Investigations of Western Batholiths

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By ESPER S. LARSEN, Jr., *and* ROBERT GEORGE SCHMIDT

INVESTIGATIONS OF WESTERN BATHOLITHS

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The nature, distribution, and age of the rocks of the Idaho batholith and their comparison with the rocks of the southern California batholith, including remarks on the origin of granitic rocks

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A RECONNAISSANCE OF THE IDAHO BATHOLITH AND COMPARISON WITH THE SOUTHERN CALIFORNIA BATHOLITH

By Esper S. Larsen, Jr., and Robert George Schmidt

ABSTRACT

The Idaho batholith and included inliers of older rocks underlie an area of about 16,000 square miles. The average rock is intermediate between a quartz monzonite and a granodiorite. The average rock of the southern California batholith is a tonalite. The Idaho batholith has very little gabbro and contains much more quartz monzonite than the California batholith. The individual bodies of a single kind of rock are much larger in the Idaho batholith than in the southern California batholith. The two batholiths fall very near the same variation curves, are about 108 million years old (middle part of the Cretaceous), and are believed to have been emplaced chiefly by magmatic injection.

INTRODUCTION

After completion of a study of the batholith of southern California (Larsen, 1948) many important related problems remained, but age and the press of other work prevented the senior author from carrying most of these forward. The following are some of the problems that were of special interest to the senior author:

1. A study of the structure and tectonics of the batholith and its bordering rocks.
2. A careful study of the regional and contact metamorphism.
3. A study of the light-colored potassium-poor rocks of the eastern part of the batholith to determine their character, distribution, and relation to the other rocks of the batholith (Larsen, 1948, p. 67–69).
4. A study of several sections across the batholith in Lower California (Böse and Wittich, 1913).
5. A careful study of parts of the Sierra Nevada batholith and comparison with the southern California batholith.
6. A study of some of the other great batholiths, especially those with different settings, or some that seem to have been emplaced largely by a single injection.

In 1947 the opportunity arose to carry out an investigation relating to the last of these problems, and the Idaho batholith was selected for study, largely because of its accessibility. This report presents the results of that study. It briefly describes the physical and chemical characteristics of the Idaho batholith, compares this batholith with the southern California batholith, and makes suggestions as to the origin of these two great bodies of plutonic rock.

Because the Idaho batholith underlies an area of about 16,000 square miles and is situated in a region of rugged mountains, thorough mapping and study of the body would take many years. It was therefore decided to learn something about the general character of the mass by making traverses along the roads, of which there are a moderate number. This procedure is similar to the Rosiwal method used in making quantitative estimates of the proportion of the constituents in a thin section or smooth surface of a rock, and it should give a rough estimate of the proportions of the various rock types, the size of the rock bodies, and the general distribution of the types. The roads are neither random nor systematic sections and for this reason they are not perfect lines for traverse, but the errors resulting from the feature are not believed to be very large.

Accordingly, in the summer of 1947, assisted for a month by Alvin Van Valkenburg, we traversed the roads within the batholith by automobile and made the traverse map shown in plate 1. Only a few small areas of the batholith are more than 15 miles from a traverse. In general, small bodies of rock less than about a mile across were not separately mapped.

Part of the laboratory investigation was made in the Division of Geological Sciences at Harvard University, and some of the analytical work was done as part of a program undertaken by the U. S. Geological Survey on behalf of the Division of Research of the U. S. Atomic Energy Commission. Chemical analyses were made by S. M. Berthold, G. E. Edgington, E. A. Nygaard, and H. F. Phillips, all of the U. S. Geological Survey. We wish to thank Alvin Van Valkenburg for his help with the field work and are indebted to many colleagues for assistance and advice.

IDAHO BATHOLITH

SIZE AND SHAPE

In general outline the exposed part of the Idaho batholith forms a rude rectangle, about 85 miles wide and 240 miles long. Arms or isolated bodies of the batholith extend beyond the main mass. On the north, east, and west of the main mass, older rocks are present at or not far from the margins of the batholith, and the limits of the batholith in these areas is approximately known. The southern contact is with younger rocks, chiefly lavas of Tertiary age, and the batholith may extend southward for many miles beneath this cover. Many bodies of older rocks, some of large size, are present within the northern part of the batholith. The batholith, including the inlying sedimentary rocks, underlies an area of about 16,000 square miles; probably nearly 85 percent of this area is actually underlain by granitic rocks.

The greater part of the batholith is in the State of Idaho, but in the northeastern part it extends a short distance into Montana. It forms the backbone of the great mountain mass north of Boise. Smaller batholithic bodies are present on either side—the Wallowa batholith in Oregon to the west and the Boulder batholith of Montana to the east. To the north and northwest are the batholiths of northern Idaho, Washington, and British Columbia.

The batholith can be divided into a southern and northern part. The southern part makes up somewhat more than half the batholith, is characterized by a lack of inliers of older rocks, and is made up of a few huge bodies of rock that are chiefly granodiorite and quartz monzonite. The coarse quartz monzonite that forms the central part of this mass is about 125 miles long in a north-south direction, is 30 to 40 miles wide, and occupies an area of more than 2,500 square miles. The other bodies of rock are nearly as large. The northern part of the batholith occupies an area extending from somewhat south of the Salmon River canyon northward. It contains many inliers of older rock. The inliers underlie about one-third of the area and the granitic rocks about two-thirds. The individual bodies of granitic rock are much smaller than those of the southern part. The rocks of the two parts are much alike, although the rocks of the northern area have more textural variety, and tonalite and porphyroblastic gneiss are more abundant than they are to the south.

OUTCROPS AND WEATHERING

The Idaho batholith is in an area of high, rugged mountains, yet over large areas weathering is so deep that it is difficult or impossible to determine the character of the bedrock. This is especially true in the high areas formed by an erosion surface of Late Tertiary age. Road traverses for many miles may show no satisfactory outcrops; even in deep road cuts, the only outcrops may be dikes of Tertiary age of other small bodies of resistant rock. This is very different from the weathering of the batholith of southern California, where friable sand (gruss) and boulders of disintegration are common. However, in a few places outcrops of this kind were seen in the Idaho batholith.

PETROGRAPHY

The batholith is made up of a moderate number of individual rock units, some of which are very large (pl. 1). The approximate dimensions of some of the large bodies are given in table 1.

TABLE 1.—*Approximate maximum dimensions of some of the larger bodies of rock in the Idaho batholith*

Rock	Locality	Dimensions (miles)		Area (sq mi)
		N.-S.	E.-W.	
Coarse quartz monzonite	Idaho City	125	30+	2, 500
Dark granodiorite	Boise River	35	70	2, 000
Do	Cascade	55	16	1, 000
Fine quartz monzonite	Stanley	52	43	2, 000
Tonalite	Pierce	53	20±	1, 000

Data on the areas underlain by the subdivisions or rock units of the batholith are given in table 2. If traverses had been made in the Wilderness areas in the east-central and northeastern parts of the batholith these estimates might be changed somewhat and in particular the estimates of the areas underlain by the granodiorites might be increased by a few percent each.

TABLE 2. *Areas underlain by subdivisions of the Idaho batholith*

Rock type	Percent of batholith	Estimated area (sq mi)	Remarks
Quartz gabbro	<1. 0	40	Northeast of Grangeville.
Tonalite	9. 0	1, 500	Chiefly in north half of batholith.
Granodiorite:			
Cascade type	11. 0	1, 800	South of Cascade.
Atlanta type	12. 5	2, 000	Boise River.
Fine-textured quartz monzonite.	25. 0	4, 000	Chiefly in eastern part of batholith. In part belongs to younger batholith.
Fine dark quartz monzonite.	2. 0	300	Elk City area.
Coarse quartz monzonite	37. 5	6, 000	Chiefly in southwestern part of batholith.
Microgranite	<1. 0	40	Chiefly in northeastern part of batholith.
Porphyroblastic gneiss	2. 5	400	Chiefly in north half of batholith.

The extreme range in the rocks of the batholith is from quartz gabbro to granite, but the quartz gabbro and the granite occur in very small amounts. The range of the main rock masses is from tonalite to quartz monzonite, and the average composition is a granodiorite near quartz monzonite. In general, the rocks are coarse grained, and some, expecially the quartz monzonites and some of the granodiorites, contain phenocrysts of microcline-microperthite as much as 3 inches long. The large phenocrysts are unevenly distributed and are abundant in parts of some rock bodies and absent in others. The chief dark minerals of the gabbro are pyroxene and secondary hornblende, those of the tonalite are hornblende with some biotite, and that of the quartz monzonites is almost entirely biotite.

QUARTZ GABBRO

The only gabbro or quartz gabbro found in our reconnaissance occupies the canyon of the South Fork of the Clearwater River near Harpster and about 9 miles northeast of Grangeville. It crops out in the canyon for a few miles north and south of Harpster. The rock is nearly black and is fine grained. The freshest rock collected is about 1 millimeter in average grain size and contains about 60 percent plagioclase tablets (An_{55}); 10 percent each of quartz, augite, hypersthene, and hornblende; a trace of orthoclase; and small amounts of secondary epidote, sericite, and uralite. In another specimen the pyroxene is largely uralitized.

In a recent paper, Anderson (1952, p. 258–260) describes three small bodies of pyroxene-hornblende-biotite diorite that we did not see—near Horseshoe Bend, in Boise Basin, and south of Hailey. These bodies are 1 to 3 miles wide and 5 to 12 miles long. His map does not include the area near Harpster. According to Anderson, the composition of these rocks is that of a calcic diorite, near gabbro; probably they are not much different in composition from the quartz gabbro described here.

TONALITE

The largest body of tonalite that we observed on our traverses occupies the canyon of the Clearwater River from Orofino to a point 20 miles to the southeast. It is covered by basalt on both sides of the river, and, further south in the vicinity of Kooskia, it is completely covered by the basalt capping. East of Kooskia the tonalite is again exposed. The actual width of this outcrop is small, but about 12 miles east of the Clearwater River and east of Pierce, similar rock crops out for about 13 miles. Assuming that the tonalite everywhere underlies the basalt, its total width is more than 30 miles. A few miles east of this body and east of Bungalow is a small body, 7 miles across, of similar tonalite. This rock is dark and tends to be porphyritic or seriate porphyritic, and the larger grains are about 10 millimeters long. The femic minerals are commonly arranged along irregular, more or less curved surfaces, probably

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shear surfaces. In part the streaking is linear. An analysis of one of these rocks is shown in table 3 (column 3).

Most of these rocks are hornblende-biotite tonalite. They contain about 10 percent each of quartz, biotite, and hornblende; little orthoclase; and a plagioclase that averages An_{30} in some rocks and An_{40} in others. Some of the rocks have no biotite. Many contain large grains of apatite and sphene. Some of the rocks of this area contain as much as 20 percent orthoclase, a plagioclase as sodic as An_{26}, abundant quartz, and little or no hornblende. The grains vary in size from more than 4 millimeters to less than 0.5 millimeter and average from 1 to 2 millimeters.

Along the South Fork of the Payette River, about 20 miles east of Lowman, is a body of unknown but probably small extent made up of hornblende-biotite tonalite rich in sphene. An analysis, norm, and mode of this rock are shown in table 3 (column 4). A similar small body of tonalite is exposed near Boyle's ranch, about 20 miles north of Stanley. The tonalite east of Lowman is less gneissic than the body of tonalite along the Clearwater River or that east of Bungalow. The tonalite near Boyle's ranch is rather fine grained and gneissic.

A body of biotite-hornblende tonalite crops out along the road from McCall to Burgdorf and beyond to the canyon of the Salmon River, a distance of nearly 40 miles. In the Salmon River canyon this body is less than 10 miles wide. The rock of this body is much like the tonalite in the Clearwater River canyon, although it contains less hornblende, more quartz, and a more sodic plagioclase (averaging about An_{35}). Many of these rocks have abundant and large crystals of sphene, allanite, monazite, and apatite.

The exposures in the canyon of the South Fork of the Clearwater River, southeast of Grangeville, are biotite tonalite with grains 1 to 2 millimeters across. This rock also contains secondary muscovite and epidote.

GRANODIORITE NEAR CASCADE

A granodiorite that is a little darker in color than the main quartz monzonite of the batholith and with irregularly scattered phenocrysts of feldspar as long as 20 millimeters is exposed along the Payette River from Cascade southward nearly to Boise, a distance of 50 miles. Somewhat similar rock is very poorly exposed along the road north of Landmark, about 30 miles northeast of Cascade. Other small bodies are near Seafoam Ranger Station, north of Stanley, and near Cape Horn, northwest of Stanley.

The large phenocrysts of this rock are microcline-microperthite (β-1.519). Myrmekite is common. The main part of the rock is characterized by grains 1 to 4 millimeters in length and contains plagioclase (An_{30}) as the most abundant mineral, much quartz, about 5 percent microcline-microperthite, and 10 percent biotite. The accessories—sphene, apatite, allanite, magnetite, and monazite—are not as abundant or large as in some of the other granodiorites. The usual secondary chlorite, epidote, and muscovite are present. An analysis, norm, and mode of a sample of this rock are given in table 3 (column 8).

GRANODIORITE OF THE ATLANTA AREA

A very large body of rather uniform rock of moderately dark color and chiefly a granodiorite but in part a quartz monzonite underlies most of the drainage of the South and Middle Forks of the Boise River. A body of the light-colored coarse-grained quartz monzonite occupies the central part of this area. This granodiorite was observed for a distance of 70 miles in a east-west direction, and it probably extends further, for it is covered by basalt on the west border and was not followed to its east limits. In a north-south direction it has a maximum width of 40 miles, with the quartz monzonite body in its central part. It occupies an area of more than 2,000 square miles. Many local variations in the mass and numerous small inclusions are present, but the main rock from the western exposure, about 10 miles southeast of Boise, up to the Middle Fork of the Boise River and up to and beyond Atlanta for a distance of over 55 miles is rather uniform. Along the other traverses the rock is similar.

The rock is seriate porphyritic with crystals of plagioclase that range in length from 4 millimeters to very much shorter. The interstitial material is small in amount and is made up of grains as small as 0.1 millimeter across. The plagioclase is rather strongly zoned, with cores of andesine and broad borders of albite, and has an average composition of about An_{32}. The fine material is chiefly quartz and microcline, in part intergrown. The rocks of the traverse along the Middle Fork of the Boise River are chiefly intermediate between quartz monzonite and granodiorite, contain little or no hornblende, and have a moderate amount of accessory minerals. Those to the south are chiefly granodiorites and contain hornblende as well as biotite. They have abundant large grains of sphene, allanite, monazite, magnetite, and apatite and contain some secondary chlorite, epidote, and minor sericite. The rocks are weathered near the surface, but they have undergone less hydrothermal or deuteric alteration than most of the rocks of the Idaho batholith. An analysis, norm, and mode of this rock are given in table 3 (column 12).

FINE-TEXTURED QUARTZ MONZONITE

Three large bodies and one small body of fine-textured quartz monzonite were traversed. Each body has its own peculiarities, but the rocks are believed to be closely related although probably not emplaced contemporaneously. All the rocks are light colored and 1 to 3 millimeters in average grain size.

A body of fine-textured quartz monzonite southwest of Hamilton, Mont., in the canyon of Lost Horse Creek, is in contact with sedimentary rocks near the mouth of the canyon and makes up the slopes from there westward to the crest of the Bitterroot Range and for an unknown distance beyond. Its width of outcrop is estimated to be about 13 miles. Over this distance it is of uniform composition and texture, is resistant to erosion, and yields the best exposures of any large body of rock seen in the batholith. Because of its structure it crops out in gently sloping, smooth, rounded rock outcrops. It has a platy and a linear structure due to the orientation and streaking of biotite plates. The platy structure dips gently eastward and the lineation plunges 5°–10° E. An analysis, norm, and mode of this rock are given in table 3 (column 14). The age of this rock was determined from two separate specimens collected by C. P. Ross and B. F. Leonard, one by E. S. Larsen, Jr., and one by R. W. Chapman. Three age determinations of zircon and four of monazite were made (table 6). The ages range from 51 to 67 million years and average 57 million years. This is somewhat younger than the average age of 68 million years obtained for the Boulder batholith (Chapman, Gottfried, and Waring, 1955).

The body of rock south of Darby also extends into Montana. It occupies 30 miles of the traverse southwest of Darby and 20 miles of the traverse to the southeast. Along these traverses the rock is very poorly exposed, and it was not possible to examine it adequately. The rock is characterized by grains about 3 or 4 millimeters in length and is a quartz monzonite. Its age was not determined.

Near Stanley, Idaho, a body of rock extends for 45 miles along a north-south traverse and for 40 miles along an east-west traverse. In this area, also, exposures are poor. Northwest of Stanley a great variety of rocks are present, and many of the bodies are very small. Metamorphic rocks were observed in several places; aplites, pegmatites, and porphyritic rocks are common; and a variety of granular rocks were seen. The chief rock is a granodiorite or quartz monzonite with a grain size of 1 to 2 millimeters. In places it contains large feldspar crystals as much as 20 millimeters long. Some of the rocks contain hornblende. The rock northeast of Stanley is similar and locally has large feldspar phenocrysts. Local bodies of tonalite and porphyroblastic gneiss are present in this area. South of Stanley the rock is more uniformly a fine-grained quartz monzonite. The rocks near Stanley (specimens 47–L113, 47–L110) proved to be between 92 and 94 million years old on the basis of zircon and thorite age determinations (table 5).

The small body of rock east of Yellow Pine, Idaho, is a fine-grained quartz monzonite with a grain size of 1 to 2 millimeters.

FINE DARK QUARTZ MONZONITE

Near Elk City, Idaho, and elsewhere, a number of small bodies of rock are found that are darker and finer grained than the coarse quartz monzonite that makes up most of the batholith. East of Elk City, in a distance of 25 miles along the road, 6 bodies of this rock were traversed. Some of these are only a mile across, whereas others are as much as 6 miles wide. In general, these rocks intrude schists and gneisses.

Most of the rock bodies in this area are quartz monzonites, but one is a granodiorite and another a granite. These rocks generally range in grain size from 1 to 2 millimeters, have biotite as their chief dark mineral, and contain a moderate amount of accessory minerals. The body of rock about 3 miles east of Big Mallard Creek is exposed only as boulders of disintegration scattered over the surface. Such boulders are unusual in the batholith. The rock has grains about 1 millimeter long and contains biotite, hornblende, and augite. The augite is partly altered to uralite. Augite is very rare in all of the rocks of the Idaho batholith and hornblende is rare in the quartz monzonite.

The body of quartz monzonite in the upper part of Bargamin Creek has grains about 1 to 2 millimeters long and contains coarse muscovite as well as biotite. A specimen from the eastern part of this body contains hornblende, no muscovite, and some myrmekite. The small body a few miles to the east is similar. That in the Selway River canyon is similar but lacks hornblende and has much perthite.

COARSE QUARTZ MONZONITE

A nearly white coarse-grained quartz monzonite is the most widespread and abundant rock of the batholith. It constitutes 32 percent of the rocks traversed, and its actual extent may be somewhat greater as only a few short traverses were made in the central part of the batholith where this type of rock is believed to predominate.

The rock is light gray to nearly white and is coarse grained. Most of the rocks are porphyritic or seriate porphyritic, with an average grain size of about 2 millimeters, and they are fairly uniform over wide areas, although there is some range in texture, expecially in the size of phenocrysts. Feldspar crystals more than a centimeter long are present in most of the rocks, and in some rocks they are more than 5 centimeters long. They are commonly flesh colored, white, or clear. The matrix feldspars are white. Biotite is present in small amounts, and large muscovite plates are present in many of the rocks.

Under the microscope the feldspar phenocrysts are seen to be chiefly orthoclase (untwinned), with some streaks of microcline along fractures. A small amount of albite is also present in very thin lamellae. The large orthoclase crystals tend to mold about and enclose quartz and plagioclase, showing that they are late crystals. They are intergrown with quartz along their borders and locally are partly replaced by myrmekite.

The plagioclase crystals are zoned with some recurrent zones, but they are chiefly cores of An_{25}, broad outer zones of An_{17}, and a skin of albite, which is best developed adjacent to orthoclase.

The biotite is partly altered to chlorite. There is secondary sericite and a few larger plates of muscovite that are probably primary. The rocks are all somewhat altered and contain secondary sericite, rare calcite, epidote, and chlorite.

Most of the rocks have nearly equal amounts of orthoclase and plagioclase, about 30 percent quartz, and a few percent biotite. Some rocks have nearly as much muscovite as biotite, others have no primary muscovite. Magnetite, zircon, monazite, apatite, allanite, and, rarely, sphene are the accessory minerals recognized, and in some specimens they are present in crystals 0.5 millimeter across. The muscovite-bearing rocks contain small amounts of garnet, xenotime, and fluorite. The accessory minerals are present in very small amounts—on the basis of heavy-liquid separations from large samples of rock, they appear to make up less than 1 part in 10,000 of the rock and probably no more than 1 part in 100,000.

In some places, for distances of a few hundred feet inward from the contacts with adjoining rocks, the coarse muscovite-bearing quartz monzonites contain abundant small (1–2 mm across) miarolitic cavities lined with well-formed crystals of quartz and orthoclase.

An analysis, norm, and mode of a typical rock with little muscovite is shown in column 15 of table 3; and an analysis, norm, and mode of a muscovite-rich rock is given in column 16.

MICROGRANITE

Only three small bodies of granite are shown on the traverse map (pl. 1), although other bodies are present, and in some places the great masses of quartz monzonite may grade into gralnite. One crops out for about 3 miles along the road from Missoua, Mont., to Pierce, Idaho, at the head of Cayuse Creek. The other two bodies are near the Selway River along the road from Elk City, Idaho, to Darby, Mont.; the one west of the Selway River is about 4 miles across, that to the east is 8 miles across.

The rock at the head of Cayuse Creek is nearly white, very fine grained, and has small miarolitic cavities. It contains some rounded and well-formed quartz phenocrysts as much as 2 millimeters across which resemble the phenocrysts in quartz porphyries. Crystals of plagioclase and microperthite are also present. The main part of the rock is made up of very well developed micropegmatite. The frets are about a millimeter across, and the individual quartz and feldspar patches range from submicroscopic in some sections to a few tenths of a millimeter across in others. The quartz bodies generally appear to be rodlike in shape, but in some orientations they are cuneiform, and in a third orientation they form a series of nearly parallel to arborescent lines. The micropegmatite tends to grow out from older crystals. The rock has very little biotite, which occurs in shreds, and few accessory minerals. The feldspar is microperthite, about half of which is albite. In some of the finer grained rocks the microperthite somewhat resembles the spherulites of rhyolites.

The two granite bodies near the Selway River are much alike. The granite is light colored and fine grained. The grains average about 1 millimeter across, but some perthite patches are 8 millimeters across. Oligoclase is about half as abundant as perthite; mica makes up about 5 percent of the rocks. The original mica is a dark-brown biotite which contains tiny inclusions of zircon surrounded by dark halos. In part the biotite has been altered to chlorite and in part to light-green biotite and muscovite. The muscovite, chlorite, and green biotite are interleaved with the brown biotite. The accessory minerals are present in very small amounts. A few large crystals of zoned zircon were seen.

APLITE AND PEGMATITE DIKES

Dikes of aplite and pegmatite are very abundant in some parts of the batholith, especially near contacts. A good example is the contact between tonalite and coarse quartz monzonite about 12 miles northeast of McCall.

PORPHYROBLASTIC GNEISS

A dark gneissic rock that contains a variable amount of microcline feldspar crystals, some of which are as long as 8 centimeters, occurs in a number of small bodies associated with older sediments. The large feldspar crystals are in a matrix that in places is quartz-mica schist and in others much like the tonalite, with every gradation between the two. The main bodies of this rock that were traversed are east and west of Elk City and in the canyon of the Salmon River near Shoup. Smaller bodies were seen east of Stanley and southeast of New Meadows, along the road to McCall.

This gneiss tends to be interlayered with schist of the Belt series, and near the contacts it forms lenses, bays, and pods in the schist. All the bodies of porphyroblastic gneiss that were traversed contain much schist. In places the gneiss with porphyroblasts and a coarse dioritic or tonalitic groundmass grades in a few feet to a crumpled fine-grained quartz-mica schist with large rounded porphyroblasts of microcline. The porphyroblastic gneiss was not found near the contacts of large bodies of granitic rock and metamorphic rocks but rather within large masses of schist and quartzite where the rocks are highly metamorphosed and soaked with granitic material.

Our preferred explanation of the origin of the porphyroblastic gneiss is that ichor from below permeated favorable zones in the metamorphosed sediments and spread out from these zones, resulting in the crystallization of porphyroblasts throughout the whole mass. The quartz-mica schists with scattered porphyroblasts might have been formed with little change in composition, but some of the "granodiorites" with abundant porphyroblasts must have undergone considerable change in chemical composition. Some of the extreme types are much like the normal tonalite of the batholith in chemical and mineral composition and texture.

The body of gneiss in the upper part of the canyon of the Salmon River, east and west of Shoup, is about 15 miles across and is made up of a mixture of porphyroblastic gneiss, highly metamorphosed sedimentary rocks, and greenstone. The contact between schist and porphyroblastic gneiss is fairly sharp on both sides of the body. Near the contact, normal schist or quartzite grades within a distance of 100 feet or less to a schist that contains large microperthite crystals. In detail, the contact between schist and porphyroblastic gneiss is sharp and the gneiss projects into the schist, in part along the bedding and in part crosscutting the bedding, as irregular rays or arms a few feet to a few yards across. Near the contact the porphyroblastic rock has a matrix of mica schist that surrounds scattered porphyroblasts of feldspar which are in part rounded and in part well-formed crystals. In places the schistosity bends around the porphyroblasts, and in other places it is crosscut by them. The porphyroblasts make up only a few percent of the rock. The central part or core of the rounded porphyroblasts is vitreous microcline and the narrow border or rim is porcelainlike albite. Parts of the porphyroblastic gneiss, chiefly at some distance from the contact, have a great abundance of porphyroblasts, and the matrix is more coarsely crystalline and grades into material that resembes the dark tonalites near Pierce. In some places the large feldspar porphyroblasts make up more than half the rock. Some of the rocks resemble porphyritic tonalite.

West of Shoup for a distance of more than 20 miles both the schist and the porphyroblastic gneiss are cut by numerous bodies of aplite; east of Shoup there are few such bodies. This aplite must have originated after the formation of the porphyroblastic gneiss.

Our study of these rocks was no more than a rapid reconnaissance, and a detailed study would certainly furnish data for some modification of our descriptions and conclusions. Such a detailed investigation would be worthwhile, and the areas near Shoup and Elk City are easily accessible by automobile.

CHEMICAL COMPOSITION

Sixteen analyses of rocks from the Idaho batholith are given in table 3 and are plotted on a variation diagram (Larsen, 1938) in figure 1. On this figure the variation curves for the analyzed rocks of the batholith of southern California are given for comparison.

In order to check the standard analyses and to test the accuracy of rapid analyses, several rocks were analyzed and the results in table 4 were obtained. The rapid analyses were made by S. M. Berthold, H. F. Phillips, and E. A. Nygaard according to the method of Shapiro and Brannock (1956) and are listed first. The standard analyses were made by G. E. Edgington and are given in the second column. The two analyses check remarkably well, especially when it is remembered that the rapid-analysis method involves an entirely different technique.

COMPARISON OF THE IDAHO AND SOUTHERN CALIFORNIA BATHOLITHS

Both the Idaho and the southern California batholiths are of Cretaceous age, and their emplacement during the middle part of that period closely followed a period of intense folding and metamorphism of the older rocks. Both underlie areas of high, mountainous terrain, partly because the areas occupied by them were folded and elevated before and after the emplacement of the granitic rocks and partly because the granitic rocks and the associated older rocks are resistant to erosion. The southern California batholith is much elongated and might be considered a huge composite dike, whereas the Idaho batholith is rectangular in form. Both batholiths have numerous large and small inliers of older rock. In the Idaho batholith these inliers are largely confined to the northern part of the mass whereas the large southern part is nearly free of them. Including the inliers of older rock, the Idaho batholith underlies about 16,000 square miles, about the same as the southern California batholith.

438954—58——3

TABLE 3.—*Analyses, norms, and modes of rocks from the Idaho and southern California batholiths*

[+=present]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Analyses (weight percent)																	
SiO_2	46.46	57.78	67.31	66.08	65.97	65.23	67.17	68.80	68.76	69.56	68.42	71.99	69.15	71.66	75.28	74.53	74.93
TiO_2	1.50	1.07	.72	.85	.91	.66	.64	.61	.47	.55	.50	.23	.30	.22	.14	.07	.05
Al_2O_3	13.27	16.28	14.44	15.86	14.97	16.94	15.80	15.84	16.23	15.29	15.01	14.71	14.49	15.48	13.14	14.06	14.24
Fe_2O_3	2.60	1.02	.55	.92	1.27	1.60	.70	1.03	.30	.86	.97	.02	.93	.56	.89	.21	.34
FeO	7.20	4.92	3.52	3.63	3.59	1.91	2.79	2.27	2.21	2.06	1.93	2.84	2.62	1.45	1.47	1.09	1.20
MnO	.20	.15	.08	.10	.12	Tr.	.06	.06	.05		.06	.09		.04	.07	.08	.11
MgO	7.32	4.60	2.58	2.28	2.26	1.31	1.52	.91	1.16	.69	1.21	.65	.41	.47	.27	.22	.20
CaO	8.20	6.65	5.19	4.16	4.24	3.85	3.79	4.00	3.31	2.81	2.60	1.97	2.14	1.97	.89	1.28	1.03
Na_2O	1.68	3.25	3.12	3.73	3.13	3.57	3.54	3.57	3.87	3.97	3.23	4.21	3.84	4.34	3.50	3.38	3.78
K_2O	1.71	2.22	1.09	2.02	2.88	3.02	2.75	1.99	2.71	3.36	4.25	2.94	3.98	3.24	4.47	4.60	3.72
H_2O-	.41	.34	.06	.07	.10	.18	.14	.23	.04		.54	.05	.02	.02	.07	.09	.08
H_2O+	3.25	.92	.46	.60	.52	.88	.86	.49	.62	.86	.73	.15	1.47	.19	.08	.35	.47
CO_2	5.50	.15				.25	.05		.05		.20						
P_2O_5	.25	.30	.28	.16	.28	.19	.17	.18	.09	.16	.13	.08	.10	.04	.03	.09	.08
S		.02		.01	.01						.02						
FeS	.37																
BaO		.12		.07	.07	.19		.11			.12	.16		.17	.01		
SnO		.07									.03						
NiO		.02															
SO_3			.05					.02				Tr.		Tr.		.04	.03
Total	99.92	99.88	99.45	100.54	100.32	99.78	99.98	100.11	99.87	100.17	99.95	100.09	99.45	99.85	100.31	100.09	100.26
Norms (weight percent)																	
Q	1.32	9.30	28.86	22.38	23.76	22.62	24.30	29.34	26.10	25.86	25.50	28.62	24.67	28.44	34.68	34.80	35.70
or	10.01	12.79	6.67	11.68	17.24	17.79	16.12	11.68	16.12	20.02	25.58	17.24	23.35	18.90	26.69	25.58	21.68
ab	14.15	27.25	26.20	31.44	26.20	29.87	29.87	30.39	32.40	33.54	26.72	35.63	32.49	36.68	29.34	29.34	31.96
an	23.63	23.63	21.96	20.57	18.07	19.80	18.35	19.74	15.57	13.07	12.33	10.56	10.56	10.01	4.45	5.00	6.12
C					.51	.90	.30		1.20	.31	.61	.69		1.22	1.00	1.42	1.73
di	13.82	6.09	1.59														
hy	20.54	15.28	10.62	10.45	9.82	4.22	7.50	4.81	6.07	3.94	5.11	6.48	4.43	2.78	2.55	2.08	2.35
il	2.89	1.98	1.37	1.52	1.52	1.37	1.22	1.22	.91	1.06	.92	.46	.61	.46	.30	.15	.15
mt	3.71	1.39	.93	1.39	1.86	2.32	.93	1.39	.46	1.16	1.39		1.39	.93	1.39	.93	.46
ap	.67	.67	.66	.34	.67	.34	.33	.34	.33	.34	.34					.33	Tr.

Modes (volume percent)

Quartz	+	+	29	23	24	+	+	30	+	+	+	29	20	29	35	36	+
Perthite		+	Tr.	8	9	+	+	7	+	+	+	12	23	35	32	30	+
Plagioclase	+	+	43	46	46	+	+	53	+	+	+	56	43	31	29	27	+
(An content)	65	Lab.	34	32	34	Olig.	63(?)	25	67(?)	Olig.	Olig.	25	25	26	20		
Muscovite								1								5	
Sericite	+						+										
Chlorite	+	+	2				+		+	+	+						
Epidote	+			2			+	1	+								
Calcite	+			Tr.													
Biotite		+	11	13	6	+	+	8	+			3	10	4	2	2	
Hornblende		+	12	6	13				+								
Diopside		+															
Hypersthene	+	+															
Fluorite																.003	
Garnet																.16	0.20
Opaque	+	+	Tr.	1	1	+	+		+	+	+	Tr.				.03	
Sphene	+	+	.1	2	1.5	+		.15		+	+	+	.0001				Tr.
Zircon			.05	.01	.003			.005				+	.005			.003	.001
Apatite			.03	Tr.	.30			.06					.04			.009	.001
Monazite												+	.025			.005	.002
Xenotime													Tr.			.001	.0015
Allanite								.015					Tr.				

1. Tonalite. Edwardsburg district, Idaho. J. G. Fairchild, analyst. (Shenon and Ross, 1936.)
2. Tonalite. Croesus mine, Hailey, Idaho. W. F. Hillebrand, analyst. (Lindgren, 1900.)
3. Tonalite (47-L227). Road from Pierce to Bungalow, Idaho, ½ mile southeast of ridge crest. G. E. Edgington, analyst, 1953.
4. Tonalite (47-L81). South Fork of Payette River, 23 miles above Lowman, Idaho, and 0.4 mile below Longjean Creek. G. E. Edgington, analyst, 1952.
5. Porphyritic tonalite (47-L113). Salmon River below Stanley, Idaho, and 1 mile below Elkhorn Creek. G. E. Edgington, analyst, 1952. Contains scattered microperthite phenocrysts 3 centimeters long.
6. Granodiorite. Silver Wreath mine, Willow Creek district, Boise County, Idaho. G. Steiger, analyst. (Lindgren, 1898.)
7. Granodiorite. Profile Gap, Edwardsburg district, Idaho. J. G. Fairchild, analyst. (Shenon and Ross, 1936.)
8. Porphyritic granodiorite (47-L70). Road along Payette River, 3 miles above Big Eddy, Idaho. G. E. Edgington, analyst, 1952.
9. Granodiorite. Profile Gap, Edwardsburg district, Idaho. J. G. Fairchild, analyst. (Shenon and Ross, 1936.)
10. Quartz monzonite or granodiorite. Schafer Butte, Boise County, Idaho. G. Steiger, analyst. (Lindgren, 1900.)
11. Quartz monzonite. Idaho-Democrat mine, Hailey, Idaho. W. F. Hillebrand, analyst. (Lindgren, 1900.)
12. Granodiorite (47-L288). Vicinity of Atlanta, Idaho. Road along Middle Fork of Boise River, at Vaughn Creek, 31 miles northeast of junction of North Fork and Middle Fork. G. E. Edgington, analyst, 1952.
13. Granite or granodiorite. Casto quadrangle, Idaho, 1 mile above mouth of Mayfield Creek. J. G. Fairchild, analyst. (Ross, 1934.)
14. Quartz monzonite (47-L166). Canyon of Lost Horse Creek, Mont., 0.2 mile below Ten Mile Creek. G. E. Edgington, analyst, 1952.
15. Coarse quartz monzonite (47-L219). 1 mile above Bungalow, Idaho. G. E. Edgington, analyst, 1952.
16. Muscovite quartz monzonite (47-L272). Silver Creek, 3 miles northerly from Garden Valley, Idaho. G. E. Edgington, analyst, 1952.
17. Muscovite quartz monzonite. Rattlesnake area, Cayumaca quadrangle, southern California. G. E. Edgington, analyst, 1952.

TABLE 4.—*Comparison of rapid and standard analyses of rock samples from the Idaho batholith*

	47–L70		47–L81		47–L113		47–L166		47–L219		47–L288	
	Rapid	Standard	Rapid	Standard	Rapid	Standard	Rapid	Standard	Rapid	Standard	Rapid	Standard
SiO_2	68.8	68.80	66.3	66.08	66.5	65.97	72.1	71.66	75.7	75.28	72.4	71.99
Al_2O_3	16.0	15.84	16.2	15.86	15.1	14.99	15.7	15.48	13.2	13.14	15.0	14.71
Total Fe as Fe_2O_3	3.6	3.52	4.8	4.91	5.2	5.11	2.1	2.15	2.5	2.51	3.2	3.12
MgO	.71	.91	1.6	2.28	2.0	2.26	.34	.47	.17	.27	.54	.65
CaO	4.0	4.00	4.0	4.16	4.2	4.24	1.9	1.97	.88	.89	2.0	1.97
Na_2O	3.9	3.57	4.0	3.73	3.3	3.13	4.6	4.34	3.8	3.50	4.5	4.21
K_2O	2.2	1.99	2.0	2.02	3.0	2.88	3.4	3.24	4.6	4.47	3.0	2.94
TiO_2	.8	.61	.73	.85	.84	.91	.22	.22	.16	.14	.26	.23
P_2O_5	.22	.18	.20	.16	.31	.28	.02	.04	.03	.03	.07	.08
MnO	.05	.06	.06	.10	.10	.12	.06	.04	.05	.07	.07	.09
Loss on ign.[1]	.58	.73	.44	.67	.40	.62	.04	.21	[2] −.06	.15	[2] −.10	.20
Total	100.86	99.91	100.33	100.82	100.95	100.51	100.48	99.82	100.09	100.45	101.04	100.19
FeO	2.0	2.27	3.5	3.63	3.6	3.59	1.4	1.45	1.9	1.47	2.7	2.84
Fe_2O_3	1.4	1.03	1.0	.92	1.2	1.27	.54	.56	.39	.87	.20	.02

[1] Includes gain due to oxidation of FeO.
[2] Gain due to oxidation of FeO was greater than losses.

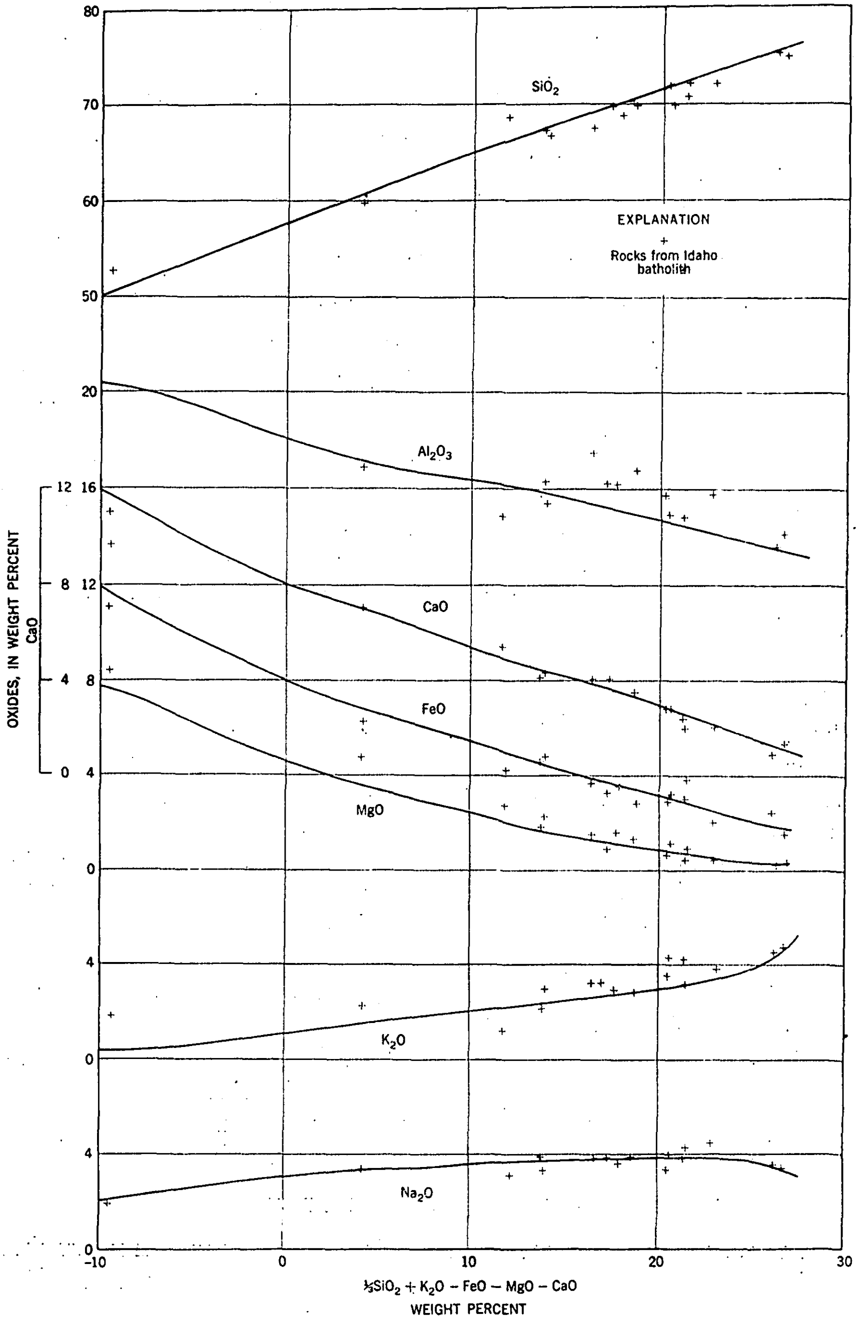

FIGURE 1.—Variation diagram of the Idaho batholith, with curves for the southern California batholith (solid lines).

Both batholiths are composed of a number of rock types, each of which is fairly uniform. Contacts between units are fairly sharp. Some of the individual rock types occur in several widely separated bodies. In the California batholith the individual bodies or map units are relatively small, the largest underlying an area of only about 200 square miles, whereas in the Idaho batholith they are much larger and several of the units underlie areas of more than 2,000 square miles.

AGE

On the basis of geologic evidence the batholith of southern California is believed to be early Late Cretaceous in age (Larsen, 1948, p. 136). The geologic evidence of the age of the Idaho batholith is not very conclusive; Ross (1936) and Anderson (1952) believe that it is of Cretaceous age.

E. S. Larsen, Jr., David Gottfried, H. W. Jaffe, and C. L. Waring (1954) made age determinations on 19 minerals from rocks of the Idaho batholith and 25 minerals from rocks of the southern California batholith by the method of age determination proposed by Larsen, Keevil, and Harrison (1952), in which the lead content of zircon and other mineral constituents is measured with the spectrograph and the radioactivity is measured by alpha counting. These rocks were selected to cover the full range in composition and area so as to sample the whole of both batholiths. The results of the age determinations are shown in table 5. The data show that the Idaho batholith and the batholith of southern California are of the same average age—108–109 million years.

In the course of these investigations it was discovered that the body of quartz monzonite southwest of Hamilton, Mont., along Lost Horse Creek, is decidedly younger in age than the rocks of the main Idaho batholith. The measured ages of 7 mineral samples separated from this quartz monzonite range from 51 to 67 million years and average 57 million years (table 6). Granitic rocks of Tertiary age are known to occur within the Idaho batholith along the Middle Fork of the Salmon River (Ross and Forrester, 1940), and it is quite possible that the quartz monzonite of Lost Horse Creek may represent a separate but related phase of this younger granite body.

CHEMICAL COMPOSITION

The rocks of the southern California batholith range from gabbro with about 43 percent SiO_2 to granite with about 77 percent SiO_2 and are predominantly tonalite. Those from the Idaho batholith, except for a few small bodies of gabbro, range from tonalite with 66 percent SiO_2 to granite with 75 percent SiO_2 and are predominantly between quartz monzonite and granodiorite. The estimated average

TABLE 5. *Age determinations of rocks from the southern California and Idaho batholiths*

Specimen	Rock type and locality	α/mg/hr	Pb (ppm)	Age (millions of years)	Mineral
	Southern California batholith				
G33	Tonalite, Mt. Wilson	143	7	122	Zircon.
7	Lakeview Mountain tonalite	646	30	115	Do.
G13	Tonalite, La Posta Ranch	594	28	117	Do.
G30	Tonalite, Palm Springs	317	14	110	Do.
G10	Tonalite, Aguanga	280	11	98	Do.
G3	Tonalite, Mountain Center (Oak Grove)	194	9	115	Do.
G11	Tonalite, El Cajon	149	6	100	Do.
Z19	Tonalite, Valverdi	170	8	117	Do.
SLR138	Green Valley tonalite	340	15	110	Do.
Average age				112	
Z16	Woodson Mountain granodiorite, Descanso Junction.	1,235	50	101	Do.
Z16	do	6,400	260	104	Xenotime.
Z20	do	786	29	92	Zircon.
Z17	Mt. Hole granodiorite	1,204	46	95	Do.
S6	Woodson Mountain granodiorite, northeast of Descanso Junction.	1,180	46	97	Do.
S6	do	6,430	360	117	Monazite.
S2	Woodson Mountain granodiorite, 1 mile south of Temecula.	433	21	121	Zircon.
G32A	Woodson Mountain granodiorite, west of Elsinore.	457	22	120	Do.
G48	Granodiorite, Stonewall Mountain	545	21	96	Do.
Average age				105	
G21	Quartz monzonite, Providence Mountain	610	23	94	Do.
G24M	Quartz monzonite, Soda Lake Mountain	4,660	180	96	Do.
Z15	Quartz monzonite, Roubidoux Mountain	2,700	106	98	Do.
EL167	Fine-grained granite, Roubidoux Mountain	725	29	99	Do.
G15	Granite, Cottonwood Springs	190	10	131	Do.
G28	Quartz monzonite, Berdoo Canyon	385	20	129	Do.
X101	Granite, Rattlesnake	1,743	80	117	Xenotime.
Average age				109	
Average age of all rocks				109	
	Idaho batholith				
CPR117	Tonalite, south of Hardy, Croesus mine	173	8	115	Zircon.
L217	Tonalite, Bungalow	225	9.5	105	Do.
L81	Tonalite, South Fork of Payette River	370	16	107	Do.
L113	Tonalite, Salmon River below Stanley	825	30	90	Do.
L113	do	1,375	70	102	Thorite.
G200	Tonalite, near Stanley	190	10	131	Zircon.
CPR118	Tonalite, south side of old road to Emmett	120	5.5	114	Do.
CPR119	Tonalite, 0.9 mile south of Diana School	116	4.5	96	Do.
Average age				108	
L288	Grandiorite, near Atlanta	700	38	135	Do.
L110	Granodiorite, below Stanley	1,000	38	94	Do.
L70	Granodiorite, below Cascade	210	9	107	Do.
HCD63	Granodiorite, near Coeur d'Alene	292	11	94	Do.
HCD62	do	1,739	100	116	Do.
Average age				109	
G199	Muscovite quartz monzonite, 15 miles northeast of Garden Valley.	1,970	90	114	Do.
G199	do	5,617	250	93	Monazite.
G199	do	6,025	220	93	Xenotime.
M60	Muscovite quartz monzonite, near Placerville.	2,983	150	105	Monazite.
O7	Muscovite quartz monzonite, placer near Idaho City.	3,241	155	100	Do.
L207	Muscovite quartz monzonite, Indian grave near Powell.	922	37	100	Zircon.
Average age				102	
Average age of all rocks				108	

compositions of the two batholiths, as computed from existing analyses, is given in table 7.

A comparison of the variation curves of the Idaho and southern California batholiths (fig. 1) shows that the two great plutons are very much alike chemically. The Idaho rocks are consistently about 2 percent lower in SiO_2 and a little higher in Al_2O_3, K_2O, and MgO. At the gabbro end of the diagram the composition of the California rocks is erratic, and at the extreme granite end the rocks of both provinces are nearly alike.

TABLE 6.—*Age of quartz monzonite from Lost Horse Canyon, Mont.*

Specimen	Location	α/mg/hr	Pb (ppm)	Age (millions of years)	Mineral
CPR-122 [1]	Lost Horse Canyon, just west of Idaho State line and 19.1 miles up creek from U. S. Highway 93.	257	6.7	63	Zircon.
CPR-122	do	3,385	90.0	55	Monazite.
CPR-123 [1]	Lost Horse Canyon, 8.15 miles up creek from U. S. Highway 93.	262	5.6	53	Zircon.
CPR-123	do	2,925	80.0	57	Monazite.
47-L166 [2]	Lost Horse Canyon, 6 miles below crest of Bitterroot Range.	2,974	96.0	67	Do.
53C210 [3]	Lost Horse Canyon	275	6.2	56	Zircon.
53C210	do	3,213	79.0	51	Monazite.
Average age				57	

[1] Collected by C. P. Ross and B. F. Leonard.
[2] Collected by E. S. Larsen, Jr.
[3] Collected by R. W. Chapman.

TABLE 7.—*Average chemical compositions of the Idaho and southern California batholiths*

	Idaho batholith	Southern California batholith		Idaho batholith	Southern California batholith
SiO_2	70.5	64.6	CaO	3.0	5.3
TiO_2	.3	.6	Na_2O	3.9	3.3
Al_2O_3	15.7	16.7	K_2O	3.1	2.0
Fe_2O_3	.8	1.3			
FeO	2.0	3.8	Total	100.0	100.0
MgO	.7	2.4			

Because the variation curves are nearly parallel for most magma series (especially if the magma series are similar), approach each other at the two ends, and are farthest apart near position 15 (on the abscissa), igneous rock series can perhaps be more conveniently compared by listing the values of the oxides at position 15. If sufficient analyses are available to define accurately the curves of variation, such a comparison brings out differences and similarities that are not apparent if single rocks are used alone, for the comparison then deals with averages.

Table 8 lists the oxide values at position 15 for the Idaho batholith, the southern California batholith, and the Potosi volcanic series and the Hinsdale formation of the San Juan Mountains of Colorado. The values for the two volcanic series are taken from data recorded by Larsen and Cross (1956). Inspection of these values shows that the Idaho and southern California batholiths are chemically very similar. In addition, it can be seen that the Potosi volcanic series bears a close resemblance to the two batholiths, although the rocks of the Potosi have a lower average content of silica and a higher average content of alkalis, especially potassium, than the batholithic series. The Hinsdale formation is more strongly alkalic and differs quite markedly from the other magma series, particularly in regard to its content of silica, alumina, and alkali.

TABLE 8.—*Values at position 15 on variation curves for the oxides of several magma series*

	Idaho batholith	Southern California batholith	San Juan Mountains, Colo.	
			Potosi volcanic series	Hinsdale formation
SiO_2	67.6	69.0	65.2	61.6
Al_2O_3	16.0	15.6	16.8	18.4
CaO	4.3	4.1	4.1	3.7
FeO	4.0	4.3	4.6	4.7
MgO	1.9	1.6	1.7	1.7
K_2O	2.5	2.3	3.8	4.8
Na_2O	3.7	3.7	3.9	4.8

MINERAL COMPOSITION

Olivine was not found in any of the rocks of the Idaho batholith, and monoclinic pyroxene is present in small amount. These minerals are rare in rocks other than gabbro in both provinces, and gabbros are rare in the Idaho batholith. Iron-rich hypersthene is present in a few of the granites of southern California but is not found in any of the Idaho rocks. In both areas biotite and hornblende are the common dark minerals in rocks ranging from tonalite to granite. The quartz monzonites and granites contain abundant muscovite and small amounts of garnet. Such rocks are more abundant in the Idaho batholith than in the batholith of southern California.

Analyses of two biotites and an amphibole from rocks of the Idaho batholith are given in table 9. The Al_2O_3 content of the biotite in the muscovite-quartz monzonite is significantly higher than that in the tonalite. Comparison of the compositions of these minerals with those from the southern California batholith (Larsen and Draisin, 1948, tables 2 and 3) shows that the dark minerals in rocks of the same type in the two batholiths are much alike.

The ratio $\frac{FeO+Fe_2O_3(\text{as }FeO)+MnO}{FeO+Fe_2O_3(\text{as }FeO)+MnO+MgO}$ for rocks, biotite, and hornblende of the Idaho batholith is plotted against position 1/3 $SiO_2+K_2O-FeO-MgO-CaO$ on the variation diagram in figure 2. The curve defined by these points is compared with a similar curve (Larsen and Draisin, 1948, fig. 5) for the rocks and dark minerals of the southern California batholith. The close correspondence of the two curves indicates that the distribution of iron and magnesia in the rocks and dark minerals of both batholiths is very similar.

TABLE 9.—*Analyses and optical properties of biotite and hornblende in rocks of the Idaho batholith*

[Analyst: G. E. Edgington, U. S. Geological Survey]

	1	2	3
SiO_2	35. 85	37. 16	44. 99
Al_2O_3	16. 99	14. 45	11. 21
Fe_2O_3	3. 38	2. 12	3. 33
FeO	20. 13	17. 44	13. 17
CaO	. 71	1. 15	12. 11
MgO	5. 76	11. 21	10. 41
Na_2O	. 84	. 29	. 97
K_2O	9. 14	8. 62	. 76
H_2O+	2. 72	2. 92	1. 48
H_2O-	. 13	. 10	. 04
TiO_2	3. 84	3. 95	1. 46
P_2O_5	. 03	. 14	. 17
SO_3	. 05	----------	----------
MnO	. 70	. 16	. 31
Total	100. 27	99. 71	100. 41
α	1. 590	1. 588	1. 650
β	1. 590	1. 588	1. 672
γ	1. 646	1. 645	1. 681
$2V$	Near 0°	Near 0°	(+) Large
$Z \wedge c$	----------	----------	17°

1. Biotite from muscovite-garnet-quartz monzonite (47-L272).
2. Biotite from tonalite (47-L227).
3. Amphibole from tonalite (47-L227). Pleochroic in brown; $\alpha<\beta<\gamma$; $\beta \| b$.

The perthite of the Idaho rocks has less intergrown albite and is in smaller forms than that of the California rocks. The anorthite content of the plagioclase from rocks of the Idaho batholith is plotted against position 1/3 $SiO_2+K_2O-FeO-MgO-CaO$ on the variation diagram, and the curve for the Idaho plagioclases is compared with a similar curve (Larsen and Draisin, 1948, fig. 4) for the plagioclase of rocks from the southern California batholith, in figure 3. The Idaho plagioclases appear to have a little lower anorthite content than those from California, but the difference is no greater than the expected error of the data.

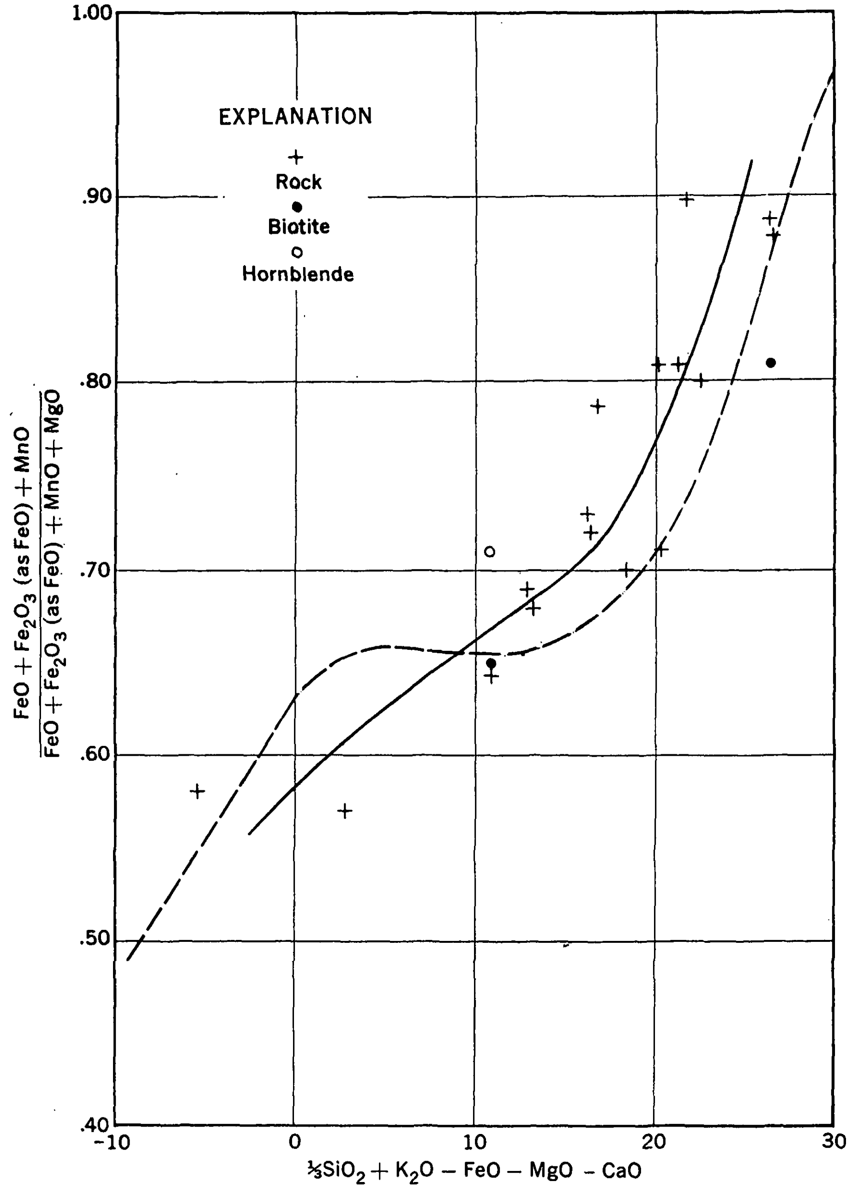

FIGURE 2.—The ratio $\frac{FeO+Fe_2O_3\text{(as FeO)}+MnO}{FeO+Fe_2O_3\text{(as FeO)}+MnO+MgO}$ for rocks, biotite, and hornblende of the Idaho batholith plotted against position of the rocks on the variation diagram. Solid line, Idaho batholith; dashed line, southern California batholith.

The accessory minerals are much alike in the Idaho and southern California batholiths. The amounts of the accessory minerals are highly variable even in similar rocks. Allanite. is more abundant and more widespread in the Idaho rocks than in the rocks of southern

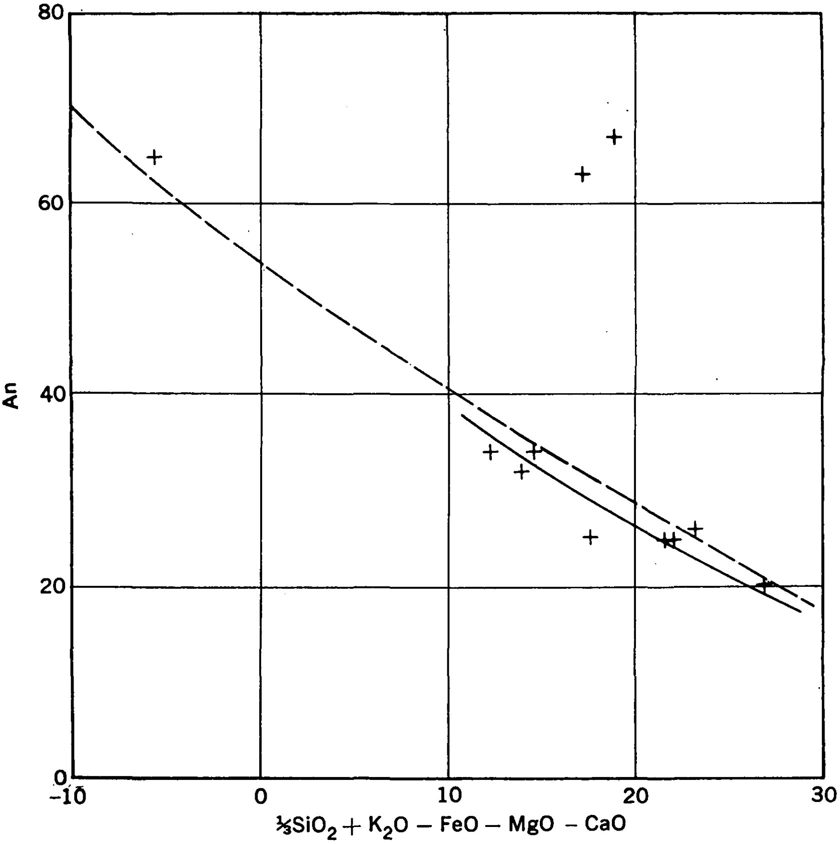

FIGURE 3.—Anorthite content of plagioclase from rocks of the Idaho batholith (crosses) plotted against position of the rocks on the variation diagram. Solid line, Idaho batholith; dashed line, southern California batholith.

California. In the Idaho batholith it is found in rocks ranging from gabbro to granite and its concentration reaches 500 parts per million in some of the tonalites, although it is commonly present in much smaller amounts in these rocks. The granodiorites contain a moderate amount of allanite, and the extreme granites little or none. In nearly all the rocks the allanite occurs as well-developed crystals as much as a millimeter long. It appears to be fresh and not metamict. A specimen of allanite from a granodiorite from Idaho (47–L70) has the following optical properties: $\alpha = 1.761$ pale yellow; $\beta = 1.770$ dark chestnut brown; $\gamma = 1.780$ very dark chestnut brown; and $2V$ near 90°, dispersion strong.

Some of the porphyritic tonalites of the Idaho batholith contain as much as 0.5 percent apatite, but most of the rocks contain much less. The quartz monzonites contain about 100 parts per million and the muscovite-quartz monzonite much less than that. The ω index of refraction of the apatites ranges from 1.634 to 1.646.

Sphene is extremely variable in amount in both batholiths. Some of the porphyroblastic gneisses and dark rocks of the Idaho batholith contain 1 percent or more, and most of the muscovite-bearing rocks contain little or none. Most of the sphene in the Idaho rocks is ordinary, with the following average optical properties: $\alpha=1.895$, $\beta=1.903$, $\gamma=2.06$, and $2V$ is small. That from a tonalite (Ra3) from Oak Grove, Calif., contains alumina and rare earths; in this sample $\alpha=1.836$, $\beta=1.844$, $\gamma=1.921$, and $2V$ is about 50°.

Zircon is rare in the gabbros of both batholiths. In the tonalites and granodiorites it is present in amounts ranging from 300 to less than 100 parts per million, and in the quartz monzonites it was found in much smaller amounts. It is commonly fresh and has the following rather uniform optical properties: $\omega=1.912$ to 1.930, and $\epsilon=1.968$ to 1.986. Some crystals are zoned, and ϵ shows a larger range than ω. Rarely the zircon shows some thin zones of reddish metamict zircon.

Monazite was found chiefly in the quartz monzonites of both batholiths and is present in nearly all the muscovite-bearing rocks. Few of the rocks contain as much as 100 parts per million of monazite. The average optical properties are $\alpha=1.798$, $\beta=1.800$, $\gamma=1.848$, and $2V$ is about 5°–10°. Xenotime was found chiefly in the extreme quartz monzonites in both provinces. It occurs only in rocks that contain monazite and garnet and rarely in rocks without coarse muscovite. Monazite comes a little earlier in the differentiation series than xenotime and is present in some biotite-quartz monzonites. Rocks with these minerals contain little zircon and apatite and no sphene or allanite. Xenotime and monazite are more widespread in the Idaho batholith than in the southern California batholith because the extreme quartz monzonites are more widespread in Idaho. Among the rocks examined, practically every one that contained garnet and muscovite also contained xenotime and monazite. Xenotime is rarely in excess of 0.003 percent. Its optical properties are $\omega=1.718$ and $\epsilon=1.815$.

Thorite was found in small amounts in a few of the rocks from both the Idaho and southern California batholiths. It is found chiefly in tonalites and quartz monzonites in amounts of a few parts per million, is isotropic (metamict), and has an index of refraction of about 1.75.

TEXTURE AND STRUCTURE

For the most part the rocks of the Idaho batholith have a coarser grain than the rocks of the southern California batholith, and large crystals or phenocrysts are more common in the former. Platy or linear structures also are more common in the rocks of the Idaho batholith. None of the large rock units of the Idaho batholith are characterized by abundant oriented reworked inclusions or schlieren as are the Bonsall tonalite and some related rocks of the batholith of southern California. Rocks containing plagioclase with resorbed calcic cores and hornblende with uralite cores are rather common in the batholith of southern California but are scarce or absent in the Idaho batholith.

ALTERATION

The rocks of the Idaho batholith contain more sericite, epidote, and chlorite but less tourmaline than the rocks of the southern California batholith. The rocks of Idaho are also much more deeply weathered to soil, and fresh exposures are not common, but they are much less altered to friable gruss than the rocks of California. Boulders of disintegration are rare in the Idaho batholith but are characteristic of weathered outcrops in the batholith of southern California.

ORIGIN OF THE GRANITIC ROCKS

Granitic rocks are generally considered to have been formed in the following ways (the reader may modify the list to fit his own experience): (1) As part of the primordial crust; (2) by recrystallization through a process of high-grade metamorphism of shales, arkoses, or other rocks, with slight change in chemical composition; (3) by replacement or granitization, in which rocks have been metamorphosed with considerable change in composition either through the agency of moving hydrothermal solutions or diffusion; (4) through direct reaction of soaking of wall rocks by granitic magma; (5) through melting or partial melting of crustal rocks; or (6) by injection of magma from depth.

Much has been written and spoken in the last few years on the origin of granite. The controversy is remindful (although the analogy is not strictly a parallel one) of political debate, where the arguments are convincing chiefly to those who were already convinced. Most of us have now shifted our views a little, and the most vigorous advocates of the magmatic origin of granites will admit that some bodies, mostly small, of granite-like rock, were formed by some process of replacement, and advocates of replacement will admit that there is such a thing as a granitic magma.

It seems to us that at this stage any argument regarding the origin of granitic rocks must be colored by one's own personal observations, and therefore the argument given here will be confined largely to the Idaho and southern California batholiths and to the senior author's own experience.

RECRYSTALLIZATION

In southern California layers in the sediments of Paleozoic age west of Rawson Canyon bear some resemblance to granite. Their position in the sediments and their gradation from "granite" to feldspathic quartzites, as well as their microstructure, indicate that the layers are in fact beds in the sediments.

Under locally favorable conditions it is also apparent that certain igneous rocks, especially those of rhyolitic or quartz latitic composition, may be transformed into "granite" or granite-like rocks through a process of simple recrystallization. An example is provided by the Temescal Wash quartz latite porphyry of southern California. Locally, for as much as several hundred yards from its contact with gabbro and other rocks of the southern California batholith, this rock has been recrystallized to a fine-grained "granite" (Larsen, 1948, p. 38).

REPLACEMENT

In the southern California batholith no large body of rock is believed to have been formed by replacement. However, in the Idaho batholith, discrete bodies of porphyroblatic gneiss are closely associated with highly metamorphosed schists, and every gradation occurs between typical schist with large porphyroblasts and porphyroblastic gneiss that closely resembles tonalite. The porphyroblastic gneiss seems to have been formed from the schists, and large bodies of tonalite associated with these rocks bear such a close resemblance to some of the gneiss that a common origin appears reasonable. The dark minerals of most of the tonalite are arranged in linear patches and give the rocks a definite schistosity. The dark varieties of porphyroblastic gneiss show a similar structure, and in these rocks the schistosity can be traced into the original foliation of the schists. The large feldspar porphyroblasts of the gneiss may either have been introduced into the schist (replacement) or they may have been derived from the schist itself during recrystallization. This question might possibly be settled by a detailed study of some of the contacts in Idaho or, better still, by a study of some that the senior author has seen in western Norway.

MAGMATIC INJECTION

The only body of granitic rock in either batholith that is unquestionably of magmatic origin is a dike of granodiorite in the southern California batholith, in Temescal Wash in the northeastern part of the Corona quadrangle. The dike cuts the Woodson Mountain granodiorite. It is about 3½ miles long and as much as 1,000 feet wide. The typical rock of this dike is a coarse-grained granodiorite much like the Woodson Mountain granodiorite. In the wider parts of the dike the rock has a narrow chill border with an aphanitic groundmass. Where the dike is 50 feet across, the central part contains plagioclase phenocrysts in an aphanitic groundmass, and for a distance of about a foot from the contact the phenocrysts become smaller and are absent at the contact (Larsen, 1948, p. 91–92). These features are taken as evidence of a magmatic origin for the dike.

COMPARISON OF PLUTONIC AND VOLCANIC ROCKS

A comparison of groups of granitic and volcanic rocks, expecially if volcanic plug rocks are included, furnishes some information that bears on the problem of the origin of granites. The Potosi volcanic series of the San Juan Mountains in southwestern Colorado and the southern California batholith form an ideal pair for plutonic-volcanic comparison. They are both large bodies of rock, both were emplaced within a short period of time, and both have rocks with a large range in chemical composition.

The southern California batholith forms the core of the great mountain range of Lower California and of southern California as far north as the Santa Ana River and the city of Riverside. It resembles a great complex dike approximately 1,000 miles long and as much as 70 miles wide. The emplacement of the batholith followed closely the folding and metamorphism of the surrounding older rocks. The batholith is a well-defined unit in space, time, relation to structure, and petrographic character. The order of emplacement of the rock types in the batholith is normal. In general, the gabbros came first, then the tonalites and granodiorites, and finally the granites.

The Potosi volcanic series of the San Juan Mountains forms a volcanic dome about 100 miles across and about a mile thick; its volume is therefore comparable in size to that of a batholith. It is made up of rocks that range from basalt to rhyolite. In general, very dark low-silica rocks are less abundant and rocks rich in silica are more abundant in the Potosi volcanic series than in the southern California batholith. The Potosi rocks also are richer in potassium than are the rocks of the batholith.

Variation curves for the rocks of the Potosi volcanic series are compared with those for the rocks of the southern California batholith in figure 4. These curves are essentially alike. The form of the curves for most petrographic provinces can be explained on the assumption that a primary magma with the composition of a basalt, lying at about position 0 along the abscissa of the diagram, was differentiated by crystal fractionation and was further modified by reaction and other processes to form the other rocks of the province, especially those of more silicic composition than the basalt. This is especially well shown by the Potosi volcanic series in which almost

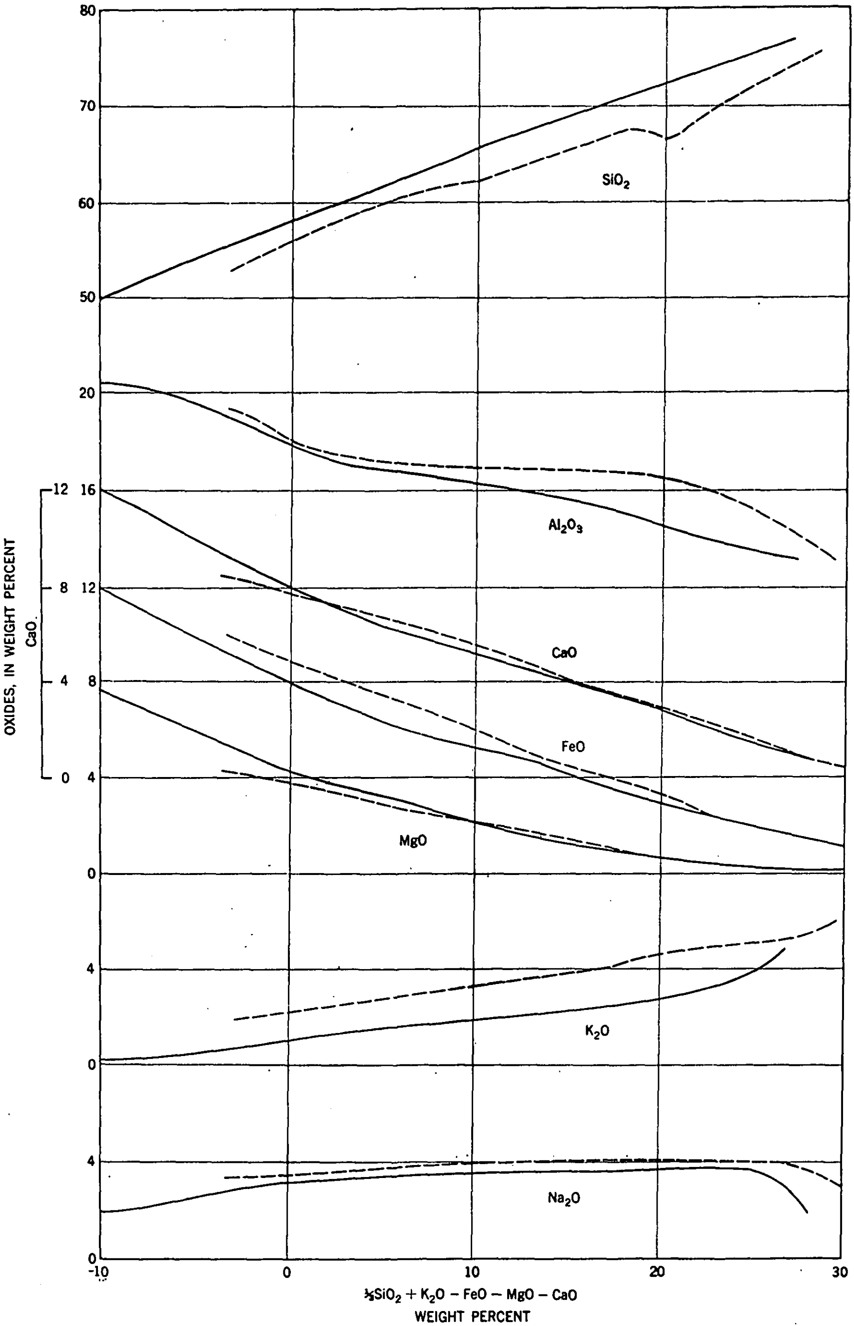

FIGURE 4.—Variation diagram of rocks of the southern California batholith (solid lines) and rocks of the Potosi volcanic series of the San Juan Mountains, Colo. (dashed lines).

all the analyses (a total of 56) fall near the variation curves (Larsen and Cross, 1956). These rocks contain from a few to more than 50 percent phenocrysts, and the composition of the groundmasses falls on the same variation curves as those defined by the bulk compositions of the rocks. This shows that the rocks of the Potosi volcanic series can be formed by the successive removal of phenocrysts actually present in the rocks.

The remarkable similarity in the chemical composition of all the rocks of the southern California batholith with those of the Potosi volcanic series seems to indicate a similar origin and early history for the two groups of rocks. The volcanic rocks are known to be of igneous origin, and therefore it seems highly probable that the comparable plutonic rocks are also of magmatic derivation.

CONCLUSIONS

Read (1948, p. 2) has said that the granite problem is "essentially one of field geology." Probably most geologists would agree to this. However, the senior author has spent about 45 long summers in the field study and mapping of various types of igneous rocks and has seen no convincing or conclusive evidence that enables him to settle in his own mind the problem of the origin of granite, to say nothing of batholiths.

From field evidence alone, only a few relatively small bodies of "granite" in the Idaho and southern California batholiths can be interpreted with reasonable assurance as having been formed by simple recrystallization, replacement, or magmatic injection. To extrapolate these interpretations to the extent of using them to explain the origin of the great granitic bodies such as the two discussed in this paper would introduce a very great uncertainty in the argument.

While it may be true that further detailed field observations will certainly throw additional light on the question of the origin of granite and thus on the origin of batholiths, future advancement toward solution of the problem very likely will depend more on evaluation of field and laboratory data in the light of chemical petrology. Along these lines, we have attempted to reach a general conclusion concerning the origin of certain granitic rocks by means of comparing the chemistry of the rocks of the southern California batholith with that of the Potosi volcanic series of the San Juan Mountains of Colorado. The comparison indicates that the two groups of rocks are very much alike in composition, which is interpreted as strong evidence of a similar origin and early history. In the senior author's judgment, the best explanation for both groups of rocks—volcanic and plutonic—is that they are the result of crystal fractionation of a primary basaltic magma, modified to some unknown degree by reaction with and assimilation of crustal material during emplacement.

The formulation of a comprehensive theory of origin of the Idaho and southern California batholiths is beyond the scope of this paper. Development of any such theory must take into account the following major features of these two great bodies of rock.

1. The largest area of the batholith of southern California occupied by a single mass of uniform rock is about 200 square miles. The batholith has previously been divided into 20 map units, most of which occupy only small areas (Larsen, 1948, pl. 1). Most of the larger units occupy several distinct areas. The rocks of the batholith range from calcic gabbro to granite and are chiefly tonalite. The Idaho batholith, on the other hand, is made up chiefly of five rock types ranging from tonalite to granite. Quartz monzonite is the predominant rock. The individual units of the Idaho batholith are much larger than those of the California batholith, the largest rock body cropping out over an area of about 2,500 square miles.

2. Both batholiths were emplaced in Cretaceous time and followed a major period of deformation and metamorphism. The time required for emplacement of the batholith of southern California, whether by magmatic injection or by granitization, was approximately a few million years (Larsen, 1945). This includes the time from the emplacement or formation of the first gabbro to that of the final granite.

3. In general, the contacts of the southern California batholith with wall rock and the contact between the various units of the batholith are sharp. In a few places where gabbro and tonalite are in contact there are a few tens of feet of mixed rock between the two. In some places the earliest rock, the gabbro, shows some effects of chilling next to its border with older rocks, but in general the rocks maintain their character to the contacts.

4. West of the southern California batholith the older sedimentary and volcanic rocks are little metamorphosed. The rocks are chiefly fine-grained argillites and chloritized volcanic rocks up to the contact of the batholith. Eastward from the west margin, large inclusions in the batholith appear to become progressively more metamorphosed and in particular more coarsely crystalline. Nearly all the metamorphism took place before emplacement of the batholith. This is true of the large inclusions as well.

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