HEAVY MINERALS IN THE GRANITIC ROCKS OF THE YOSEMITE REGION

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The Sierra Nevada batholith consists of a large number of intrusive units. In some parts of the Sierra Nevada these units can be clearly distinguished by careful mapping but this has been done in only a few scattered areas. The best-known profile of the granitic rocks is in the Yosemite region where Calkins[1] has defined and described the rocks across the entire width of the Sierra Nevada, and Cloos[2] has mapped the structural features.

The present study was undertaken to determine whether the intrusive units established by other methods can be distinguished by their heavy mineral assemblages. A grant from the Board of Research of the University of California to defray a part of the field and laboratory expenses is gratefully acknowledged.

The field work was done in 1931 and 1933. Large, fresh, and typical specimens were collected from about fifty localities in the Yosemite region and the northern Sierra Nevada. Only the results on the rocks of the Yosemite region are here reported. Scattered observations on rocks from other localities suggest that the results may be typical for the granitic rocks of the Sierra Nevada.

METHODS

Samples averaging about 275 grams were crushed in a jaw crusher and then further crushed in a disc crusher or iron mortar with frequent sieving to 60 or to 100 mesh. The samples were then reweighed, washed to remove powder, and again reweighed. The washing loss was kept below 15% in all cases and the total loss below 20% in most cases.

Two 10 or 15 gram portions of each of the samples thus prepared were treated with bromoform of density 2.88. The light fractions included all muscovite and chlorite and a little altered biotite. After removal of magnetite from the heavy fraction by a hand magnet, separation into further fractions by use of an electromagnet was attempted but did not yield consistent results. This may have been due to the fact that most of the rocks contained far more ordinary ferromagnesian minerals than accessories. Accordingly, the procedure after removal of magnetite was varied to fit each sample. One of the duplicate fractions was boiled briefly

[1] Calkins, F. C., The granitic rocks of the Yosemite region: *U. S. Geol. Survey, Professional Paper* **160,** pp. 120–129, 1930.

[2] Cloos, E., Der Sierra-Nevada Pluton in Californien: *Neues Jahrb. f. Min. etc.*, **BB 76B,** pp. 355–450, 1936.

with dilute hydrochloric acid, resulting in the solution of apatite and leaching of biotite without affecting any of the other heavy minerals, whereupon the leached biotite was separated by a second bromoform treatment. In those cases where hornblende was an important constituent it was separated from sphene and other heavy accessories by treatment with a thallium formate solution having a density of about 3.3. In a few cases the thallium formate separation was also used without preliminary acid treatment, thus saving the apatite.

In view of the great bulk of many of the heavy fractions no complete grain counts were made. Instead several partial counts were made on each of the separations obtained as just described. In some cases the proportions of the accessories could only be estimated by comparison of counts on several separations. In biotite-rich rocks, apatite could be counted only in the presence of a flood of biotite. If the abundance of apatite was to be compared with that of sphene and zircon, but zircon was not sufficiently abundant for accurate estimate in the presence of biotite, then apatite and sphene were counted in the fraction containing biotite, whereas zircon and sphene were counted in the weighed fraction denser than 3.3, obtained from the initial separation, and the proportions of all three established in a satisfactory manner.

All rocks were examined in two or more thin-sections. One or two micrometric analyses were made of each of the finer grained rocks to check the other work. All separations that failed to check with their duplicates or with the micrometric analyses were repeated on new crushings.

Material

The location of each specimen is shown on the sketch map of Fig. 1 which covers precisely the same area as Calkins' "Generalized Geologic Map of Part of the Yosemite Region, California."[3] The symbols used are those of Calkins who has described each of the types collected. The El Capitan granite and the Bridalveil granite had been named earlier by Turner.[4]

The rocks examined are listed in the legend of Fig. 1 in order of their presumed age, the Johnson granite porphyry being youngest. Calkins recognized several other types not included in this list. The Half Dome quartz monzonite, the Cathedral Peak granite and the Johnson granite porphyry make up an eastern mass of concentric intrusions. The remaining rocks, all exposed in the wall of Yosemite Valley, are older than this eastern mass but their age relations are somewhat uncertain.

[3] *U. S. Geol. Survey, Professional Paper* **160,** plate 51, 1930.

[4] Turner, H. W., The Pleistocene geology of the south central Sierra Nevada with especial reference to the origin of Yosemite Valley: *California Acad. Sci. Proc.*, 3rd ser., vol. **1,** pp. 304, 308, 1900.

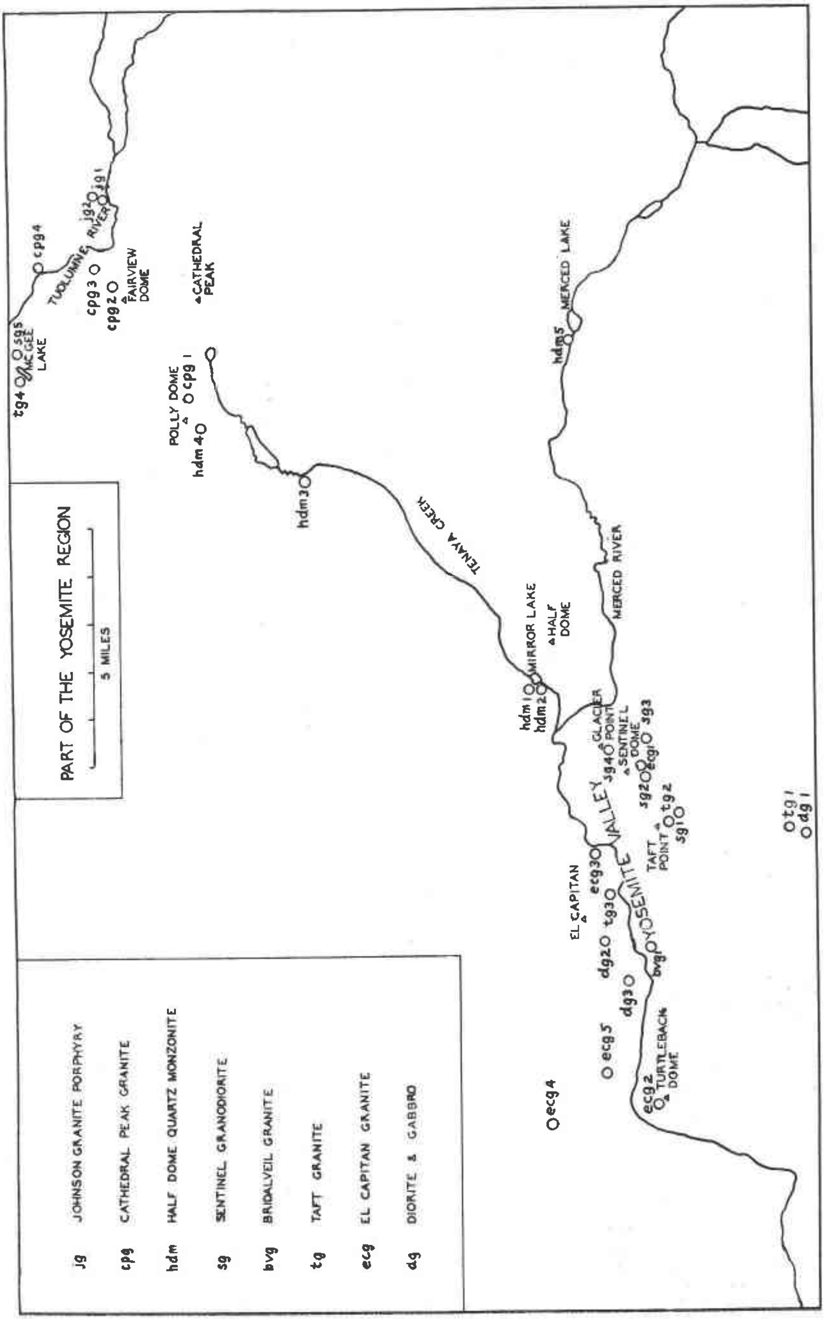

FIG. 1. Sources of specimens studied.

Results

Table 1 gives the results of the examination of the heavy concentrates. Numerical indications, with the exceptions noted, refer to weight percentages and are based on actual weighings. The index figures and the percentages of magnetite are based on duplicate determinations. The remaining numbers, for the most part, are based on single determinations. The qualitative indications of frequency are based on multiple, but incomplete, grain counts. In each case the minerals listed as abundant, or very common, are of less frequent occurrence than the least abundant of those for which percentage figures are given. Whereas, the relative abundance of the accessories in a particular rock may be satisfactorily indicated in this way, it is feared that these indications need some adjustment in comparing different samples, especially where there is a great difference in the index figure. In a few cases it might have been possible to indicate more than five orders of abundance. This was avoided in order not to burden the table and to keep the presentation as uniform as possible.

There has been a great variation in the methods of studying accessory minerals and the manner of presenting the results. Taylor[5] has recently stressed the necessity of using quantitative methods. It is felt that quantitative methods have been carried as far as is feasible in the present study. The purely qualitative statement of a part of the results is used to avoid a semblance of accuracy which would not be justified by the data.

Varietal features, though characteristic in a few of the rocks, are not recorded in the table because features suitable for comparison of the whole series were not found.

The number of accessory minerals is small in all of the rocks. In the suite as a whole, sphene, apatite and zircon are the most important accessories, differences being limited largely to changes in the proportions of these three. Sphene is a common constituent of all granitic rocks of the Yosemite region. Pyrite is common in some specimens but cannot be considered characteristic of any of the rock types. Tourmaline is only a sporadic constituent and rutile, anatase and spinel were only found as occasional grains, not certainly identified.

The differences between the accessory minerals of closely related rocks are striking in spite of the small number of varieties concerned. For instance, apatite is uniformly more abundant in the El Capitan granite than in the Taft granite, whereas the Taft granite is not only richer in

[5] Taylor, J. H., A contribution to the study of accessory minerals of igneous rocks: *Am. Mineral.*, vol. **22,** pp. 686–700, 1937.

TABLE 1. HEAVY MINERALS IN THE GRANITIC ROCKS OF THE YOSEMITE REGION

	Index figure	Magnetite	Biotite	Hornblende	Sphene	Apatite	Zircon	Ilmenite	Augite	Allanite	Zoisite	Clinozoisite	Epidote	Tourmaline	Pyrite
Johnson granite porphyry															
jg 1 Soda Springs	1.7	0.7	0.8	r	vc	vc	r	a	—	vr	r	—	c	—	—
jg 2 Soda Springs	1.9	0.8	0.8	r	vc	c	vr	a	—	c	—	—	vc	—	—
Cathedral Peak Granite															
cpg 1 Polly Dome	8.6	1.6	5.0	1.3	0.6	c	vr	—	—	—	r	—	r	—	—
cpg 2 Fairview Dome	4.4	1.2	2.2	0.5	0.4	c	vr	—	—	—	—	—	r	—	—
cpg 3 Tuolumne Meadows	4.8	1.6	1.5	1.1	0.5	c	vr	—	—	—	—	—	r	—	—
cpg 4 Tuolumne River	5.3	1.2	2.4	1.9	0.6	c	vr	—	—	—	—	—	r	—	—
Half Dome quartz monzonite															
hdm 1 Mirror Lake	7.5	1.0	4.2	1.8	0.4	vc	vr	—	—	—	—	r	vr	—	—
hdm 2 Mirror Lake	9.1	1.4	4.4	2.5	0.5	c	vr	?	—	—	—	r	vr	—	—
hdm 3 Tenaya Creek	10.8	2.0	4.2	3.6	0.9	c	r	—	—	—	—	—	r	—	—
hdm 4 Polly Dome	10.9	2.1	4.9	2.7	1.1	c	r	—	vr	—	—	vr	vr	—	—
hdm 5 Merced Lake	12.0	2.0	6.5	2.5	0.8	c	vr	?	—	—	—	—	r	—	—
Sentinel granodiorite															
sg 1 near Taft Point	21.1	2.1	9.8	8.1	1.1	a	c	—	—	—	—	vr	—	—	—
sg 2 Sentinel Dome	19.5	2.2	11.3	4.7	1.1	a	c	—	—	—	—	—	—	—	—
sg 3 Illilouette Trail	27.9	1.4	13.4	12.2	0.7	a	vr	?	c	—	—	—	r	r	—
sg 4 Glacier Point	25.4	1.3	10.9	9.2	0.8	a	vr	?	r	—	—	—	vc	—	—
sg 5 McGee Lake	27.7	2.4	15.0	12.0	0.8	a	c	—	c	—	—	—	r	—	—
Bridalveil granite															
bvg 1 Bridalveil Falls	9.4	0.5	8.7	r	vc	vc	r	—	—	r	—	r	a	—	r
Taft granite															
tg 1 Sec. 18, R. 22E., T. 3 S.	1.0	0.3	0.6	r	vc	r	c†	vc	r	?	—	vr	—	vr	r
tg 2 Taft Point	1.9	0.2	1.5	vc	vc	r	c†	c	c	?	—	vr	—	—	c
tg 3 foot of El Capitan	2.7	0.5	2.0	r	vc	r	vc†	vc	r	—	—	c	—	—	—
tg 4 McGee Lake	1.3	0.4	0.7	r	c	r	c	vc	—	—	—	vc	—	—	r
El Capitan granite															
ecg 1 near Sentinel Dome	2.7	0.8	1.8	r	vc	c	r	—	—	vr	vr	—	r	—	—
ecg 2 Turtleback Dome	3.9	0.6	3.2	vr	a	c	c	—	—	r	c	—	vc	—	—
ecg 3 Rocky Point	11.0	0.9	6.3	a	a	vc	r	—	—	—	r	—	c	—	—
ecg 4 near Tamarack Flat	6.2	0.7	5.3	r	a	vc	vc	—	—	vr	vr	—	c	—	—
ecg 5 Big Oak Flat Road	8.9	0.1	8.7	vr	a	vc	c	—	—	r	r	—	c	—	—
Diorite and gabbro															
dg 1 Glacier Point Road	48.8	0.2	1.0‡	42.5‡	vc	—	vr	—	4.8‡	—	—	—	vr	—	r
dg 2 El Capitan	32.0	0.1	14.0	17.3	0.5	a	vr	—	—	—	—	—	vr	—	—
dg 3 Oak Flat Road	38.7	0.2	16.4	21.7	0.3	vc	r	r	—	—	—	—	r	—	—

a = abundant; vc = very common; c = common; r = rare; vr = very rare.
* Includes unidentified heavy, black, non-magnetic grains.
† Two varieties of zircon; see text.
‡ Figures from micrometric measurements

zircon but contains two distinct varieties of zircon in contrast to all of the other rocks in which it was impossible to distinguish more than one variety.

The rocks described as diorite and gabbro, probably belonging to several different intrusions, show great differences in the accessory minerals.

The Minerals

Sphene. Euhedral crystals of sphene are megascopically conspicuous in the Cathedral Peak granite, Half Dome quartz monzonite, and Sentinel granodiorite. Most of the grains in the concentrates are fragments of larger crystals, but from thin-section observations and the appearance of small crystals it can be said that sphene is dominantly euhedral in the Yosemite rocks, showing the familiar "envelope" habit. Exceptions occur in the Sentinel granodiorite which carries both euhedral and anhedral sphene, and in the diorite and gabbro in which the sphene is mostly anhedral. Most of the sphene is clear and pale colored in small fragments. Only a few pieces were found to enclose other crystals.

Apatite. A short prismatic habit with pyramid and basal plane terminations is common to apatite in all of the rocks. The size of the crystals varies greatly in most specimens, maximum dimensions of about 0.1×0.2 mm. being common. No cloudy, altered or embayed apatite was seen and only a few of the larger crystals from the Half Dome quartz monzonite and the Sentinel granodiorite showed rod-like cores. Large anhedral fragments of apatite were observed in several concentrates but only in the Bridalveil granite do they reach the abundance of the euhedral crystals.

Zircon. Euhedral zircon occurs in every one of the specimens examined. For the most part the clear crystals show first and second order prisms and pyramids and ditetragonal pyramids. The larger crystals, which may reach dimensions of 0.1×0.2 mm. or more, are commonly crowded with minute unoriented prismatic inclusions. The zircons in the Sentinel granodiorite near Glacier Point, sg 3 and sg 4, are unusual in that they are rather ragged and broken and show a conspicuous development of the basal plane. Only in the Taft granite was it possible to recognize two equally abundant varieties of zircon—clear crystals similar to those in most of the other rocks and pale brown, rather stubby crystals, irregularly cracked but without inclusions. The brown, inclusion-free variety is lacking in the specimen from McGee Lake. This rock, mapped as Taft granite by Calkins, is not visibly connected with the areas of Taft granite near Yosemite Valley.

Allanite. Several of the more siliceous rocks contain a little allanite. Its presence in the El Capitan and Bridalveil granites was noted by Calkins. Reis[6] has recorded the occurrence of allanite in pegmatite veins in blocks at the foot of Eagle Peak.

Local Concentrations

The occurrence of swirls or dark streaks together with large orthoclase phenocrysts containing zones of ferromagnesian minerals in the Cathedral Peak granite along the Tuolumne River offered opportunity for a detailed study of the distribution of heavy minerals in different phases of the granite. In Table 2 are given data on the heavy minerals in the normal granite, in a swirl, and in the orthoclase phenocrysts. The method

[6] Reis, H., Note on the occurrence of allanite in the Yosemite Valley, California: *Science*, N.S., vol. **11**, pp. 229–230, 1900.

of presentation is intentionally different from that of Table 1 since these closely related rocks can thus be treated to better advantage. The ratios give the proportions of the grains found in the counts.

TABLE 2. HEAVY MINERALS IN SWIRL AND IN PHENOCRYSTS OF CATHEDRAL PEAK GRANITE, ALONG TUOLUMNE RIVER NEAR MOUTH OF DINGLEY CREEK

	Index figure	Weight percentage of heavy separate				Grain count ratios		
		magnetite	biotite	hornblende	sphene	apatite/sphene	zircon/sphene	apatite/zircon
Granite	5.3	22.6	45.2	17.0	11.3	0.2	0.02	10
Swirl	48.5	42.8	37.1	10.9	9.1	0.2	0.05	4
Phenocrysts	2.0	45.0	27.5	15.0	10.0	0.14	0.02	7

TABLE 3. HEAVY MINERALS IN DARK PHASES OF THE HALF DOME QUARTZ MONZONITE

	Index figure	Weight percentage of heavy separate				Grain count ratios		
		magnetite	biotite	hornblende	sphene	apatite/sphene	zircon/sphene	apatite/zircon
Polly Dome								
quartz monzonite	10.9	19.2	45.0	24.8	10.0	0.22	0.025	9
swirl	38.0	11.3	61.8	21.8	4.7	0.15	0.03	5
Merced Lake								
quartz monzonite	12.0	16.7	54.1	20.8	6.7	0.3	0.03	10
autolith	31.4	11.2	56.1	28.0	3.5	1.0	0.1	10

The weight percentages of biotite, hornblende, and sphene include apatite, epidote, and zircon, respectively. In each case the mineral listed in the table is far the more abundant, and the figure can be taken to apply to this constituent alone. Taking into account densities and average grain sizes approximate corrections can be obtained from the grain count ratios. The corrections are very small. Epidote was found in small amount in all three concentrates, whereas zoisite was not recorded. A single grain of rutile was seen in the concentrate from the swirl.

The general character of the heavy concentrate varies little in spite of the wide variation of the index figure. The proportion of magnetite among the heavy constituents is greatly increased in both phenocrysts and swirl. Other changes are not striking, though the increase of the zircon/sphene ratio in the swirl may indicate the early entrapment of zircon.

Autoliths are not abundant in the Half Dome quartz monzonite and are found principally in the outer parts of the mass. Table 3, which is drawn up in the same fashion as Table 2, gives data on the heavy minerals in a swirl and in an autolith of this rock from two widely separated sources well within the mass. Data for the adjoining normal quartz monzonite are repeated from Table 1. The figures show clearly that the character of the concentration is similar in the swirl and in the autolith. The results are also very much like those given in Table 2, except that magnetite is not enriched in the dark phases.