = 1\cdot78 \pm 0\cdot02$. As one result of the centrifuging in Clerici solution during the purification process, we gained information on the specific gravities of the various fractions analyzed. This information (Table 1) is more exact for some fractions than for others. For example, we know only that the specific gravity for 151-MW-61 is greater than 3·77 and that the value for 14-MW-60 is between 3·84 and 4·07, but for 152-MW-61 the value is fixed at $3\cdot93 \pm 0\cdot02$. The information on physical properties outlined here is important

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allanites from the Mt. Wheeler area, Nevada (Harry Bastron, analyst)

31-DL-61	152-MW-61	8-DL-61	40A-MW-60	16-MW-60	38-MW-60²	40B-MW-60	27-DL-61	98-DL-62	21A-MW-60	43-DL-61
0·13	0·15	0·14	0·18	0·13	0·2	0·20	0·11	0·12	0·12	0·11
6·45	5·51	7·16	6·80	5·98	5·4	6·10	5·45	5·52	6·45	7·62
8·35	8·84	9·58	11·17	9·46	10·4	8·47	8·01	7·91	9·82	9·70
1·57	1·45	1·45	1·45	1·93	1·1	1·93	2·02	1·50	1·45	1·69
3·50	3·38	3·96	3·73	3·38	3·0	3·03	3·03	2·82	3·15	3·50
0·61	0·56	0·59	1·00	0·86	0·8	0·70	0·46	0·44	0·74	0·54
0·026	0·038	0·030	0·042	0·038	0·05	0·035	0·029	0·032	0·028	0·026
0·22	0·16	0·23	0·20	0·16	0·2	0·20	0·16	0·17	0·15	0·17
0	0	0	0	0	0·1	0	0	0	0	0
0·10	0·092	0·10	0·11	0·094	0·1	0·090	0·074	0·080	0·11	0·092
0·030	0·038	0·030	0·030	0·029	0·03	0·030	0·023	0·020	0·030	0·026
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0·0050	0·0047	0·0057	0·0071	0·0041	0·005	0·0067	0·0036	0·0044	0·0051	0·0040
0	0	0	0	0	0	0	0	0	0	0
21·0	20·2	23·3	24·7	22·1	21·4	20·8	19·4	18·6	22·0	23·5
0·91	1·08	0·93	1·48	1·37	0·9	1·14	1·08	1·36	1·01	1·00
21·9	21·3	24·2	26·2	23·5	22·3	21·9	20·5	20·0	23·0	24·5
0·89	1·12	0·89	1·07	0·85	1·4	1·45	0·82	0·92	0·81	0·72
31·72	28·16	31·72	28·45	28·05	26·1	30·25	29·19	30·64	30·24	33·49
38·86	42·74	40·19	44·22	41·97	47·6	39·78	40·38	41·52	43·58	40·32
7·38	7·08	6·15	5·80	8·67	5·1	9·17	10·29	7·95	6·50	7·11
16·65	16·73	17·02	15·11	15·35	14·0	14·56	15·64	15·16	14·29	14·88
2·82	2·65	2·45	3·90	3·75	3·6	3·22	2·31	2·29	3·25	2·23
0·11	0·18	0·12	0·16	0·16	0·2	0·15	0·14	0·16	0·12	0·10
0·97	0·74	0·92	0·73	0·68	0·9	0·87	0·77	0·87	0·63	0·68
0	0	0	0	0	0·4	0	0	0	0	0
0·44	0·41	0·40	0·41	0·38	0·4	0·39	0·34	0·39	0·43	0·35
0·13	0·17	0·11	0·11	0·11	0·2	0·13	0·10	0·09	0·12	0·10
0	0	0	0	0	0	0	0	0	0	0
0·02	0·02	0·02	0·03	0·01	0·02	0·02	0·02	0·02	0·01	0·01
78·0	78·0	78·1	78·5	78·7	78·9	79·2	79·9	80·1	80·3	80·9
2·21	2·39	2·24	2·73	2·59	3·1	2·48	2·45	2·58	2·89	2·58
0·80	0·95	0·82	1·01	0·97	1·2	0·89	0·90	0·91	0·98	0·83
2·33	2·55	2·36	2·93	2·73	3·4	2·73	2·58	2·74	3·05	2·71
3·87–4·03	3·93±0·02	3·87–4·03	3·79–4·02	3·84–4·07	3·88–4·02	3·97±0·02	>3·65	>3·65	3·83–4·03	3·91±0·02

[Partial columns from the facing page, visible at the left margin:]

vities of accessory

W-60,	25-DL-61	126-MW-61
6	0·20	0·24
5	6·68	5·51
3	9·70	8·10
7	1·94	1·81
0	4·08	3·03
5	0·77	0·70
42	0·039	0·028
1	0·23	0·24
	0	0
3	0·13	0·11
47	0·040	0·032
	0	0
	0	0
056	0·0062	0·0074
	0	0
	23·8	19·8
5	1·36	1·36
	25·2	21·2
3	1·27	1·80
0	28·93	28·67
1	39·79	39·89
6	8·04	9·02
4	17·14	15·27
3	3·10	3·38
9	0·14	0·13
89	0·92	1·13
	0	0
53	0·49	0·52
9	0·14	0·14
	0	0
02	0·02	0·03
7	76·8	77·5
44	2·16	2·34
97	0·86	0·91
61	2·32	2·61
4–	3·72–	3·77–
·07	4·00	4·01

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in that it points up the fresh and unaltered nature of these allanites. The difference in degree of fractionation of rare earths, then, as expressed by values of Σ ranging from 61·3 to 80·9, must be related to the main magmatic stage and cannot be ascribed to any late post-consolidation process. We will return to a discussion of these allanites later.

Table 2 lists, in order of increasing value of Σ, 13 analyses of accessory monazites recovered from the same granitic intrusive rocks as were the allanites just described. Beryllium was found in four of these monazites in the following amounts: 63-MW-60, 25 ppm; 205-MW-61, 15 ppm; 229-MW-61, 7 ppm; and 49-DL-61, 6 ppm. Since the accessory allanites in these rocks are all but devoid of beryllium, the beryllium contents of these monazites are somewhat surprising.

D. E. LEE and H. BASTRON

Table 2. Rare-earth and thoria contents of accessory monazites from the Mt. Wheeler area, Nevada (Harry Bastron, analyst)

Sample number	63-MW-60	49-DL-61	22-MW-60	229-MW-61	238-MW-61	230-MW-61	205-MW-61	190-MW-61	190-DL-62	71-MW-60	234-MW-61	120-MW-60	135-DL-62
Weight per cent													
Y_2O_3	2.18	3.33	2.02	2.26	3.45	2.41	1.32	2.21	2.46	1.93	2.60	1.04	0.98
La_2O_3	10.0	14.7	11.7	11.4	14.3	12.8	8.13	13.5	16.2	17.4	17.1	17.1	16.5
CeO_2	17.6	27.3	21.4	19.8	27.8	24.0	13.6	22.8	25.5	26.5	30.3	27.6	28.4
Pr_6O_{11}	4.54	4.78	3.14	3.15	4.69	4.31	3.18	4.44	3.01	3.21	5.92	3.01	2.96
Nd_2O_3	10.8	14.2	11.1	10.1	11.5	11.7	6.92	10.7	11.5	11.8	13.1	12.9	12.2
Sm_2O_3	3.27	4.29	3.18	2.74	4.54	3.13	1.61	2.59	2.10	2.27	3.08	2.11	2.02
Eu_2O_3	0.058	0.075	0.070	0.050	0.069	0.051	0.029	0.056	0.079	0.076	0.093	0.14	0.11
Gd_2O_3	1.87	2.60	2.18	1.57	2.47	1.71	0.76	1.34	1.67	1.53	1.68	1.31	1.29
Tb_4O_7	0.22	0.35	0.30	0.26	0.33	0.27	0.12	0.24	0.22	0.21	0.22	0.12	0.13
Dy_2O_3	0.84	1.14	0.87	1.02	1.20	1.18	0.52	0.98	0.80	0.77	1.17	0.56	0.45
Ho_2O_3	0.14	0.18	0.15	0.16	0.19	0.16	0.10	0.12	0.18	0.18	0.17	0.22	0.13
Er_2O_3	0	0	0	0	0	0	0	0	0	0	0	0	0
Tm_2O_3	0.028	0.043	0.023	0.030	0.048	0.031	0.016	0.023	0.023	0.021	0.035	0.023	0.011
Yb_2O_3	0.065	0.14	0.039	0.077	0.14	0.072	0.038	0.044	0.049	0.040	0.074	0.015	0
Lu_2O_3	0	0	0	0	0	0	0	0	0	0	0	0	0
Total R. E. oxides	51.6	73.1	56.2	52.6	70.7	61.8	36.3	59.0	63.8	65.9	75.5	66.1	63.2
ThO_2	9.80	8.90	14.8	12.1	12.2	14.3	7.65	10.2	6.46	6.44	11.5	5.92	6.34
R. E. oxides + thoria	61.4	82.0	71.0	64.7	82.9	76.1	44.0	69.2	70.3	72.3	87.0	72.0	69.5
Atomic per cent of total rare-earth elements													
Y	6.23	6.71	5.32	6.32	7.17	5.76	5.35	5.51	5.68	4.32	5.08	2.34	2.30
La	19.75	20.47	21.41	22.08	20.62	21.18	22.85	23.32	25.87	26.97	23.19	26.64	26.94
Ce	32.92	36.02	36.91	36.30	37.84	37.56	36.25	37.38	38.63	39.00	38.89	40.68	40.70
Pr	8.60	6.38	5.49	5.85	6.47	6.84	8.55	7.35	4.60	4.78	7.67	4.48	4.61
Nd	20.79	19.22	19.56	19.05	16.10	18.71	18.83	17.97	17.79	17.72	17.13	19.50	19.31
Sm	6.05	5.59	5.42	4.96	6.11	4.84	4.23	4.18	3.13	3.30	3.90	3.07	3.07
Eu	0.11	0.10	0.12	0.09	0.09	0.08	0.07	0.09	0.12	0.11	0.12	0.20	0.16
Gd	3.34	3.27	3.58	2.74	3.20	2.55	1.92	2.09	2.40	2.15	2.05	1.84	1.89
Tb	0.38	0.42	0.48	0.44	0.41	0.39	0.29	0.36	0.31	0.28	0.26	0.16	0.18
Dy	1.45	1.39	1.39	1.73	1.51	1.71	1.28	1.48	1.12	1.04	1.38	0.77	0.64
Ho	0.24	0.22	0.24	0.23	0.23	0.23	0.24	0.18	0.25	0.25	0.20	0.29	0.18
Tm	0.04	0.05	0.04	0.05	0.06	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0
Yb	0.11	0.16	0.06	0.12	0.17	0.10	0.09	0.06	0.06	0.05	0.08	0.01	0.02
Σ(La + Ce + Pr)	61.3	62.9	63.8	64.2	64.9	65.6	67.6	68.0	69.1	70.8	69.8	71.8	72.2
Ce/(Nd + Y)	1.22	1.39	1.48	1.43	1.62	1.53	1.50	1.59	1.64	1.77	1.75	1.86	1.88
Ce/(La + Nd)	0.81	0.91	0.90	0.88	1.03	0.94	0.87	0.90	0.88	0.87	0.96	0.88	0.88
Ce/Nd	1.58	1.87	1.89	1.90	2.35	2.01	1.92	2.98	2.17	2.20	2.27	2.09	2.11

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VARIATION OF RARE-EARTH ELEMENTS IN ALLANITES AND MONAZITES OF THE MT. WHEELER MINE AREA

In a definitive study of the systematic variation of rare-earth elements in cerium-earth minerals, MURATA *et al.* (1957) relate atomic percentages of individual rare-earth elements to the quantity Σ for 26 samples of monazite from various

Fig. 2. Relation between the atomic percentages of the individual rare-earth elements and the sum of the atomic percentages of La, Ce and Pr for allanite and monazite. Curve A taken from MURATA *et al.*, (1957, Fig. 1, p. 143). Based on 26 samples of monazite from various localities. Curve B based on 21 allanites (circles) from the Mt. Wheeler area, Nevada (Table 1). Curve C based on 13 samples of monazite (triangles) from the Mt. Wheeler area, Nevada (Table 2).

parts of the United States and from Brazil, Australia, and India. We follow the scheme of these writers in comparing present results with theirs (Fig. 2).

Remembering that the monazites analyzed by MURATA *et al.* represent many different geologic environments whereas the allanites and monazites described

here all were recovered from within about 20 square miles of intrusive outcrop area, let us consider the various curves for each of the rare-earths featured in Fig. 2. For some elements, especially La and Ce, these cruves depart rather widely from actual coincidence, but their slopes agree remarkably well. Murata et al. (1953) were able to duplicate the plots (called "A" in Fig. 2) for their 26 monazites by calculation based on a process of repeated fractional precipitation of the rare-earth elements, assuming a starting solution containing the following numbers of gram atoms of the different elements: 15 La, 38 Ce, 5 Pr, 26 Nd, and 16 (Sm + Gd + Y). For the restricted outcrop area with which we are concerned, it is plausible that composition of the "starting solution" might not be the same as one deduced from a study of 26 monazites collected from various parts of the world. The important fact here is that the trends in variation of rare-earth elements in the Mt. Wheeler allanites and monazites parallel those ("A", Fig. 2) that can be explained so nicely on the basis of a process of fractional precipitation in which the less basic cerium-earth elements are preferentially precipitated, with the mother liquor becoming progressively richer in the more basic elements. We will relate this thought to the geology of the Mt. Wheeler intrusive rocks in a later section of this paper.

There is a suggestion (Fig. 2) that the allanite and monazite structures may have slightly different preferences for certain of the rare-earth elements in a chemical system such as the igneous outcrop area under study here. Note that La, Ce, Pr, and Sm curves for the Mt. Wheeler allanites ("B") and monazites ("C") do not coincide. Moreover, in each case it is the monazite curve that is closer to the curve (monazite) of Murata and co-workers. Finally, for Nd (Fig. 2) there is the marked divergence between our curves and that of Murata and co-workers. We are unable to explain this divergence.

Degree of Rare-Earth Fractionation as Related to CaO Content of Whole Rock

Study of the intrusive rocks of the Mt. Wheeler, Nevada area still is in progress and unanswered questions remain. It is clear, however, that a most important feature of this geology involves host rock influence on the chemistry and mineralogy of the intruding rocks. Two factors combine to make this an ideal area in which to observe the effects of assimilation: first, the igneous rocks under study probably have not been eroded to a depth of more than 1000 ft anywhere; and second, these rocks are exposed above and below the 330–440 ft thick Lower Cambrian Pioche Shale which separates two thick and chemically distinct formations, Lower Cambrian Prospect Mountain Quartzite and Middle Cambrian Pole Canyon Limestone (see Drewes, 1958; Whitebread and Lee, 1961; Whitebread et al., 1962).

As outlined in the introduction and shown in Fig. 1 and by Lee and Dodge (1964), the CaO content of the whole rock, which itself depends upon proximity of limestone, has a profound influence on the types of accessory minerals developed. From Fig. 3 we see that CaO content of whole rock (logarithmic scale) also bears a striking relationship to the Σ value of constituent allanite and monazite.

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Clearly the more basic rare-earths, $Ce + La + Pr$, are concentrated in those cerium-earth minerals present in rocks with the higher CaO contents.

We note in passing that results for the five coexisting allanite–monazite pairs in Fig. 3 suggest that under certain conditions the more basic rare earths prefer the structure of monazite to that of allanite. Each of the four pairs connected by dotted lines shows monazite with the higher Σ value. For the other pair (circle and superimposed triangle) Σ values of allanite and monazite are about the same.
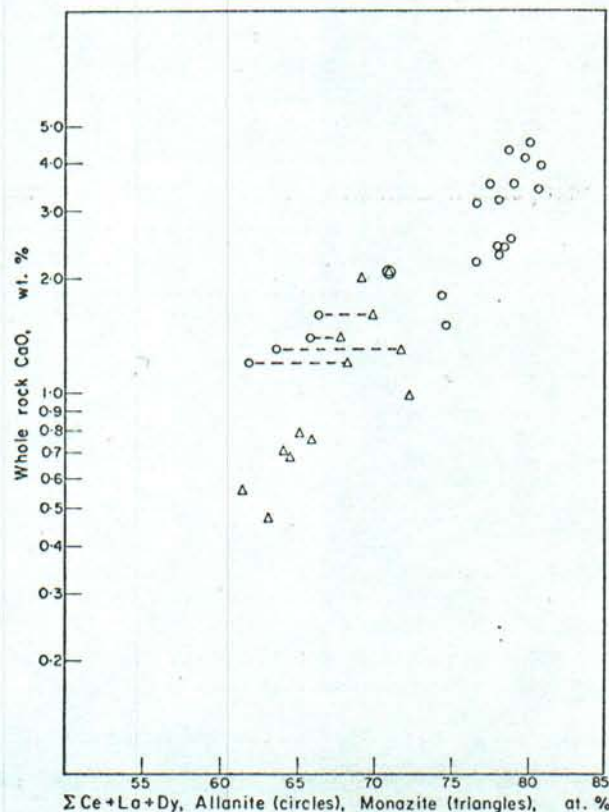
Fig. 3. Relation between CaO content of whole rock (Table 3) and the sum of the atomic percentages of La, Ce and Pr of constituent allanite (circles, Table 1) and/or monazite (triangles, Table 2). Dashed lines connect coexisting allanite–monazite pairs.

Are the chemical processes that have been operative here somehow similar to those that contribute to the formation of alkalic rocks and their associated carbonatites? We are led to consider this possibility because of the close relationship between the geology of these rocks and the cerium-earth contents of their accessory allanites and monazites, and because some of the allanites show a degree of concentration of the most basic rare earths usually found only in minerals from alkalic rocks and carbonatites.

The predominance of the most basic rare-earth elements in alkalic rocks was noticed first by GOLDSCHMIDT et al. (1933) and later by HABERLANDT (1947), and

Table 3. Major[1] and minor[2] element contents of rocks   from which allanites

Weight per cent

	49-DL-61[3]	63-MW-60[3]	229-MW-61[3]	230-MW-61[3]	238-MW-61[3]	135-DL-62	190-MW-61[3]	120-MW-60	205-MW-61[3]	147-MW-61[3]	234-MW-61[3]	151-MW-61[3]	190-DL-62	71-MW-60	14-MW-60	8-DL-61[3]	40A-MW-60
SiO_2	75.9	76.0	75.6	76.4	74.9	72.3	74.5	71.6	74.6	73.4	72.8	73.2	71.4	71.4	71.2	70.9	71.8
Al_2O_3	13.4	12.9	13.4	13.0	13.7	14.9	13.5	15.5	13.3	14.1	14.3	14.3	15.4	14.8	14.5	14.6	14.3
Fe_2O_3	0.33	0.42	0.44	0.48	0.41	1.2	0.72	0.88	0.65	0.68	0.70	0.68	0.79	1.1	1.4	1.2	1.2
FeO	0.23	0.21	0.18	0.31	0.52	0.77	0.38	0.38	0.49	0.95	1.2	0.78	1.1	1.0	0.80	1.1	0.90
MgO	0.17	0.21	0.11	0.13	0.16	0.58	0.20	0.45	0.24	0.83	0.34	1.2	0.80	0.82	0.28	0.88	0.85
CaO	0.47	0.55	0.68	0.75	0.78	0.98	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.1	2.2	2.3	2.4
Na_2O	3.7	3.7	3.5	3.4	3.7	3.2	3.2	3.9	3.3	3.6	3.5	3.6	3.8	3.5	3.6	3.6	3.4
K_2O	4.4	4.3	4.5	4.3	4.4	4.0	4.5	4.2	4.5	4.0	4.1	3.6	3.6	3.8	3.5	3.2	3.8
$H_2O(-)$	0.08	0.04	0.13	0.08	0.09	0.23	0.15	0.17	0.04	0.16	0.15	0.07	0.12	0.18	0.17	0.06	0.44
$H_2O(+)$	0.84	0.85	0.92	0.66	0.87	1.2	0.85	0.45	0.87	0.72	0.90	0.79	0.78	0.66	0.93	1.1	0.35
TiO_2	0.08	0.08	0.07	0.09	0.11	0.24	0.14	0.86	0.15	0.19	0.21	0.19	0.25	0.82	0.33	0.33	0.29
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.07	0.02	0.01	0.02	0.06	0.06	0.06	0.10	0.06	0.11	0.10	0.09
MnO	0.01	0.03	0.03	0.03	0.03	0.02	0.05	0.08	0.04	0.04	0.06	0.04	0.06	0.10	0.04	0.05	0.05
CO_2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total	100	99	100	100	100	100	99	100	100	100	100	100	100	100	99	99	100

Semiquantitative spectrographic analyses (ppm)

	49-DL-61[3]	63-MW-60[3]	229-MW-61[3]	230-MW-61[3]	238-MW-61[3]	135-DL-62	190-MW-61[3]	120-MW-60	205-MW-61[3]	147-MW-61[3]	234-MW-61[3]	151-MW-61[3]	190-DL-62	71-MW-60	14-MW-60	8-DL-61[3]	40A-MW-60
Ba	500	700	200	150	500	500	300	1000	300	2000	500	1500	700	1500	2000	2000	2000
Be	5	3	3	3	3	3	3	7	3	3	5	2	5	5	3	3	3
Ce	—	—	—	—	—	—	100	—	200	—	100	—	—	—	—	100	—
Co	—	3	10	3	10	7	3	7	5	5	5	10	7	50	7	7	5
Cr	15	5	10	3	10	7	3	7	5	7	5	10	<2	10	15	5	20
Cu	20	5	1.5	2	7	2	10	50	7	20	30	20	15	30	30	7	1.5
Ga	30	30	30	30	20	30	20	30	20	150	20	30	—	30	30	20	20
La	—	—	—	—	10	50	—	10	7	10	7	3	—	20	70	50	50
Nb	10	30	10	10	50	—	10	10	5	—	—	—	7	20	10	5	15
Ni	—	—	—	—	—	2	—	5	—	50	50	50	50	50	7	—	5
Pb	70	70	70	70	50	50	50	50	70	50	50	50	50	50	50	30	30
Sc	3	5	5	5	5	—	5	—	7	3	7	3	5	7	7	2	5
Sr	100	300	100	100	300	300	300	700	500	1500	500	1000	500	1000	1000	700	1000
V	10	10	7	7	15	20	15	15	20	20	20	30	30	70	70	30	50
Y	20	70	—	15	30	7	10	10	30	15	15	10	20	20	20	20	20
Yb	2	7	—	1.5	5	1	1	—	3	15	1	1	2	2	2	1.5	2
Zr	70	70	70	100	50	70	70	70	150	70	200	100	70	150	100	150	200

[1] Major element determinations by Paul L. D. Elmore, S. D. Botts, Ivan H. Barlow, Gillison Chloe, H. Smith and Lowell Artis, using methods similar to those described in *U.S. Geol. Survey Bull.* 1036-C (SHAPIRO and BRANNOCK, 1956).
[2] Semiquantitative spectrographic determinations of minor elements by Chris Heropoulos, Robert E. Mays and Ivan H. Barlow. Besides elements listed, 0.7 ppm Ag and 3 ppm Mo were found in 126-MW-61; 3 ppm Mo in 49-DL-61; 7 ppm B in 14-MW-60; and 150 ppm Nd in 205-MW-61.
[3] Included in study of LEE and DODGE (1964).
[4] Xenolith.

others. More recently MURATA *et al.* (1957) emphasized the fact that cerium-earth minerals from alkalic rocks and carbonatites are rich in the most basic rare earths, having Σ values in excess of 80 at.%. Indeed, these writers (p. 153) state:

"Thus the rare-earth elements emphasize the peculiarity of the geochemistry of alkalic rocks and may eventually provide valuable clues as to the origin of these rocks .... The processes that form alkalic rocks appear to be unusually efficient in fractionating the rare-earth elements—efficient in the sense that a highly selected assemblage is produced without sacrificing the bulk of these elements".

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	151- MW- 61³	190- DL- 62	71- MW- 60
2·8	73·2	71·4	71·4
·3	14·3	15·4	14·8
·70	0·68	0·79	1·1
·2	0·78	1·1	1·0
·34	1·2	0·80	0·82
·6	1·8	2·0	2·1
·5	3·6	3·8	3·5
·1	3·6	3·6	3·8
·15	0·07	0·12	0·18
·90	0·79	0·78	0·66
·21	0·19	0·25	0·82
·06	0·06	0·10	0·06
·05	0·04	0·06	0·10
·05	<0·05	<0·05	<0·05
	100	100	100

Semiquantitative spectro-

	1500	700	1500
5	2	5	5
00	—	—	—
5	5	—	7
10	10	7	50
5	10	<2	10
30	20	15	30
			30
7	3	—	20
—	—	7	20
50	50	50	50
7	3	5	7
00	1000	500	1000
20	30	30	70
15	10	20	20
1	1	2	2
00	100	70	150

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14- MW- 60	8-DL- 61³	40A- MW- 60	31- DL- 61³	38- MW- 60	25- DL- 61³	152- MW- 61³	21A- MW- 60	40B- MW- 60⁴	126- MW- 61³,⁴	43- DL- 61³	27- DL- 61⁴	16- MW- 60	98- DL- 62⁴
71·2	70·9	71·8	70·9	71·5	70·3	71·1	62·0	65·8	62·1	66·3	66·2	63·7	57·4
14·5	14·6	14·3	15·0	14·2	15·5	15·0	16·4	16·3	16·6	16·5	15·6	17·1	18·3
1·4	1·2	1·2	1·2	1·1	0·85	1·0	1·1	2·9	2·5	1·7	1·6	2·5	3·5
0·80	1·1	0·90	1·1	1·2	1·5	1·2	3·2	1·7	3·6	1·9	2·6	2·3	3·9
0·28	0·88	0·85	0·98	0·91	0·90	0·38	1·9	0·92	2·1	1·6	2·7	2·2	2·8
2·2	2·3	2·4	2·4	2·5	3·1	3·2	3·4	3·5	3·5	3·9	4·1	4·3	4·5
3·6	3·6	3·4	3·5	3·4	3·8	3·8	4·0	4·2	4·2	4·0	3·7	3·4	4·0
3·5	3·2	3·8	3·3	3·8	2·3	2·5	3·3	2·8	2·1	1·8	1·8	2·7	2·6
0·17	0·06	0·44	0·08	0·40	0·06	0·08	0·09	0·50	0·24	0·12	0·13	0·19	0·21
0·93	1·1	0·35	0·87	0·41	0·91	0·96	2·2	0·42	1·3	1·4	0·97	0·35	1·4
0·33	0·33	0·29	0·34	0·31	0·34	0·30	0·64	0·60	0·77	0·55	0·52	0·73	1·0
0·11	0·10	0·09	0·10	0·11	0·12	0·10	0·23	0·22	0·33	0·19	0·17	0·23	0·56
0·04	0·05	0·05	0·04	0·07	0·04	0·04	0·05	0·10	0·17	0·05	0·12	0·08	0·14
<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	0·17	<0·05	<0·05	0·09	0·14
99	99	100	100	100	100	100	99	100	100	100	100	100	100

graphic analyses (ppm)

2000	2000	2000	2000	1500	1000	2000	1500	1500	700	2000	1000	1500	300
3	3	3	2	3	2	3	3	5	5	2	1·5	7	2
—	100	—	100	—	100	200	200	150	150	100	—	150	—
7	7	5	5	5	3	7	15	7	20	20	15	15	15
15	5	20	10	15	10	15	30	10	20	30	100	100	10
30	7	1·5	20	1·5	7	15	15	15	30	15	30	70	30
30	20	20	20	30	20	15	20	30	30	20	15	50	70
70	50	50	30	50	30	200	150	70	50	50	30	70	70
10	5	15	5	10	5	3	5	30	15	5	—	15	—
7	—	5	—	7	—	—	50	5	50	30	50	50	10
50	30	30	30	50	20	30	10	30	20	15	15	30	15
7	2	5	3	5	2	7	5	10	20	10	—	15	15
1000	700	1000	700	1000	1000	1500	1500	1000	1000	1500	500	1500	500
70	30	50	50	50	50	50	100	100	150	70	100	200	150
20	20	20	7	15	3	10	10	70	30	15	20	30	15
2	1·5	2	1	1·5	—	1	1	7	3	1·5	1·5	3	1·5
100	150	200	150	150	150	200	300	300	700	200	70	300	150

syntexis hypothesis for the origin of alkalic rocks and carbonatites. Nevertheless, the obviously strong influence of limestone and shale assimilation on the geochemistry of our intrusive rocks, and the direct relationship between calcium and the most basic rare earths (Fig. 3) are consistent with this hypothesis.

WHOLE ROCK CONTENTS OF SOME MINOR ELEMENTS AS RELATED TO CaO

The chemistry of these intrusive rocks resembles that of alkalic rocks and carbonatites in another respect. It is well known that some of the rarer elements are found in unusually large concentrations in these rock types. In a summary

paper on carbonatites, Pecora (1956, p. 1544) emphasizes that rare earths, Zr, P, Ti, Ba, Sr and Nb often are found in alkalic rocks and carbonatites in amounts that well exceed average abundance figures for igneous rocks. Table 3 lists, in order of increasing CaO content, major and minor elements for each of the rocks from which the constituent allanites and monazites (Tables 1 and 2; Figs. 1–3) were recovered. We will consider the relationship between calcium and each of these rare constituents.
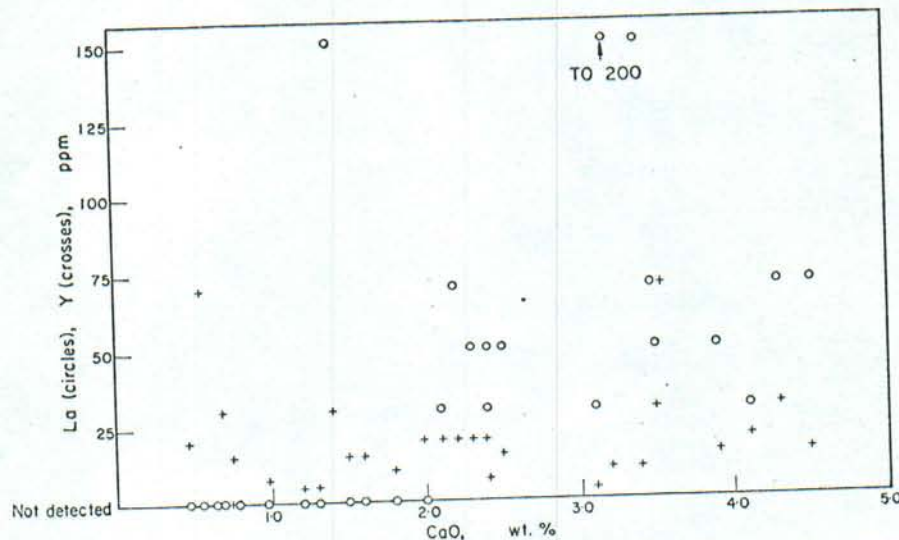
Fig. 4. Relation between whole-rock contents of CaO and La and Y. Based on Table 3.

· If we assume that most of the rare earths in these rocks are present in the allanite and monazite structures, and if we take 20 and 60 wt.%, respectively, as the average content of rare-earth oxides in the two, then inspection of Fig. 1 shows that total rare-earth and CaO contents of these rocks increase together. Also the concentrations of the spectrographically determinable rare-earth elements, viz. La, Ce, Y, Yb, presented in Table 3 indicate the same covariation of total rare earths and CaO. Figure 4 shows the trend toward increasing La:Y ratio (i.e. a more basic rare-earth assemblage) with increasing CaO content of the rock. Earlier we (Lee and Dodge, 1964, Fig. 4) found that weight per cents of zircon and CaO vary directly in these rocks. The same trend (for Zr) is suggested by Fig. 5. There is covariance between CaO and both P_2O_5 and TiO_2, as is seen in Figs. 6 and 7, respectively.

The trend for Ba is not well defined, but Fig. 8 suggests sympathetic increase with CaO. We found barite (trace amount) in only one of the rocks (43-DL-61) listed in Table 3, so presumably most of the Ba^{2+} substitutes for K^+ in silicate minerals. Since whole-rock contents of CaO and K_2O tend to vary inversely (Table 3) it will be interesting to learn how the Ba contents of the individual mineral phases change with whole-rock CaO.

Fig. 5. Rela

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Fig. 6. Rela
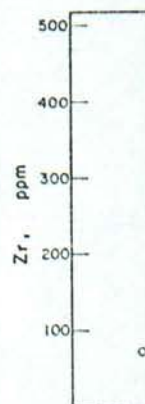
Fig. 5. Relation between whole-rock contents of CaO and Zr. Based on Table 3.

In a comprehensive study of the geochemistry of strontium, TUREKIAN and KULP (1956) found that for granitic rocks there is an increase in strontium content with an increase in calcium not only for samples from a single batholith but also when extended to a universal sampling. The same relation holds for the granitic rocks included in our study (Fig. 9).

A scatter diagram of Nb versus CaO for these rocks shows, if anything, an antipathetic relationship between the two. The calcium-poor rocks (Table 3) are in contact with Prospect Mountain quartzite. Preliminary study of a suite of about 20 samples of this quartzite, collected at random from the area under study, shows that each contains rutile as an accessory mineral, and textural evidence
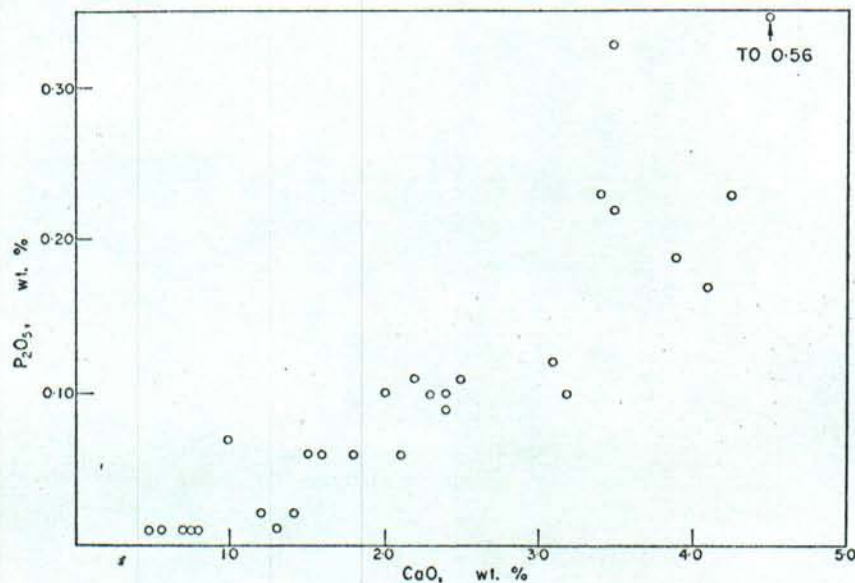
Fig. 6. Relation between whole-rock contents of CaO and P_2O_5. Based on Table 3.
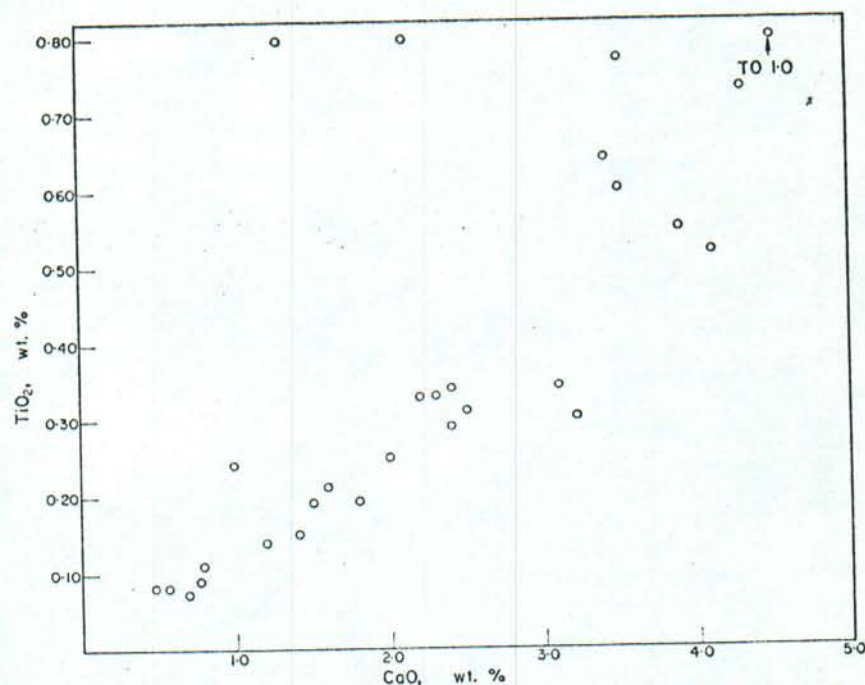
Fig. 7. Relation between whole-rock contents of CaO and TiO_2. Based on Table 3.

suggests that this rutile may have been authigenic in the original sandstone. We have recovered two fractions of this accessory rutile pure, and spectrographic analysis shows that each contains niobium in the range of hundreds of parts per million. The quartzite may have contributed to the niobium contents of the calcium-poor intruded rocks, though the evidence for this admittedly is far from conclusive as yet.
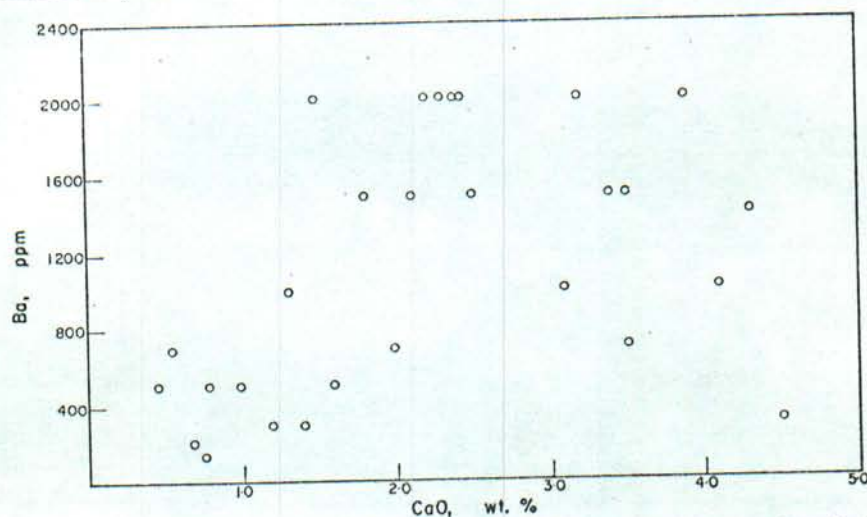
Fig. 8. Relation between whole-rock contents of CaO and Ba. Based on Table 3.
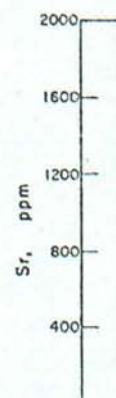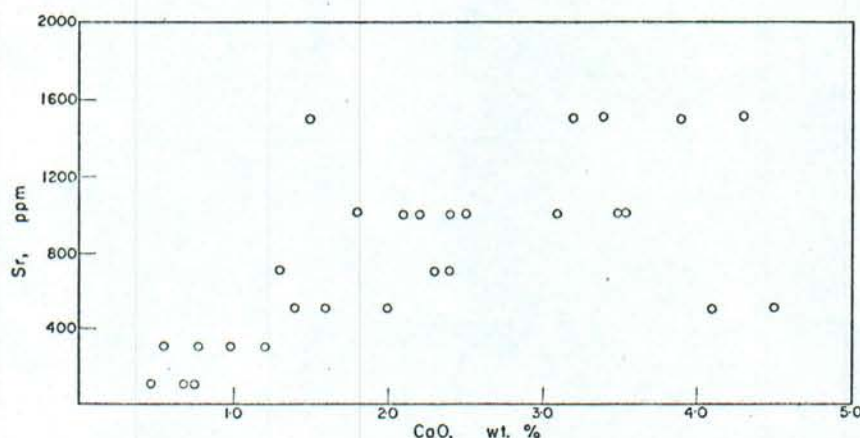
Fig. 9. Relation between whole-rock contents of CaO and Sr. Based on Table 3.

DISCUSSION OF RESULTS

In this study we have somewhat arbitrarily set other chemical variables against CaO content of the whole rock. From Table 3 it is clear that if a given trend is based on CaO, the same trend can be shown for Al_2O_3, or the opposite for SiO_2. We are faced with the familiar predicament of separating cause from effect.

Our reasons for correlating other trends with CaO are as follows. First, as we saw the importance of assimilation to the chemistry of the intrusive rocks, we thought in terms of their increased calcium content where the country rock is limestone rather than quartzite. Also, we must account for the development of such calcium-bearing accessory minerals as apatite, allanite, sphene, and epidote (LEE and DODGE, 1964) where the intrusive rocks are most clearly contaminated by limestone. And finally, because of the ionic sizes involved, we intuitively emphasized calcium as the large range of composition of accessory allanite in terms of the rare-earth elements became apparent.

If the complete transition from calcium-poor (0·5% CaO) to calcium-rich (4·3% CaO) intrusive rocks were not continuously exposed where the change is well exemplified, one would likely consider the granodiorite and quartz monzonite portions as differentiates of a parent magma, with granodiorite of course being the earlier. As it is, this can hardly be the case, and we must involve assimilation and contamination to account for the range in whole-rock chemistry seen in Table 3. The fractionation of the rare-earth elements and the concentration gradients of the minor elements illustrated in Figs. 4–9 thus must be explained in context of the chemistry of assimilation rather than of magmatic differentiation.

The best continuous exposure of the transition from calcium-poor to calcium-rich rocks extends over a horizontal distance of about 3 miles; within this distance CaO content of the rock rises from about 0·6 to 4·3% for an average gradient of 1·2% CaO/mile. Along this same distance Σ values of the accessory cerium-earth minerals rise from 64 to 81 at.%, giving an "average gradient" of 5 at.%/mile, so to speak. Now let us consider the fact that four of the allanites described earlier were recovered from xenoliths (see LEE and BASTRON, 1962, p. 1328) for these

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Table 4. Whole rock weight per cent CaO and allanite Σ value for xenoliths and associated igneous phases

	Xenolith			Associated igneous phase	
Sample number	Whole rock CaO	Allanite Σ value	Whole rock CaO	Allanite Σ value	Sample number
40B-MW-60	3·5	79·2	2·4	78·5	40A-MW-60
126-MW-61	3·5	77·5	1·6	66·4	234-MW-61
27-DL-61	4·1	79·9	3·1	76·8	25-DL-61
98-DL-62	4·5	80·1	1·4	65·9	205-MW-61

provide evidence that where the relation between CaO and Σ values is concerned we are dealing with a mosaic equilibrium superimposed on the regional gradients outlined above. Table 4 gives CaO content of each xenolith and Σ value of each constituent allanite; the same information is listed for the main intrusive phase associated with each xenolith. The xenolith numbered 27-DL-61 has a volume of hundreds of cubic feet; each of the other xenoliths in Table 4 was about the size and shape of a large coconut. These data suggest that in a chemical system such as we are concerned with here, degree of fractionation of the rare earths responds to whole-rock composition over distances of a few yards or less.

Perhaps the base calcium oxide acts as a selective precipitating agent for the basic rare earths under certain conditions, as has been suggested by LYAKHOVICH's (1962) study of the rare-earth contents of accessory minerals from hybrid granites. In this connection we present finally Fig. 10, in which the ThO_2 contents of the
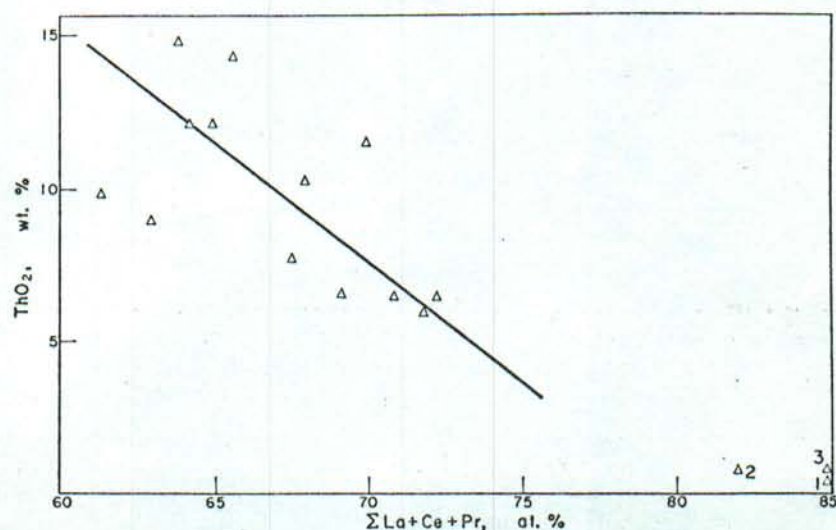
Fig. 10. Relation between weight per cent ThO_2 and the sum of the atomic percentages of La, Ce and Pr for monazite. Unnumbered triangles from Table 2. Numbered triangles: 1—MURATA et al. (1957); 2—VON KNORRING and CLIFFORD (1960); 3—HEINRICH and LEVINSON (1961).

monazites are plotted against the Σ values of their rare-earth elements. The percentage of thoria in these monazites decreases with increasing sigma (and thus with the increasing CaO content of the host rock). An extrapolation of this trend would attain the compositional field of skarn and carbonatite monazites that characteristically contain less than 1% ThO_2 and have sigma values greater than 80 at.% (MURATA et al., 1957; KNORRING and CLIFFORD, 1960; HEINRICH and LEVINSON, 1961).

We have recovered pure fractions of all of the mineral phases present in each of about 30 rock samples, including almost all of those listed in Table 3; spectrographic and chemical work on these minerals now is in progress. It is interesting to note here that preliminary results for about 30 accessory apatites from these rocks show weight per cents of rare-earth metals ranging from 0·25 to 0·90, with Σ values lower than those for coexisting allanites and monazites, but also tending to rise with whole-rock CaO.

We are also studying the chemistry of the limestone, shale and quartzite host rocks of the area to help us determine both how the regional gradients of the major and minor elements in the intruded rocks may have been effected, and also the probable composition of the "original", "uncontaminated" magma.

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Temperature conditions and formation sequence in deposition of fluorite-phenacite-bertrandite ores

Ya.A. Kosals, et al.

At present, much attention is being given by investigators to the fluorite-phenacite-bertrandite mineral association. In works devoted to the study of deposits of this type (3-6, 8, 9), the geology, structure, and material composition of the rocks and ores, and the origin of the deposits are described; temperature conditions of mineral-formation have been partly touched on (1, 4, 6).

In this article, we shall consider the nature and sequence of the processes of hydrothermal metamorphism and temperature conditions of formation of one of the beryllium deposits of the fluorite-phenacite-bertrandite type.

BRIEF GEOLOGIC CHARACTERISTICS OF DEPOSIT

The deposit is located in the northern part of a small Mesozoic basin, in a zone of tectonic disturbance involving a long-continuing deep-seated fault. It is restricted to a large xenolith of sedimentary-metamorphic rocks (Pt3) among granitoids of Proterozoic (?) and Paleozoic age, cut by Mesozoic granitoids (age 138-155 m.y.). The sedimentary-metamorphic rocks consist of massive coarsely and finely laminated dolomites and limestones, interlayered with biotite-feldspar, biotite, and biotite-amphibole schists and sandstones, forming a synclinal fold. The Proterozoic (?) granitoids consist of medium-grained gneissose granites and granodiorites, and the Paleozoic, of close- and medium-grained biotite granites, diorite-porphyrites and biotite-hornblende syenite-porphyries.

Among the Mesozoic granitoids, three phases have been recognized (table 1). Phase I includes leucocratic subalkaline granites and granosyenites, forming stock- and dike-like bodies, cutting the sedimentary-metamorphic rocks and transecting the central part of the synclinal fold and its limbs.

The subalkaline granites and granosyenites are medium- and close-grained, pinkish-gray and pink rocks with porphyritic texture. These rocks have undergone intense metasomatic alterations (microclinization, albitization, quartzification, and fluoritization). They are characterized by quite a uniform mineral composition: microcline-perthite (40-60%), oligoclase An12-16 (10-15%), and quartz (30-45%); decomposed hornblende and aegirine are present in small amounts. Accessory minerals are sphene, zircon, allanite, xenotime, and titanomagnetite.

The leucocratic microsyenite-porphyry dikes belong to Phase II. From the dip and strike they are inconstant, often branching, and have numerous geniculate ridges. The dikes extend for 800 m and are from 1-20 m thick.

The microsyenite-porphyries are rocks of pinkish-gray color, massive, and with porphyritic and microporphyritic texture. The phenocrysts are mainly prismatic and tabular microcline-perthite. The groundmass consists of prismatic and lath-like microlites of K-feldspar-microperthite with a small amount of xenomorphic quartz grains (5-10%). Accessory minerals are zircon, sphene, and ilmenite. A beryllium mineralization has been superposed on the dikes, with a wide development of processes of hydrothermal metamorphism (microclinization, albitization, fluoritization, carbonatization, and chloritization).

Phase III includes a dike of felsite-porphyry, cutting all the previous dikes and fluorite metasomatites with phenacite and bertrandite. The felsite-porphyry is a massive rock of lilac, lilac-gray, or pink color with a microaplitic, microspherulitic, and felsitic texture of the groundmass. The rare porphyritic phenocrysts consist of tabular K-feldspar and very rarely quartz. The groundmass consists of prismatically granular microlites of K-feldspar and plagioclase, and also biotite (up to 1%).

TABLE 1. Stages, phases and temperatures of mineral formation in the deposit.

Phases of crystallization and stages of mineral formation	Phases of postmagmatic process (after D.S. Korzhinskiy)	Phases of mineral formation		Minerals examined	Temperature intervals of homogenization or decrepitation of inclusions, deg C
		In granitoids	In country rocks		
I. Granosyenite-porphyries and alkaline granites 1. Gangue (skarn) stage	Early alkaline	Formation of peri-skarn amphibole- and pyroxene-orthoclase rocks and pyroxene-garnet endo-skarns	Formation of pyroxene-garnet and vesuvianite varieties of exo-skarns (after limestones)	Vesuvianite	420-400°
	Acid leaching		Hysterogenic breakdown of skarns: epidotization, actinolitization, solution and recrystallization of skarns and formation of epidote-, quartz-calcite, and other veinlets	Calcite	320-290° (220-160°)*
	Early alkaline	Early albitization (perthites, replacements, rims of albite)	Weak albitization	Albite I	550-450°**
	Acid leaching	Quartzification — growth of quartz porphyroblasts (porphyroblastic albite-microcline apogranites)	Quartzification of shales and skarns	Quartz II	500-430° (370-100°) depth 140 m 100-320° (300-190°) depth 80 m 360-290° (300-90°) surface
	Late alkaline	Late albitization (albite laths, replacing porphyroblastic quartz	Albitization of shales and skarns (about and near oro-bodies)	Albite II	450-350°**
II. Microsyenite-porphyries (dikes)		Late microclinization (gangue hornblende-microcline and fluorite-microcline metasomatites with phenacite I)	Late microcliniza-tion — formation of microcline (gangue) and fluorite-microcline metasomatites with phenacite I	Microcline II Quartz II Fluorite I	420-320°** 400-310 (280-220°) 360-300° (280-100°)
II. Beryllium stage		Muscovitization and formation of muscovite veinlets	Muscovitization of shales, skarns, and less frequently limestones, and formation of muscovite veinlets		380-290°
		Fluoritization of metasomatites of preceding phases with formation of feldspar-fluorite metasomatites with phenacite II and bertrandite	Fluoritization — formation of fluorite metasomatites with phenacite II and bertrandite (after limestones, and less frequently shales) and helvite (after skarns)	Fluorite, depth 250 m Phenacite	400-310° (270-210°) 285-255°
				Fluorite I, depth 50 m Phenacite	310-200° (160-90°) 235-200°
				Bertrandite, depth 50 m	230-180° (180-100°)
	Residual solutions	Quartz veins and veinlets, and quartzification of fluorite metasomatites	Quartz veins and veinlets, and quartzification of fluorite metasomatites	Fluorite II, surface	290-200° (180-100°)
				Bertrandite, surface	200-140° (150-90°)
		Carbonatization of metasomatites of preceding	Carbonatization of metasomatites of preceding	Quartz IV	230-180° (180-100°)
				Calcite I	220-120° (150-90°)

	Mineral / process	Mineral, depth	Temperature
	Fluoritization of metasomatites of preceding phases with formation of feldspar–fluorite metasomatites with phenacite II and bertrandite	Fluorite, depth 250 m, Phenacite	400-310° (270-210°); 285-255°
	Fluoritization — formation of fluorite metasomatites with phenacite II and bertrandite (after limestones, and less frequently shales) and helvite (after skarns)	Fluorite I, depth 50 m, Phenacite	310-200° (160-90°); 235-200°
		Bertrandite, depth 50 m	230-180° (180-100°)
Residual solutions	Quartz veins and veinlets, and quartzification of fluorite metasomatites	Fluorite II, surface	290-200° (180-100°)
		Bertrandite, surface	200-140° (150-90°)
		Quartz IV	230-180° (180-100°)
	Carbonatization of preceding phases, and carbonate veinlets with galena	Calcite I	220-120° (150-90°)
	Veins and veinlets of chalcedony- and opaline quartz with galena	Fluorite III Calcite II	175-45°

*Temperatures of homogenization of secondary inclusions.
**Temperatures obtained by decrepitation method.

Accessory minerals are sphene, apatite, zircon, and rutile. Secondary minerals (albite, sericite, epidote, chlorite, and carbonate) occur in small amounts.

An analysis of the geologic structure of the deposit, the relationships between the postmagmatic mineral formation and the rocks of early phases, and the temperature conditions of formation enable us clearly to separate two stages (see below).

SEQUENCE AND TEMPERATURE CONDITIONS OF FORMATION OF THE DEPOSITS

The first, gangue (skarn) stage of mineral formation is clearly associated spatially and in time with the subalkaline granites and granosyenites of Phase I. The microsyenite-porphyry dikes (phase II) clearly cut the mineralization of stage I and the rocks of Phase I, separating the superimposed, later beryllium mineralization of stage II from them. The early alkaline phase was the most intense during stage I, with the formation of contact-infiltration skarn zones.

The sequence in the formation of the skarn minerals (pyroxene-garnet-vesuvianite) determines the sequence of development of the skarn zones. The skarns are restricted to the middle carbonate-shale horizon of the sedimentary-metamorphic strata, and in the southern part of the deposit, to the limestones of the lower horizon. A small portion of the skarns (about 5%) has been formed at the expense of the granitoids, amphibole-scapolite rocks, shales, and sandstones.

On the basis of experimental data (7), the upper boundary of the temperature of formation of the skarns has been provisionally accepted at 700° C. In the pyroxene and garnet, the gas-liquid inclusions are very small (< 0.0005 mm), and therefore their homogenization seemed difficult. Vesuvianite is characterized by the extremely insignificant saturation in primary inclusions. The inclusions, having irregular shape and dimensions of 0.005-0.02 mm, are arranged in individual groups without association with sealed cracks. Only two-phase gas-liquid inclusions have been found here. The gas-liquid phase ratio varies from 30-40 to 60-70%. The primary inclusions become homogenized to liquid at 420-400° C, and the secondary inclusions at 235-225° C. These figures agree well with the empirical data of Michelle Levy, who has synthesized vesuvianite in an alkaline medium at 600-400° C.

The temperature at which the next stage of the hysterogenetic decomposition of skarn

takes place was determined on inclusions in calcite of epidote, actinolite, recrystallized granite and vesuvianite. The inclusions in the calcite vary in shape, but xenomorphic, slightly elongated crystals with dimensions of the order of 10^{-3} mm are most common. Liquid inclusions are common, while gas-liquid ones are infrequent. The ratio of the phases (gas-liquid) occurs with the limits from 10-90 to 20-80%; the inclusions are homogenized in the range of 320-290° C, and the secondary types, at 220-160° C. The formation of epidote and actinolite is somewhat preceded by the deposition of calcite. From this we may conclude that the lower boundary of the temperature of formation of vesuvianite at 400° C is simultaneously the beginning of hysterogenic breakdown of skarns. Synthesis of actinolite was achieved in the range of 450-320° C (7). Consequently, the mineral formation of the phase of hysterogenic breakdown of skarns took place in the 400-200° C range (even up to 160° C).

Injections of dikes of leucocratic microsyenite-porphyries (phase II) determined the second (beryllium) stage of mineralization, in which occurred the formation of porphyroblastic albite-microcline and close-grained microcline-albite apogranites after subalkaline granites and granosyenites of Phase I, various albite and microcline metasomatites after apogranites, microsyenite-porphyries, shales, granitoids, and skarns, and also quartz-feldspar-fluorite and fluorite metasomatites mainly after limestones, and less frequently shales, skarns, and apogranites. All this varied metasomatic mineralization was the result of subsequent processes of hydrothermal metamorphism: early albitization-quartzification-late albitization-late microclinization (quartz-feldspar metasomatism)-muscovitization-fluoritization-quartzification-carbonatization.

The earliest formations of this type are the porphyroblastic albite-microcline apogranites. Their formation began with the development of perthites replacing microcline, the appearance of albite borders, and checkerboard albite, corroding the quartz of the original subalkaline granites and granosyenites.

With increase of early albitization in the upper horizons and marginal parts of the stock, metasomatic quartz of rounded and hexagonal shape has developed, corroding the microcline-perthite and early albite. According to the growth of the quartz porphyroblasts in the rock, the amount of microcline-perthite decreased (to 30%) and the amount of albite II increased. This process is a typical high-temperature (500-300° C) hydrothermal quartzification (acid phase of leaching), developed in the rear of the front of early albitization.

The late albitization was accompanied by a decrease in the amount of quartz (to 15-20%) and calcite (to 15-30%). Widespread and intense albitization appeared around the ore bodies (fluorite metasomatites).

The crystallization of the early albite from the porphyroblastic albite-microcline apogranites, determined by the decrepitation method, varies from 550-450° C.

The method of homogenization of the gas-liquid inclusions in the quartz porphyroblasts from the porphyroblastic albite-microcline apogranites taken from drillholes at a depth of 140 m has established that the inclusions are homogenized at 500-430° C. The inclusions are very small (thousandths of a millimeter), irregular in shape, oval, weakly elongated, incompletely terminated, mainly liquid, and less frequently gas-liquid. The ratio of the phases (gas-liquid) fluctuates from 20-80 to 40-60%. Homogenization of the inclusions in the quartz porphyroblasts, taken from rocks at a depth of 80 m, takes place at a lower temperature (400-320° C). Homogenization takes place, as a rule, into the liquid phase. At the same depth, along the periphery of the large (from 4 to 1 cm) quartz porphyroblasts, the primary inclusions are homogenized in the 360-290° C interval into the liquid phase (the same temperature range has been established on the surface). The volume of the liquid phase increases in them with a gas-liquid ratio from 5-95 down to 35-65%. It has been established that the quartz porphyroblasts replacing albite I and in its turn corroded by late lath-like albite II, contain gas-liquid inclusions which are homogenized at 500-350° C. The homogenization temperature of the inclusions in the quartz porphyroblasts corroding albite II and containing its inclusions is 400-290° C. These data not only indicate the considerable temperature range (500-290° C) of development of porphyroblasts (quartzification - acid leaching) in the apogranites, but also the possibility of making an approximate estimate of the crystallization temperature of albite I and II. Since the maximum crystallization temperature of quartz, corroding albite I, is 500-400° C, then albite I began to crystallize at a temperature above 500° C. And since the maximum temperature of formation of the quartz, corroding albite II, is not less than 400° C, we may provisionally accept 450° C as the temperature of the end of crystallization of albite I and the beginning of crystallization of albite II. The end of crystallization of albite II may be judged from its corrosion by quartz with a minimum homogenization temperature of about 350°C. The decrepitation method emphasizes the recognized temperature intervals of the albites: early albite (550-450° C) and late albite (450-350° C).

Late microclinizatio[n]
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Late microclinization, replacing albitiza-
tion, is particularly widely developed in the
southern part of the locality. This has led to
the formation of numerous vein- and lens-like
bodies of microcline metasomatites in the form
of a band of sublatitudinal strike (more than
300 m long and about 20 m wide) through vari-
ous rocks. Thicker (up to 30 m) and more
extensive bodies of massive microclinites are
developed after granitoids and shales, than
after skarns (vein- and nest-like bodies and
veinlets from a few centimeters up to 2 m).
These are brownish-red and pink, sometimes
with a lilac tint, medium- and coarse-grained
rocks, consisting of microcline-perthite (70-
90%), albite (up to 5%), pyroxene and amphi-
bole (up to 3%), fluorite (2-10%), quartz
(up to 15%) and accessory minerals (sphene,
apatite, zircon, monazite, and phenacite).
The microcline metasomatites occur in the
form of relics among the later fluorite meta-
somatites with phenacite and bertrandite.

In the northern part of the deposit there is
stock-like body of hornblende-microcline meta-
somatites, consisting of microcline-perthite
(70-95%) and lath-like albite, partly corrod-
ing the hornblende, and a variable amount of
decomposed pyroxene (up to 10%) and horn-
blende (1-10%); biotite, chlorite, and iron
hydroxides have been developed after the latter.
In the joint zones of the metasomatites, there
are irregular grains and veinlet segregations
of quartz and a coarsely tabular muscovite.
The muscovite has been developed after the
microcline metasomatites in the contact portion,
especially through the skarns.

The metasomatic nature of the rocks is in-
dicated by 1) the weakly microclinized xeno-
liths of shales, skarns, and granite-gneisses;
2) the vague contacts with the country rocks,
and also the varying degree of microclinization
of the granites, shales and skarns in the zones
of intense jointing at the exocontact with the
stock-like body; 3) the removal of silica, typi-
cal of late alkaline metasomatism; and 4) the
removal and fluctuating amounts of MgO.

Homogenization of the gas-liquid inclusions
in the quartz from the pyroxene-hornblende
microcline metasomatites takes place in the
400-310° C range. The decrepitation tempera-
ture of the microcline occurs within the 420-
320° C range.

Our observations have shown the wide de-
velopment of muscovitization after microcline
metasomatites, skarns, and other rocks. Re-
placement of vesuvianite, pyroxene, hornblende,
and less frequently garnet, by muscovite has
been recorded in the skarns. The most intense
muscovitization is typical of the outer zone of
late microclinization and along the flanks of
the metasomatites, where they are cut by mus-

covite veinlets. The temperature of muscoviti-
zation may be defined indirectly by its super-
position on the microcline metasomatites (420-
300° C) and by their intersection by the fluorite
metasomatites with phenacite and bertrandite
(310-200° C). The probable temperature range
of muscovitization may be fixed within the 380-
290° C range.

The fluorine-beryllium phase ended with
the formation of the fluorite metasomatites
with phenacite and bertrandite. These are lens-
oid and irregularly shaped bodies, developing
after seams of carbonate rocks (especially
along the contacts with the aluminosilicate rocks)
and through the intensely albitized rocks and
microcline metasomatites. Three types of
mineral parageneses have been recognized on
the basis of composition. The most common
(75%) are the fluorite metasomatites with
phenacite and bertrandite (close- and medium-
grained rocks of violet color, massive, with
cellular, honeycomb, sieve-like, and mottled,
and less frequently, rhythmically banded
structure. Their mineral composition is fluor-
ite (10-60%), phenacite, bertrandite, albite
(2-5%), microcline (50-10%), quartz (up to
15%), muscovite (up to 15%, rarely up to
60%), calcite (up to 5%), and sulfides (pyrite,
chalcopyrite, sphalerite, and galena). Acces-
sory minerals are allanite, monazite, rutile,
zircon, and bastnaesite.

The mineral composition of the fluorite-
bertrandite metasomatites, developed only on
the surface, is extremely variable: fluorite
(40-70%), bertrandite, microcline (up to 15%),
carbonate (up to 15%), quartz (up to 5%),
and sulfides (up to 4%). The accessory min-
erals are sphene, apatite, zircon, and mona-
zite. Albite and sericite are present in signif-
icant amounts.

The fluorite-phenacite association, like
the previous one, has a limited distribution
and is developed mainly in the deep-seated
horizons, less frequently in the form of indi-
vidual sectors among the phenacite-bertrandite-
fluorite association.

Thus a vertical zonation in the distribution
is recognized not only for phenacite and ber-
trandite, but also for the vein minerals. At
depths of more than 150 m, only phenacite is
developed, being replaced upward by the
phenacite-bertrandite association, and on the
surface by bertrandite. Here, microcline
and carbonates predominate, and the amount
of quartz increases with depth. Albite and
muscovite occur instead of microcline; the
amount of sphalerite increases with depth, and
toward the surface, there is an increase in
the amount of galena.

The interrelations of the minerals also define their sequence of precipitation during the course of the mineral formation of the fluorite-beryllium phase: microcline, albite, muscovite, fluorite, apatite, pyrite, quartz, phenacite, fluorite II (helvite), bertrandite, meliphanite, calcite, sphalerlite, chalcopyrite, and galena.

A study of the inclusions in fluorite from the fluorite metasomatites of the basic ore bodies of the deposit has shown that in the fluorite-bertrandite association on the surface, the homogenization temperature of the inclusions is 290-200° C; at a depth of about 50 m it increases to 310-200° C; at a depth of 250 m (in the fluorite-phenacite association) it reaches 400-310° C. In fluorite from the latter association, the liquid and gas-liquid inclusions with ratio of phases (gas-liquid) from 10-90 to 30-70% are homogenized into the liquid phase. The shape of the inclusions is variable, often oval, and weakly elongated; occasionally there are incompletely terminated rhombohedra. The inclusions in quartz from the microcline-quartz-phenacite-fluorite association are homogenized at temperatures of 350-310° C. Two types of inclusions have been recognized (liquid and gas-liquid), occurring in approximately the same amounts. Their shape is that of negative crystals, often incompletely terminated, elongate, and equidimensional. The ratio of the gas-liquid phases is from 5-30 up to 95-70%. The inclusions are homogenized into the liquid phase. Allowing for the fact that quartz fills the spaces between the microcline crystals and partly corrodes them, it may be assumed that the microcline has a somewhat higher crystallization temperature. The phenacite of short-prismatic habit is characterized by a high saturation with gas-liquid inclusions. The primary gas-liquid inclusions have simple shapes of negative crystals. Therefore with a high degree of confidence it may be stressed that the shape of the primary inclusions in the phenacite is a growth shape, and not one of solution. The inclusions are homogenized only into the liquid phase at 285-235° C.

In the phenacite-bertrandite-fluorite association, the small prismatic crystals of phenacite and bertrandite form radiating-fibrous aggregates, distributed in the form of phenocrysts or monomineralic inclusions in the close-grained fluorite. Fluorite, phenacite, and bertrandite have been studied from this association. Numerous inclusions have been identified in the fluorite: two-phase, gas-liquid, three-phase (with liquid carbon dioxide or a solid phase of satellite minerals), and two-phase with liquid carbon dioxide (liquid carbon dioxide and gas phase).

The two-phase gas-liquid inclusions without carbon dioxide and the three-phase inclusions with solid phases, and also with an insignificant amount of carbon dioxide (up to 10%) are homogenized only into the liquid phase over a wide temperature range (290-160° C). The gas phase of the inclusions, identified by the gas extraction method on weighed samples of the fluorite-bertrandite association, consists of nitrogen (51-55%), carbon dioxide (28-32%), and methane (16-17%). The presence of hydrogen (1.66%) is rarely defined. The composition of the hydrous extracts from the fluorite and phenacite inclusions is set out in Table 2.

In the multiphase gas-liquid inclusions, the captive minerals, consisting of prismatic crystals, are not dissolved when heated to 450° C. The differences in the homogenization temperatures of the monotypical inclusions in the fluorite from one and the same association in different sectors of the ore bodies are explained by the zonation of deposition. From the carbon dioxide inclusions, the pressures of the mineral-forming solutions of the defined association have been identified (table 3).

In the phenacite from this association, the gas-liquid inclusions are homogenized into the liquid phase at 235-200° C. In the bertrandite, the inclusions often have the shapes of negative crystals, incompletely terminated. The phase ratio (gas-liquid) is from 5-95 to 20-80%. Homogenization takes place into the liquid phase, and in the bertrandite-fluorite association on the surface, the temperature is 200-140° C, whereas at a depth of 50 m in the phenacite-bertrandite-fluorite association it is 230-180° C.

Thus the formation of the fluorite-phenacite-bertrandite association takes place from hydrothermal solutions within the 310-140° C range and at pressures of 620-750 atm.

The established crystallization temperature for phenacite in the upper horizons is in the 265-230° C range, and at a depth of more than 250 m, probably reaches 350-300° C. The upper limit of the crystallization temperature for bertrandite does not exceed 300° C. Apparently at 350-300° C only phenacite crystallizes; at 300-200° C, phenacite-bertrandite; at 200-140° C, only bertrandite, which is supported by experiments (2). Thus, from the data on homogenization of inclusions in fluorite and bertrandite, the formation of the upper horizons of the fluorite metasomatites took place in the 290-140° C range, and in the deep-seated horizons, at 400-250° C. On the whole the formation of the ore bodies of the fluorite-beryllium phase took place over a wide range of temperatures (400-140° C).

The fluorite metasomatites are cut by quartz veins, veinlets, and lenses, filling cracks and veins of northeasterly strike.

TABLE 2. Results of microchemical analyses of bulk hydrous extracts from minerals of the fluorite-phenacite-bertrandite association.

Material studied	Weighed portion, g	Cations						Anions							pH of doubly distilled water	pH of hydrous extract	Formula for salt composition of extract
		Na^+	K^+	Ca^{++}	Mg^{++}	Σ_κ	HCO_3''	Cl'	F'	$HSiO_3'$	Σ_V						

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TABLE 2. Results of microchemical analyses of bulk hydrous extracts from minerals of the fluorite-phenacite-bertrandite association.

Material studied	Weighted portion, g		Cations					Anions					pH of doubly distilled water	pH of hydrous extract	Formula for salt composition of extract
			Na^+	K^+	Ca^{++}	Mg^{+++}	Σ_K	HCO_3''	Cl'	F'	$HSiO_3$	Σ_A			
Fluorite with phenacite segregation	100.0	mg/250 mlit	0.50	3.42	7.50	not det.	4.55	4.55	0.25	1.89	3.39				
		mg/Eq 250 mlit	0.022	0.088	0.347	—	0.484	0.075	0.007	0.095	0.044	0.221	5.47	7.20	$[HCO_3]_{34}\cdot Fe[HSiO_3]_{20}Cl_3$ / $Ca_{77}Na_4K_{18}$
		mg-Eq % 250 mlit	4.5	18.2	77.3	—	100	34.0	3.0	43.0	20.0	100%			
Radial-fibrous phenacite	98.8	mg/250 mlit	0.73	0.80	6.25	0.70	—	17.92	0.36	0.90	3.07				
		mg/Eq. 250 mlit	0.032	0.021	0.312	0.058	0.423	0.294	0.010	0.047	0.040	0.391	5.47	8.12	$[HCO_3]_{75}\cdot F_3Cl_2[HSiO_3]_{10}$ / $Ca_{74}Na_7K_5Mg_{14}$
		mg-Eq % 250 mlit	7.5	5.0	73.8	13.7	100	75.2	2.5	12.0	10.3	100%			

Analyses carried out by Zh. Simkiv (L'vov University).

TABLE 3.

Mineral association	Mineral in which inclusions have been studied	Homogenization temperatures of gas-liquid inclusions with CO2	Homogenization temperatures of pure CO_2 inclusions	Density of liquid carbon dioxide, g/cm^3	Pressure (atm) at time of homogenization
Fluorite-phenacite-bertrandite	Fluorite	220° C	25.0° C	0.703	750
Quartz-fluorite-bertrandite	Elongate-prismatic quartz	220-200° C	26.0° C	0.66	620-680

They consist of milky quartz in the form of columnar and drusy aggregates with a small amount of fluorite and galena. At the contact, recrystallization of fluorite and redeposition of the box-like crystals of bertrandite are observed.

In the quartz from these formations the inclusions are homogenized at 230-180° C. The inclusions are gas-liquid and liquid (the latter predominate). There are inclusions with carbon dioxide. The phase ratio (gas-liquid) is from 5-95 to 30-70%.

Subsequent carbonatization and the formation of carbonate, quartz-, and chlorite-carbonate veinlets and veins with bavenite, milarite, fluorite, and galena are widely developed in the deposit and have been superimposed on the metasomatites of the preceding phases, especially the skarns and the upper parts of the ore bodies. The carbonate replaces all the minerals, including phenacite and bertrandite, as a result of which a carbonate-bavenite association develops. Milarite is probably formed in the forefront of mineral formation as a result of the influence of carbonic acid solutions on phenacite and bertrandite and the solution of beryllium-bearing vesuvianite and fluorite. During the subsequent interactions between the residual carbonate solutions and milarite, redeposition of beryllium took place in the form of bavenite. The deposition of chlorite has been achieved under conditions of high activity of CO_2 and increased potential of sodium. The sequence of mineral formation is as follows: albite, fluorite, milarite, carbonate, chlorite, bavenite, and galena. Milarite and calcite have been studied from this mineral association.

Light-green prismatic crystals of milarite form a segregation in the thin (up to 4 cm) veinlets of coarsely crystalline calcite of white color. In the milarite, only secondary mono-phase inclusions have been observed, arranged along the cracks and oriented parallel to the length of the crystal. In the calcite containing the milarite segregations there are numerous two-phase gas-liquid inclusions, often oval in shape (up to 0.01 mm long); less frequently the inclusions have the shape of four-sided prisms. The ratio of gas and liquid phases is 20-80%. All the inclusions studied were homogenized into the liquid phase only at 220-210° C. Such an order of temperature of formation is also typical of milarite. Therefore the mineral-thermometric data obtained demonstrate the inaccuracy of existing ideas on the exceptionally low-temperature conditions of the formation of milarite. Judging by the data on the homogenization of the inclusions, carbonatization took place at 220-120° C.

Mineralization ended with the formation of veins and veinlets of apple-green chalcedonic and opaline quartz in the zones of fractures. In the fluorite-beryllium metasomatites, superimposition of opal-chalcedony mineralization has not caused substantial alterations. A local solution and redeposition of carbonates and partly of fluorite have been observed, sometimes with a small amount of galena.

Fluorite and calcite have been studied from this association, because the small dimensions (0.0005 mm) of the inclusions in the opaline quartz do not permit measurement of their homogenization temperatures. The light-violet fluorite is characterized by a high saturation in monophase inclusions, arranged along the cracks. In individual cases, segregated two-phase inclusions of irregular fringed shape up to 0.02 mm in size have been observed. During heating they are homogenized into the liquid phase at 85-80° C. In the light-green fluorite associated with white coarsely crystalline calcite, mono- and two-phase inclusions have been identified, having the shape of irregular tetrahedra, up to 0.01 mm in size. The two-phase gas-liquid inclusions contain in all about 5% of the gas phases and are homogenized at a temperature of 45-50°C. Inclusions are very rare in the calcite, with monophase liquid types predominating, located along the cracks. The primary gas-liquid inclusions having the shape of flat rhombohedra and elongate prisms (up to 0.01 mm in size) are homogenized into the liquid phase at 170-150° C (1) and down to 90-80° C. Fluorite

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fills the cavities in the calcite. Therefore the temperature values obtained for homogenization of the inclusions in calcite and fluorite unequiv-ocally indicate the order of precipitation of the minerals studied. Hence this association was formed over a wide temperature range (170-45° C), which makes it possible to esti-mate the temperatures of the late silicic meta-somatism.

CONCLUSIONS

1. The processes of hydrothermal meta-morphism preceded ore formation, and took place at 550-350° C (see table 1).

2. The formation of the fluorite meta-somatites with phenacite and bertrandite, that is the ore formation itself, began from hydro-thermal solutions at 400-350° C and ended at 200-140° C and pressures of 750-620 atm, which are higher than assumed by some inves-tigators (1, 4). The solutions were enriched in CO_2 with high density (0.66-0.703 g/cm^3). The gas phase consists of CO_2 and CH_4.

3. The replacement of phenacite by ber-trandite in time (substitution) and space (verti-cal zonation) was controlled by lowering of temperature and increase in the alkalinity of the solutions toward the rear part of the meta-morphic front. The role of the temperature factor in the crystallization of phenacite and bertrandite has been demonstrated in the work of G.V. Bukin (2), who recorded that at tem-peratures below 300° C the amount of bertrand-ite increases with respect to phenacite, and depending on the degree of lowering of tempera-ture, the bertrandite intensely corrodes the phenacite.

4. The subsequent low-temperature (230-180° C) quartzification, intensely developed in the upper horizons of the ore bodies, was accompanied by corrosion of the bertrandite and its recrystallization.

5. The carbonatization which replaced it was characterized by the breakdown of phena-cite and bertrandite and the redeposition of beryllium in the forefront of carbonatization in the form of milarite (200-150° C), and of bavenite in the rear part of the front (150-100 C).

6. Beryllium minerals did not appear in the phase of opaline and chalcedonic quartz veins, which terminated the mineral formation (170-45° C) in the deposit.

7. The above information emphasizes the regular lowering of temperatures of mineral formation from the beginning to the end of the stages, established in other rare-metal deposits. The temperature of commencement of each subsequent phase is 20-100° C higher than the end of the preceding phase.

8. During an analysis of the sequence of development of the processes of hydrothermal metamorphism, the changes in the mineral parageneses and alterations in the chemical composition of the rocks are expressed in the regular evolution in the activities of the com-ponents (Na-Si-Na-K-F, Be-Si-Ca-Si), re-flecting the change in the regime of the acid-alkaline condition of the solutions.

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ALLANITE FROM THE MOUNT WHEELER AREA, WHITE PINE COUNTY, NEVADA[1]

DONALD E. LEE AND HARRY BASTRON, *U. S. Geological Survey, Menlo Park, California.*

ABSTRACT

Previous workers have shown that allanite can contain up to several per cent beryllia. Accessory allanite from a quartz-monzonite stock exposed near the area of beryllium mineralization in the Snake Range of eastern Nevada contains less than 2 ppm beryllium. This fails to support the hypothesis of a relation between the intrusive rock and the beryllium mineralization.

INTRODUCTION

The occurrence of beryllium minerals at the Mount Wheeler mine in the Snake Range, White Pine County, Nevada, was first described by Stager (1960). Whitebread and Lee (1961) report additional discoveries of beryllium minerals more than a mile north of the Mount Wheeler mine, and present information on the areal geology of the "Wheeler limestone" member that is host to the beryllium mineralization. Whitebread and Lee (1961) also describe the spatial relations between the beryllium deposits and a quartz-monzonite stock that is exposed just north and east of the mineralization in a westward-trending band 1 to 3 miles wide. They also note that there is no apparent evidence to support the working hypothesis of a direct relation between the beryllium mineralization and the igneous rocks in this area, even though the quartz-monzonite stock may be present at depth below the Mount Wheeler mine.

In order to further test such a working hypothesis, a study of the area of intrusive outcrop is in progress. It is already clear that the texture, mineralogy and degree of alteration of this intrusive are rather widely variable from place to place, and it is possible that more than one intrusive phase is represented in the total outcrop area of about 20 square miles (see the maps of Drewes, 1958, and Whitebread, *et al.*, 1962). One part of the intrusive is distinct from the rest in that it contains epidote and allanite as persistent accessory minerals. The presence of allanite is especially interesting here, for this mineral has been reported to contain significant amounts (as much as 5.5 per cent) of BeO (see for example Beus, 1956; Warner, *et al.*, 1959).

The allanite-bearing "phase" of the stock includes the entire portion of the igneous outcrop area (about 5 square miles) drained to the east by Snake Creek (see map of Drewes, 1958). It is a medium-grained rock that is slightly porphyritic in places. The rock is almost always well-jointed

and the sets within the system, in order of consistency, typically have these approximate trends:

(1) N. 40°E., steep SE to 90°
(2) N. 40°W., moderate NE or SW to 90°
(3) E.–W., moderate N. or S. to 90°

The N. 40°E. set may carry aplites (garnet-bearing) and/or quartz veinlets; these are not abundant. Silicification is rather common along the planes of the N. 40°E. set; because of this the joints often stand out about an inch high and an inch or two wide on weathered surfaces. This silicification locally is accompanied by a concentration of fine-grained epidote (but not allanite). Inclusions of finer-grained more mafic material up to several inches across are common in the allanite-bearing "phase" of the quartz-monzonite stock, but they are rare in other parts of the intrusive. These inclusions are tentatively interpreted to represent fragments of shaly rock in process of assimilation.

CHEMICAL AND PHYSICAL PROPERTIES OF ALLANITE

In order to determine the beryllium and rare-earth contents of the accessory allanite that is present in the intrusive "phase" described above, a pure fraction was recovered from sample 38-MW-60, which was collected at an elevation of 8520 feet on the northeast side of the Snake Creek road, at 38°55'52" N. and 114°15'26" W. (see maps of Drewes, 1958, and Whitebread, *et al.*, 1962). The specific gravity of the allanite analyzed was determined in Clerici solution by means of the suspension method to be within the range 3.88–4.02. In thin sections the mineral is present as euhedral crystals 0.5–1.5 mm long, usually associated with epidote, biotite and sphene. The allanite is commonly twinned (Fig. 1) and shows little evidence of zoning within individual crystals. There is no evidence of metamictization, although a few of the euhedral crystals exhibit a very narrow, discontinuous reaction rim (Fig. 1).

Indices of refraction of the analyzed allanite were measured in sodium light by means of the immersion method. The other optical properties listed were determined by means of universal stage plots of three twinned and two untwinned crystals.

$\alpha = 1.762 \pm .005$
$\beta = 1.782$
$\gamma = 1.795$
$\gamma - \alpha = .032$
Biaxial (−); 2V near 55°
  X = very pale brown
  Y = light brown
  Z = reddish brown
  Z > Y > X

Dispersion r > v, strong
Optic plane = 010
Composition plane of twinning = 100
$X \wedge c = 32°$

0.5 mm
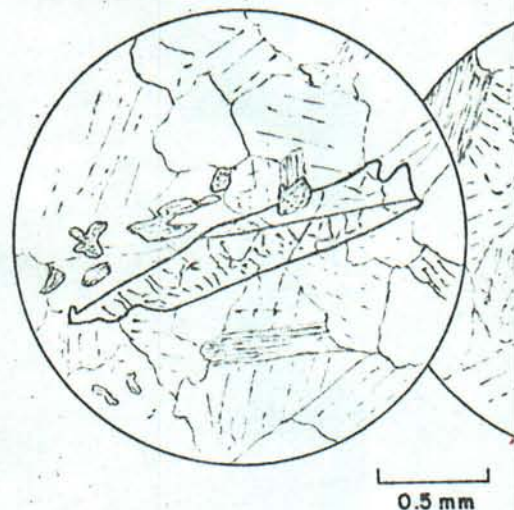
FIG. 1. Twinned allanite from the Mount Wheeler
A. (left) Composition plane (100) inclined at an a
Note the epidote [2V = 80(−)] intergrown with the s
from the free end of this epidote. The irregularly-shap
epidote. Other minerals are quartz, feldspar and biotit

B. (right) Composition plane (100) inclined at an
The material at the ends of the allanite crystal is interp
ment of a reaction rim. The black blebs in the allanite
appears to be quartz. The mineral with high relief to t
irregularly-shaped patches with high relief in feldsp
are biotite and quartz.

There is little mention of allanite twinn
(1937) describes an occurrence, but gives
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(1951) describes an unusual linear feature i
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A quantitative spectrographic analysis
from sample 38-MW-60 (Table 1) faile
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PROPERTIES OF ALLANITE

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Dispersion r>v, strong
Optic plane = 010
Composition plane of twinning = 100
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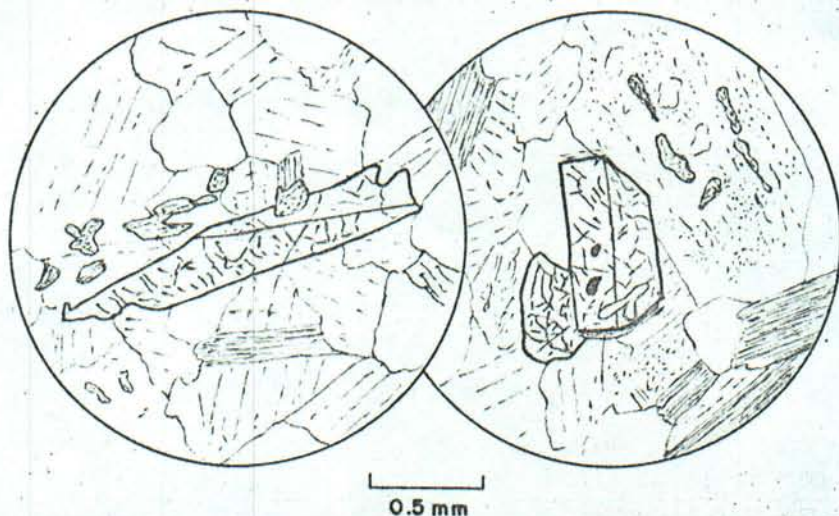
FIG. 1. Twinned allanite from the Mount Wheeler area, White Pine County, Nevada.

A. (left) Composition plane (100) inclined at an angle of 50° from the perpendicular. Note the epidote [2V = 80(−)] intergrown with the smaller twin; biotite is growing out from the free end of this epidote. The irregularly-shaped patches with high relief are also epidote. Other minerals are quartz, feldspar and biotite.

B. (right) Composition plane (100) inclined at an angle of 9° from the perpendicular. The material at the ends of the allanite crystal is interpreted to represent incipient development of a reaction rim. The black blebs in the allanite are unidentified; the light inclusion appears to be quartz. The mineral with high relief to the left of the allanite is epidote. The irregularly-shaped patches with high relief in feldspar are also epidote. Other minerals are biotite and quartz.

There is little mention of allanite twinning in the literature. Russell (1937) describes an occurrence, but gives no crystallographic data except to state that extinction is inclined to the composition plane. Hutton (1951) describes an unusual linear feature in allanite, but concludes from the optical behavior of the mineral that this feature does not seem to represent twinning. Volborth (1962), writing on allanite pegmatites in Nevada and California, states: "Many of the allanite crystals are apparently twins with (100) as composition plane (twin-plane?)."

A quantitative spectrographic analysis of the pure accessory allanite from sample 38-MW-60 (Table 1) failed to detect the presence of beryllium; thus if this mineral contains any beryllium, it probably is present in amounts of less than 2 parts per million. In view of the fact that allanite sometimes contains significant amounts of beryllium, the present results certainly do not support the idea of a direct relation between the beryllium mineralization and the igneous rocks in this area. In

TABLE 1. SPECTROGRAPHIC ANALYSIS OF ALLANITE FROM SAMPLE 38-MW-60[1]
Harry Bastron, analyst

Rare-earth and thorium oxides (weight per cent)		Rare-earth elements, atomic per cent of total rare earths	
Y_2O_3	0.2	Y	1.4
La_2O_3	5.4	La	26.1
CeO_2	10.4	Ce	47.6
Pr_6O_{11}	1.1	Pr	5.1
Nd_2O_3	3.0	Nd	14.0
Sm_2O_3	0.8	Sm	3.6
Eu_2O_3	0.05	Eu	0.2
Gd_2O_3	0.2	Gd	0.9
Tb_4O_7	0.1	Tb	0.4
Dy_2O_3	0.1	Dy	0.4
Ho_2O_3	0.03	Ho	0.2
Er_2O_3	0	Yb	0.02
Tm_2O_3	0		
Yb_2O_3	0.005	Σ La+Ce+Pr	78.9
Lu_2O_3	0	Ce/(Nd+Y)	3.1
ThO_2	0.9	Ce/(La+Nd)	1.2
Total	22.3		
Looked for but not detected: Be			

[1] See Bastron, *et al.* (1960) for a description of the spectrographic method used.

this regard there are, however, two facts to bear in mind. First, as noted above, it is possible that more than one intrusive phase is represented in the outcrop area of this quartz-monzonite stock. Secondly, all beryllium-bearing allanites reported to date are from pegmatitic environments, whereas the allanite described here is present as an accessory mineral in a medium-grained quartz monzonite.

Murata, *et al.* (1957) discuss the systematic variation of rare-earth elements in cerium-earth minerals. These same authors introduce as an index of composition of all cerium-earth minerals with respect to the rare-earth elements a quantity called sigma (Σ), which is the sum of the atomic percentages of La, Ce and Pr. They also point out that a highly selective fractionation of the rare-earth elements is more commonly attained in alkali rocks than in granitic rocks, and therefore cerium-earth minerals from alkalic rocks usually have the higher Σ values. The allanite described here (Table 1) has $\Sigma = 78.90$; this is relatively high for a cerium-earth mineral from a granitic rock. Further work is in progress to determine the range in Σ values of the accessory allanite in this intrusive rock, and to investigate further the possibility of a direct relationship between the intrusive rocks and the beryllium mineralization exposed in this area.

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Bastron, analyst

Rare-earth elements, atomic per cent of total rare earths	
Y	1.4
La	26.1
Ce	47.6
Pr	5.1
Nd	14.0
Sm	3.6
Eu	0.2
Gd	0.9
Tb	0.4
Dy	0.4
Ho	0.2
Yb	0.02
Σ La+Ce+Pr	78.9
Ce/(Nd+Y)	3.1
Ce/(La+Nd)	1.2

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mineralization exposed in this area.

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ACCESSORY SPHENE FROM HYBRID ROCKS OF THE MOUNT WHEELER MINE AREA, NEVADA

By DONALD E. LEE,[1] ROBERT E. MAYS,[2] RICHARD E. VAN LOENEN,[1] and HARRY J. ROSE, JR.,[3] [1]Denver, Colo., [2]Menlo Park, Calif., [3]Washington, D.C.

Abstract.—Chemical data, unit-cell parameters, and optical properties are listed for 14 accessory sphenes recovered from hybrid granitoid rocks exposed north of the Mount Wheeler mine, White Pine County, Nev. The environment of these sphenes is well known from a careful field and laboratory study that included chemical, spectrographic, normative, and modal analyses for each of the rocks from which they were separated. These sphenes contain a rather large assemblage of rare-earth and other minor elements, and their physical properties and major- and minor-element contents do not show the same obvious response to whole-rock chemistry observed for their coexisting allanites and zircons. Four sphenes contain detectable amounts of Bi, and 13 sphenes contain Mo in the general range of 7–20 parts per million; the sphene structure appears to be a preferred site for the Bi and the Mo present in these rocks. All 14 sphenes contain a much less basic (and heavier) assemblage of rare earths than do the allanites that coexist with them.

Granitoid rocks crop out a few miles north of the Mount Wheeler mine in the southern part of the Snake Range, about 50 miles southeast of Ely, Nev. These rocks are exposed in intrusive contact with Prospect Mountain Quartzite, Pioche Shale, and Pole Canyon Limestone, all of Cambrian age (Drewes, 1958). They range in composition from grandiorite with a CaO content of more than 4.5 percent to quartz monzonite with a CaO content of about 0.5 percent, and a detailed field and laboratory study (Lee, unpub. data) has shown that this range in composition is related to magmatic assimilation of the chemically diverse host rocks. The change from high to low CaO values is rather systematic over a horizontal distance of about 3 miles, and other major elements (and most minor elements) tend to vary either directly or inversely with CaO. Amounts of quartz, microcline, plagioclase, and biotite respond to the major-element chemistry of these hybrid rocks. With a few notable exceptions the well-defined chemical and mineralogical gradients exposed are much what one would expect to find in a series of differentiates. The relation between the chemistry and accessory-mineral contents of these rocks was described by Lee and Dodge (1964), who found a sympathetic increase of sphene with CaO.

This paper presents minor-element analyses and optical data for 14 accessory sphenes recovered from these hybrid rocks. We also list major-element data for 13 of these sphenes and unit-cell parameters for 8. The location, major- and minor-element analyses, norms, and modes for the granitoid rocks from which these constituent sphenes were recovered will be presented in a later paper. The chemistry and physical properties of some of the accessory minerals coexisting with these sphenes have been discussed by Lee and Bastron (1967) and Lee, Stern, Mays, and Van Loenen (1968).

SPHENE ANALYSES AND PHYSICAL PROPERTIES

After the preliminary work described by Lee and Dodge (1964), the sphene concentrates were ground to −150 mesh (about 100 microns) and washed in tap-water to remove material smaller than about 40 microns. Purification was achieved by centrifuging repeatedly in methylene iodine and by use of the Frantz isodynamic separator. As the final step in the cleaning, each sphene fraction was subjected to ultrasonic vibration in distilled water for about an hour. With the exception of sample 190–MW–61, each sphene analyzed was at least 99 percent pure. During optical study of the analyzed fractions no discrete grains of impurity were found, but when each fraction was observed in oil with an index refraction equal to the *a* index of the sphene, tiny euhedral inclusions were found in some of the grains. From their optical properties these inclusions appear to be zircon and apatite, minerals that tend to be closely associated with sphene in these rocks.
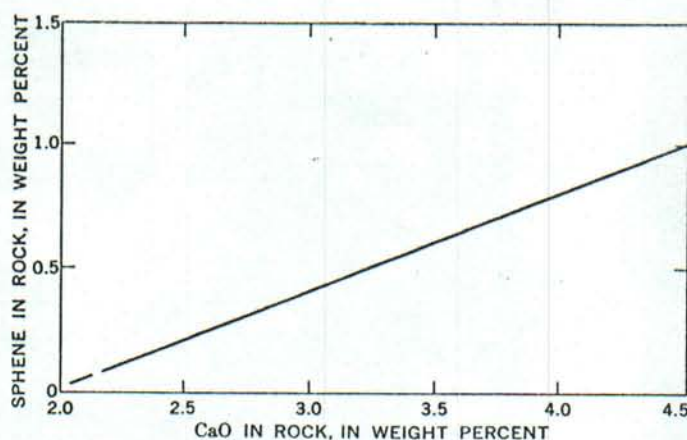
FIGURE 1.—Relation between contents of CaO and accessory sphene in hybrid granitoid rocks of the Mount Wheeler mine area, Nevada.

As background for the following discussion, the general relation between weight percentages of sphene and CaO in these hybrid rocks is shown in figure 1. However, although almost all rocks having less than 2.2 percent CaO are practically devoid of sphene and the most mafic rocks generally contain the most sphene, we emphasize that the relation shown in figure 1 is idealized and is not nearly as systematic and well defined as the covariance between amounts of CaO and other accessory minerals such as apatite, allanite, and zircon (Lee and Dodge, 1964).

Optical properties and unit-cell parameters

The sphenes analyzed are listed (table 1) according to CaO content of the rocks from which they were recovered. The a refractive indices are all in the rather narrow range of 1.895–1.910. Optic axial angles were not systematically determined, but from inspection during mineral purification work all appear to be 25–35(+), and all grains checked show the typically strong sphene dispersion, with r>v. Unit-cell parameters (table 1) were calculated for eight of the analyzed sphenes by least-squares refinement of powder diffractometer data, using an internal standard of CaF_2 and a self-indexing computer program developed by Evans, Appleman, and Handwerker (1963). All the results are in rather good agreement with the data for sphenes listed by Deer, Howie, and Zussman (1962, p. 69).

Major elements

Thirteen of the sphenes were analyzed for SiO_2, Al_2O_3, TiO_2, total iron(as Fe_2O_3), and CaO by means of X-ray fluorescence (table 1). In general the major-element chemistry is rather similar from one sample to another. The TiO_2 contents of these sphenes tend to increase as these hybrid rocks become more mafic (fig.

2), but variations in amounts of other oxides appear to be random and unrelated to chemical differences among whole rocks.

Sphene 27–DL–61, highest in TiO_2 and CaO and lowest in SiO_2, also is the only one in table 1 recovered from a large xenolithic mass, where assimilation is relatively incomplete. Related investigations in the area show that hornblende is dominant over biotite in such xenolithic masses where assimilation is only incipient. The high TiO_2 content of sphene 27–DL–61 probably results at least in part from the dearth of coexisting biotite, for where biotite is well developed it is the main reservoir of the TiO_2 present in the area's hybrid rocks, much as has been described for granitoid rocks elsewhere by Znamensky (1957). If we assume that sphene in the more mafic parts of the main intrusive phase originally formed in equilibrium with larger amounts of hornblende (since replaced by biotite), the same reasoning outlined for sphene 27–DL–61 might also help to explain the TiO_2 trend shown in figure 2. The tendency for hornblende in hybrid rock to be replaced by biotite as assimilation proceeds has been recognized by many previous writers.
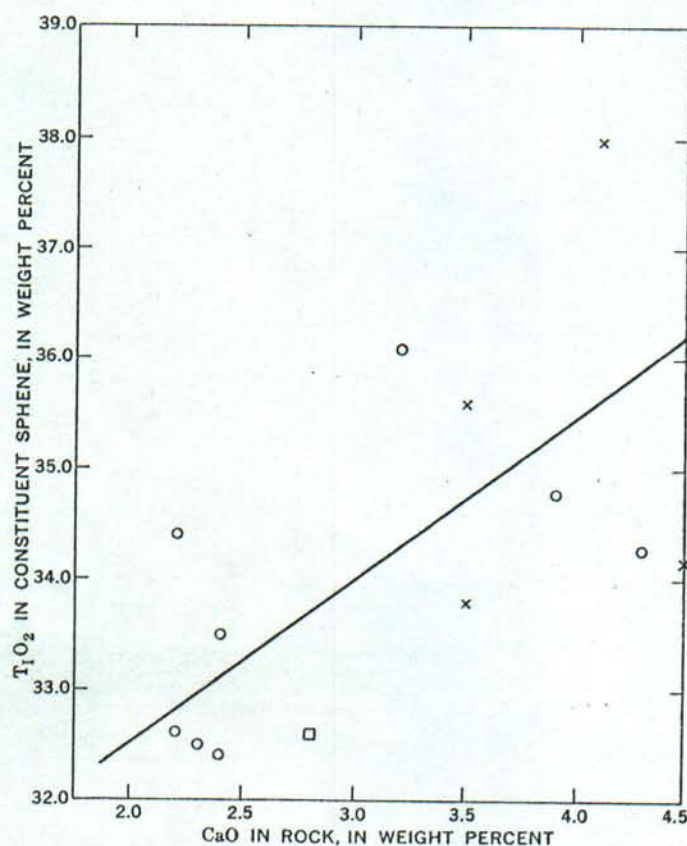
FIGURE 2.—Relation between CaO content of rock and TiO_2 content of constituent sphene. ○, sample from main intrusive phase; ×, xenolith; □, lamprophyre.

TABLE 1.—*Analytical data and physical properties for accessory sphenes from the Mount Wheeler mine area, Nevada*

[Samples arranged in order of increasing CaO content. CaO analyses by Paul Elmore, Samuel Botts, H. Smith, and Gillison Chloe. Indices of refraction: α determined in sodium light by the immersion method, β and γ not determined. Cell parameters were obtained by least-squares refinement of powder diffractometer data by R. E. Van Loenen, using a self-indexing computer program developed by Evans, Appleman, and Handwerker (1963). The internal standard was CaF2. Margin of error for a, b, and c was ±0.004 A.. Semiquantitative spectrographic analyses by R. E. Mays. Results are based on their identity with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth, and are reported arbitrarily as midpoints of these brackets, 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, respectively. The precision of a reported value is approximately plus or minus one bracket at 63-percent, or two brackets at 95-percent confidence]

Sample No.	190-MW-61	14-MW-60	36-DL-61	8-DL-61	40A-MW-60	31-DL-61	150-MW-60[1]	152-MW-61	40B-MW-60[2]	126-MW-61[2]	43-DL-61	27-DL-61[2]	16-MW-60	98-DL-61[2]
CaO in rock (weight percent)	1.2	2.2	2.2	2.3	2.4	2.4	2.8	3.2	3.5	3.5	3.9	4.1	4.3	4.5
α Index of refraction														
α (±0.005)	1.900	1.902	1.900	1.902	1.900	1.895	1.900	1.905	1.908	1.900	1.903	1.910	1.902	1.898
Cell parameters														
a	----	6.544	6.549	6.546	6.543	6.546	6.551	Not determined	----	----	6.543	Not determined	----	6.539
b	----	8.696	8.701	8.698	8.703	8.700	8.699		----	----	8.674		----	8.703
c	----	7.435	7.439	7.437	7.436	7.437	7.435		----	----	7.435		----	7.433
Volume (±0.2A³)	----	367.0	367.6	367.2	367.1	367.3	367.9		----	----	366.2		----	366.9
β (±2°)	----	119°50'	119°52'	119°52'	119°54'	119°52'	119°44'		----	----	119°49'		----	119°51'
Major element oxides (determined by X-ray fluorescence)														
SiO2	----	35.6	31.9	31.0	34.0	30.8	32.9	31.5	35.3	33.9	34.6	27.0	30.1	31.1
Al2O3	----	3.70	3.60	3.60	3.75	3.60	3.40	3.06	3.20	2.90	3.00	3.30	3.65	3.60
TiO2	----	32.6	34.4	32.5	32.4	33.5	32.6	36.1	33.8	35.6	34.8	38.0	34.3	34.2
Fe2O3[3]	----	1.90	1.65	1.80	1.85	2.25	1.90	1.65	1.70	1.85	1.60	2.25	1.75	2.20
CaO	----	26.2	26.1	25.2	26.6	27.5	27.0	27.6	26.0	27.1	25.6	30.2	26.4	26.6
Semiquantitative spectrographic analyses (weight percent)[4]														
Mg	0.15	0.02	0.01	0.03	0.02	0.03	0.03	0.05	0.007	0.015	0.05	0.03	0.15	0.05
Na	.03	----	----	.03	----	----	----	----	----	----	----	----	----	----
P	.15	----	----	----	.15	----	----	----	----	----	----	----	----	----
Mn	.07	.07	.07	.07	.07	.07	.05	.05	.07	.07	.07	.07	.1	.07
Ba	.007	.001	----	.002	.002	.005	.03	.005	.0005	.1	.03	.07	.05	.001
Be	----	----	----	----	.0003	----	----	.0007	----	----	----	.07	.01	----
Bi	.01	.002	.005	.005	.005	.005	.002	.002	.0003	----	----	----	----	.0015
Cr	.002	.005	.002	.0005	.007	.0007	.003	.007	.0007	.003	.01	.02	.007	.0005
Cu	.0015				.001		.001	.0015	.0005	.0005	.0005	.002	.002	
Ga	.001	.0007	.0007	.002	.002	.002	.0015	.001	.0007	.001	.015	.1	.001	.007
Mo	.0007	.15	.15	1	1	.07	.001	1	.002	.015	.1		.07	.002
Nb	.07	.0015			.002	.002	.001	.007	.005	.001	.005	.002		.05
Pb	.015	.05	.005	.007	.005	.007	.001	.007	.01	.01	.005	.01	.002	.007
Sc	.05	.03	.02	.02	.02	.03	.02	.015	.02	.02	.015	.03	.015	.02
Sn	.03	.02	.003	.003	.01	.003	.007	.005	.003	.015	.005	.002	.007	.003
Sr	.002	.003												
Th	.7													
U	.2													
V	.15	.2	.2	.2	.2	.15	.15	.15	.15	.2	.15	.2	.15	.15
Zr	.2	.07	.07	.03	.07	.07	.07	.1	.05	.1	.07	.1	.07	.1

[1] Sphene from lamprophyre.
[2] Sphene from xenolith.
[3] Includes total iron.
[4] Leaders (....) indicate that element was looked for but not found.

Minor elements

The minor-element contents of these sphenes (except for rare earths) are listed in table 1. The suite of elements represented is rather large, although it is well recognized that the sphene structure often carries significant amounts of elements not represented in the type formula. (See, for example, Zabavnikova, 1957; Deer and others, 1962).

As noted previously, the sample of sphene 190–MW–61 analyzed probably was less than 99 percent pure, but minor-element data for it are included here because it is the only sphene fraction we were able to obtain from a rock having less than 2.2 percent CaO. Only about 10 milligrams of this mineral was recovered from more than 1,000 grams of crushed rock. The sphene grains were etched and pitted, suggesting disequilibrium with other minerals present in the rock.

Each of the other 13 sphenes analyzed was more than 99 percent pure. However, in view of the fact that some of the tiny inclusions already described probably are zircon, some of the Zr content shown in table 1 may not be present in the sphene-structure. For example, as little as 0.1 percent zircon contamination would be equivalent to about 700 parts per million Zr. The high P content is not so readily explained, but it seems likely that P might be part of the structures of some sphenes in table 1, even though some of the tiny inclusions described appear to be apatite, because about 0.8 percent apatite would be required to produce a P content of 1,500 parts per million.

The most notable aspect of the hybrid rock exposed north of the Mount Wheeler mine area is the large number of rather systematic chemical and mineralogical trends that have been found to accompany the general change from felsic to mafic representatives. Even major- and minor-element contents of constituent accessory minerals exhibit these trends. Such systematic differences, if indeed they are present in these sphenes, are not great enough, however, to be apparent from the semiquantitative data in table 1. These sphenes (with the exception of sample 190–MW–61 already described) are well crystallized and are usually seen in thin section as well-formed euhedra. There is nothing to indicate that any of these sphenes is secondary or deuteric.

In view of the summary works cited above, the significance of most of the minor-element data in table 1 is evident, but the Mo and Bi values deserve comment. Sphene must have scavenged most of the Mo present in the magmatic environment, for the element was rarely detected in any minerals coexisting with these sphenes. Sphene must have scavenged Bi too, for this element was not detected in any other minerals present in these rocks.

Rare earths

Rare-earth contents of the sphenes are listed in table 2, along with calculated atomic percentages of the rare-earth assemblage present in each sphene. Also listed for each is the quantity $\Sigma La + Ce + Pr$ (in atomic percentage of total rare-earth elements) as a numerical index of the composition and of the stage of fractionation attained by the rare-earth elements. This quantity sigma ($\Sigma La + Ce + Pr$) was introduced by Murata, Rose, and Carron (1953) in a study of the total range of variation in the composition of monazite with respect to the rare-earth elements. Later studies (especially Murata and others, 1957) confirmed that this quantity sigma is meaningful in comparing such analyses, and it has therefore been used (table 2) in appraising the rare-earth contents of accessory minerals that coexist with the sphenes.

Some 21 allanite and 13 monazite samples from these hybrid rocks have sigma values that vary from 61.3 to 80.9 atomic percent, which is an appreciable range of composition in terms of the rare-earth elements (Lee and Bastron, 1967). Moreover, sigma values of the allanites and monazites vary directly with CaO content of their host rocks, and allanites from the most mafic rocks show a concentration of the most basic rare earths (La, Ce, and Pr). Rare-earth contents of 25 accessory zircons from these hybrid rocks are much smaller than amounts listed for the sphenes in table 2, but generally they express the same trend as that shown by the allanites and monazites; that is, the heavier lanthanides are present in largest amounts in zircons from the more felsic rocks, whereas the lighter and more basic lanthanides increase in abundance with increasing lime content of the rock (Lee and others, 1968).

The analyses of sphenes in table 2 fail to express the same trend, for the sigma values of the sphenes are not very obviously related to the CaO contents of the rocks from which they were recovered. Were the trend for sphenes as well defined as for allanites, monazites, and zircons, it would be clearly shown by even the semiquantitative data in table 2. Sphenes, then, do not show the regular minor-element trends found in minerals coexisting with them.

Each sphene in table 2 has a sigma value much lower than that of its coexisting allanite (Lee and Bastron, 1967), indicating a much less basic and heavier assemblage of rare earths in the sphenes. In discussing the distribution of rare earths in accessory sphene, Uskov (1967) concluded, after a study of sphenes collected from several widely diverse geologic environments, that the chemistry of the rock-forming medium is more important than crystallochemical selection in determining

TABLE 2.—*Rare-earth contents of accessory sphenes from the Mount Wheeler mine area, Nevada*

[Semiquantitative spectrographic analyses by R. E. Mays. General limitations of the method are given in table 1]

Rare earths in sphene (weight percent)

Sample No.	190-MW-61	14-MW-60	36-DL-61	8-DL-61	40A-MW-60	31-DL-61	150-MW-60[1]	152-MW-60	40B-MW-61	126-MW-61[2]	43-DL-61	27-DL-61[1]	16-MW-60[1]	98-DL-62[2]
CaO in rock (weight percent)	1.2	2.2	2.2	2.3	2.4	2.4	2.8	3.2	3.5	3.5	3.9	4.1	4.3	4.5
Y	0.15	0.3	0.3	0.2	0.2	0.2	0.15	0.2	0.2	0.2	0.2	0.3	0.15	0.15
La	.1	.07	.07	.05	.05	.05	.02	.03	.07	.1	.05	.05	.02	.07
Ce	.5	.2	.2	.2	.5	.5	.15	.2	.5	.5	.5	.5	.15	.5
Pr	.05	.07	.07	.05	.07	.07	0	.02	.1	.1	.07	.07	0	.1
Nd	.3	.7	.7	.5	.5	.5	.1	.3	.7	.7	.7	.7	.15	.7
Sm	.07	.2	.2	.3	.3	.15	.05	.15	.3	.3	.2	.5	.07	.2
Eu	0	.02	.02	.03	.03	.03	.01	.02	.02	.03	.03	.03	.01	.03
Gd	.03	.07	.07	.2	.2	.15	.05	.1	.2	.2	.2	.5	.05	.15
Tb	0	0	0	.005	.005	0	0	0	.005	.005	.005	.015	0	.005
Dy	.03	.07	.07	.15	.2	.1	.05	.1	.15	.15	.1	.2	.05	.1
Ho	.005	.02	.02	.02	.02	.015	.005	.01	.02	.02	.015	.015	.005	.015
Er	0	.03	.03	.03	.03	.03	0	.02	.03	.02	.02	.05	0	0
Tm	.007	.015	.015	.007	.007	.005	0	.007	.007	.007	.007	.01	.002	.005
Yb	.015	.015	.02	.015	.015	.015	.007	.015	.015	.01	.015	.02	.007	.02
Lu	.005	0	0	.003	.003	.003	0	.003	.003	.003	0	.003	0	0
Total	1.262	1.780	1.785	1.760	2.130	1.818	0.592	1.175	2.320	2.342	2.112	2.963	.664	2.045

Total rare-earth elements in sphene (atomic percent)

	190-MW-61	14-MW-60	36-DL-61	8-DL-61	40A-MW-60	31-DL-61	150-MW-60[1]	152-MW-60	40B-MW-61	126-MW-61[2]	43-DL-61	27-DL-61[1]	16-MW-60[1]	98-DL-62[2]
Y	17.9	25.0	24.9	17.7	14.7	16.9	36.0	25.4	13.5	13.3	14.7	15.8	32.6	11.5
La	7.7	3.7	3.7	2.8	2.3	2.7	3.0	2.5	3.0	4.3	2.4	1.7	2.7	3.4
Ce	37.8	10.6	10.6	11.2	23.3	26.8	22.9	16.2	21.4	21.2	23.3	16.8	20.6	24.3
Pr	3.7	3.7	3.7	2.7	3.3	3.8	0.7	1.6	4.2	4.2	3.3	2.4	0	4.8
Nd	22.0	36.0	35.9	27.3	22.6	26.0	14.7	23.5	29.1	28.8	31.6	22.8	20.0	33.0
Sm	5.0	9.8	9.8	15.7	13.0	7.5	7.0	11.3	12.0	11.9	8.7	15.6	9.1	9.1
Eu	0	.97	.96	1.6	1.3	1.5	1.5	1.5	.79	1.2	1.3	.94	1.3	1.4
Gd	2.0	3.5	3.5	10.0	8.3	7.1	6.8	7.2	7.6	7.5	8.3	15.0	6.2	6.5
Tb	0	0	0	.25	.21	0	0	0	.18	.18	.20	.42	0	.19
Dy	1.9	3.2	3.2	7.2	8.0	4.7	6.6	7.0	5.5	5.4	4.0	5.8	6.0	4.2
Ho	.32	.89	.89	.96	.79	.67	.64	.70	.73	.71	.58	.42	.57	.61
Er	0	1.3	1.3	1.4	1.2	1.3	0	1.4	1.1	.71	.78	1.4	0	0
Tm	.42	.67	.67	.31	.27	.22	0	.46	.24	.24	.26	.27	.18	.19
Yb	.94	.67	.88	.71	.60	.66	.86	1.0	.54	.36	.58	.56	.75	.81
Lu	.32	0	0	.17	.13	.15	0	.24	.12	0	0	.09	0	0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Σ(La+Ce+Pr)	49.2	18.0	18.0	16.7	28.9	33.3	25.9	20.3	28.6	29.7	29.0	20.9	23.3	32.5

[1] Sphene from lamprophyre dike.
[2] Sphene from xenolith.

fractionation of rare earths in sphene. For the hybrid rocks in the Mount Wheeler mine area, in contrast, crystallochemical selection was more important than the chemistry of the rock-forming medium. In the terminology of Uskov, our sphenes contain a "selective yttrium" (as opposed to "selective cerium") assemblage of rare earths.

SUMMARY AND CONCLUSIONS

In the hybrid granitoid rocks exposed north of the Mount Wheeler mine the abundance of sphene tends to increase directly with lime content of the rock. However, when sphenes are compared to other minerals from the same rocks, their physical properties and major- and minor-element contents show relatively little response to whole-rock chemistry.

These sphenes contain a rather large assemblage of rare earths and other minor elements. They scavenged Mo and Bi, and they contain a heavier, less basic assemblage of rare earths than do the coexisting allanites.

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Occurrence of Nonpegmatite Beryllium in the United States

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and EUGENE N. CAMERON

NEVADA ONLY

·nese and tungsten. A sample from the deposit at Golconda contained 0.016 percent BeO, and one from Sodaville contained 0.0075 percent.

NEVADA

ELKO COUNTY

STAR MINE, HARRISON PASS

The deposits of the Star mine are in the Ruby Range on both sides of Harrison Pass Creek Canyon, about 2 miles east of the pass. They are readily accessible by road from Elko by way of Jiggs, thence by the road over Harrison Pass. The area is described briefly by Hess and Larsen (1921, p. 305); the deposits were mapped by M. R. Klepper and P. Joralemon of the U. S. Geological Survey in 1943.

The Ruby Range consists largely of a stock of biotite granite and quartz monzonite that intrudes limestone and quartzite of Paleozoic age. The contact east of Harrison Pass is very irregular; and many dikes and apophyses of aplitic granite cut the sediments, which have been metamorphosed to silicated marble and hornfels. Scheelite-bearing tactite occurs intermittently along the contact. Four ore bodies have been mined on the property of the Star mine and several others have been prospected. The principal workings, which are in the Main, North, and South ore lodes, were inaccessible in 1949. The No. 7 ore body and the ore bodies in the North opencut and the South shaft were examined briefly.

The North opencut exposes a tactite body along the irregular boundary between granite and marble. The body is 1 inch to 30 inches thick, not more than 20 feet long, and probably contains no more than 200 tons of rock. The tactite consists of garnet, diopside, epidote, quartz, and calcite.

The South shaft ore body is a tactite mass about 200 feet in strike length and 1 to 4 feet wide. A vertical shaft, 43 feet deep, has been sunk near the middle of the outcrop. From the bottom of the shaft a drift extends along the base of two stopes; the south stope is blind, the north stope extends to the surface. The tactite body appears to be cut off at depth either by a fault or by a change in strike of the contact of the granite and marble. Reserves are no more than a few hundred tons.

A belt about 1,500 feet wide along the irregular eastern margin of the granite stock consists of marble, silicate-bearing marble, and calc-silicate hornfels. The beds range from fractions of an inch to 3 feet in thickness. Garnet, diopside, and epidote are the principal minerals, but actinolite, idocrase, and tremolite characterize some beds.

Samples were taken of the metamorphosed rocks of the contact aureole, as well as of the tactite deposits. Sample descriptions and analytical results are given in the table 17.

TABLE 17.—*Beryllia in samples from Harrison Pass area*

Sample	Description	BeO (percent)
	NORTH OPEN CUT	
329–1039	Chip sample of aplitic granite 10 to 30 ft from tactite	0. 0002
1040	Chip sample of tactite	. 0044
1041	Chip sample altered aplitic granite immediately adjacent to tactite	. 0098
1042	Silicated marble 0 to 3 ft from tactite	<. 0001
	SOUTH SHAFT ORE BODY	
329–1043	Chip sample of tactite body, north end of south stope at its base	. 029
1044	Chip sample from tactite body, top of south stope	. 056
1045	Chip sample of silicated marble adjacent to tactite, bottom of north stope	<. 0001
1046	Chip sample of silicated marble adjacent to tactite, base of shaft	<. 0001
1047	Chip sample of granite outcrop adjacent to tactite, north of shaft	. 0078
	CONTACT-METAMORPHOSED ROCKS	
329–1048	Chip sample of recrystallized marble, 0 to 15 ft from contact	<. 0001
1049	Chip sample of blue and gray marble, partly silicified, 15 to 70 ft from contact	<. 0001
1051	Chip sample of blue and gray silicified limestone, 150 to 170 ft from contact	<. 0001
329–1054	Chip sample across beds of idocrase-bearing(?) marble, 345 to 365 ft along road from contact	<. 0001
1055	Chip sample of interbedded pure and silicated marble, 656 to 681 ft from contact	<. 0001
1057	Chip sample across beds of bluish-gray, fine- to medium-grained marble, 1,053 to 1,233 ft along road from contact	. 0008
1059	Chip sample across beds of blue-black limestone, 1,520 to 1,540 ft along road from contact	. 0008
1061	Chip sample of silicated marble and hornfels, south slope of Harrison Pass Creek Canyon, between No. 7 ore body and Main ore body	<. 0001
1063	Chip sample of porphyritic granite, summit of Harrison Pass	<. 0001

The analytical data clearly indicate that beryllium is contained in the tactite bodies and in the granite immediately adjacent to them. It appears to be lacking in the other rocks of the contact aureole and in the interior of the granite stock. Presumably the solutions that formed the tactite bodies and related tungsten ores were those which brought in beryllium. The beryllium-bearing mineral or minerals have not been identified. If most of the beryllium is in helvite, some byproduct recovery may be possible in connection with future mining of tungsten in the area.

GOOD HOPE BARITE MINE, TUSCARORA RANGE

The Good Hope mine is on one of a series of barite vein deposits in the Tuscarora Range. The mine is

reached by a road leading north to Lynn from U. S. Highway 40 at Carlin, Nev. At 7.4 miles from U. S. 40 and just south of the mouth of Maggie Creek Canyon, a mine road turns westward. The mine is about 1.3 miles from this point on the northeast side of a small canyon.

The deposit, as exposed in the main and upper working, is an irregular vein of massive, fine- to coarse-grained, white barite that apparently occupies a shattered zone in partly silicified interbedded limestone, shale, and sandstone. The vein strikes N. 38° W. and dips 70° to 80° E. The lower working consists of a 41-foot drift along the vein, which is 4 to 5 feet wide, and an adit that extends northward from the mouth of the drift. A chip sample (329–1071) of the vein from the upper working contain 0.0007 percent BeO.

HUMBOLDT COUNTY

GOLCONDA MANGANESE-TUNGSTEN DEPOSIT

The Golconda manganese-tungsten deposit is in the Edna Mountains about 3 miles east of Golconda. The mine is a short distance north of U. S. Highway 40 and immediately east of the road to the Getchell mine. The deposit has been described by Kerr (1940; 1946a, p. 171–173). It was mined for manganese during World War I and for tungsten during World War II. The deposit consists of layers of manganiferous ocher and calcareous tufa, with some rubble derived from underlying Triassic sedimentary rocks, and is capped by tufa and fanglomerate. The ore bodies extend northward along the slopes for about a mile. Toward the east they rest directly on the beveled edges of the Triassic sedimentary rocks, but toward the west an increasing thickness of sedimentary rocks intervenes between the deposits and the bedrock surface. A typical pediment-alluvial fan relation is indicated. The tungsten-bearing manganese oxides and ferruginous ocher, together with the tufa, were deposited by hot springs thought to have been most active during the Pleistocene epoch. Fissure veins in the underlying Triassic sedimentary rocks contain ore material similar to that in the overlying ocherous deposits.

For the present purpose the workings are divided into two groups: the north workings, which consist largely of opencuts and stopes, and the south workings, which are a series of large opencuts.

NORTH WORKINGS

The workings of this group may be subdivided into the northwest workings, which are a series of adits that lead to gently inclined stopes, and the Bed Springs Hill workings, which consist of opencuts around the eastern end of the hill and underground workings of unknown extent.

In the northwest workings, two parts of the stopes were sampled. The section exposed in the stopes is as follows, from top to bottom:

4. Thin layer of gravels.
3. Coarse rubble (fanglomerate?) cemented by calcareous tufa; as thick as 6 feet. This is the cap of the deposit.
2. Rubble tufa with manganese oxides and ocher, 1 to 3 feet thick. Apparently this zone was mined for manganese.
1. Rubble poorly cemented by tufa. Thickness more than 3 feet; bottom is not exposed. Contains some manganese oxides and ocher, but much less than zone 2.

At Bed Springs Hill, in the opencuts near the north end, the beds dip gently westward and are as follows, from top to bottom:

5. Thin layer of gravels.
4. Calcareous tufa caprock, as thick as 5 feet. The lower 12 inches in places is manganese rich.
3. Layer rich in manganese oxide and ocher, ranging along strike from iron-rich to manganese-rich; 9 to 18 inches thick.
2. Gray shale rubble as much as 2 feet thick. Low in manganese and iron content.
1. Soft shale of Triassic age, forming the surface upon which zones 2 to 5 were laid down. Manganiferous and ferruginous. This material has been mined to a depth of at least 10 feet in the opencut.

Descriptions and analytical data for samples from the north workings are given in table 18.

TABLE 18.—*Beryllia in samples from north workings, Golconda manganese-tungsten deposit*

Sample	Description	BeO (percent)
BED SPRINGS HILL		
329–1073	Chip sample, calcareous tufa, zone 4	0. 0008
1074	Chip sample, manganese-rich material, base of zone 4	. 0026
1075	Channel sample, manganese-rich material, zone 3	. 0045
1076	Channel sample, ocher-rich material, zone 3	. 0037
1077	Channel sample, zone 1	. 0016
1078	Chip sample, small lens of ocherous tufa in zone 1	. 0058
NORTHWEST WORKINGS		
329–1079	Chip sample, zone 3	. 0007
1080	Channel sample, zone 2	. 0058
1081	Channel sample, zone 1	. 001

SOUTH WORKINGS

The south workings consist of three large opencuts arranged roughly along a line trending northeast for about 2,000 feet. The northeastern cut is about 600 feet long and 200 feet in maximum width; the middle one measures about 700 feet by 700 feet. The southeastern cut was not measured. It is the largest and deepest of the three cuts, but its walls are not accessible for sampling.

In the northeastern cut the section is as follows, from the top down:

4. Tufa cap, more than 3 feet thick.
3. Manganese-rich layer, thickness greater than 4 feet; bottom not exposed. Mined in underground workings of unknown extent.
2. Shale rubble, at least 4 feet in maximum thickness. This material is highly variable. In part it appears nearly barren of iron and manganese oxides, in part it is rich in one or the other.
1. Shales of Triassic age containing manganese and iron oxides.

In the middle cut samples were obtained from the east wall and the southwest wall. Along the east wall the section is as follows, from the top downward:

4. Fanglomerate, 6 to 8 feet thick; rests on the uneven top of of a layer of compact calcareous tufa.
3. Calcareous tufa, 3 to 7 feet thick, bottom gently undulating.
2. Manganiferous fanglomerate, 9 inches to 2½ feet thick.
1. Ferruginous fanglomerate, thickness more than 4 feet; bottom concealed.

Along the southwest wall the section is as follows:

5. Fanglomerate, a maximum of 4 feet in thickness.
4. Manganese-bearing, fractured tufa, 3 to 4 feet thick.
3. Manganese-rich tufa, 2 to 3 feet thick, forming a series of lenses in the tufa cap. The largest lens is about 30 feet long.
2. Manganese-free tufa, 4 to 4½ feet thick.
1. Crossbedded green and brown gravels, containing ocherous layers and manganiferous layers as thick as 2 inches.

Data for samples from the south workings are given in table 19.

TABLE 19.—*Beryllia in samples from south workings, Golconda manganese-tungsten deposit*

Sample	Description	BeO (percent)
	NORTHEASTERN CUT	
329–1084	Channel sample, zone 3	0. 0023
1085	Channel sample, manganese-rich rubble, zone 2, southeast wall of cut	. 0023
1087	Chip sample, ocherous material overlying shale rubble of zone 2, southeast wall of cut	. 016
1086	Composite channel sample, zone 1	. 0024
	MIDDLE CUT, EAST WALL	
329–1088	Chip sample, zone 3	< . 0001
1089	Composite channel sample, zone 2	. 0035
1099	Composite channel sample, zone 1	. 0002
	MIDDLE CUT, SOUTHWEST WALL	
329–1092	Chip sample, zone 4	. 0027
1094	Chip sample, zone 1	. 005

OCCURRENCE AND DISTRIBUTION OF BERYLLIUM

Analytical data indicate that beryllium in the Golconda deposit is contained mainly in the manganiferous ocher, which has been mined for its tungsten content, rather than in the tufa caprock or the underlying Triassic sediments. Presumably, the beryllium is genetically related to solutions which deposited the

tungsten-bearing material. According to Kerr (1940, p. 1385–1387), warm spring waters rose along fissures in the Triassic rocks, the outflow resulting in beds of calcareous tufa, together with tungsten-bearing limonitic and manganiferous material. He concludes that iron and manganese were precipitated as gel products, which adsorbed tungstic oxide from the solutions, a process which could just as well result in the presence of beryllium. Tungsten occurs in hydrated ferric oxide, psilomelane, and hollandite; the beryllium-bearing minerals are not known.

The thickness and composition of the layers in the Golconda deposits are extremely variable along strike and dip. Only detailed exploration and sampling would serve as a basis for estimating reserves.

LANDER COUNTY

BARITE DEPOSITS, BATTLE MOUNTAIN AREA

Many barite deposits, some of commercial importance, are found in northern Lander County, northern Eureka County, and west-central Elko County, especially in the Tuscarora and Shoshone Ranges. The barite deposits are of two general types: vein deposits of white barite, in some areas associated with metalliferous deposits; and bedded gray barite generally considered to have formed by replacement of limestone. The veins have supplied small tonnages of barite, some of exceptional purity. The bedded deposits contain large tonnages of barite ranging from 80 to 93 percent barium sulfate and are the main producers. Samples from deposits of the latter type were obtained from mines of the California-Nevada Barite Co. and the Barium Products Corp., Ltd.

CALIFORNIA-NEVADA BARITE CO. MINE

The California-Nevada Barite Co. mine is reached by about 2 miles of steep but well-graded gravel road that turns south from U. S. Highway 40 at a point 12.9 miles east of the junction of U. S. Highway 40 and State Highway 8A. The mine is near the crest of the northwest spur of the Shoshone Range.

The workings are a series of opencuts extending for about 2,200 feet along the eastern side of the ridge. The principal workings are in the southern 900 feet and consist of five opencuts and several minor openings. The workings are in a belt 300 feet wide that trends about N. 20° W. The mine is owned and operated by the California-Nevada Barite Co., subsidiary of the Glidden Co.

The deposit consists of beds of barite, with an aggregate thickness of at least 40 feet, interbedded with thin beds of chert, silicified limestone, and shale. The barite beds mostly range from an inch to a foot in

thickness and appear to be thickest and least interrupted by chert partings in the southern 900 feet. The structure of the deposit is highly complex. The barite beds in general appear to be dipping to the east at moderate angles, but there is local folding and much faulting. Table 20 gives the beryllia content of samples.

TABLE 20.—*Beryllia in samples from the California-Nevada Barite Co. mine*

Sample	Description	BeO (percent)
329–1064	Chip sample, bed by bed of about 15 ft of chert beds immediately above main barite zone	<0. 0001
1065	Chip sample, bed by bed across main barite zone; represents about 30 ft of beds	<. 0001
1066	Chip sample, bed by bed, of 5 ft of interbedded barite and chert immediately beneath footwall of main barite zone	. 001

BARIUM PRODUCTS CORP., LTD., MINE

The Barium Products Corp., Ltd., mine is 26 miles south of Battle Mountain in Lander County, by way of State Highway 8A. A good gravel road leads from the highway about a mile to the mine. The workings consist of an opencut about 260 feet long, 210 feet wide, and 20 feet in maximum depth. The deposit is a warped and moderately faulted westward-dipping sheet that extends from the crest of a low hill down the northwest slope for about 280 feet. The deposit is probably about 375 feet in strike length.

The barite is similar to that at the California-Nevada Barite Co.'s mine. It overlies thin-bedded chert. The overlying beds are not exposed.

A bed-by-bed chip sample (329–1072) taken across a 20-foot thickness of barite, beginning a few feet above the footwall contains 0.0007 percent BeO.

LINCOLN COUNTY

TEM PIUTE DISTRICT

Scheelite-bearing tactite deposits occur at the north end of the Tem Piute Range in the west-central part of Lincoln County, Nev., about 85 miles west of Caliente. The district is reached by 40 miles of desert road from U. S. Highway 93 at Crystal, near Hiko. The principal mines of the district are the Lincoln and the Schofield, the former accounting for most of the production. A mill at Hiko processes the ore. The deposits were explored by the U. S. Bureau of Mines in 1942 and 1944 (Binyon, Holmes, and Johnson, 1950), and were mapped and described by D. W. Lemmon (written communication).

The district comprises steeply dipping limestone, shales, and sandstones of Paleozoic age which have been intruded by two small granite stocks and several narrow basalt dikes. For a distance of 700 feet from the granite contacts the limestone is bleached and in places

recrystallized. Shales are altered to hornfels and sandstones to quartzite. West of the south stock are thick tactite bodies in bands parallel to the bedding; little tactite has been found near the north stock.

Minerals observed in the tactite and listed in approximate order of abundance are: garnet, quartz, actinolite, calcite, fluorite, pyrite, pyrrhotite, diopside, sphalerite, scheelite, chlorite, hematite, clinozoisite, epidote, molybdenite, and powellite. Most of the scheelite occurs in garnet tactite but some rich deposits have been found in small masses of calcite-fluorite-sphalerite rock formed in marble remnants adjoining tactite bodies.

Products of the mill at Hiko were sampled for the Mine, Mill and Smelter Survey in 1943. Data for these samples are given in table 21.

TABLE 21.—*Beryllia in mill products from the Tem Piute district*

Sample	Description	BeO (percent)
49–DGW–20	Grab sample of scheelite tailings, and sulfide float tails (1942–43 production)	0. 002
21	Same (1940–42 production)	. 003
22	Grab sample of test run on scheelite mill tailings	. 001
23	Scheelite concentrate (composite of samples collected by company)	. 001

MINERAL COUNTY

RAWHIDE DISTRICT

Tactite deposits containing scheelite occur in the southern part of the Sand Springs Range about 4 miles east of the old mining camp of Rawhide. The deposits are in secs. 1 and 12, T. 13 N., R. 32 E., near the south border of the Carson Sink quadrangle. The deposits can be reached by a graded road that turns off U. S. Highway 50 about 35 miles east of Fallon, on the east slope of the Sand Springs Range just below the summit, or by graded roads leading northeasterly for about 45 miles from the town of Hawthorne. The deposits were mapped by R. F. Stopper and others of the U. S. Geological Survey in 1944. The geology of the area and locations of the mines are shown on figure 5. The Nevada Scheelite, Hooper No. 2 and Yankee Girl mines were visited and sampled.

The tungsten deposits are tactite bodies in metamorphosed limestone and hornfels at or near the margins of a body of granite about a mile wide in outcrop. The limestone is part of a thick sequence of folded and faulted sediments and metavolcanic rocks that were intruded by granite. The main limestone unit is estimated by Stopper (written communication) to be 400 to 750 feet thick. Other limestone units are thin beds included in hornfels that overlies the main limestone unit. The productive deposits are along the west and north margins of the granite where for some thousands
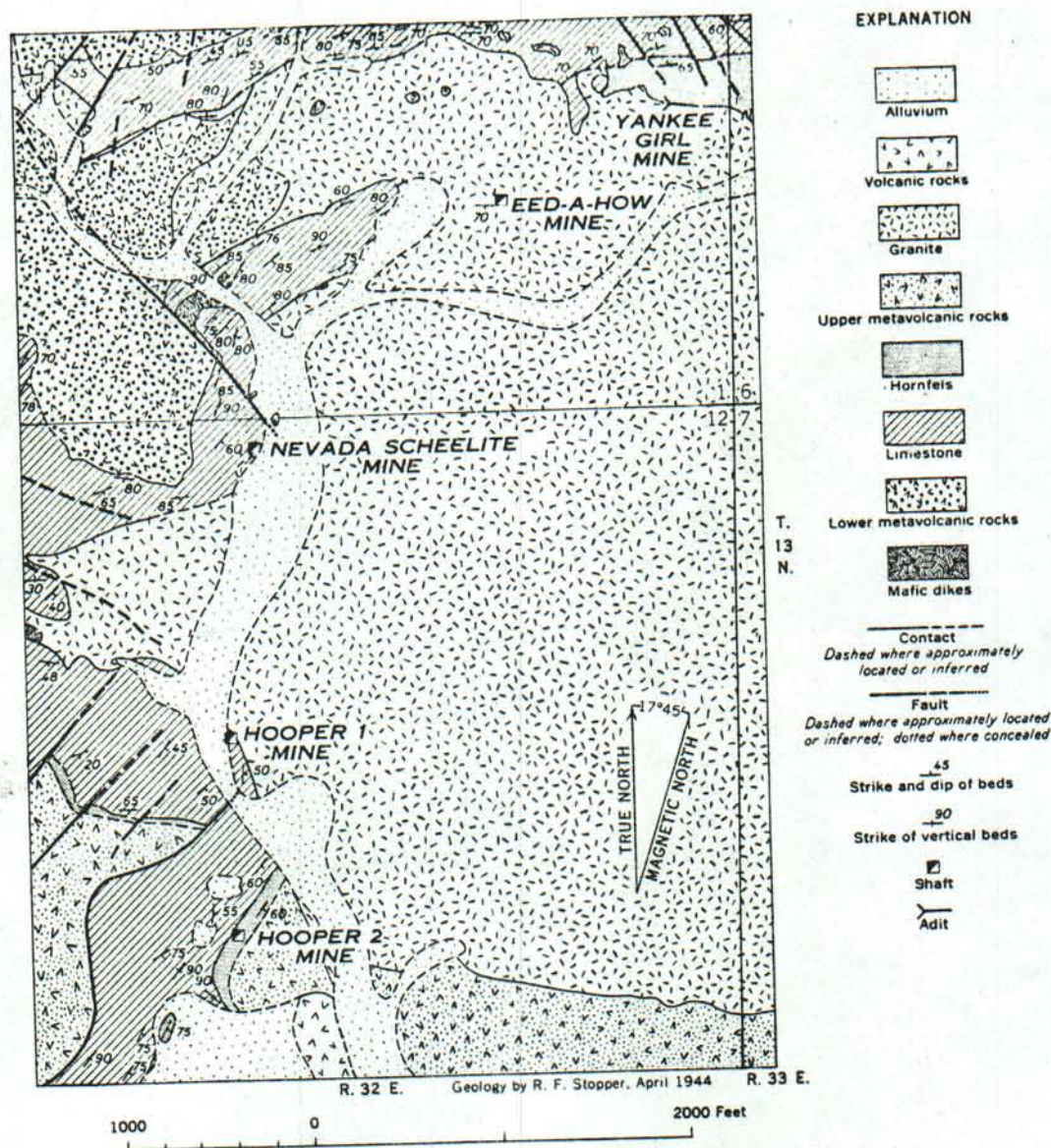
FIGURE 5.—Geologic map of part of the Rawhide district, Mineral County, Nev.

of feet it is in contact with the main limestone or with the overlying hornfels. Tactite bodies, however, occur only at intervals along the contact; elsewhere limestone or marble is directly against the granite. The tactite bodies range in thickness from a few inches to 50 feet. The fresh tactite consists of andradite garnet with various proportions of calcite, quartz, amphibole, epidote, pyroxene, wollastonite, pyrite, magnetite, scheelite, and chalcopyrite.

NEVADA SCHEELITE MINE

The Nevada Scheelite mine consists of an inclined shaft leading to levels at 100, 200, and 300 feet, together with a series of stopes between the levels. The mine is on the west side of the granite stock near a sharp bend in the contact (see fig. 5). The limestone beds at the mine strike northeast and dip from vertical to steeply southeast. A tactite body 2 to 50 feet wide occurs along the contact in an irregular zone about 1,800 feet long. In the northern and southern parts of the zone, the contact between limestone and granite is nearly vertical and mainly concordant with bedding in the limestone. In the middle part of the zone, the contact strikes northwest and dips 30° to 40° NE., cutting sharply across the bedding. This part of the contact is believed by Stopper to follow a pregranite fault along which the beds northeast of the fault have been offset about 350 feet to the northwest. The tactite body is thickest along the middle part of the contact and is absent in places to the north and south, granite being directly against marble. The tactite in this mine

is in large part oxidized. Oxidation is marked on the 200- and 100-foot levels and extends in places below the 300-foot level, which is probably about its lower limit.

Samples of tactite, granite, and marble were obtained. No systematic variation in any of these rocks was noted. The marble is in marked contrast to that associated with tactite in other contact metamorphic deposits sampled, because it contains few silicate minerals representing lower grades of metamorphism. The change from tactite to marble commonly is abrupt, there being no clearly defined light-colored silicated marble zone. Table 22 gives beryllia contents.

TABLE 22.—*Beryllia in samples from the Nevada Scheelite mine*

Sample	Description	BeO (percent)
329–1189	Chip sample across 15-ft thickness of marble beds adjoining granite, north end of drift on 300-ft level, about 540 ft north of shaft. (No tactite zone present here.)	0. 0008
1190	Chip sample of granite in contact with marble, north end of drift on 300-ft level, 500 to 520 ft north of shaft	. 0007
1191	Chip sample across full width (5 ft) of tactite zone at intersection of headings about 460 ft north of shaft, 300-ft level	. 0028
1192	Chip sample across full width (30 ft) of tactite zone, stope 390, 24 to 30 ft above 300-ft level	. 0024
1194	Chip sample across 15-ft thickness of marble beds in west drift of 200-ft level, 200 ft northeast of shaft	. 0004
1195	Chip sample of marble, in part silicated (thickness, 7 ft), northeast end of main drift, 200-ft level	<. 0001
1228	Chip sample of granite taken at intervals along face of drift, 100 to 150 ft south of shaft, 200-ft level	<. 0001

HOOPER NO. 2 MINE

The Hooper No. 2 mine consists of an inclined shaft 110 feet deep, a drift extending 140 feet northeast from the shaft, and a 16-foot winze that extends downward from the shaft and leads to a 20-foot drift. The workings follow a tactite layer in thin-bedded andalusite-biotite hornfels. The tactite layer is about 20 feet stratigraphically above the main limestone formation. Three samples taken at the mine are described in table 23.

TABLE 23.—*Beryllia in samples from the Hooper No. 2 mine*

Sample	Description	BeO (percent)
329–1225	Chip sample across 3-ft thickness of hornfels immediately overlying tactite, main level, north end	<0. 0001
1226	Chip sample across full width (5 ft) of tactite pillar on main level	<. 0001
1227	Chip sample across 5-ft thickness of hornfels overlying tactite, mouth of winze	<. 0001

YANKEE GIRL MINE

At the Yankee Girl mine a 40-foot adit leads to two drifts, one extending about 65 feet northeasterly, the other extending about 90 feet east-southeast. Each of the drifts is connected with the surface by a shaft. A 25-foot inclined winze leads from the floor of the east-southeast drift to a small stope.

The mine is along the contact of the granite with the hornfels that overlies the main limestone unit. Inclusions of limestone that have been metamorphosed to tactite and marble are exposed in the workings. Hornfels is in contact with granite at several places in the mine. Sampling data are given in table 24.

TABLE 24.—*Beryllia in samples from the Yankee Girl mine*

Sample	Description	BeO (percent)
329–1229	Chip sample of hornfels 6 in. to 12 in. from contact with granite, near end of northeast drift	<0. 0001
1230	Chip sample of granite 6 in. to 12 in. from contact with hornfels of sample 329–1229	<. 0001
1231	Chip sample across 5-ft thickness of hornfels at end of northeast drift	<. 0001
1232	Chip sample across silicated marble beds at and near bottom of winze	<. 0001
1233	Chip sample across tactite zone, 31 ft from end of northeast drift	<. 0001
1234	Chips from various outcrops of fresh granite from lower part of gulch below mine	<. 0001

DESERT SCHEELITE AND GUNMETAL MINES, PILOT MOUNTAINS

The Desert Scheelite and Gunmetal mines are on the east slope of the Pilot Mountains, in Mineral County. The Desert Scheelite mine is 2.4 miles S. 22° E. of Graham Spring (Tonopah quadrangle). The Gunmetal mine is about 2 miles S. 10° W. of Graham Spring. Both deposits are reached by a graded gravel road extending east from Mina across the mountains. A short distance east of the summit a desert road leads southward past Graham Spring and connects with the mine access roads.

DESERT SCHEELITE MINE

The workings at the Desert Scheelite mine consist of two opencuts, a 50-foot inclined shaft with a small stope at the bottom, a 65-foot vertical shaft, and several trenches and short adits. The workings are in an east-trending belt of interbedded gray and white marble and silicated marble. This belt contains a tabular body of tactite (see fig. 6). The rocks dip 45° to 80° N. The tactite body extends westward for 700 feet from the 65-foot vertical shaft (shaft A) and probably connects beneath covered ground with the tactite zone exposed at the surface and in the 50-foot inclined shaft (shaft B). The total length of the tactite body therefore may be more than 1,400 feet. It consists of tactite beds with irregular blocks and partings of marble and silicated marble. Tactite formation is controlled primarily by bedding, but in part its distribution is related to cross fractures cutting the marble beds. The thickness of the tactite varies markedly from place to place.
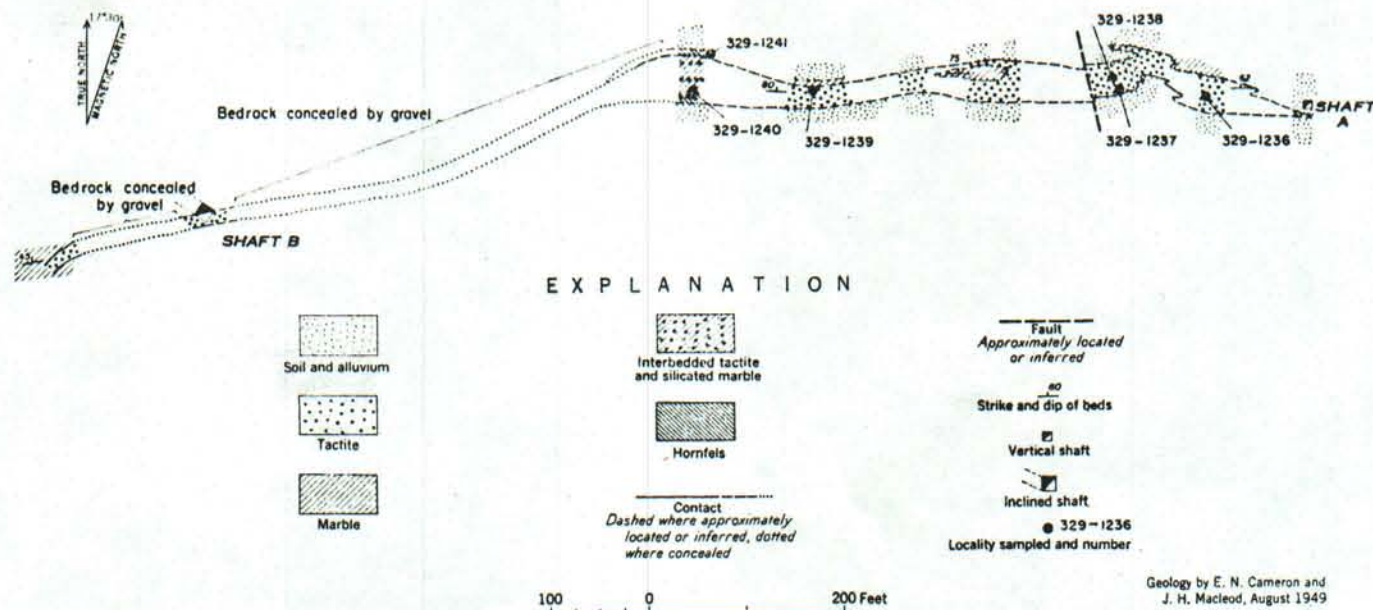
FIGURE 6.—Geologic map of part of the Desert Scheelite mine, Mineral County, Nev.

The tactite is fine- to coarse-grained, massive to layered rock consisting of garnet with some quartz, carbonates, and epidote. The color of the garnet ranges from red to greenish brown or yellowish brown. The mineral proportions vary locally and in places the tactite is rich in epidote. The silicated marble is mainly a thin-bedded fine-grained rock of indeterminate composition. The marbles are gray to white, and fine grained to medium grained. The white marble evidently formed along bedding and cross fractures by recrystallization of gray marble. The gray marble was derived from blue-black fine-grained limestone similar to that exposed outside the tactite zone. Samples were taken as listed in table 25 and shown on figure 6.

TABLE 25.—*Beryllia in samples from the Desert Scheelite mine*

Sample	Description	BeO (percent)
329–1236	Chip sample across full width of tactite	<0. 0001
1237	Chip sample, bed by bed, across 15-ft thickness of marble and silicated marble directly underlying tactite, south wall of opencut	<. 0001
1238	Chip sample across full width of tactite (includes 4 ft of interbedded tactite and light silicate rock)	<. 0001
1239	Chip sample across full width of tactite	<. 0001
1240	Chip sample across lower 10 ft of tactite	<. 0014
1241	Chip sample across 5-ft thickness of dense thin-bedded green hornfels immediately overlying tactite	<. 0001

GUNMETAL MINE

The Gunmetal mine is in gently dipping tactite layers interbedded with marble and silicated marble along the contact of the beds with quartz-monzonite. The tactite beds extend as much as 100 feet from the contact. The main working consists of two adits that lead to stopes on three levels. The tactite is prevailingly garnet-rich but contains also quartz, calcite, epidote, and scheelite.

A chip sample (329–1242) was taken across the lowest tactite layer exposed in an old foundation excavation north of the adits leading to the main workings. This layer is exposed for 60 feet along the strike and averages 3 feet in thickness. A second sample (329–1243) was taken across the main tactite bed exposed in a wall between the mouths of two adits in the first stope of the main workings. The samples showed no BeO, the limit of sensitivity being 0.0001 percent.

MANGANESE-TUNGSTEN DEPOSIT AT SODAVILLE

The Sodaville manganese-tungsten deposit, also known as the Black Jack claim, is on a pediment about half a mile west of U. S. Highway 95 opposite the former railroad station at Sodaville. The deposits are mostly on the crests and flanks of two small knobs that rise above the pediment. They have been described by Kerr (1946a, p. 178).

The deposits are veins in two steeply dipping north- to northeast-trending fracture zones cutting cherty rock that forms the knobs and underlies the pediment. The richest veins are on the eastern knob and the adjacent part of the pediment. They range from less than 1 inch to 2 feet in width and are as much as 20 feet in length. The veins consist largely of tungsten-bearing psilomelane, with varying amounts of pyrolusite, wad, iron oxides, calcite, gypsum, quartz, and chalcedony. The tungsten content of the psilomelane is reported to be 4.88 percent (Kerr, 1946a). Reserves

are small, and operations at the deposits have never gone beyond the prospecting stage.

For comparison with the larger deposit at Golconda, a chip sample (329–1235) of high-grade manganese-tungsten ore was taken from blocks on various small ore piles. It contained 0.0075 percent of BeO.

ANDALUSITE DEPOSITS NEAR THORNE

The andalusite deposits that are exposed on both edges of the Soda Spring Valley a few miles east of Thorne, Mineral County, occur in a belt about 7 miles long that traverses the lower foothills of the Gillis Range (Hawthorne quadrangle). Another andalusite deposit is exposed at the Deep mine, a prospect on the southeast side of a prominent knoll immediately south of Highway 95, about 8 miles east-southeast along the highway from the center of Hawthorne.

Two deposits on the south edge of the Gillis Range, the Green Talc mine and a mine of unknown name about 0.4 mile west-northwest of the Green Talc mine, were visited and sampled.

GREEN TALC MINE

The Green Talc mine is on the lower southeast end of a spur of the Gillis Range. The mine consists of three opencuts and a series of prospect pits scattered over an area about 500 feet long and 125 feet wide, trending northeast across the spur. The main working, near the southwest end of the area, is an opencut 100 feet long, 90 feet wide, and about 40 feet in maximum depth. At the northeast end of the area is a second opencut about 45 feet long, 45 feet wide, and 25 feet in maximum depth. A third, small opencut is immediately north of the main opencut.

The principal body of andalusite-bearing rock appears to be the one exposed in the main working. The core of this body strikes N. 5° W. across the opencut and is more than 125 feet in exposed length and 10 to 15 feet thick. It is exposed to a maximum depth of about 12 feet and appears to dip steeply east. The core consists principally of 10 to 50 percent andalusite in blue to lavender crystals and clusters of crystals 1/8 inch to 1 inch in diameter and 1/2 inch to 4 inches long, set in a green to brownish-green matrix of pyrophyllite. The andalusite crystals are stout, rounded prisms apparently showing marginal alteration to pyrophyllite. In places a brownish granular material, possibly a carbonate, is present in the greenish matrix, and locally this is the dominant constituent. Enveloping the andalusite-bearing rock is a variety of altered volcanic rocks.

The northeast cut exposes dark volcanic rocks irregularly altered to pyrophyllite, with varying amounts of the brown granular mineral. Irregular bodies of similar pyrophyllitic rocks are scattered over the crest of the hill between the northeast opencut and the main working. The largest of these bodies appears to be about 50 feet long and 20 feet wide.

Samples taken at the Green Talc mine are described in table 26.

TABLE 26.—*Beryllia in samples from the Green Talc mine*

Sample	Description	BeO (percent)
329–1197	Chip sample across 10-ft thickness of pyrophyllite-carbonate(?) rock, northeast wall of lower part of northeast opencut, above layer of dark, altered volcanic rock	<0.0001
1198	Chip sample across 10-ft layer of dark altered volcanic rock, underlying rock of sample 329–1197	<.0001
1199	Chip sample across full width (8–10 ft) of andalusite-bearing core rock. Small opencut north of main working	<.0001
1200	Chip sample across full width (15 ft) of andalusite-bearing core rock, north wall of main working	<.0001

MINE NEAR GREEN TALC MINE

An unnamed mine 0.4 mile west-northwest of the Green Talc mine consists of a glory hole about 60 feet in diameter and about 60 feet in maximum depth. On the southeast side of the pit there is a vertical shaft reported to be about 75 feet deep.

The mine is in a lens of andalusite-pyrophyllite rock that strikes N. 65° E. and is nearly vertical. The lens is about 40 feet in maximum width and its strike length is probably not much more than 60 feet. On its northwest side the lens appears to grade irregularly into altered volcanic rock, and on its southwest side it is cut off by a steeply southeast-dipping, gouge-filled fault zone.

Chip sample 329–1224 was taken across an andalusite-bearing lens exposed in the southwest wall near the bottom of the glory hole. It showed no BeO, the limit of sensitivity being 0.0001 percent.

NYE COUNTY

GABBS AREA

We spent one day near Gabbs, Nev., sampling deposits of scheelite, magnesite, and brucite. The main purpose of the visit was to sample the scheelite-leuchtenbergite vein in the Paradise Range described by Kerr and Callaghan (1935). Examination revealed, however, that the vein is poorly exposed and probably of small tonnage; consequently no samples were taken. The newly developed Victory tungsten deposits were examined and sampled. A few samples were taken at the mine of the Sierra Magnesite Co. and from the brucite deposits at Gabbs.

VICTORY TUNGSTEN DEPOSITS

The Victory tungsten deposits are in the northwestern part of the Tonopah quadrangle and on the southwest slope of the Mammoth Range about 3 miles west-southwest of Marble. They are in the north part of sec. 22, T. 13 N., R. 36 E., and are accessible by a dirt road that turns northeast off State Highway 23 at a point about 1 mile northwest of the Gabbs airport entrance road. The deposits are on the crest and northeast side of a spur and are at the west border of a northward-trending body of granodiorite. The granodiorite mass is probably more than a mile long and is at least a quarter-mile wide. The deposits are of two types: disseminated scheelite in granodiorite, and scheelite-bearing contact-metamorphosed calcareous rocks.

Deposits of the first type are exposed in a series of 5 trenches 30 to 75 feet in length. The surface slopes 22° E. and the trenches extend for about 250 feet along a line that trends northwest. The trenches are excavated in a medium- to coarse-grained biotite granodiorite locally containing streaks and patches of quartz. Examination by ultraviolet light shows that scheelite is disseminated through the rock, but the content varies markedly from place to place. A chip composite sample (329–1248) was taken along 57 feet of the second trench (counting from north to south along the line of trenches) and 37 feet of the third trench. Spectrographic analysis showed 0.0034 percent BeO in the sample.

The second type of deposit is exposed west of the first, in a series of trenches at and near the crest of the same spur. The trenches are 15 to 30 feet in length and are spaced at intervals along a line trending northeast for at least 200 feet. They expose an undulating contact of granite with limestone and quartzite. At the crest of the spur the contact is nearly horizontal, but it appears to dip west where exposed on the west side of the spur. Along parts of the contact where limestone abuts against granite, a zone of silicated marble 6 inches to 2 feet thick is present. The minerals present include biotite, chlorite, and possibly amphibole and pyroxene.

In the two southernmost trenches a well-exposed contact zone, according to local report, contains the best showing of tungsten along the west contact of the granodiorite. A chip sample (329–1249) of the contact-metamorphosed material was taken along the 25-foot length of the southernmost trench and was found to contain 0.014 percent BeO. In view of the relatively high beryllium content of this sample, further study of the deposit seems advisable.

BRUCITE AND MAGNESITE DEPOSITS

The brucite deposits at Gabbs are on the west slope of the Paradise Range, east of town. They are being worked by the Basic Refractories Co. The workings consist of two series of large irregular opencuts, one in an upper deposit, the other in a lower one. The workings visited are in the upper deposit. They have a maximum depth of more than 350 feet and extend along the strike of the deposit for about 800 feet.

The deposits are in a thick series of magnesite and dolomite beds along the contacts of a northward-projecting prong of a granodiorite stock. The brucite formed by hydrothermal alteration of the carbonate rocks. Irregular masses of dolomite and magnesite in various stages of alteration are contained in the brucite. The deposits are capped by blankets of supergene hydromagnesite that are as much as 50 feet thick. The whole assemblage of dolomite, magnesite, and brucite is cut by an intricate network of granodiorite dikes, each bordered by serpentine. The high-grade brucite is compact and appears soapy. It grades into rock locally called "limy brucite" that contains much dolomite and calcite.

Two grab samples of the brucite were obtained from the lower level workings of the east (upper) ore body. Sample 329–1245, high-grade brucite, contained less than 0.0001 percent BeO; sample 329–1246, limy brucite, contained 0.0014 percent BeO.

The extensive deposits of magnesite in this area have been described by Rubey and Callaghan (Hewett and others, 1936, p. 142–143). A sample (329–1244) of raw magnesite obtained from the crusher at the mine of the Sierra Magnesite Co. contained less than 0.0001 percent BeO.

PERSHING COUNTY

ROCKS IN THE WEST HUMBOLDT RANGE

The West Humboldt Range is noteworthy for the association of scheelite and beryl in two deposits on the west slope of the range—the Humboldt Canyon beryl-scheelite prospect and the Oreana tungsten mine. With the idea that these deposits might indicate the presence of an unusual amount of beryllium in one or more of the several types of granitic intruded rocks exposed in the range or in the contact-metamorphic rocks bordering them, a fairly extensive program of sampling was undertaken.

LIMERICK CANYON AREA

Large masses of aplite have been described by Knopf (1924, p. 33) and Jenney (1935, p. 34, 35) from the Rochester mining district and the area immediately north of it. The aplite is a fine-grained massive rock that, according to Jenney, consists mainly of quartz, orthoclase, and albite, with traces of magnetite, sphene, tourmaline, zircon, and biotite.

No exhaustive study of the aplite was attempted, but

two samples were taken from exposures in Limerick Canyon (see fig. 7), as follows:

329–1126. Chip sample from various exposures on the north side of Limerick Canyon (0.0007 percent BeO).

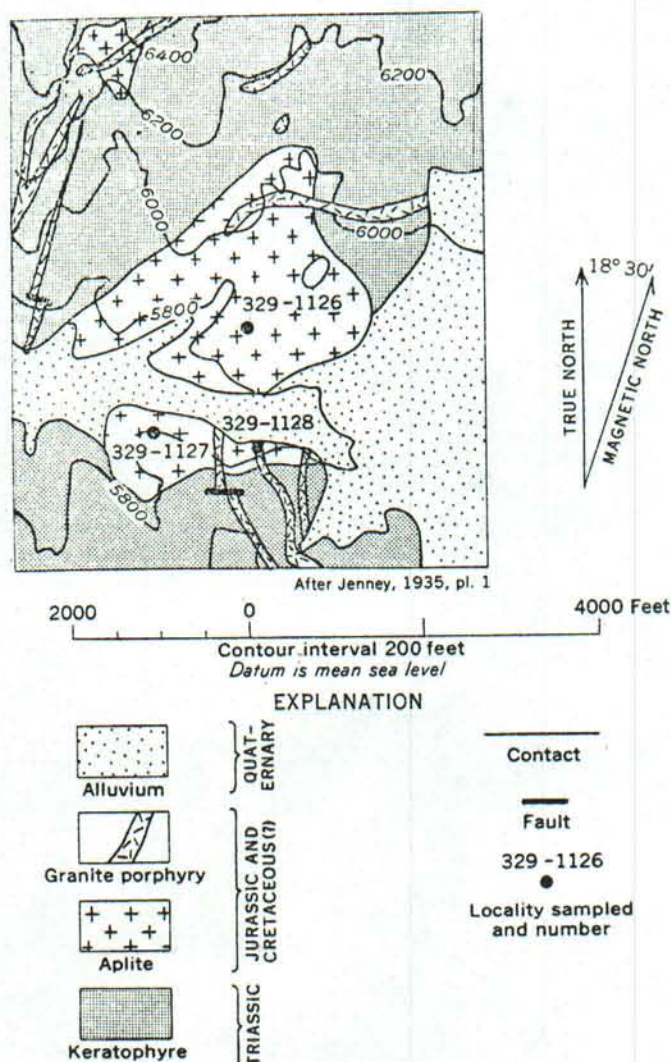1127. Chip sample from various exposures on the south side of Limerick Canyon (0.0011 percent BeO).

After Jenney, 1935, pl. 1

2000   0   4000 Feet

Contour interval 200 feet
Datum is mean sea level

EXPLANATION

FIGURE 7.—Geologic map of part of Limerick Canyon, West Humboldt Range, Pershing County, Nev.

Dikes of granite porphyry cut aplite on the south side of Limerick Canyon (fig. 7). Sample 329–1128 consisted of chips from various exposures of five dikes. The BeO content proved to be less than 0.0001 percent. This same rock forms large bodies in the area extending north from the Rochester mining district toward Unionville Canyon.

PANTHER CANYON AREA

The Panther Canyon area has been described by Vitaliano (1944). In Rye Patch Agnes Canyon quartz monzonite underlies an area of 20 acres, and contact-metamorphosed rocks associated with it underlie large parts of an area 2,400 feet by 3,200 feet, extending from the south side of Rye Patch Agnes Canyon across Panther Canyon (see fig. 8). Because Vitaliano's report includes detailed maps of both the intrusive body and the associated contact aureole, the area appeared to offer excellent ground for sampling.

The quartz monzonite is a light-gray medium-grained massive rock reported by Vitaliano to consist mainly of quartz, feldspar, and mica, with accessory sphene, apatite, magnetite, and pyrite, and traces of epidote, calcite, hematite, chlorite, and zircon. It is finer grained than the granite in Rocky Canyon (fig. 11) and contains more plagioclase. The quartz monzonite shows little variation. At a few places it grades into aplite.

Outcrops of the quartz monzonite along Rye Patch Agnes Canyon were carefully examined, for beryl and for indications of uncommon minerals. A chip sample of granite (329–1124) was taken from outcrops at 15-foot intervals along the bottom of Rye Patch Agnes Canyon, from the east contact nearly to the midpoint of the granite body. The sample contained 0.0016 percent BeO.

Two principal groups of rocks have been affected by contact metamorphism in the Panther Canyon area: calcareous argillite, now represented by hornfels layers; and limestones, ranging from pure to argillaceous and including thin layers of argillite.

The hornfels is mainly represented by three layers of a brownish (limonitic) sugary textured rock from 6 to 50 feet in width. The easternmost layer was sampled (329–1123) on the north side of Rye Patch Agnes Canyon just above the canyon bottom. At this point it is about 45 feet thick. The rock consists largely of quartz and orthoclase, with subordinate amounts of diopside, epidote, and other minerals. The sample contained 0.0008 percent BeO.

The limestone layers are an extremely varied assemblage, ranging from blue-black, fine-grained marble that apparently has undergone recrystallization but little silicification, through blue-black marble containing streaks and patches that range from white marble and silicated marble to tactite. Metamorphosed limestone occurs mainly in two zones: an inner zone immediately contiguous to the quartz monzonite in Rye Patch Agnes Canyon, and an outer zone east of this body and, extending roughly north from the south side of Rye Patch Agnes Canyon across the south fork of Panther Canyon (see fig. 8).

In the inner zone, silicification of the limestone series is only locally complete and the rocks consist largely of blue-black marble with streaks, patches, lenses, and lay-
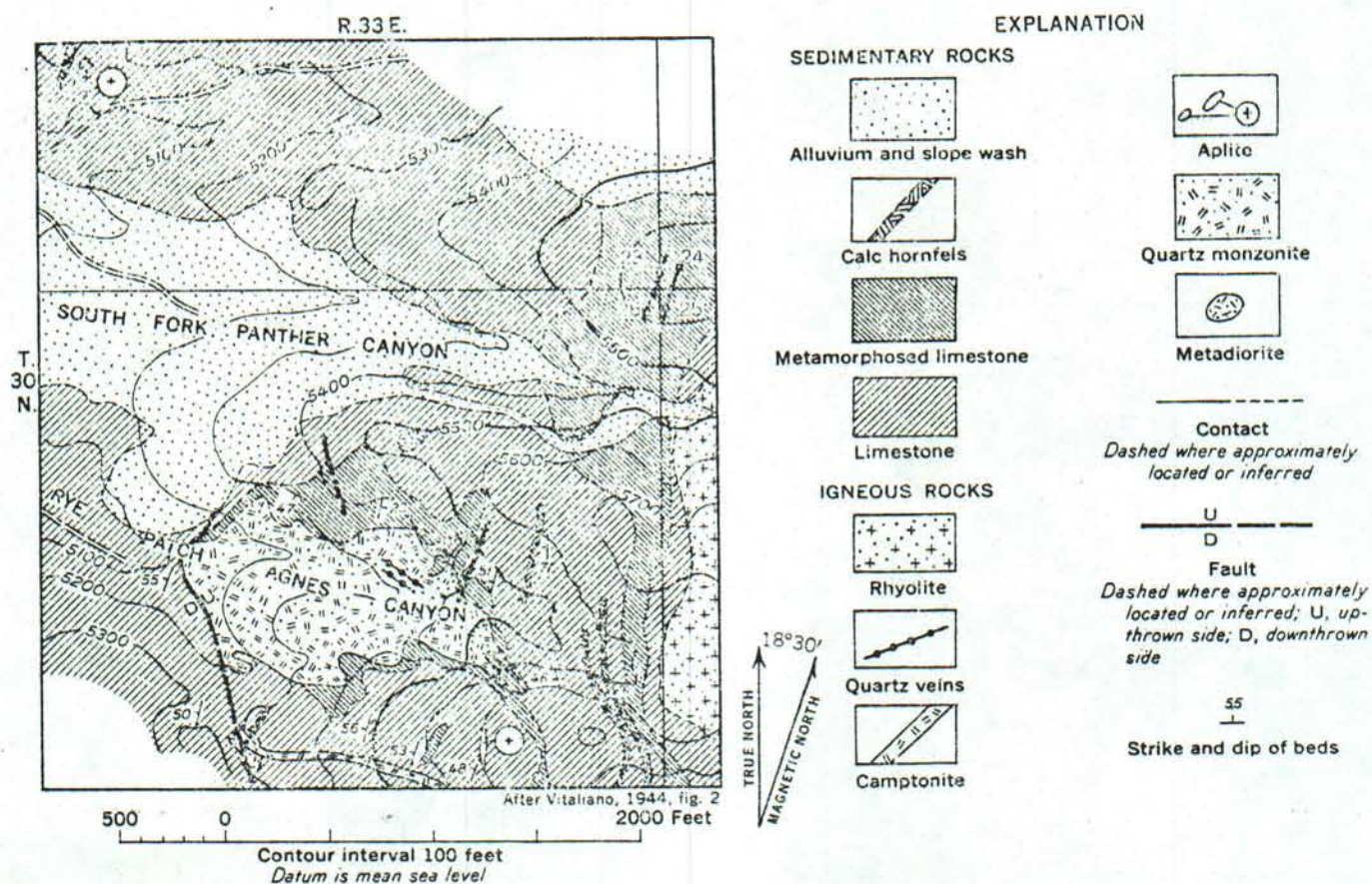
FIGURE 8.—Geologic map of a part of Panther Canyon area, Rye Patch, Nev.

ers of white marble and silicated marble. Samples taken and analyzed for BeO are described in table 27.

TABLE 27.—*Beryllia in samples from inner contact zone, Panther Canyon area*

Sample	Description	BeO (percent)
329–1111	Chip sample taken at intervals across a series of thin layers of silicated marble intercalated with marble. Zone is 40 ft across strike and 200 ft long	< 0. 0001
1112	Chip samples across zone of interbedded gray, white, and blue-black marble containing layers of silicated marble. Total thickness of zone is 54 ft; 18 ft is silicated marble (329–1112) and 36 ft is marble (329–1113)	. 0078
1113	____do____	. 0013
1122	Grab sample of tremolite marble from limestone area north of quartz monzonite	. 0013
1125	Chip sample from various outcrops of blue-black marble containing patches of white marble and veins of silicates	. 0016

The outer contact-metamorphic zone includes rocks that are thoroughly silicated. These rocks range from hornfels and silicated marble to tactite and can best be seen in the ridges separating the North and South forks of Panther Canyon. The section exposed on the north wall of the south fork is typical (fig. 9). The structure of the outer zone is complicated by a steeply dipping fault that marks the eastern margin of the zone, at least between the North and South Forks of Panther Canyon (fig. 10), and there may also be one or more faults along the bottom of the south fork of the
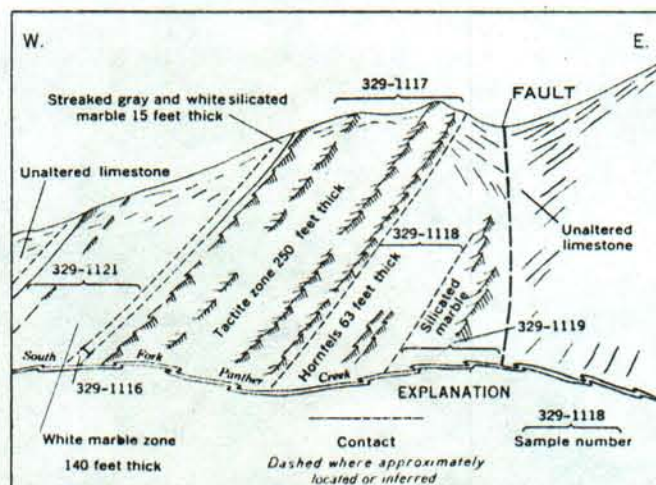
FIGURE 9.—Sketch of part of north wall, South Fork Panther Canyon, Pershing County, Nev.

canyon. Sampling was restricted largely to the north wall of South Fork Panther Canyon, west of the fault; sampling data are given in table 28.

TABLE 28.—*Beryllia in samples [1] from outer contact zone, Panther Canyon area*

Sample	Description	BeO (percent)
329–1115	Chip sample across belt of silicated marble, north side Rye Patch Agnes Canyon	0. 0007
1116	Chip sample across beds approximately 15 ft thick in lower part of section of silicated marble	. 0009
1117	Chip sample across tactite zone, taken along crest of ridge	. 0037
1118	Chip sample across beds of hornfels	. 0026
1119	Chip sample across 15-ft thick zone of silicated marble	. 0029
1121	Chip sample across 140-ft thickness of beds, mostly marble	. 0036

[1] Samples 329–1116 to 329–1121 are from the section on north side of South Fork of Panther Canyon. See figure 9 for locations.

ROCKY CANYON-WRIGHTS CANYON AREA

The area extending from Rocky Canyon to Wrights Canyon includes the Oreana tungsten mine, described by Kerr (1938; 1946a, p. 189–192), where scheelite and beryl occur in pegmatite. The general geology of the area is shown in figure 10, and detailed geology in the vicinity of the Oreana mine is shown in figure 11. The rocks sampled include limestone in various stages of recrystallization and silicification, hornfels, granite and aplite. Locations of samples are shown on figures 10 and 11, and sampling data are given in table 29.

TABLE 29.—*Beryllia in samples from the Rocky Canyon-Wrights Canyon area*

Sample	Description	BeO (percent)
	ROCKY CANYON AREA	
329–1130	Chip sample across pegmatite-aplite dike, north side of canyon	0. 0001
1131	Chip sample of aplite from composite dike on south side of canyon	. 0011
1132	Chip sample of granite; chips taken at 150-ft intervals for 4,000 ft up canyon from mouth	. 0011
1133	Composite sample of six pegmatite-aplite dikes, north side of canyon	. 0007
1135	Chip sample of granite; chips taken at intervals along ridge south of canyon	. 001
	WRIGHTS CANYON (OREANA) AREA	
329–1137	Chip sample across aplite dike	. 0011
1138	Chip sample across hornfels layer	. 0008
1139	Chip sample across aplite dike or sill	. 0015
1140	Chip sample across lens of silicated marble and tactite between aplite dikes	. 0031
1141	Chip sample across silicated marble	. 0015
1142	Chip sample across aplite dike, north side Wrights Canyon	. 001

The granite is exposed in the gorge forming the lower part of Rocky Canyon. It is a medium- to coarse-grained massive biotite granite. Apart from patches of biotite-rich material present locally, particularly near the mouth of the gorge, it appears homogeneous.

OREANA TUNGSTEN MINE   After Jenney, 1935, pl. 1

2000   0   4000 Feet

Contour interval 200 feet
Datum is mean sea level

EXPLANATION
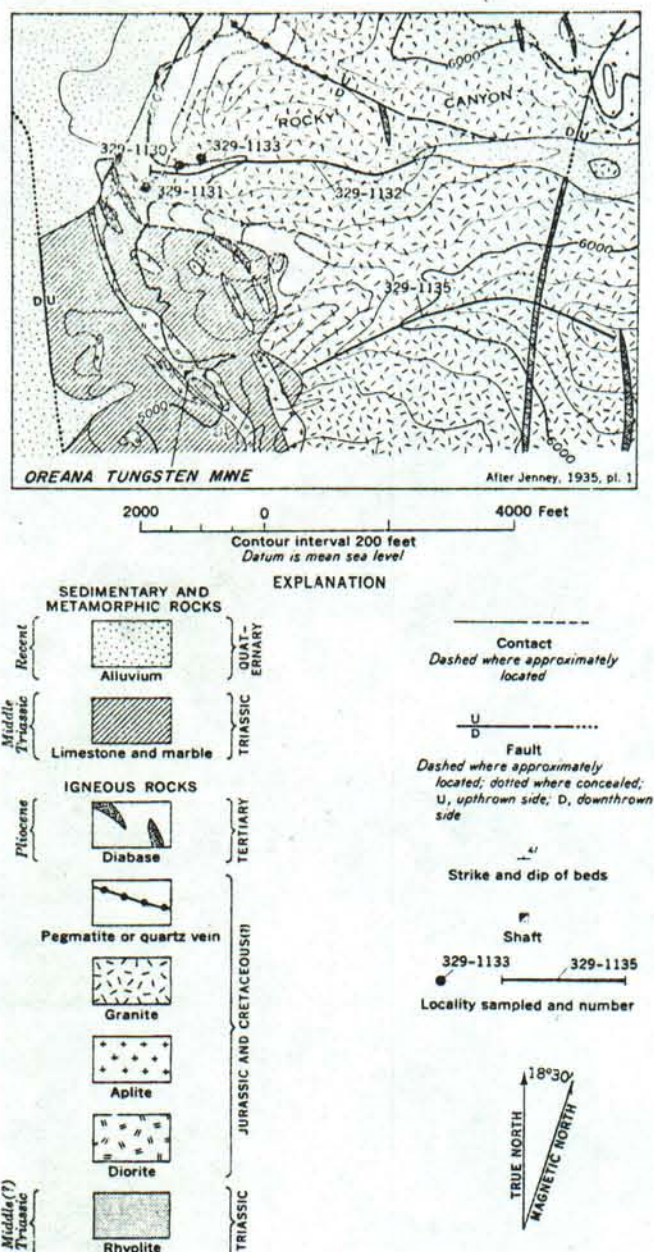
FIGURE 10.—Geologic map of part of Rocky Canyon and vicinity, West Humboldt Range, Pershing County, Nev.

The granite was examined for beryl, but none was found.

Aplite-pegmatite dikes are found in great profusion. Proportions of aplite and pegmatite material in the dikes vary markedly, even from place to place within the same dike, but the aplite fraction predominates. In general the dikes strike N. 30° to 45° W. and dip 35° to 50° NE.; some strike northeast and are vertical. They range from a few inches to many feet in width, and some are exposed for hundreds of feet along strike or dip. Apparently, they are of several generations and some of the older are sill-like bodies in rhyolite
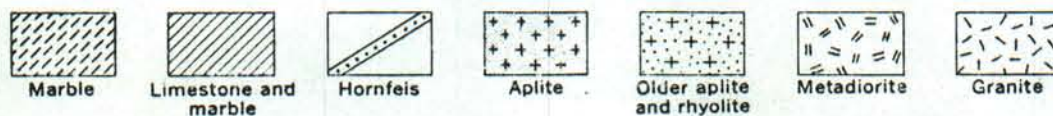
Adapted from map by Kerr, 1946a, pl. 7

500   0   1000 Feet

EXPLANATION

| Marble | Limestone and marble | Hornfeis | Aplite | Older aplite and rhyolite | Metadiorite | Granite |

Contact
Dashed where approximately located or inferred

Fault
Dashed where approximately located

5
Localities sampled

●3

LOCALITY AND SAMPLE NUMBER

1.	329–1137	4.	329–1140
2.	329–1133	5.	329–1141
3.	329–1139	6.	329–1142

FIGURE 11.—Geologic map of vicinity of Oreana tungsten mine, Pershing County, Nev.

(Kerr, 1946a, p. 189–190, pl. 7). Beryl was not found in the dikes examined.

In the area east of the Oreana mine, contact-metamorphosed rocks consisting of blue-black limestone and marble, silicated marble, tactite, and hornfels were sampled. These rocks are in contact with metadiorite on the west and granite on the east (see fig. 11).

RESULTS OF SAMPLING

In view of the occurrence of beryl in scheelite deposits in the West Humboldt Range, analytical results of the rock samples collected in this region are disappointing. Of the 27 samples of all rock types that were analyzed spectrographically, only 1 (329–1112) contained more than 0.005 percent BeO, and only 3 others contained more than 0.003 percent. The average BeO content of the other 23 samples is less than 0.002 percent.

Sample 329–1112, containing 0.0078 percent BeO, represents material which might some day be of commercial interest, though the tonnage probably is small. The sample is from a zone of silicated marble adjacent to the intrusive quartz monzonite in Rye Patch Agnes Canyon. The zone is more than 50 feet wide and persists for at least 200 feet along the strike. It is estimated to contain about 3,500 tons for each 10 feet of depth. The beryllium-bearing mineral is not known, and there is no assurance that the beryllium is recoverable.

In evaluating results of the sampling, it should be emphasized that the metasedimentary rocks at each of the localities sampled in the Humboldt Range are of extremely diverse composition. Hundreds of samples, each taken from a single bed, would be needed to determine the exact distribution of beryllium. Considerable contamination is inherent in the present sampling; thus further investigation might reveal material of much higher beryllium content than that indicated by the analyses given above. However, the present work gives no indication of large individual deposits of relatively high-grade beryllium-bearing material.

TUNGSTEN AREA, MILL CITY DISTRICT

The tungsten deposits at Tungsten, near Mill City, Nev., are among the most important of the tactite type in the United States. The deposits, which are worked by the Nevada-Massachusetts Co., are on the southeast slopes of the Eugene Range, in Pershing County. They have been described by Kerr (1946a, p. 182–188).

At Tungsten three steep-sided stocks of granodiorite cut a series of calcareous strata interbedded with hornfels. In general the beds strike nearly north and dip steeply east or west. The beds are offset by both pre- and post-mineralization faults. The deposits are in parts of the calcareous beds that have been converted to tactite and impregnated with scheelite. Scheelite-bearing tactite has been found in some of the beds for distances as great as 2,000 feet from the nearest intrusive body, and the deepest workings have reached 1,700 feet without sign of bottoming of the beds against granite.

No one of the calcareous beds is uniformly mineralized. In general, a bed traced along dip or strike will be found to show four facies, as follows:

1. Tactite, consisting chiefly of garnet, epidote, diopside, and quartz in various proportions.
2. Silicated marble, with pale-green silicates and pale garnet.
3. White marble, commonly with some light-colored silicates and grading in places into silicated marble.
4. Blue-black fine-grained marble grading into limestone. Certain beds contain partings or lenses of hornfels.

The number of calcareous beds is large and the workings are extensive; no attempt at overall sampling could be made. Two groups of beds, known locally as the Sutton beds and the George beds, were selected for the major part of the sampling, because each was easily accessible in several opencuts. A few samples were also taken from beds on Humboldt Hill and Stank Hill. The various ore-bearing beds and surface workings are shown on figure 12.

None of the samples from this area contains sufficient beryllium to be of commercial interest at present. In view of the large number of samples taken and the variety of rock types represented, the prospect that substantial quantities of higher grade material is present seems unlikely.

SUTTON BEDS OF LOCAL USAGE

The rocks known locally as the Sutton beds consist of two calcareous layers separated by about 40 feet of hornfels. Samples were taken from these beds in the Baker workings, the workings immediately north of the Springer stock, and the south opencut of the Sutton mine. The samples are described in table 30.

TABLE 30.—*Beryllia in samples from the Sutton beds of local usage*

Sample	Description	BeO (percent)
EAST SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (NORTH WALL)		
329–1143	Chip sample, layer by layer, across east ore bed, thickness 9 to 9.5 ft. Interbanded tactite, white marble, silicated marble, quartz, and hornfels. Tactite includes both garnet-rich and epidote-rich material	<0. 0001
1144	Chip sample of west ore bed, 8.5 ft thick. Garnet-epidote-quartz-calcite tactite with minor hornfels layers	. 0017
1145	Chip sample of blue-black and gray hornfels from 40-ft thickness of beds separating the two ore beds	. 0016
1146	Chip sample from same beds as 329–1145 but consisting of hornfels altered along layering and cross fractures to a green fine-grained rock	. 0012

TABLE 30.—*Beryllia in samples from the Sutton beds of local usage*—Continued

Sample	Description	BeO (percent)
EAST SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (NORTH WALL)—continued		
329–1147	Chip sample across 6 ft of hornfels immediately overlying the west ore bed	0. 0018
1148	Chip sample of 4 ft of hornfels immediately underlying the east ore bed	< . 0001
SOUTH SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (SOUTH WALL)		
329–1149	Chip sample across east ore bed, 44 in. thick at base of cut. Mostly marble and silicated marble, with some tactite	. 0025
1150	Chip sample of hornfels separating the two ore beds; thickness about 41 ft	. 001
1151	Chip sample across west ore bed, 9 ft thick at base of cut; gray marble, and silicated marble, with inclusions of blue-black marble, garnet-rich and epidote-rich tactite	. 0032
1152	Chip sample across 6 ft of hornfels immediately overlying (west of) the west ore bed	. 0013
1153	Chip sample across 4 ft of hornfels immediately beneath (east of) the east ore bed	. 0013
1154	Grab sample of the blue-black marble from broken material near the north end of the opencut	. 0006
OPENCUT EAST OF BAKER WORKINGS; EXPOSURES AT BASE OF HEADWALL. (THE CORRELATION OF THESE BEDS WITH THE SUTTON BEDS OF LOCAL USAGE IS UNCERTAIN.)		
329–1155	Chip sample across west ore bed, about 5.5 ft thick. Consists mostly of silicated marble containing garnet. Includes 2 ft of blue-black marble and gray marble	. 004
329–1156	Chip sample across east ore bed, about 15 ft thick. Upper half mostly diopside-epidote rock and garnet rock. Lower half mostly fine-grained to medium-grained marble	. 0029
BAKER WORKINGS; EXPOSURES IN ENTRANCE CUT AND SOUTH WALL OF OPENCUT		
329–1157	Chip sample across west ore bed, 125 ft thick. Consists mostly of dense, light-green calc-silicate rock. Upper 2 ft is garnet marble	. 0027
1158	Chip sample across 6 ft of hornfels immediately adjacent to west (hanging) wall of west ore bed	. 0023
1159	Chip sample across east ore bed, 5 ft thick. Mostly epidote-rich tactite veined by quartz	. 0026
1160	Chip sample across 4-ft thickness of hornfels forming east (foot) wall of the east ore body	. 002
1161	Chip sample across an aplite dike cutting the ore beds and enclosing hornfels in the south part of the opencut. The dike strikes N. 55° W. and dips 77° SW. It is 6 to 15 ft thick and at least 100 ft long	. 0008
1162	Chip sample across 40-ft thickness of hornfels separating the two ore beds	. 0012
OPENCUT NORTH OF THE BAKER WORKINGS; EXPOSURES IN SOUTH END OF OPENCUT		
329–1163	Chip sample across east ore bed, 2½ ft thick. White and blue-black marble, silicated marble, and epidote-garnet-quartz tactite	. 0022
1164	Chip sample across west ore bed, 26 in. thick. Epidote-quartz and garnet-quartz tactite	. 003

GEORGE BEDS OF LOCAL USAGE

The rocks known locally as the George beds are a varied assemblage of layers of marble, calc-silicate rocks, and tactite composed of diopside, garnet, and epidote in various proportions. In part the diopside-garnet rocks appear to have been formed by alteration of dark-gray hornfels, not of limestone. This is clearly shown in workings 2,000 feet north-northwest of the summit of Humboldt Hill. Here the George beds are about 19 feet thick and nearly vertical. They consist of garnet-diopside tactite, grading into hornfels, and blue-black marble partly recrystallized to white marble. Samples from the George beds are described in table 31.

TABLE 31.—*Beryllia in samples from the George beds of local usage*

Sample	Description	BeO (percent)
SHALLOW CUT ON SADDLE NORTHWEST OF SUMMIT OF HUMBOLDT HILL		
329–1165	Chip sample across lower (east) part of beds, consisting, from east to west, of (1) garnet-quartz-epidote tactite 14–21 in. thick; (2) interlayered gray-green calc-silicate rock, hornfels, and fine-grained tactite, 32–40 in. thick; (3) interlayered hornfels and calc-silicate rock 32 in. thick; (4) garnet-rich and epidote-rich tactite 71 in. thick	0. 003
1166	Chip sample of beds overlying beds of 329–1165: (1) white marble, in part silicated, containing blocks of blue-gray marble, 85 in. thick; (2) garnet tactite 3–12 in. thick; and (3) white and blue-black marble	. 0008
1167	Chip sample of upper beds, comprising (1) garnet and garnet-epidote tactite, 33 in. thick; (2) garnet and garnet-epidote tactite interbanded with gray-green calc-silicate rock, 12–16 in. thick; (3) garnet and garnet-epidote tactite, 30 in. thick, and (4) fine-grained green calc-silicate rock, 12 in. thick	. 0013
OPENCUT IN GULCH ABOUT 1,500 FEET WEST OF SUMMIT OF HUMBOLDT HILL; EXPOSURES IN LOWER PART OF SOUTH FACE OF CUT		
329–1172	Chip sample across (1) 21 in. of interbanded gray hornfels and diopside(?) hornfels, with a few thin garnet bands; (2) 25 in. of interbanded diopside(?) and garnet tactite, and (3) 9 in. of dense green calc-silicate rock	. 0021
1173	Chip sample across 3.5-ft thickness of blue-black marble in large part converted to white marble, partly silicated	. 0007
1174	Chip sample across 6.5 ft of diopside and diopside-quartz rock, with thin garnet layers and lenses	. 0026
1175	Chip sample across 6 ft of hornfels immediately east of the George beds of local usage	. 0016

OTHER ROCKS SAMPLED

The Humboldt beds of local usage were sampled in the opencut near the summit of Humboldt Hill where they have a total thickness of about 13 feet. The beds comprise epidote-quartz and garnet-quartz tactite, sili-
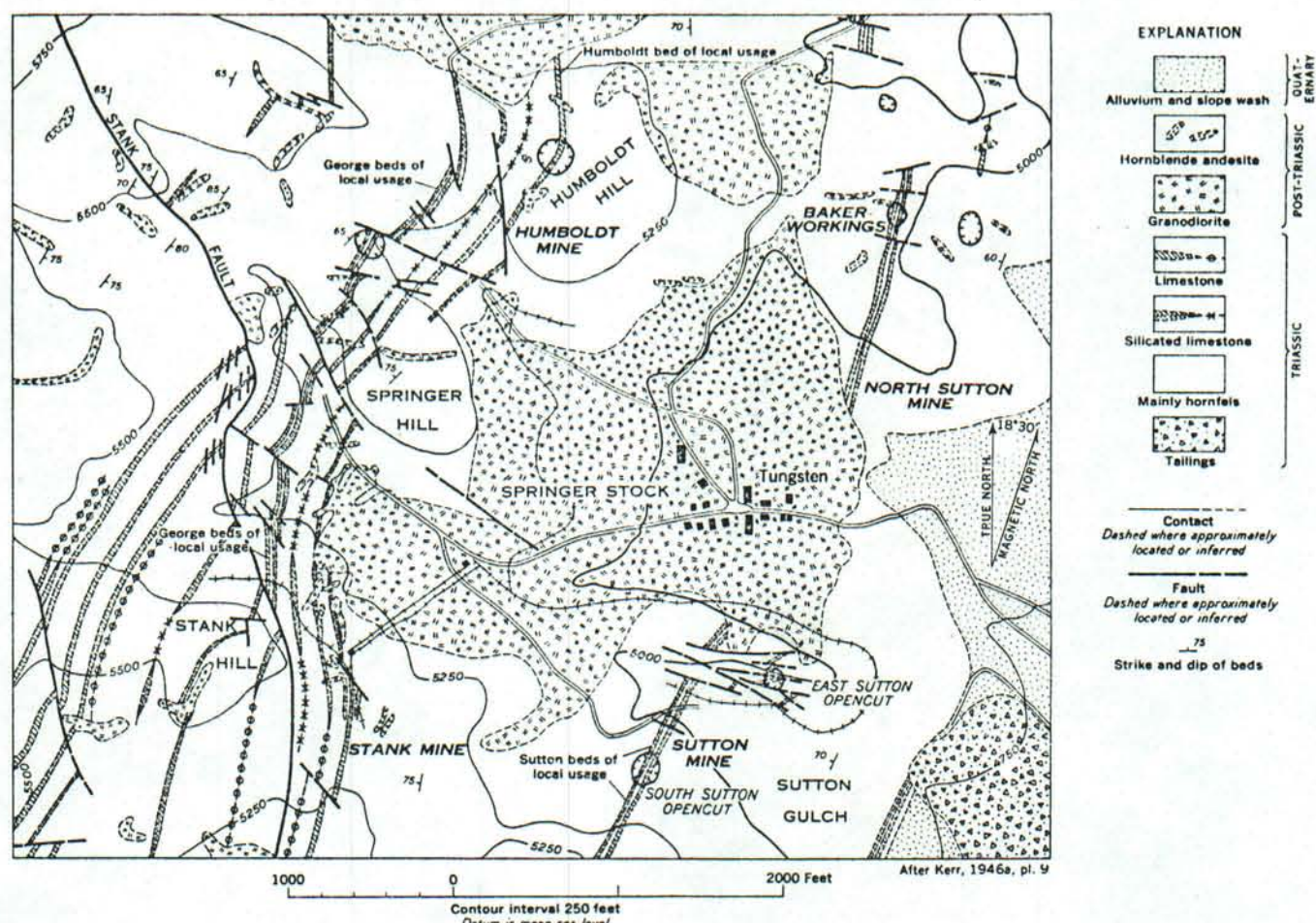
FIGURE 12.—Geologic map of part of Tungsten area near Mill City, Pershing County, Nev.

cated marble, white marble, and blue-black marble. The beds on the west side of Stank Hill were sampled in the hope of getting representative material from the outer fringes of the mineralized area. Samples from these localities are described in table 32.

TABLE 32.—*Beryllia in samples from Humboldt Hill and Stank Hill*

Sample	Description	BeO (percent)
	HUMBOLDT BEDS OF LOCAL USAGE; OPENCUT ON HUMBOLDT HILL	
329–1168	Chip sample across the full width of the beds	0. 0033
1169	Chip sample of 5-ft thickness of hornfels immediately beneath (east of) the ore beds	. 0014
1170	Chip sample from various layers of garnet tactite	. 0036
1171	Chip sample of white marble having abundant pale garnet	. 0022

TABLE 32.—*Beryllia in samples from Humboldt Hill and Stank Hill*—Continued

Sample	Description	BeO (percent)
	BEDS WEST OF STANK HILL	
329–1176	Chip sample of 6-ft thickness of argillite immediately east of (overlying) the ore beds	0. 0023
1177	Chip sample across 32 in. of silicated marble and 30 in. of interbanded diopside and garnet tactite. These beds form the top (east) part of the main zone of calcareous strata	. 0016
1178	Chip sample across 6-ft thickness of blue-black and white marble and silicated marble forming the middle part of the main zone of calcareous strata	. 0005
1180	Chip sample across 4½-ft thickness of hornfels overlying (east of) the main zone of calcareous strata and separating them from 2.5 ft of blue-black and white marble	. 0014

A composite (329–1181) of granodiorite from various outcrops in the southwestern part of the Springer stock had a BeO content less than 0.0001 percent.

ROSE CREEK MINE

The Rose Creek tungsten mine is in the northeastern part of the East Range, 11 miles south-southwest of Winnemucca. A detailed study of the deposit was made by R. J. Roberts (1943). Rocks of the area include dolomite, limestone, argillite, and quartzite which have been cut by a small granite body (see fig. 13). Argillite next to the granite has been altered to hornfels, and tactite has formed in the limestone.

The main, or upper, workings consist of an adit that extends westerly for about 400 feet and connects with a series of drifts, raises, and stopes (see fig. 14). An inclined winze extends down the ore bed to the northwest. A lower adit was driven westerly from a point 370 feet northeast of, and 117 feet lower than, the portal of the upper adit to intersect the winze (fig. 13). This adit was flooded at the time of the present investigation. A sublevel consisting of a few short drifts was excavated after Roberts' survey. It joins the winze about 35 feet vertically below the upper adit.

The deposit is a bed of scheelite-bearing tactite enclosed in interbedded quartzite and hornfels. The bed is 2 to 4 feet thick, averaging about 2½ feet. The average thickness of the parts of the bed remaining in the underground workings is probably 1½ to 2 feet. The bed strikes northeasterly and dips northwesterly at a moderate angle. It is offset by a number of postmineralization faults, mostly of small displacement, and is cut by preore lamprophyre dikes and postore diabase dikes. Mining has been confined to the richer and thicker parts of the bed.

The tactite is fine grained and is composed chiefly of
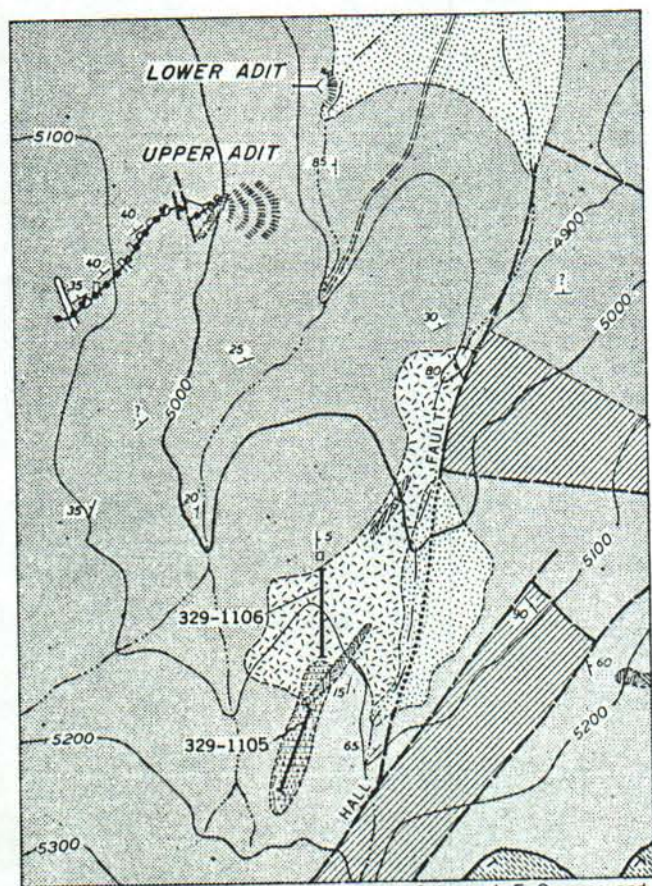
EXPLANATION

After R. J. Roberts, A. E. Granger, and M. W. Cox (Roberts, 1943, pl. 2)

250 0 1000 Feet

Contour interval 100 feet
Datum is mean sea level
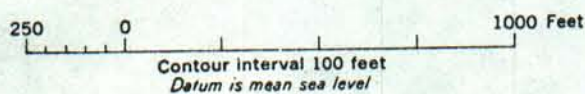
FIGURE 13.—Geologic map of the Rose Creek mine and vicinity, Pershing County, Nev.
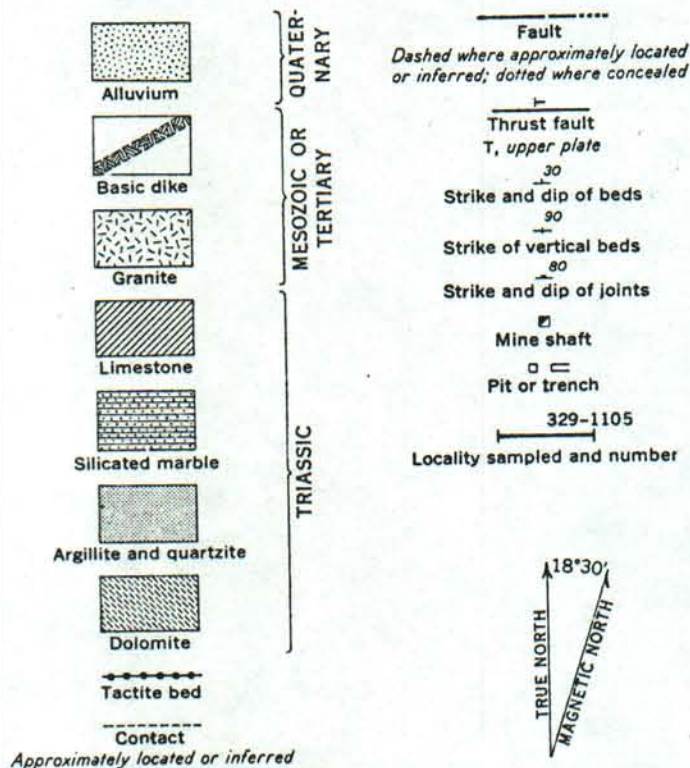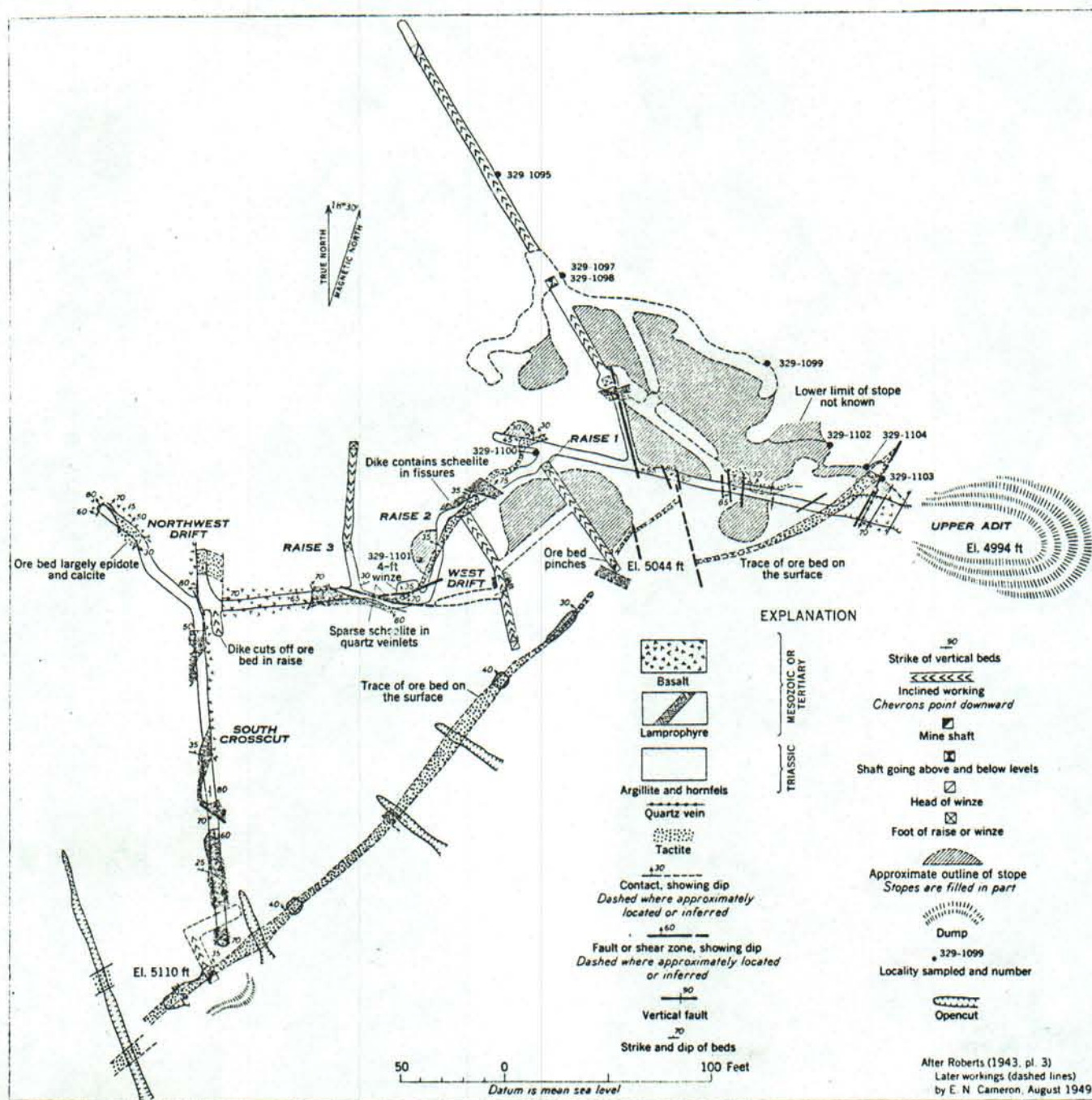
FIGURE 14.—Geologic map of the Rose Creek mine workings, Pershing County, Nev.

diopside, actinolite, feldspar, quartz, calcite, epidote, and zoisite in varying proportions. Minor amounts of other minerals, including sulfides, are present in quartz veins or disseminated through the tactite. Pyrite and chalcopyrite are the common sulfides. The absence of garnet and prominence of pyroxene and amphibole distinguish this deposit from the ordinary tungsten-bearing tactite of the region.

Sampling was done mainly in the underground workings, because surface exposures are poor. One sample each of silicated marble and granite was obtained from surface outcrops. Sampling data are given in table 33; locations of samples are shown on figures 13 and 14.

Analytical results of the sampling show that parts of the tactite bed contain beryllium in abnormal amounts, but that its distribution in the tactite is quite

irregular. For the six tactite samples analyzed the range in BeO content is from 0.0032 percent to 0.024 percent, the average being about 0.007 percent. The average BeO content of the rocks may, of course, differ markedly from this in view of the small number of samples taken. The beryllium-bearing mineral is not known.

TABLE 33.—*Beryllia in samples from the Rose Creek mine*

Sample	Description	BeO (percent)
329–1095	Chip sample across full width of tactite (21–32 in.), northeast wall of winze, 80–85 ft above bottom	0. 0033
1097	Chip sample across full width of tactite (16–29 in.), intersection of sublevel and winze	. 024
1098	Chip sample of 3-ft thickness of quartzite overlying tactite at locality of 329–1097	. 0015
1099	Chip sample across full width of tactite (15 in.) at east end of sublevel	. 0074
1100	Chip sample across full width of tactite (13 in.), junction of upper adit and raise No. 1	. 0042
1101	Chip sample across full width of tactite (13 in.), underhand stope, upper adit level, 25 ft southwest of raise No. 2	. 0047
1102	Chip sample across full width of tactite (2.5 ft), east end of stope extending down from upper adit level, 45 ft inside portal	. 0032
1103	Chip sample of 5-ft thickness of gray hornfels, footwall of tactite, portal of upper adit	. 0013
1104	Chip sample of black hornfels overlying tactite, opencut at portal of upper adit	<. 0001
1105	Chip sample of silicated marble from ridge southeast of tungsten mine	. 0012
1106	Chip sample from granite outcrops southeast of tungsten mine	. 0015

Roberts (1943, p. 13) estimated the amount of ore in the mine to be about 6,000 tons but a large part of the ore between the sublevel and the surface appears to have been subsequently removed. It is doubtful that more than a few thousand tons of tactite remains in the mine. That much larger reserves might be disclosed by further development seems unlikely.

RAGGED TOP AREA

The Ragged Top tungsten mine is on the west side of the Trinity Range, in sec. 11, T. 25 N., R. 28 E., Lovelock quadrangle. It is accessible from U. S. highway 40 by about 8 miles of gravel road leading west from Toulon. The mine consists of a series of small shafts, opencuts, adits, and test pits excavated to explore scheelite-bearing tactite deposits along the contacts of limestone and granodiorite.

The mine is described briefly by Kerr (1946a, p. 192) and was mapped during World War II by Ward C.

Smith of the U. S. Geological Survey. It is near the southeast edge of an area of granodiorite containing inclusions or pendants of limestone. The limestone patches are contact-metamorphosed, along their margins where in places tactite containing scheelite is formed. Most of the tactite bodies are small but one about 1,000 feet northwest of the mine has a strike length of more than 1,000 feet (fig. 15).

Since Smith's map was made, a series of shallow cuts and trenches has been excavated along the length of the tactite body. These excavations indicate that the body is more complex than was supposed. In trench A (fig. 15) it consists of two principal southeastward-dipping layers of garnet and garnet-diopside tactite separated by a limestone parting. The lower layer of tactite is probably about 15 feet thick, and the limestone parting probably has roughly the same thickness. The upper layer may be as much as 35 feet thick, but this figure includes a few feet of limestone. The lower layer is exposed in trench B, but its thickness of southeastward-dipping beds abutting against granodiorite includes about 4 to 5 feet of tactite in two layers separated by 5 to 6 feet of limestone. The bottom of the lower layer is not exposed, but it probably is not more than a few feet thick. Trench C exposes a single zone of tactite, 18 to 25 feet wide, containing blocks of silicated marble. In cut E a width of 62 feet of tactite is exposed, but the mass appears to be dipping gently to the southeast and may bottom on granodiorite at shallow depth. At the head of the cut it contains a mass of blue limestone and silicated marble. North of this cut the width of tactite decreases and it finally pinches out, though small pods of tactite are present here and there along the granodiorite-marble contact for some distance. Samples taken from the tactite body are described in table 34.

TABLE 34.—*Beryllia in samples from the Ragged Top area*

| Sample	Description	BeO (percent)
329–1182	Chip sample along 110 ft from upper tactite layer (which includes limestone parting) to east edge of trench A	<0. 0001
1183	Chip sample covering 8 ft along western end of trench A, from upper part of lower tactite layer	. 0016
1184	Chip sample, full width of lower tactite layer, trench B	. 0014
1185	Chip sample of silicated marble forming parting 4.5 ft thick between tactite layers trench D	. 0005
1186	Chip sample across full width of tactite layer, cut E	. 0016
1187	Grab sample of granodiorite from chunks of rock on dump of Ragged Top mine	. 0013
1188	Chip sample of tactite from low knoll east of mine road 2,300 ft N. 10° E. of north end of tactite body shown on figure 15	. 0019
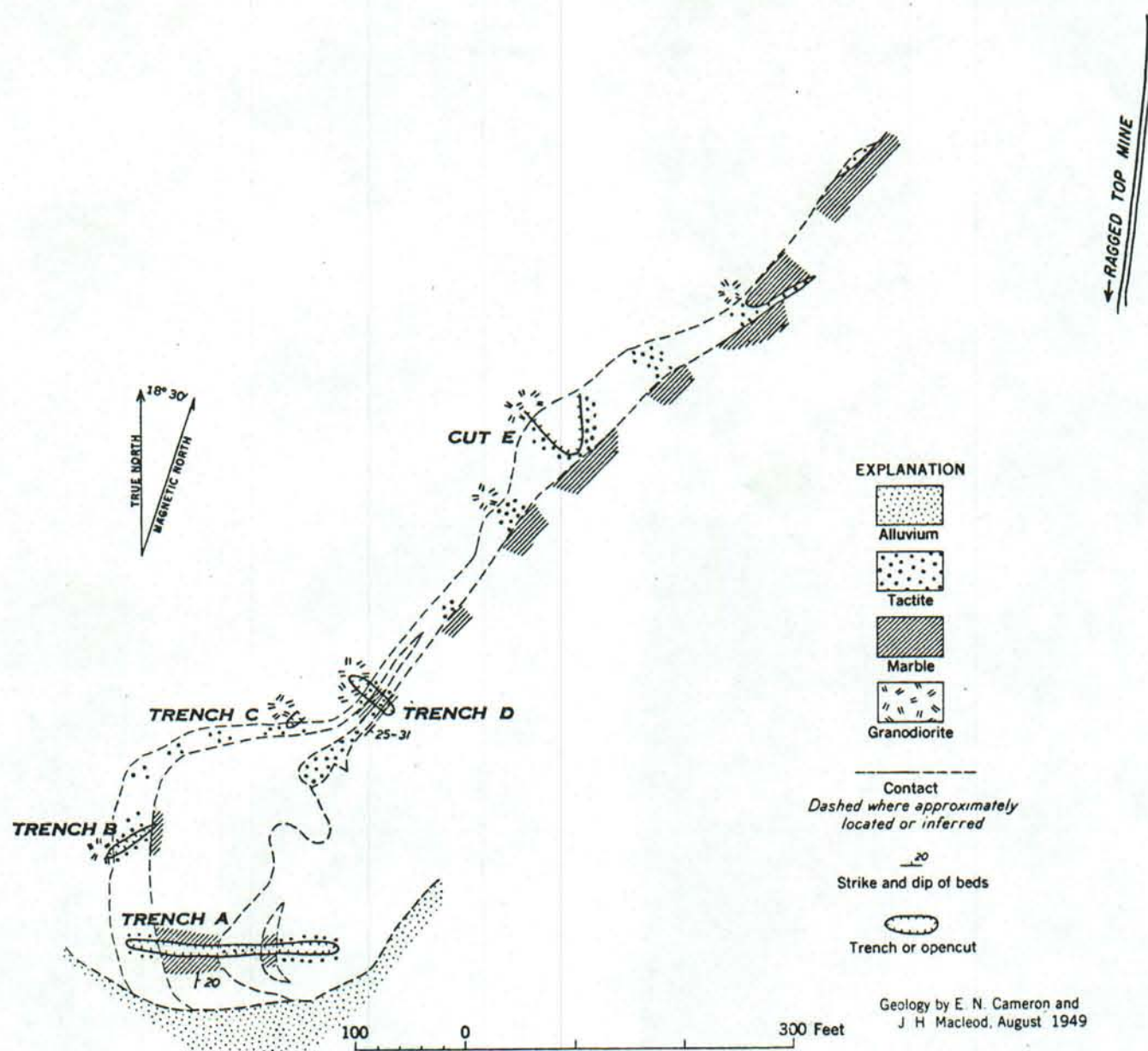
FIGURE 15.—Geologic map of tactite body near Ragged Top mine, Pershing County, Nev.

CHAMPION DUMORTIERITE MINE

The dumortierite mine of Champion Sillimanite, Inc., is near the head of Humboldt Queen Canyon, on the west side of the Humboldt Range, about 5 miles east of Oreana, Nev. A gravel road branching northeastward from the Oreana-Limerick Canyon road gives access to the mine. Geology at the mine has been described by Kerr and Jenny (1935).

Dumortierite occurs in two zones of andalusite-quartz-albite-sericite rock. These rocks are most abundant on the north side of Humboldt Queen Canyon. The zones are about 225 feet apart, stratigraphically; they strike N. 10° to 20° E. and have an aver-

age dip of about 40° W. The rocks of the two zones have been described as schists, but they are mostly gneisses with subordinate mica.

According to Kerr and Jenney (1935), the andalusite was formed by replacement of tuffaceous schist and the dumortierite by replacement of andalusite. Dumortierite in the western zone is largely in veinlets, some of which contain quartz. A small amount of prospecting in this zone has failed to discover sizable bodies of dumortierite.

The mine workings are in the eastern zone, which is roughly 60 feet thick. They extend from the canyon bottom up the north side of the canyon for about 1,000

feet, through a vertical distance of about 600 feet. The lower part of the workings, extending from the canyon floor upward through a vertical distance of about 270 feet, appear to have furnished all the production. The workings, which consist of opencuts and, at various levels adits leading to inclined stopes, extend as much as 600 feet into the canyon wall. Most of the stopes are inaccessible.

Owing to the poor condition of the workings and the lack of satisfactory cross-sectional exposures, systematic sampling was not attempted. The samples collected and analyzed are described in table 35.

TABLE 35.—*Beryllia in samples from the Champion mine*

Sample	Description	BeO (percent)
329–1108	Chips from various blocks of lavender dumortierite-bearing rock on the dumps, main workings	0. 0011
1109	Chips from various blocks of andalusite-bearing rocks on the dumps, main workings	. 0006
1110	Chips from various blocks of pink dumortierite-bearing rock on the dumps, main workings	. 0013
1129	Chip sample across full width of the east zone, from exposures above the uppermost stope and its connected opencut	<. 0001

WHITE PINE COUNTY
CHERRY CREEK DISTRICT

The tungsten deposits of the Cherry Creek district are in the Egan Range, west and northwest of the town of Cherry Creek. They are in a northeastward-trending belt extending more than 2½ miles southwestward from a point northeast of the Ticup mine. The main part of the belt, which is in the vicinity of the Ticup mine, has been mapped and described briefly by M. R. Klepper (1943, fig. 3).

The belt is underlain by northwestward-dipping interbedded limestone and shale resting on quartzite. In the Ticup mine area, the mineralized parts of the belt lie mostly northwest of a northeast-trending silicified fault zone. Tungsten mineralization appears to be related both to the fault zone and to certain shattered limestone units. The mineralized beds and the fault zone converge southwestward toward the Ticup mine area, where the principal tungsten deposits are located.

HAPPY CLAIMS

The Happy claims are in limestone southwest of the area mapped by Klepper, presumably in the same general mineralized belt. In 1949 they were being explored and mined on a small scale by the Cherry Creek Tungsten Mining Corp. The claims lie between the Cherry Creek-Arthur road and the Ticup mine area and are accessible by a good mine road that turns northeastward from the Cherry Creek-Arthur road a few hundred yards southeast of the pass over the Egan Range.

The deposits on the Happy claims are in a shattered zone in westward-dipping blue-black limestone; the zone trends roughly north and is traceable for at least 400 feet along the axis of the ridge in which the mine workings lie. The limestones are irregularly mineralized with quartz, calcite, and minor amounts of scheelite. The ore bodies apparently consist of more heavily mineralized parts of the zone that contain scheelite in minable amounts and are large enough to warrant exploration.

There are two ore bodies, both near the south end of the crest of the ridge. The west ore body, reportedly worked during World War I, was mined by an irregular opencut 30 feet long. The ore consisted of extremely coarse calcite with quartz and scheelite. Little ore remains, and the deposit was not sampled.

The ore body being mined in 1949 is northeast of the west ore body and appears to be connected with it by small irregular stringers of calcite and quartz. Mining is chiefly from an opencut 60 feet long. At its north end the cut leads to an inclined stope trending northwest. The ore body dips steeply eastward and appears to have been highly irregular in outline. In the inclined stope it is a more regular veinlike body striking N. 5° W. and dipping 42° E. It consists of quartz, calcite, and accessory scheelite. The average grade of ore in the stope is reported to be about 1.5 percent WO_3. Sampling data for the Happy claims are shown in table 36.

TABLE 36.—*Beryllia in samples from the Happy claims*

Sample	Description	BeO (percent)
329–1024	Chip sample of ore from walls of inclined stope	0. 0009
1025	Fines scooped up from floor of stope	<. 0001
1035	Sample of table concentrates from about 400 tons of ore	<. 0001
1038	Sample of tailings from about 400 tons of ore	<. 0001

CHERRY CREEK MINE

The Cherry Creek mine consists of workings south and southeast of the Ticup mine. Three types of scheelite ore bodies have been mined, and they are known as the "A" ore body, the "B" ore body, and the quartzite ore body. The "A" body is a pipe-shaped ore shoot reported to contain from 1 percent to 3 percent WO_3. The shoot lies along the contact between dense, light-gray limestone and blue-black limestone. The ore consists of varying proportions of coarse calcite, quartz, and scheelite, cementing silicified limestone. The pipe apparently formed at the intersection of northwest-trending fissures with a shattered zone in the limestones. The shoot is surrounded by an envelope of low-grade ore of unknown thickness reported to contain

about 0.5 percent WO_3. A dump sample (329–1034) of this ore contained less than 0.0001 percent BeO.

The "B" ore body consists of a series of podlike lenses of shattered and mineralized blue-black limestone. Two lenses were examined and sampled. These are the southernmost body shown on Klepper's map and an adjacent body to the northwest that did not crop out. One sample of ore-bearing limestone was obtained from each of the lenses (samples 329–1028 and –1029). Each contained 0.0007 percent BeO.

The quartzite ore body is mostly on the northwest side of the silicified fault zone that extends southwestward from the Ticup mine area. The hanging wall of the body is of limestone and the footwall is of quartzite. The ore body is reported to have been traced for more than 3,000 feet on the surface, and the ore is largely low grade, containing about 0.5 percent WO_3. A sample (329–1031) of fines from the floor of a stope in the quartzite ore body continued less than 0.0001 percent BeO.

A considerable tonnage of tailings has been settled in various parts of the valley below the company's mill in Cherry Creek Canyon. Two samples of tailings (329–1036 and –1037) representing large tonnages of ore from the "A" and "B" ore bodies were taken. They did not contain as much as 0.0001 percent BeO.

SNAKE RANGE

SACRAMENTO PASS MINE

The Sacramento Pass mine is in sec. 18, T. 15 N., R. 68 E., one-fourth of a mile south of U. S. Highway 6, and 2.5 miles west of Sacramento Pass. The deposit consists of two shattered beds of limestone of Cambrian age that dip 20° to 25° W. The shattered parts of the beds have been cemented by a varying mixture of quartz and calcite, with small amounts of scheelite. In the more markedly mineralized parts of the beds, fragments of limestone have been silicified to varying degrees. A small tonnage of scheelite has been recovered. Scheelite occurs as coarse crystals in quartz, with which coarse calcite is associated, and in adjacent silicified limestone. The mineralization was highly erratic, and there is no well-defined ore body.

The workings consist of an inclined stope and a small irregular cut near the north end of a ridge. Prospect pits have been dug on the ridge crest south of the workings, and an adit and at least two shafts enter the west slope of the hill. The adit and a connecting shaft were accessible but showed only stringers of quartz and carbonate. The principal scheelite ore body, and apparently the only one at all productive, is in the inclined

stope, which is probably in the upper of the two limestone beds.

A single chip sample (329–1000) was taken of various types of vein material at a number of points along the face of the inclined stope. A piece of altered limestone was included. The sample contained 0.001 percent BeO.

DIRTY SHIRT MINE

The Dirty Shirt mine is on the west slope of the Snake Range, one-fourth of a mile north of Mary Ann Canyon in sec. 24, T. 14 N., R. 67 E., southeast of Osceola, Nev. In 1941–43, about 120 units of WO_3 were produced from 100 tons of ore. The workings consist of an incline nearly parallel to the dip of the vein, with a small stope southwest for about 50 feet from the upper part of the incline, and small extensions northwest from the incline at two places. At 70 feet below the collar of the incline a drift about 40 feet long has been run southward, and 120 feet below the collar a second drift has been run southward for about 80 feet.

The deposit is a vein that strikes about N. 47° E. and dips about 45° SE. It cuts westerly dipping quartzite, and in places a dark greenish rock locally called "metadolerite" forms the hanging wall. The full thickness of the vein could be seen only at one place, where it is about 10 feet. The vein consists of quartz with varying amounts of calcite, feldspar (probably plagioclase), and minor amounts of scheelite, galena, and possibly various other sulfides. The vein is everywhere partly oxidized; so the original sulfide content may have been somewhat higher than is now apparent.

An adit 650 feet long, driven at a point several hundred feet north of the incline and about 200 feet lower, is considered to be on the same vein. A brief inspection indicated that the vein in this adit ranges from a few inches to at least 6 feet in thickness and is partly in quartzite, partly in "metadolerite." Much of the variation in thickness is due to postmineralization movement along the vein walls, whereby the vein has been pinched out in places. The vein consists of quartz with minor amounts of plagioclase. It appears to contain little if any carbonate, scheelite, or sulfides, and is thus in marked contrast to the vein exposed in the main working.

Chip samples were taken at various places across the exposed parts of the vein in the incline and stopes. As mining centered on the footwall part of the vein and the hanging-wall side was accessible at only one place, the 6 to 8 feet of the vein from the footwall upward is better represented. Sampling data are given in table 37.

TABLE 37.—*Beryllia in samples from the Dirty Shirt mine*

Sample	Description	BeO (percent)
329–1005	Chip sample of parts of vein next to footwall below scheelite ore shoot	0. 0008
1008	____do____	. 0006
1007	Same as 1005 but from hanging-wall side	. 0008
1009	Chip sample across vein, north wall of incline	<. 0001
1010	Chip sample across scheelite ore body	<. 0001
1011	Chip sample across vein in pillar separating main stope from incline	<. 0001

SAN PEDRO MINE

The San Pedro gold mine is about 2 miles northeast of Sacramento Pass and is reached by a road that branches to the north off Highway 6 at a point a few hundred yards east of the Sacramento Inn. About a mile north of the main highway a road leads northwest up a canyon to the mine.

The workings include adits at three levels. The upper adit is just below the ridge crest and is about 275 feet long. Inclined stopes extend at intervals upward 5 to 30 feet from the adit, and downward for as much as 85 feet. The middle adit is 75 feet lower and intersects the lower parts of the stopes. The third adit which is about 100 feet below the second, was not fully explored, but it appears to be connected by raises to the level above. Surface workings consist of a series of shallow pits, trenches, and shafts.

The mine workings are chiefly in a mineralized zone in fractured quartzite. The zone is more than 900 feet long and at least 180 feet in maximum width. The quartzite dips westerly and is overlain by quartzitic conglomerate, which appears to mark the effective limit of mineralization. Part of the lowest working is in phylite, which may underlie the quartzite, but exposures in the vicinity suggest that the structure of the beds may be far from simple.

The mineralized zone is in fractured quartzite. Quartz veins fractions of an inch to several feet thick have formed along the major fractures that strike N. 55° E. and dip 45° SE. These veins are in places intricately connected by cross veins; thus the mineralized zone ranges from a sheeted lode to a stockwork. There is much variation from place to place in the spacing of the veins. The workings that constitute the gold mine are along what apparently is the thickest and most persistent vein in the zone. The vein ranges from a few inches to 6 feet or more in thickness and in most places it has no sharp contacts but appears to grade outward into shattered quartzite. The veins, so far as accessible, consist solely of quartz.

Chip sample 329–1003 was taken across the main vein from a pillar in the upper adit level. Sample 329–1004 consisted of chips taken at intervals across 40 feet of mineralized zone exposed east of the mouth of the

upper adit. Neither contained as much as 0.0001 percent BeO.

MINERVA DISTRICT

The deposits of the Minerva tungsten district are southeast and east of Shoshone, Nev., on the west slope of the Snake Range. Studies by R. F. Stopper [5] and others during World War II indicated that the district has seven principal veins. The veins are thought to occupy normal faults that strike east and dip 45° to 70° N. The fault zones range in width from a few inches to 30 feet and in length from 1,000 to 4,000 feet. Scheelite ore shoots form where a favorable bed, locally called the "upper white limestone," is intersected by the vein. The shoots plunge gently westward. They are of small vertical extent but have pitch lengths as great as 900 feet.

The veins consist of quartz and carbonates (iron-bearing in part) with minor amounts of scheelite and traces of other minerals. Horses and fragments of limestone in various stages of silicification are numerous. Scheelite occurs mostly in the veins but small quantities are found in the enclosing wall rocks. It is closely associated with quartz. The carbonates mainly formed late, occurring along fractures in the other minerals. All veins of the district are offset by postmineralization faults. Sampling data for the three veins examined by Cameron—the Chief, Oriole, and Everit—are shown in table 38.

TABLE 38.—*Beryllia in samples from the Minerva district* [1]

Sample	Description	BeO (percent)
329–1015	Chip sample across full width of Chief vein	0. 0008
1019	____do____	<. 0001
1020	Chip sample of mineralized limestone from footwall of Chief vein	<. 0001
1021	Chip sample across full width of Oriole vein, lower level	. 0007
1022	Same as 1021 but from upper level	. 0017
1023	Chip sample across full width of vein, upper level, East Everit mine	<. 0001
1016	Tailings, Minerva mill, from mixed ores of Canary Yellow and Chief mines	. 0006

[1] Chip samples taken by R. F. Stopper, then manager, Minerva Scheelite Mining Co.

CALIFORNIA

INYO COUNTY

TUNGSTEN HILLS DISTRICT

A series of tungsten deposits of the tactite type occurs in the Tungsten Hills at the east base of the Sierra Nevada about 10 miles west of Bishop, Calif. The deposits have been worked periodically for tungsten since about 1916, and have been described by Knopf (1917), Hess and Larsen (1921, p. 268–274),

[5] Manager of Minerva Scheelite Mining Co. at time of our visit.

is described from the Montrose and San Miguel county localities, where it was thought to be possibly analogous to the vanadium mica roscoelite, as under the microscope it was found to present a chloritic appearance. The color is a bright green, very similar to the green minerals described above, with perhaps a very slightly deeper tinge of blue.

At places near both prospects the rock is stained with the more common iron deposits (oxides and hydrates), which color it rusty brown or ocher-yellow.

The deposits as a group resemble in general character the previously described occurrences of this mineral, both the Coal Creek deposits and those still farther south in Colorado and Utah. The association of silicified wood noted at the Coal Creek locality has not been found, the latter possibly being rather of an accidental nature than bearing any genetic relation to the deposition of the minerals.[b] As stated, the minerals are very evidently mere crusts or coatings, or surficial impregnations in sheared, brecciated, and jointed zones in the rock mass. These zones of brecciation evidently mark the path of the mineralized solutions from which the deposits have been derived.

The extent and practical value of the Blue Mountain deposits is not yet shown to be of much importance. Nowhere had development work been carried more than 10 or 15 feet in from the surface. At none of the prospects seen did there appear to be any great quantity of the minerals exposed by present developments. The occurrence of the minerals is of itself an interesting feature, and there is a possibility of further discoveries.

a Hillebrand, W. F., and Ransome, F. L., On carnotite and associated vanadiferous minerals in western Colorado: Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 134.
b Cf. Boutwell, J. M., op. cit., p. 209.

TUNGSTEN DEPOSITS IN THE SNAKE RANGE, WHITE PINE COUNTY, EASTERN NEVADA.

By F. B. WEEKS.

INTRODUCTION.

A brief description of the tungsten deposits in the Snake Range, eastern Nevada, was published by the writer (2)[a] in 1901, and in 1902 F. D. Smith (6) published an account of the occurrence and development of the prospects. In October, 1907, the writer made a more detailed study of the development at this locality and the character and occurrence of the ore deposition.

SITUATION.

In 1900 a mining district was formed under the name Tungsten mining district, embracing several square miles along the western slope of the Snake Range south of Wheeler Peak (locally known as Jeff Davis Peak). This range as an orographic feature begins about 25 miles south of this locality and extends northward from its southern limit about 135 miles between latitude 38° and 40°. It includes the Deep Creek or Ibanpah Range and the group of connecting hills known as "Kern Mountains." This is one of the most extensive and prominent ranges between the Wasatch and the Sierra Nevada. Its highest point, Wheeler Peak, reaches an elevation of 12,000 feet. (See fig. 5, p. 118.) In the area of the tungsten prospects the surface of the mountain slope is dissected by several wide, shallow gulches which are dry except when occupied by melting snow or storm waters. There are several small springs, but at present the water sinks in the gulch gravels.

The region is about 45 miles southeast of the nearest railroad at Ely, Nev. This road—the Nevada Northern—is 140 miles long and connects with the Southern Pacific Railroad at Cobre, Nev. The wagon road to Ely is an excellent mountain road which crosses the

a Numbers in parenthesis refer to corresponding numbers in "List of recent publications" at end of this paper.

Schell Creek Range (see map, fig. 5) over a comparatively low pass with no very steep grades. Prior to September, 1906, the outlet to the railroad was via Osceola over the Snake Range to Newhouse, Utah, a distance of 100 miles.

GEOLOGY.

The rocks of the region are granites, which may be in part the oldest rocks: Cambrian argillites, quartzites, shales, and limestones, and an intrusive granite porphyry which is younger than any of the sedimentaries. Within the Tungsten mining district the only rocks exposed are the granite porphyry and the quartzites and argillites.

The granite porphyry ranges from fine to coarse in texture and from light to dark gray and red in color. It occupies the lower part of the mountain slope and forms a portion of a considerable mass which extends to the northeast for several miles and is exposed on the eastern side of the range. There seem to be slight indications of deformation within the eruptive mass, and contact metamorphism is developed only to a limited extent. Apparently the intrusion took place since the formation of the mountain range. In general character and mode of occurrence this intrusion of granite porphyry resembles many intrusive masses in other parts of Utah and Nevada. Some of these are known to be post-Carboniferous and they may be of much more recent occurrence.

The base of the sedimentary rocks is not exposed in the Tungsten mining district. Only a small area of purplish argillite is exposed in the northwest corner of the district, overlain by 100 to 200 feet of quartzite. The quartzites are gray, blue, and purple, the gray quartzite forming the larger part of the series. The strata are cut by many quartz veinlets which are probably of secondary origin, formed during the silicification of the original sandstone. The rocks are fine grained and the alteration by silicification is very complete. In thickness the beds range from a few inches to 2 feet. The argillite is a compact purple rock in rather thick layers. In this area it is little altered, but in other parts of this region the process of metamorphism has progressed much farther and the rock has been called "silvery slate."

GEOLOGIC STRUCTURE.

The Snake Range in this region is a quaquaversal dome, having its center near Wheeler Peak. Subsequent to the uplift there was an intrusion of a considerable mass of igneous rocks that tilted the beds to a high angle in some parts of the region and displaced them in others. The steep southerly dips in Wheeler Peak and the high ridges to the south flatten to 25° in the Tungsten district. North

of Wheeler Peak the fold has been broken by several northeast-southwest faults of considerable displacement, the beds having a northeast-southwest strike and dipping 45° NW.

In the area shown on the map the metamorphism and deformation which accompanied the intrusion are not so extensive as in other parts of the region.

VEINS.

GENERAL DESCRIPTION.

The veins carrying the tungsten ore are not vertical, but pitch to the northwest or southeast at varying angles, ranging from 55° to 75°, the general direction being northeast and southwest. The actual outcrop is usually limited to a few feet. From the close proximity of some of the veins it might be considered that they are branches from a main vein, but neither outcrops nor underground workings have shown this to be the case. In some places the vein splits into several narrow veins separated by the country rock. Their occurrence is irregular and from the débris it appears probable that there are veins now covered by "slide rock." In width they range from a few inches to 3 feet. The composition of the vein material is essentially quartz and hübnerite, with here and there a little fluorite, pyrite, and scheelite. The quartz is compact and contains no pores, vugs, or honeycombed areas. A few assays have been made which show the presence of gold and silver, but the amount is small and no attempt has been made to recover it. Well-defined walls are of common occurrence, but they are not persistent.

OCCURRENCE OF THE TUNGSTEN ORES.

The hübnerite occurs irregularly through the vein material. In some places there has been a concentration of the ore near the walls. Hübnerite crystals, varying in size and completely surrounding the quartz crystals, and also quartz crystals inclosing the hübnerite, are abundant. The greater part of the ore is disseminated in fine grains through the quartz or in irregular massive bodies. Where the veins pinch to a few inches in width the hübnerite occurs in thin stringers or is interlaminated with the quartz. No wolframite has yet been determined from this region. In 1901 Dr. W. F. Hillebrand made a qualitative test of two or three specimens from the principal vein which showed the ore to be hübnerite. Scheelite has been found very sparsely disseminated in zones which appear to indicate shearing. It occurs in small flakes instead of the usual granular or massive forms.

EXTENT OF MINERALIZATION.

There appears to be a general consensus of opinion among prospectors and others interested in tungsten deposits that these ore-bearing veins do not extend in depth. No workings have thus far been put down which determine this point. It may be true that some, possibly most, of the individual veins do not extend to great depths. In considering the question of depth, however, it should be remembered that in this region the intrusive mass is a part of a magma of unknown depth, which has been forced through a considerable thickness of sedimentary strata. In the area under discussion erosion has removed at least 300 feet from the upper part of the principal vein. In the light of present knowledge of veins of this kind it seems probable that there may be ore-bearing veins within the igneous mass which have not yet been exposed by erosion.

ORIGIN OF THE VEINS.

The magma which intruded the sedimentary strata probably cooled entirely beneath the surface and is now exposed by erosion as a body of granite porphyry. Before complete consolidation the magma was subjected to strains which produced cracks and fissures. These fissures, varying in width and vertical extent, were distributed irregularly through a portion of the rock, but in the main strike in a nearly uniform direction. The latest phase of consolidation consisted in the deposition of the fissure filling by magmatic waters carrying in solution silica and a small amount of certain rare metals.

MINING DEVELOPMENTS.

About 30 claims have been located within the Tungsten mining district, and at present all of them are controlled by the Tungsten Mining and Milling Company.

The principal underground workings are on the Hub claim (No. 1 on map, fig. 13). Tunnel No. 1 (fig. 13) is 225 feet in length, and the face is 125 feet below the surface, which forms the deepest working on any of the veins. At 150 feet from the mouth of the tunnel an upraise has been made to join an incline from the surface. In this tunnel nearly all the various features described under the headings "Veins" and "Occurrence of the tungsten ore" are exhibited. The vein ranges from a few inches to 3 feet in width, strikes N. 68° E., and dips 65° NW. Present developments show that this is the largest and most prominently mineralized vein in the region. Tunnel No. 2 is about 125 feet vertically above No. 1 and is 59 feet in length. This portion of the vein is split into four parts, separated by the granite porphyry. There is about 18 inches of streaky ore in the face of this tunnel. Shaft No. 1 is 37 feet in depth. Near

the surface the vein is pinched, but about midway of the shaft it is about 3 feet wide. Shaft No. 2 shows the vein about 30 inches in width, with a small amount of ore. In the face of the tunnel near shaft No. 2 the vein is 24 inches wide, with ore in streaks.
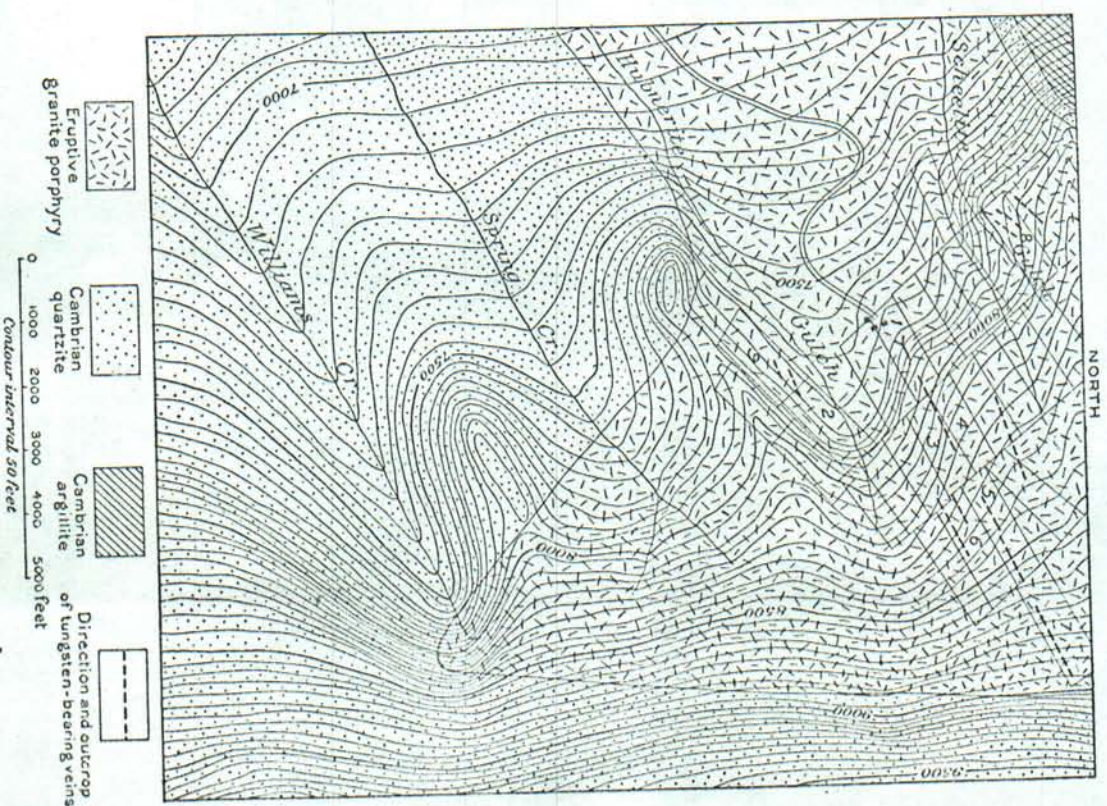
On the slope below the outcrop of this vein several tons of ore, which was reported to average about 68 per cent of tungstic acid, were picked up among the "slide rock" and shipped before underground work was begun. Grains of hübnerite are disseminated

FIG. 13.—Geologic and topographic sketch map of Tungsten mining district, White Pine County, Nev.

Eruptive granite porphyry

Cambrian quartzite

Cambrian argillite

Direction and outcrop of tungsten-bearing veins

Contour interval 50 feet

0 1000 2000 3000 4000 5000 feet

NORTH

through the finer material of the slope and the bottoms of the gulches. Considerable ore has also been gathered from time to time and added to the dumps.

The development work on the Tungsten claim (No. 3 on map) consists of two tunnels and a shaft. On the Wolframite and Great Eastern claims (Nos. 4 and 5 on map) are several small trenches exposing narrow veins with ore. On the Eagle claim (No. 7 on map), just below the contact of the granite porphyry and quartzite, the vein is exposed in a trench, standing nearly vertical and striking N. 40° E. Hübnerite with a small amount of scheelite is found here. In the quartzite débris it was found that small veinlets of quartz penetrate the quartzite, a few of them carrying a little hübnerite. It is probable that this ore occurs near the contact zone. The region is said to have been thoroughly prospected and very little material of this kind has been found in the quartzite, which therefore seems unlikely to yield a deposit of commercial importance.

In the Side Issue claim (No. 2 on map), on the south side of Hübnerite Gulch, a mineralized vein is exposed in a 10-foot cut pitching 80° S. and striking N. 45° E. On the lower side of the cut the vein is 2 feet wide and it is said that from this place a piece of solid hübnerite was taken weighing 114 pounds. On the upper side of the cut the vein is split into two 6-inch veins separated by 4 feet of granite porphyry. In the bottom of the gulch these veins have pinched to a thickness of 3 inches each. The country rock is a coarse-grained, light-colored porphyry which, it is said, can be worked more easily than the rock in other parts of the district.

On the Tungstic claim (No. 9 on map) is a 4-foot vein striking N. 65° E. which shows very little ore. About 50 feet above is a 3-foot quartz vein in which no ore was seen.

In the ridge west and a little north of the Hub claim a hübnerite-bearing vein is exposed in several places. Several small veins appear to extend in a direction about N. 60° E.

The Star claim (No. 8 on map) is developed by a tunnel 32 feet long in which the vein ranges from 6 inches to 2 feet in thickness, pitching 55° SE. and striking N. 30° E. In this tunnel scheelite associated with hübnerite occurs in larger quantity than in any other known locality in the district. About 55 feet and 70 feet south of this vein are two hübnerite-bearing veins striking N. 42° E. The country rock is granite porphyry of a more pronounced reddish color than in other parts of the area. A short distance north of the tunnel a 1-foot vein striking N. 42° E. and showing considerable hübnerite is exposed in a shallow trench.

METHODS OF MINING.

The vein material is exceedingly hard and difficult to mine. Drills quickly become dulled and the rock does not shoot well. The work is all done by hand labor and tunneling is said to cost nearly $30 per running foot. At present it would appear advisable to develop the vein by open cuts at different levels with a steel-lined shoot on the surface on each side—one to care for the waste and the other for the ore. A much larger amount of material would be dislodged by each shot than when confined in a tunnel or shaft. There would be no expense for hoisting and there would always be good light for sorting. In handling the material care should be taken to save the fines, as a considerable part of the hübnerite occurs in grains disseminated through the quartz. The scheelite also is likely to be thrown away in the waste on account of its general resemblance to quartz.

On account of the large percentage of waste a considerable amount of hand sorting is necessary. After crushing, the hübnerite is easily separated from the quartz. A hand-made jig, operated by horse-power, was used and afterwards replaced by a 5-horsepower gasoline engine.

SUMMARY.

The occurrence and character of the vein material vary so much within a few feet that the depth and width of the veins and the amount of hübnerite can not be estimated. Nature has, however, done much to assist in determining the other factors which affect the commercial value of these deposits. Several springs of small flow occur at a considerable elevation above the natural location for a concentrating plant and their combined flow would be sufficient for milling purposes. Williams Creek has an estimated flow of 700 cubic feet per minute and would furnish power to generate electricity for a mill and drilling purposes. There is still sufficient timber on the higher mountain slopes to furnish mine timbers. The lower slopes are covered in spots with mountain mahogany, which makes a good domestic fuel. There are ranches in the valley which could furnish general supplies. Railroad facilities are now at a considerable distance, but surveys have been made for a railroad to connect Ely with southwestern Nevada and Salt Lake to the northeast. One of these surveyed lines crosses the Schell Creek Range into Spring Valley opposite Osceola, about 20 miles north of the Tungsten mining district.