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ACCESSORY MINERALS IN SOME SIERRA NEVADA GRANITIC ROCKS AS A FUNCTION OF CALCIUM CONTENT

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ABSTRACT

Calcium content of the rock is related to abundance of heavy accessory minerals in granites of the northwest part of the Bass Lake quadrangle, California, and because the early granitic rocks contain more calcium than later ones, calcium relation appears to provide a means of determining paragenesis of the heavy minerals. For example, zircon and apatite are most abundant in the rocks with highest calcium contents, suggesting these minerals tended to crystallize early. On the other hand allanite and, above about 3.8 weight percent CaO, epidote become more abundant as calcium content decreases, indicating that in these rocks epidote and allanite tend to develop late. Calcium relation to magnetite abundance suggests a slight tendency for this mineral to crystallize late in rocks containing more than about 2.8 percent CaO. In rocks with CaO content greater than 3 percent, sphene and ilmenite appear to have formed late and early, respectively, and low amounts of sphene in adamellite are probably the result of low calcium content of that unit, titanium then being taken up to form abundant ilmenite.

INTRODUCTION

In a paper that dealt with relation of calcium content to heavy accessory mineral constituents in some California and Nevada granitic rocks, Lee and Dodge (1964) found that the CaO content of these rocks has an important connection with abundance of heavy minerals developed in them. When this paper appeared, the present writer (Snetsinger, 1965) had values already at hand for weight percents of accessory minerals in a series of granitic rocks exposed in the northwest corner of the Bass Lake 15′ quadrangle, just south of Yosemite National Park, California, and it seemed of interest to determine if a comparable situation regarding calcium applied to these granites. Accordingly, CaO was determined in rocks that had been subjected to heavy mineral study. The results show that calcium has a relation to granitic accessory mineral abundance in the Bass Lake area and an attempt is made to use the calcium relation to determine paragenesis of the minor accessories.

GEOLOGIC RELATIONS

Granites in the northwest part of the Bass Lake quadrangle consist of two plutons, a small, homogeneous body of adamellite (outcrop area 10 square miles) which has been intruded by a large zoned pluton (55 square

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miles total outcrop area) that varies in composition from tonalite to granodiorite. Field evidence strongly suggests that the rocks are of magmatic origin, and compositional variations are probably due to differentiation, although some border contamination by basic rocks may have taken place during intrusion of the large pluton (Snetsinger, 1965).

Heavy Accessory Minerals as a Function of Calcium Content

Three samples from the adamellite and nineteen from the zoned pluton were studied. Separatory procedure was comparable to that of Dodge (1963), and Lee and Dodge (1964), and weight percentage of heavy minerals from grain counts of concentrates was calculated by a computer program devised by S. H. Burch, Department of Geology, Stanford University.[1] Values for CaO were obtained spectrographically by N. H. Suhr, Pennsylvania State University.

CaO content of Lee and Dodge's rocks ranged from 0.47 to 3.9 weight percent whereas values for rocks from the present area ranged from 0.93 to 6.6, with fifteen examples above 3.9.[2] Thus, in the current study, notably more calcic rocks are being investigated than those dealt with by Lee and Dodge.

In the case of zircon, apatite and epidote, plots of weight percent CaO in the rock *vs.* weight percent of these minerals in the rock illustrate the relation of mineral abundance to calcium. With allanite, sphene and ilmenite, however, it was found necessary to plot weight percent CaO *vs.* mineral abundance expressed as weight percent of the total non-ferromagnetic fraction in order to reveal a calcium relation, because amounts of these minerals in the rocks showed little or no relation to CaO content. The latter was also true of magnetite, and for this mineral a plot of weight percent CaO against weight percent magnetite in the total heavy fraction was made. Graphs of zircon, apatite and epidote abundance in the total non-ferromagnetic fraction *vs.* CaO content are not presented because these give essentially the same result as plotting calcium against weight percent of these minerals in the rock. Why allanite, sphene, ilmenite and magnetite should behave differently from the other accessories is not clear at present.

Figure 1 demonstrates that zircon becomes more abundant in the rocks with increasing CaO content, but the tendency is not so marked as that noted by Lee and Dodge; apatite also increases in abundance with increasing CaO (Figure 2) although again the tendency is not so well developed as found by those writers. The weight apatite/zircon ratio in

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[2] CaO values of 1.25 percent and below represent samples of the adamellite.

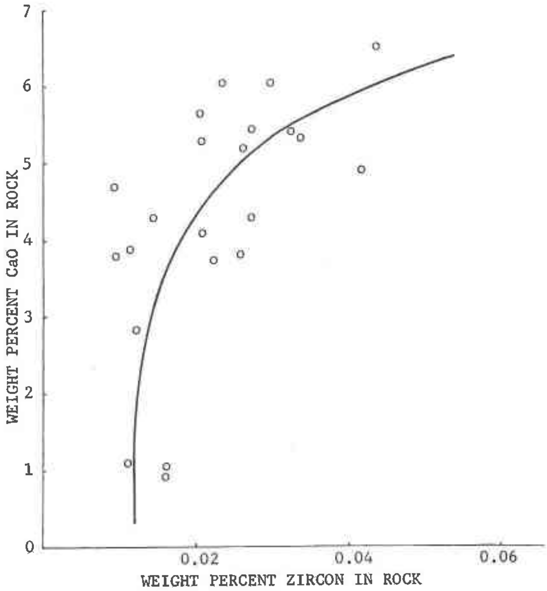

FIG. 1. Weight percent CaO *vs.* weight percent zircon.

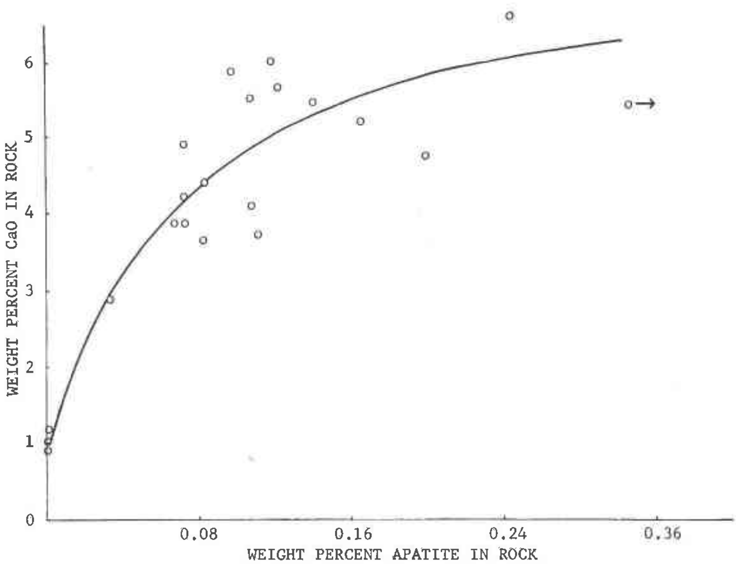

FIG. 2. Weight percent CaO *vs.* weight percent apatite.

the rock is plotted in Figure 3 *vs.* weight percent CaO in the rock; the graph suggests that, with increasing CaO, apatite increases more in amount than zicron.

Allanite shows only a questionable tendency of decrease in amount with increasing calcium content of the rocks, but Figure 4 shows that as CaO increases allanite tends to decrease in abundance in comparison with the other non-ferromagnetic heavy minerals. Insufficient monazite-bearing samples are available to obtain a satisfactory number of points,

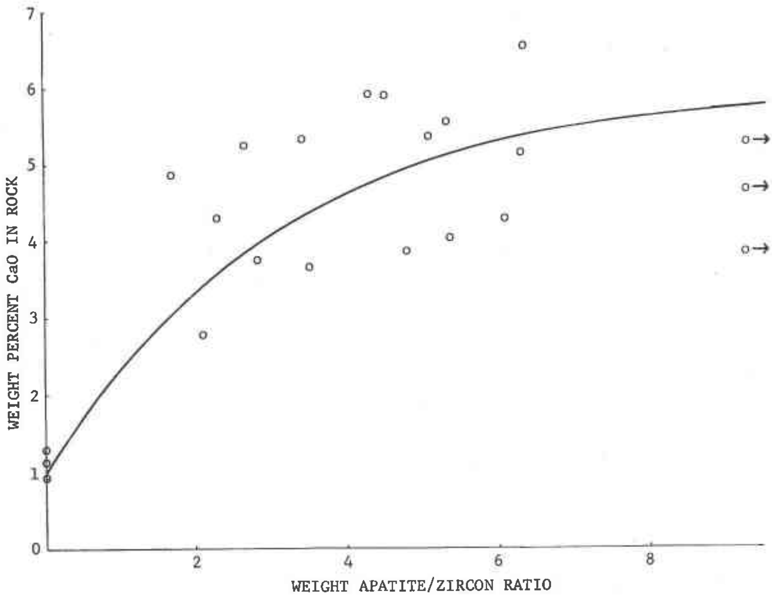

FIG. 3. Weight percent CaO *vs.* weight apatite/zircon ratio.

but the antipathetic relation of monazite to allanite, noted by Lee and Dodge (1964), is also found in rocks of the present area: allanite is present to the exclusion of monazite in rocks containing 2.8 or more weight percent of CaO, whereas below 2.8 percent monazite is present and allanite is absent or very rare.

Up to about 3.8 percent CaO, epidote (clinozoisite-epidote) appears to increase in abundance slightly with increase in CaO, but above that value a strong tendency for decrease is apparent (Figure 5). In the CaO range 0.47 to 3.9 weight percent Lee and Dodge found that epidote increases with increasing CaO.

Magnetite abundance bears no relation to CaO content of the rock, but

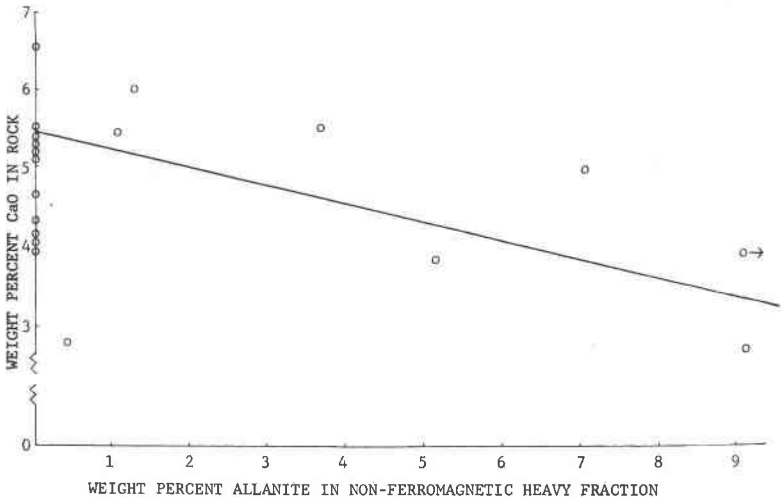

FIG. 4. Weight percent CaO *vs.* weight percent allanite in non-ferromagnetic heavy fraction.

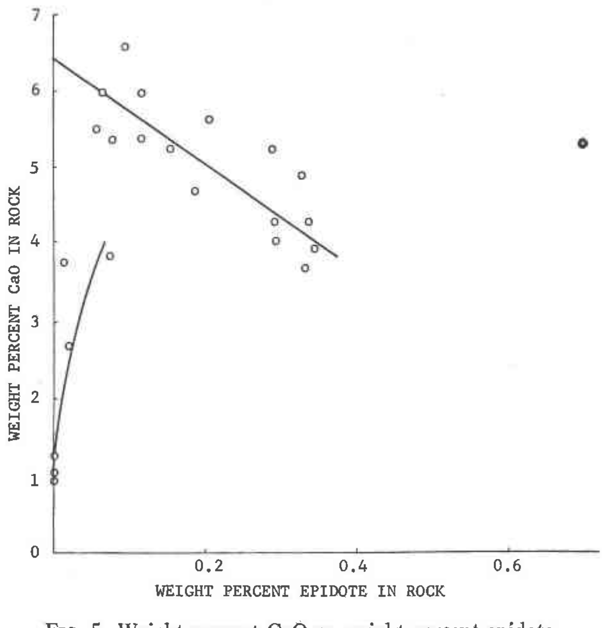

FIG. 5. Weight percent CaO *vs.* weight percent epidote.

the mineral does show a slight tendency to increase in amount with decreasing CaO over the other minerals in the total heavy fraction (Fig. 6). Weight percent of ilmenite in the rock is also not a function of calcium, but the statement of Lee and Dodge (1964, p. 1663) that ". . . ilmenite is present where CaO content is low, but is rare or absent where CaO content is high. . ." generally describes the situation shown by Figure 7. In

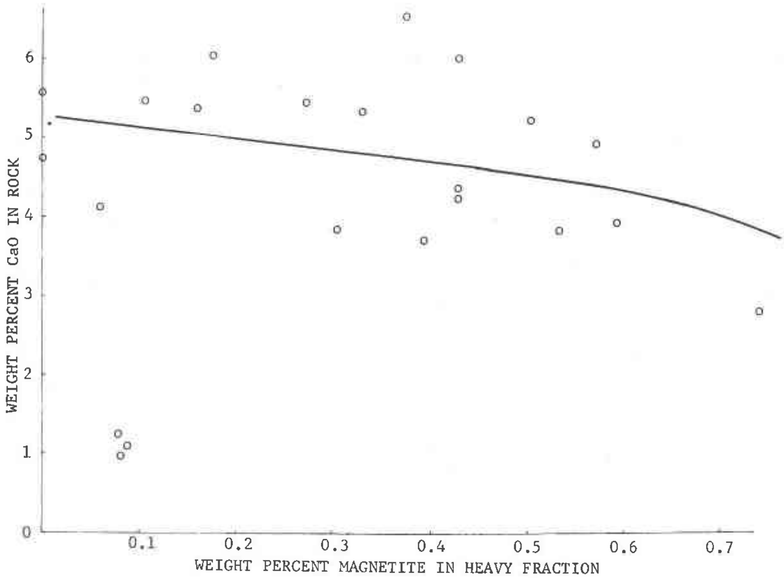

FIG. 6. Weight percent CaO *vs.* weight percent magnetite in total heavy fraction.

addition it can be seen that above 3.7 weight percent CaO ilmenite tends to increase slightly in abundance over the other non-ferromagnetic accessory minerals with increasing CaO content of the rocks, a result that is not unexpected because ilmenite is abundant in many diorites and gabbros (*cf.* Dodge, 1963, p. 58). Data from two studies of CaO influence on heavy mineral assemblages thus suggest that ilmenite is common in low-calcium rocks (CaO content below, say, 2 percent), rare in rocks of intermediate calcium content (CaO ranging from about 2 percent to 5 or 6 percent) and abundant in rocks high in calcium (CaO content greater than 6 or 7 weight percent).

Weight percent of sphene in the rock shows no relation to weight percent CaO, but for the calcium range of rocks studied by Lee and Dodge (1964) sphene tended to increase with increasing CaO. So far as variation of sphene with respect to the other non-ferromagnetic heavy accessory minerals is concerned, Figure 8 shows that in the present rocks sphene tends to decrease in abundance relative to the other minor minerals above about 3 weight percent CaO.

Garnet is present only in the granites that have CaO less than 2.8 weight percent and this was observed for the rocks studied by Lee and Dodge.

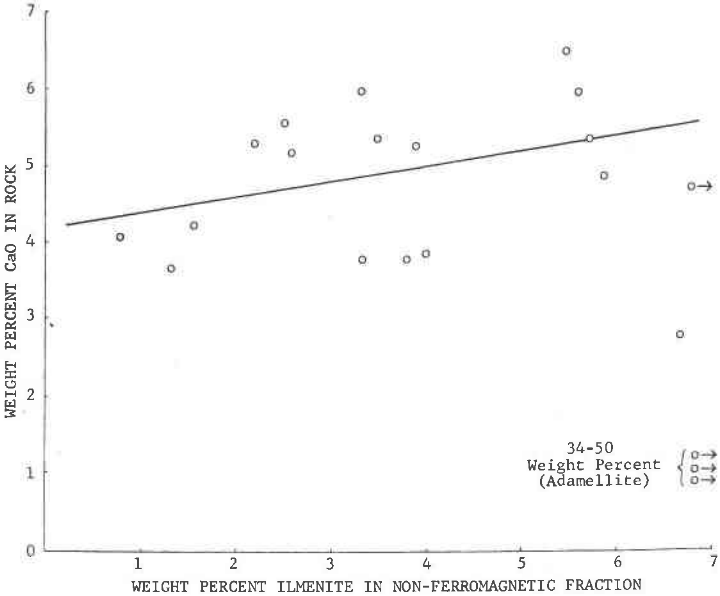

FIG. 7. Weight percent CaO *vs.* weight percent ilmenite in non-ferromagnetic heavy fraction.

SIGNIFICANCE OF THE CALCIUM RELATION TO THE HEAVY MINERALS

Compositional variations in these granites are probably due to differentiation and the calcium relation noted above is, therefore, considered a result of age connection of calcium with the heavy minerals: calcium in magmatic granites is usually more abundant in early-formed rocks,[1] and heavy minerals that form early may be expected to show increase in abundance with increase in CaO, while those that crystallize late will tend to show decrease in abundance with increasing calcium. Calcium relation may thus, in the present area, be helpful in establishing

[1] *Cf.* Bateman *et al.*, 1963, figure 13, variation diagram for Sierran granitic rocks, where CaO shows the greatest variation of any of the common oxides, exhibiting a steady decrease in amount with increasing silica. By "early-formed" the present writer therefore means early with respect to a differentiated series of igneous rocks.

paragenesis, and, together with some textural considerations, it is so used in the following section. With regard to the Mount Wheeler mine area, however, where the calcium relation is also found, Lee and Dodge (1964, p. 1661) note that variation of the intrusive rocks is controlled by differences in composition of the host rocks: where the stock intrudes limestone, it is granodioritic in composition, and where it intrudes quartzite, quartz monzonite has developed. Apparently calcium may be related to

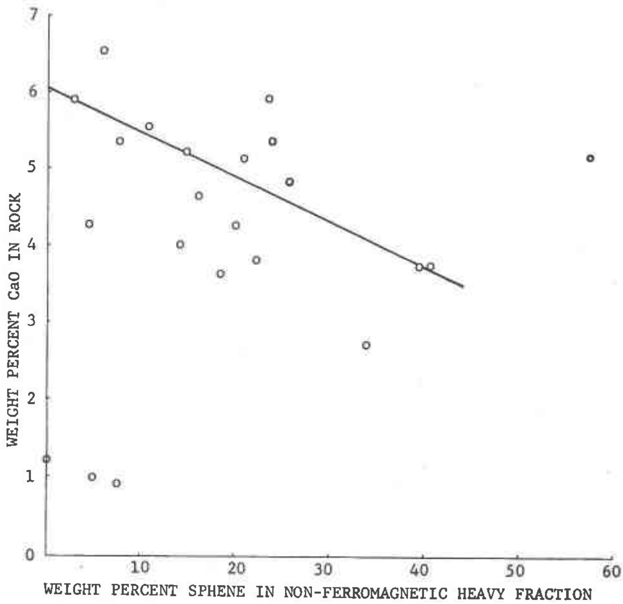

FIG. 8. Weight percent CaO *vs.* weight percent sphene in non-ferromagnetic heavy fraction.

heavy minerals even if the element is in part extraneous to the magma, and in such a case application of calcium relation to determination of paragenesis of heavy minerals may not be valid.

PARAGENESIS OF THE HEAVY ACCESSORY MINERALS

That zircon and apatite have formed early is indicated by their relation to calcium: both minerals increase in abundance with increasing CaO. Apatite increases in amount more than zircon with calcium and this suggests apatite tended to crystallize somewhat earlier than zircon. There is no textural evidence—such as abrasion or corrosion of crystals—that zircon or apatite have been recycled from pre-existing rocks, and the relation of zircon and apatite to calcium is considered evidence these minerals are primary: if reworked or recycled they would have been randomly incorporated in magma of varying calcium content, and the writer would suggest this initial lack of relation to calcium would have been retained upon solidification of the melt.

Epidote seldom occurs at cores of plagioclase in rocks of the present area[1] and the writer is therefore led to consider a primary origin for this constituent. Increase in abundance of epidote with decreasing CaO content in rocks containing more than approximately 3.8 percent CaO suggests that in these more calcic rocks epidote tends to crystallize late, at a time when calcium is becoming relatively less abundant. This seems anomalous because epidote contains 22–24 percent CaO. But considering that plagioclase, the major calcium-bearing mineral, is at late stages approaching a more albitic composition, partition of the element might increasingly favor the formation of other calcium-bearing minerals. Hydroxyl and ferric iron, both constituents necessary for development of epidote, might have become more available at late stages and combined with calcium to form epidote. The opinion is therefore offered that epidote, in rocks containing more than about 3.8 percent CaO, is orthomagmatic and tends to form late. Below that calcium value, however, epidote appears to increase slightly in abundance with calcium, and it is tentatively suggested that (1) in rocks in the lower calcium range, epidote abundance may be directly related to abundance of calcium, partition of the element to plagioclase being less important because more sodic plagioclase is forming, or (2) that formation of allanite influences the amount of epidote that forms.

Allanite, present in significant amounts only in the granites that contain more than 2.8 percent CaO, does not show any evidence of secondary mode of occurrence in its host rock, and it tends to increase in abundance in heavy mineral assemblages with decreasing calcium in the rock. These observations suggest it is primary, tending to develop late. Conceivably allanite crystallized later than epidote, at a time when the larger-radius rare earth cations were becoming more plentiful, and greater availability of these cations may actually have favored formation of allanite at the expense of epidote.

Magnetite has often been regarded as an early product of crystallization in magmas, but Figure 6 suggests a slight tendency for the mineral to crystallize late in rocks containing more than about 2.8 percent CaO. Occurrence of quartz as occluded material in magnetite from several of these samples is, in addition, evidence that magnetite has formed in part late.

[1] A plot of weight percent epidote in the rocks *vs.* anorthite content of cores of plagioclase grains shows no trend, and this is further evidence for lack of association of epidote with plagioclase.

Above approximately 2.8 percent CaO sphene decreases in abundance compared to the other non-ferromagnetic heavy minerals with increasing calcium, and this indicates the mineral is late in these rocks. Sphene is for the most part euhedral and is only rarely associated with chloritized biotite; these relations suggest the mineral is primary.

Ilmenite is particularly abundant in assemblages from the adamellite; ilmenite cutting K-feldspar was noted in one of these samples, possibly reflecting a late, orthomagmatic origin of ilmenite of this unit. In more calcic rocks the mineral exhibits a tendency of increase in abundance over the other heavy constituents with increasing calcium, and this suggests it is on the whole early in those granites. Ilmenite and sphene, the two titanium-bearing heavy minerals, show an antipathetic relation (*cf.* Figures 7 and 8) and this may tentatively be accounted for as follows. At relatively high temperatures and high calcium contents titanium is being used to form ilmenite, but little titanium enters sphene because calcium is being preferentially used to form calcic plagioclase. As temperature falls and total calcium decreases, a more sodic plagioclase forms and partition of calcium between sphene and the plagioclase tends increasingly to favor sphene. Thus titanium enters sphene at the expense of ilmenite, and sphene forms more abundantly than ilmenite. At low calcium values, however, only small amounts of sphene can form and therefore titanium is again concentrated in ilmenite. Sphene therefore is not abundant in the adamellite, owing to low calcium content of that unit, titanium then being used to form abundant ilmenite.

A mechanism involving change in plagioclase composition influencing abundance of epidote and sphene has been suggested so it is well to consider why, in contrast to the behavior of these minerals, the calcium-bearing mineral apatite should tend to form early, in rocks with highest CaO content and most calcic plagioclase. Phosphorus is concentrated early in Sierran granitic rocks because, as Figure 9 shows, it tends to increase in abundance with increasing calcium in the analyses presented by Bateman *et al.* (1963). Apatite is the only phosphate mineral in most of the rocks dealt with in the present study[1] and the suggestion is therefore made that partition of calcium to calcic plagioclase was insufficient to prevent early development of apatite.

Acknowledgments

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[1] Monazite in adamellite is the one exception.

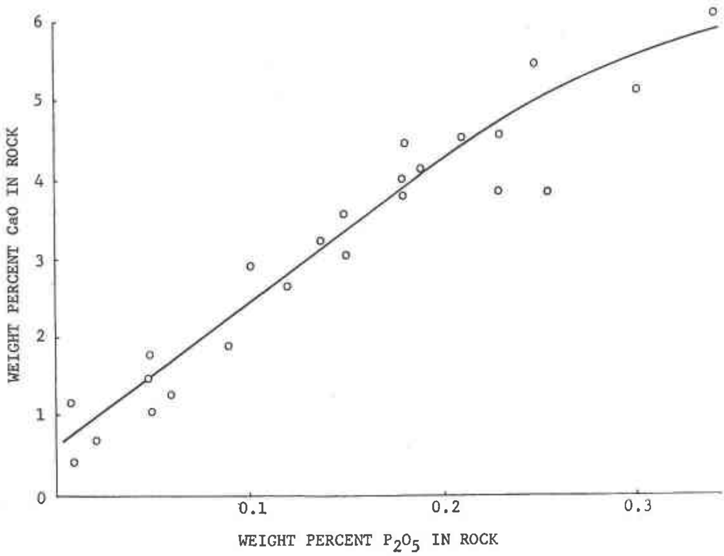

FIG. 9. Weight percent CaO *vs.* weight percent P_2O_5 in some Sierra Nevada granitic rocks (data from Bateman, *et al.*, 1963, p. 29, Table 3).

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