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ACCESSORY MINERALS IN SOME GRANITIC ROCKS IN CALIFORNIA AND NEVADA AS A FUNCTION OF CALCIUM CONTENT[1]

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ABSTRACT

Studies of accessory minerals separated from granitic rocks from the Mount Wheeler mine area, Nevada, and from the Yosemite Valley area, California, show that the calcium content of the rock has an important influence on the species of heavy accessory minerals developed. Typical calcium-rich and calcium-poor assemblages from the Mount Wheeler mine area are:

Calcium-rich		*Calcium-poor*
(CaO$>$1.8 per cent)		(CaO$<$0.7 per cent)
apatite	P	monazite
allanite	Cerium-earths	
sphene	Ti	ilmenite
epidote magnetite	Fe	garnet

Assemblages are similar in rocks from Yosemite Valley, but garnet is rare.

These studies also suggest that zircon is more abundant in calcium-rich than in calcium-poor granitic rocks.

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Introduction. During the past three years the writers independently have been doing field and laboratory work on granitic intrusive rocks in two widely separated areas, Lee in the area of the Mount Wheeler mine, Snake Range, White Pine County, Nevada, and Dodge in the Yosemite Valley area, California.

The laboratory phase of each of these studies has included mineral-separation work on crushed samples of the intrusive rocks. Although our results are not directly comparable, we have found that accessory-mineral species in the rocks of both areas clearly are related to the calcium content of the rocks. This paper presents the evidence supporting this conclusion.

Mount Wheeler mine area, Nevada. Intrusive rocks near the Mount Wheeler mine are exposed in a westward-trending band 1 to 3 miles wide with a total outcrop area of about 20 square miles (see the maps of Drewes, 1958, and Whitebread *et al.*, 1962). The highly variable min-

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[1] Publication authorized by the Director, U. S. Geological Survey.

eralogy and texture of the intruding rocks led Lee and Bastron (1962) to suggest the possibility of more than one intrusive phase. Study of these rocks is still in progress, but recent results have shown that mineralogical differences in the intrusive rocks are controlled primarily by variations in the composition of the host rock.

The intrusive rocks described here were referred to by Drewes (1958) as a granodiorite stock and by Whitebread and Lee (1961) and Lee and Bastron (1962) as a quartz-monzonite stock. More recently, analytical results for 16 rock samples (Table 1) collected from various parts of the stock show that either classification is applicable, depending upon position within the intrusive body. Molecular norms (Fig. 1) calculated from the analyses indicate a range in composition extending from granodiorite to quartz monzonite. Where the stock cuts the Cambrian Prospect Mountain Quartzite, it is quartz monzonite; where it intrudes the Cambrian Pole Canyon Limestone, it is granodiorite.

Weight per cents of the accessory minerals present in these 16 samples have been determined. Weight of samples used for mineral separation was between 500 and 1,000 grams of −80 mesh material. After elutriation

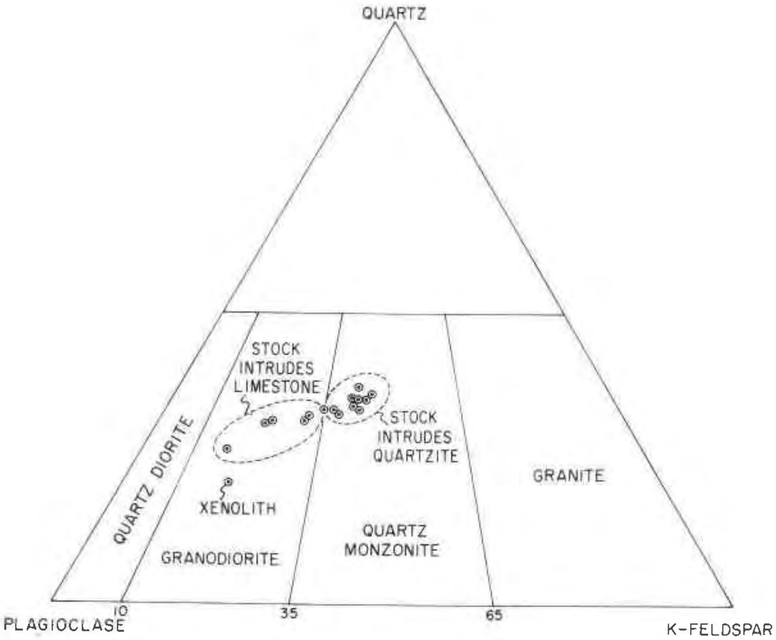

FIG. 1. Molecular norms of 16 samples collected from various parts of the stock near the Mt. Wheeler mine, White Pine County, Nevada. Based on Table 1.

TABLE 1. ANALYSES AND MOLECULAR NORMS OF 16 SAMPLES COLLECTED FROM VARIOUS PARTS OF THE STOCK NEAR THE MT. WHEELER MINE, WHITE PINE COUNTY, NEVADA[1]

Sample Number	63-MW-60	126-MW-61 (Xeno-lith)	147-MW-61	151-MW-61	152-MW-61	190-MW-61	205-MW-61	229-MW-61	230-MW-61	234-MW-61	238-MW-61	8-DL-61	25-DL-61	31-DL-61	43-DL-61	49-DL-61
SiO_2	76.0	62.1	73.4	73.2	71.1	74.5	74.6	75.6	76.4	72.8	74.9	70.9	70.3	70.9	66.6	75.9
Al_2O_3	12.9	16.6	14.1	14.3	15.0	13.5	13.3	13.4	13.0	14.3	13.7	14.6	15.5	15.0	16.5	13.4
Fe_2O_3	.42	2.5	.68	.68	1.0	.72	.65	.44	.48	.70	.41	1.2	.85	1.2	1.7	.33
FeO	.21	3.6	.95	.78	1.2	.38	.49	.18	.31	1.2	.52	1.1	1.5	1.1	1.9	.23
MgO	.21	2.1	.83	1.2	.38	.20	.24	.11	.13	.34	.16	.88	.90	.98	1.6	.17
MnO	.03	.17	.04	.04	.04	.05	.04	.03	.03	.05	.03	.05	.04	.04	.05	.02
CaO	.55	3.5	1.5	1.8	3.2	1.2	1.4	.68	.75	1.6	.78	2.3	3.1	2.4	3.9	.47
Na_2O	3.7	4.2	3.6	3.6	3.8	3.2	3.3	3.5	3.4	3.5	3.7	3.6	3.8	3.5	4.0	3.7
K_2O	4.3	2.1	4.0	3.6	2.5	4.5	4.5	4.5	4.3	4.1	4.4	3.2	2.3	3.3	1.8	4.4
TiO_2	.08	.77	.19	.19	.30	.14	.15	.07	.09	.21	.11	.33	.34	.34	.55	.08
P_2O_5	.01	.33	.06	.06	.10	.02	.02	.01	.01	.06	.01	.10	.12	.10	.19	.01
H_2O^+	.85	1.3	.72	.79	.96	.85	.87	.92	.66	.90	.87	1.1	.91	.87	1.4	.84
H_2O^-	.04	.24	.16	.07	.08	.15	.04	.13	.08	.15	.09	.06	.06	.08	.12	.08
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Total	99	100	100	100	100	99	100	100	100	100	100	99	100	100	100	100
Molecular Norm																
Apatite	0.0	0.8	0.2	0.2	0.3	0.1	0.1	0.0	0.0	0.2	0.0	0.3	0.3	0.3	0.5	0.0
Ilmenite	0.0	1.2	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.4	0.2	0.4	0.4	0.4	0.6	0.0
Orthoclase	26.0	13.0	24.0	21.5	15.0	27.5	27.5	27.5	26.0	24.5	26.5	20.0	14.0	20.0	11.0	26.5
Albite	34.0	38.5	32.5	32.5	35.0	29.5	30.0	32.0	31.5	32.0	33.5	33.0	35.0	32.0	36.5	34.0
Anorthite	3.0	15.0	6.5	7.5	15.0	6.0	7.0	3.5	3.5	7.0	4.0	10.5	14.5	11.0	18.5	2.5
Corundum	1.2	2.3	1.7	2.0	0.7	1.4	0.6	1.7	1.6	1.9	1.7	1.5	1.7	1.8	1.4	1.9
Magnetite	0.5	2.7	0.8	0.8	1.1	0.8	0.8	0.4	0.4	0.8	0.5	1.4	0.9	1.4	1.8	.3
Ferrosilite	0.0	3.0	0.6	0.4	1.0	0.0	0.2	0.0	0.0	1.0	0.4	0.4	1.0	0.4	1.4	.2
Enstatite	0.6	6.0	2.2	3.4	1.0	0.6	0.8	0.2	0.4	1.0	0.4	2.6	2.6	2.8	4.6	.4
Quartz	34.7	17.5	31.1	31.3	30.5	33.9	32.8	34.5	36.4	31.3	32.8	29.9	29.6	29.9	23.7	34.2
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	100.0	100.0

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[1] Analyses by Paul Elmore, Samuel Botts, H. Smith and Gillison Chloe, using methods similar to those developed by Shapiro and Brannock (1956).

to remove rock powder, about 15 weight per cent of the crushed sample, a separatory funnel was used to recover the heavy fraction (specific gravity greater than 2.70 mixture of bromoform and methanol). The heavy fraction was then split into separate mineral fractions by centrifuging in heavy liquids and by use of the Frantz isodynamic separator. Recovery of any mineral was assumed to be 70 per cent of the total amount present in the original crushed and unwashed fraction.

The CaO content of the analyzed rocks (Table 1, Fig, 1), was found to have a striking relationship to the accessory minerals present. For example, allanite is present to the exclusion of monazite in rocks that contain more than 1.8 weight per cent CaO (Fig. 2), but only monazite is present in rocks that contain less than about 0.7 per cent CaO. Both allanite and monazite are present at intermediate CaO values. Abundance of apatite also is related to CaO content of the rock (Fig. 3). Similar plots for epidote, sphene, and magnetite give scatter diagrams showing that amounts of these minerals also tend to increase with CaO content. On the other hand, ilmenite is present where CaO content is low, but is rare or absent where CaO content is high. Garnet is confined to calcium-poor rocks. Zircon content shows a fairly systematic increase with increase of CaO (Fig. 4).

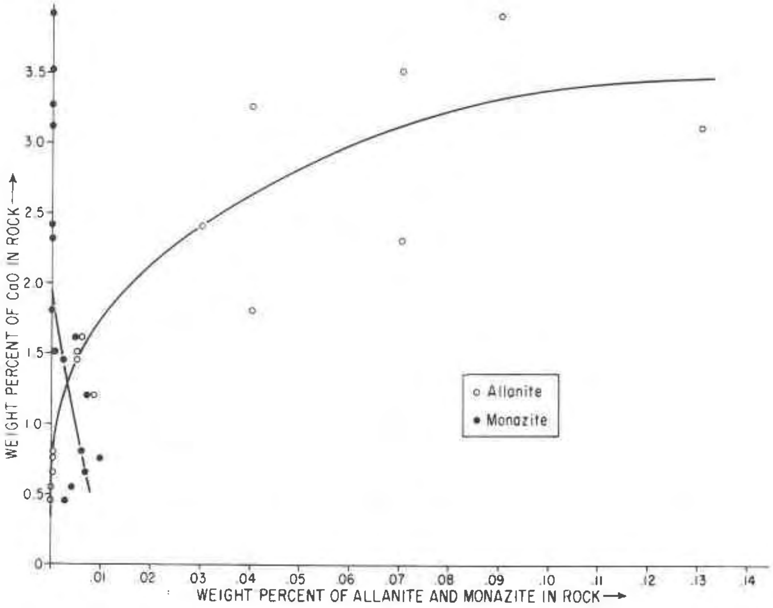

Fig. 2. Relation between amounts of CaO and allanite and monazite in samples plotted in Fig. 1.

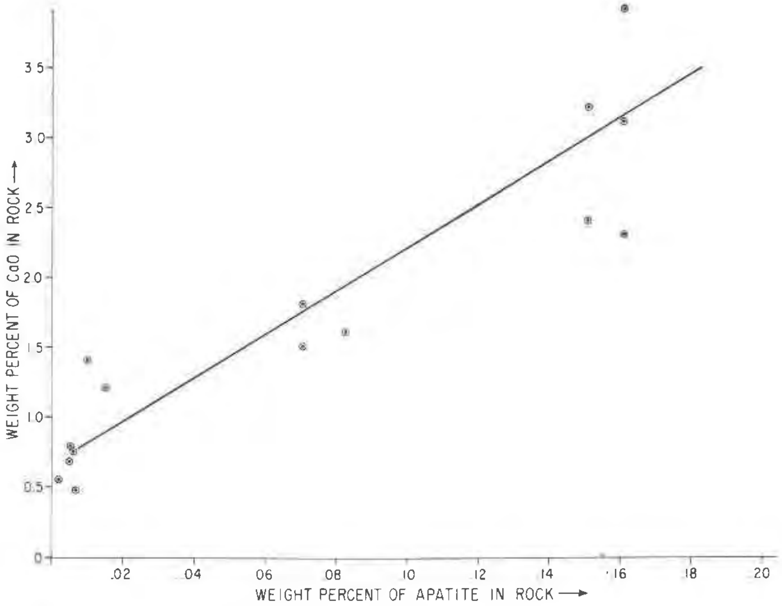

FIG. 3. Relation between amounts of CaO and apatite in samples plotted in Fig. 1.

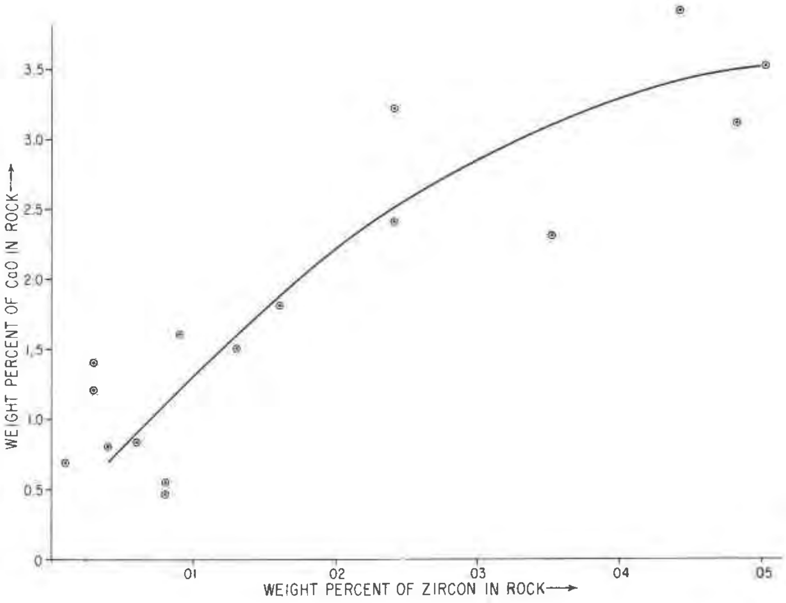

FIG. 4. Relation between amounts of CaO and zircon in samples plotted in Fig. 1.

Yosemite Valley area, California. Yosemite Valley has been carved into a small portion of the Sierra Nevada batholith, roughly at right angles to major structural trends in the batholithic rocks, affording a natural cross section of some granitic bodies of the Sierran province. Steeply dipping intrusive contacts and primary foliation suggest that erosion has cut deeply into the batholith in the valley area. Eight recognizable granitic rock units are exposed in the near-vertical 4,000-foot walls of the valley. Descriptions of these units have been presented by Turner (1894, 1900), Calkins (1930), Smith (1958), and Calkins and Peck (1962). The modal analyses in Table 2 do not necessarily substantiate the petrographic names assigned to these units by the foregoing authors. However, because the current study covers only a small portion of the outcrop area of the major units, no attempt has been made to revise the terms.

Previously Pabst (1938) examined heavy minerals in granitic rocks collected from a large area which included a part of the valley, and Dodge (1963) studied the mineralogy of rocks from the valley in the area covered by the U. S. Geological Survey Topographic Map of Yosemite Valley, Edition of 1938. Results of Dodge's work did not entirely agree with those of Pabst; reexamination of Pabst's original material by the authors corroborated Dodge's results.

The average weight per cent of accessory mineral constituents from each lithologic unit studied is given in Table 2. Magnetite was removed with an AC magnet and weighed. Floods of biotite and hornblende, which masked accessory minerals, were removed from heavy fractions (specific gravity greater than 2.85) by treatment with heavy liquids and with the Frantz isodynamic separator. The entire non-ferromagnetic, heavy accessory fraction was weighed directly. Weight percentages of accessory constituents in the total rock were determined from counts of a minimum of 600 grains from a -60, $+170$, and a -170 mesh-size fraction, with proper adjustment according to mineral density.

Two accessory mineral suites are present in the granitic rocks of Yosemite Valley. A low-calcium assemblage, ilmenite-monazite-zircon, with minor amounts of epidote, apatite, and allanite, is generally characteristic of the Taft Granite. Only one of the five samples of this granite contains significant amounts of apatite and allanite, with little monazite; this seemingly anomalous assemblage may be the result of assimilation of El Capitan Granite. Nonferromagnetic accessories from other rock units consist of modifications of the assemblage allanite-apatite-epidote-sphene-zircon. Generally, the proportion of each mineral present is reasonably constant within a single unit, with greater variation occurring between units.

Difference in calcium content of the granitic rocks is shown by differ-

TABLE 2. MODAL ANALYSIS, PLAGIOCLASE COMPOSITION, AND ACCESSORY-MINERAL CONTENT OF GRANITIC ROCKS OF THE YOSEMITE VALLEY AREA

	Average Slab Modal Analyses General Calcium Increase							
	Taft Granite	Bridalveil Granite	El Capitan Granite	Biotite granite of Arch Rock	Half Dome Quartz Monzonite	Leaning Tower Quartz Monzonite	Sentinel Granodiorite	Granodiorite of The Gateway
Quartz	35.9	30.1	31.5	31.9	28.0	15.4	20.7	19.3
K-feldspar	36.7	18.2	17.5	14.3	18.6	8.4	7.2	0.9
Plagioclase	25.4	43.2	42.2	41.8	41.9	56.1	50.7	57.9
Mafic minerals	1.0	8.5	8.8	12.0	11.5	20.1	21.4	21.9
Plagioclase composition (per cent An)	10–25	18–45	22–32	25–37	25–40	24–38	38–48	32–50
	Average Weight Per cent of Heavy Accessory Minerals in Total Rock, Calculated from Grain Counts							
Allanite	0.006	—	0.058	0.010	0.011	0.020	—	0.010
Apatite	0.003	0.019	0.035	0.077	0.077	0.051	0.098	0.089
Epidote[1]	0.003	0.087	0.073	0.326	0.274	0.344	0.160	0.128
Ilmenite	0.040	—	—	—	—	—	0.035	—
Magnetite[2]	0.499	0.165	0.463	0.804	1.437	0.380	1.522	1.402
Monazite	0.015	—	—	—	—	—	—	—
Sphene	—	—	0.079	0.528	0.713	0.557	0.542	0.688
Zircon	0.017	0.004	0.044	0.019	0.022	0.030	0.018	0.030
Other species[3]	0.001	—	0.003	—	—	0.010	0.036	0.039
Number of specimens	5	2	22	3	17	2	17	5

[1] Includes clinozoisite, pistacite, and zoisite.

[2] Direct weights.

[3] Includes anatase, augite, chalcopyrite, garnet, molybdenite, pyrite, and xenotime.

ence in plagioclase abundance and composition (Table 2) and by other mineralogical features. Although these data do not indicate absolute calcium contents, they do provide a relative measure. For example, the Taft Granite, which has a low percentage of sodic plagioclase relative to the other rocks, also is devoid of hornblende, and thus probably has lower calcium than the other units. The Sentinel granodiorite and the granodiorite of The Gateway have high calcium contents, judging by high contents of fairly calcic plagioclase and appreciable hornblende. The low-calcium assemblage is confined to the unit lowest in calcium, whereas calcium-bearing accessories are abundant in more calcic rocks. In addition, content of magnetite and zircon is generally greater in those units bearing the high-calcium accessory assemblage.

CONCLUSIONS

Studies of the granitic intrusive rocks in the Mount Wheeler mine area, Nevada, and in the Yosemite Valley area, California, indicate that the calcium content of the whole rock has an important influence on the assemblage of heavy accessory mineral developed. If the rock is relatively high in calcium, the calcium minerals apatite and sphene tend to be abundant. Cerium-earths are present in allanite, also a calcium mineral. Magnetite usually is abundant. In contrast, if calcium content is relatively low, apatite, sphene, and allanite are absent or sparse, and magnetite is present in lesser amounts. Cerium-earths and phosphate are present as monazite, and titanium is contained in ilmenite. Epidote tends to be restricted to calcium-rich rocks, and, in the Mount Wheeler mine area, garnet to calcium-poor rocks. The calcium-rich and calcium-poor assemblages that follow are typical for rocks in the Mount Wheeler mine area:

Calcium-rich ($\text{CaO} > 1.8$ per cent)		Calcium-poor ($\text{CaO} < 0.7$ per cent)
apatite	P	monazite
allanite	Cerium-earths	
sphene	Ti	ilmenite
epidote	Fe	
magnetite		garnet

Similar assemblages, except for garnet which is rare, characterize rocks in the Yosemite Valley area. These studies also indicate that zircon tends to be more abundant in calcium-rich assemblages than in calcium-poor assemblages.

Probably it is more than coincidence that the relations described have been observed in two different geologic provinces, where the intrusive rocks apparently are exposed at different levels of erosion. Some of these relations have been observed in other areas. For example, Mackie (1928) examined accessories in Scottish granites and noted that wherever sphene is present, monazite is absent. He also found a similar relation between monazite and allanite. McAdams (1936) noted that sphene and monazite seldom occur together in a granitic unit in Texas. An antipathetic relationship between apatite and monazite in Sierran granites east of the main crest was discussed by Shawe (1953) and was also found by Spotts (1958) in granitic rocks of the California Coast Ranges. Mackie's observation that allanite is seldom found in large amounts in association with monazite was repeated by Lyakhovich (1962) during study of accessory minerals of granites from various localities within the U.S.S.R. No mention of antipathetic mineral relations was made by Derby (1891), but he noted that both xenotime and monazite appear to be dependent on potash, as they are abundant in potash granites but not in sodic rocks. Additional studies of accessory minerals in granitic rocks, carried out with the aid of mineral-separation work, will be necessary to determine whether general control of the heavy-accessory suite by calcium content of the whole rock is as pronounced as indicated by the results of the two studies described here.

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