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Idaho Batholith and Its Southern Extension

ABSTRACT

Distribution of minerals and rock types, emplacement structures, and postconsolidation history are more complex within the Idaho batholith than most published descriptions suggest. Hornblende occurs in some areas many miles within the batholith, and planar structure also is present in some of its interior regions.

In the vicinity of the Cascade Reservoir in west-central Idaho, field relationships and modal data for granitic rocks are inconsistent with the conclusion (Schmidt, 1964) that the bedrock systematically and gradationally changes from schist and gneiss to directionless granitic rock along 35-mi traverses west to east across the border and interior of the batholith.

Major fault blocks within the Idaho batholith invalidate the concept (Hamilton and Myers, 1966) of a resistant mass that defied internal deformation during the Cenozoic evolution of western North America.

Gabbro and norite typically occur west of the batholith. Granitic intrusions near the batholith in western Idaho are characterized by megascopic crystals of epidote. Interstitial zeolites also occur in satellite masses rather than in granitic rocks of the batholith.

Granitic rocks of southwest Idaho are correlated with the Idaho batholith primarily by the location and trend of gneissic border rocks on either side of the Snake River Plain. The trend of S. 20° W. in the gneissic border zone north of the Snake River Plain also is present in rocks lying between 40 and 55 mi to the south-southwest where gneissic granitic rocks reappear in the westernmost exposures of pre-Tertiary rocks south of the Snake River. Gross mineralogical characteristics of granitic rocks near the Snake River in southwest Idaho closely resemble those in the west part of the batholith just north of the Snake River Plain.

Southwest structural trends in granitic rocks of southwest Idaho near the Snake River begin to deviate to the southeast about 25 mi due south of Marsing. Farther to the south, trends for 28 mi in the most westerly exposures of the batholith are about S. 20° E. Southeast trends also occur near South Mountain in pre-Tertiary country rocks west of the southernmost exposures of the batholith. The southeast trends within and outside the batholith indicate that a significant change in structural direction occurs in southwest Idaho in the region near South Mountain.

The locations of the south and southeast contacts of the Idaho batholith are uncertain, but some inferences regarding the position of the batholith are possible from isolated occurrences of Ordovician sedimentary rocks south of Twin Falls and from exposures of pre-Tertiary sedimentary and igneous rocks near the Idaho-Nevada state line.

Northward continuity of the Sierra Nevada batholith to the Nevada-Oregon boundary is well established. The trend of the batholith bends toward the northeast before the batholith disappears under Cenozoic volcanic rocks in southeast Oregon and northern Nevada. The distribution and composition of the plutonic rocks near the Nevada-Oregon border suggest that the quartz diorite boundary line is about 160 mi east of the inferred location (Moore, 1959) in northern California.

If the Idaho and Sierra Nevada batholiths are connected, the Idaho batholith southeast of South Mountain must veer sharply west beneath Cenozoic volcanic rocks. Any connecting link between the two batholiths must be confined to a narrow belt that extends east-northeast for about 75 mi near the Idaho-Nevada and Oregon-Nevada boundaries.

An appreciable change in the relative position of the Idaho and Sierra Nevada batholiths has occurred since Oligocene time. If the suggested magnitudes of displacement from normal faulting, dike intrusion, and right-lateral faulting are approximately correct, the east-west change in the alignment of the batholiths is as much as 50 mi.

Gravity and seismic data considered in terms of surface geology and the distribution of gra-

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Smith rocks are consistent with the interpretation that models of crustal structure should include a granitic layer underlying nearly all of southwest Idaho.

INTRODUCTION

Purpose

During 1967 field studies of post-Oligocene dikes and dike swarms of the Basin and Range structural province (Taubeneck, 1969, 1970), gneissic granitic rocks similar to the distinctive border zone rocks of the west part of the Idaho batholith were observed south of the Snake River Plain in southwest Idaho. Moreover, the structural trends in these rocks were found to be on strike with trends in the gneissic border rocks on the north side of the plain. These discoveries in southwest Idaho focused my attention on the possible continuity of Mesozoic granitic rocks between the Idaho batholith and the Sierra Nevada batholith.

This paper (1) presents new data on the Idaho batholith, (2) recognizes a southward extension of the batholith that includes nearly all granitic rocks of southwest Idaho, (3) discusses a possible connection between the Sierra Nevada batholith and the Idaho batholith, and (4) concludes that models of crustal structure should show a layer of low-velocity ("granitic") continental crust underlying nearly all of southwest Idaho.

Methods

Field studies concentrated on relationships of granitic rocks in Idaho and Nevada included 19 days in northern Nevada, 17 days in southwest Idaho, and 34 days along the west border of the Idaho batholith in west-central Idaho. In addition, observations of granitic rocks in central and south-central Idaho were made during 23 days of reconnaissance studies of Cenozoic dikes and dike swarms within the Idaho batholith. Knowledge of pre-Tertiary rocks in western Idaho, several miles or more west of the batholith and between the Snake River Plain and the Clearwater River some 150 mi to the north, was acquired mostly in 36 days, during which Cenozoic dikes were studied.

Except in glaciated alpine areas, rocks of the Idaho batholith commonly are deeply weathered (Russell, 1902, p. 40; Larsen and Schmidt, 1958, p. 3), especially near the Snake River Plain where fresh specimens generally are difficult or impossible to obtain. Therefore, few specimens from near the plain were collected for modal analyses. In northern Nevada, on the other hand, excellent exposures of granitic rocks imposed no restrictions on sampling. Each modal analysis (Tables 1 to 9) represents at least 2000 points for each of two to seven thin sections per rock; the number of thin sections for each analysis is a function of grain size.

Structural trends (Fig. 1) in some areas of granitic rocks in Idaho vary as much as 15° within 100 ft or less. Such variations are more common in exposures in southwest Idaho more than 17 mi south-southwest of the Snake River. Wherever possible, trends shown in Figure 1 represent the average of 20 to 40 observations in an area of at least 1 sq mi.

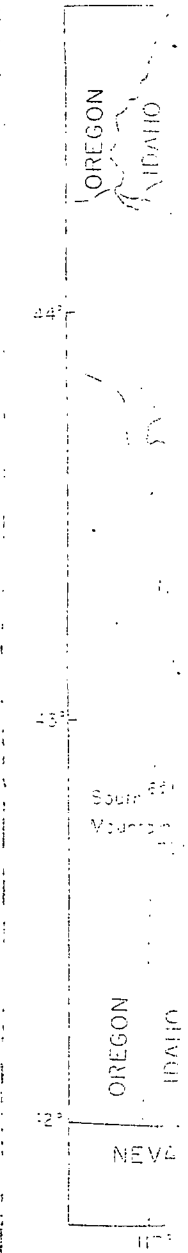
THE IDAHO BATHOLITH

The Idaho batholith is the least known of the large batholiths of the western United States. Although hundreds of papers discuss various aspects of the batholith, almost no detailed petrographic studies are available (Ross, 1963, p. 45).

General knowledge of the batholith was summarized most recently by Ross (1963), near the end of a lifetime devoted largely to the geology of Idaho. His conclusions were based partly on a reconnaissance of much of the batholith during the summer of 1962. Ross (1963, p. 53) correctly reported that "both the border zone and the interior mass are more complex in detail than would be supposed from published descriptions."

The batholith traditionally has been described in terms of a gneissic shell of quartz diorite that encloses quartz monzonite and granodiorite (for example, Ross, 1936). Some modern generalizations are rather misleading in referring to the rocks within the gneissic shell as "continuous massive granodiorite and quartz monzonite" (Hamilton, 1962, p. 513). Planar structure, in some areas many miles within the batholith, will permit detailed structural studies that ultimately will provide considerable information regarding its emplacement history.

Another misconception regarding the Idaho batholith is that hornblende occurs only in border rocks. Actually, hornblende is present in some interior parts of the batholith, especially south and southwest of Atlanta (Fig. 1). Near Trinity Peak, about 21 mi southwest of Atlanta, granitic rocks contain several percent of hornblende. The distribution of hornblende is ...



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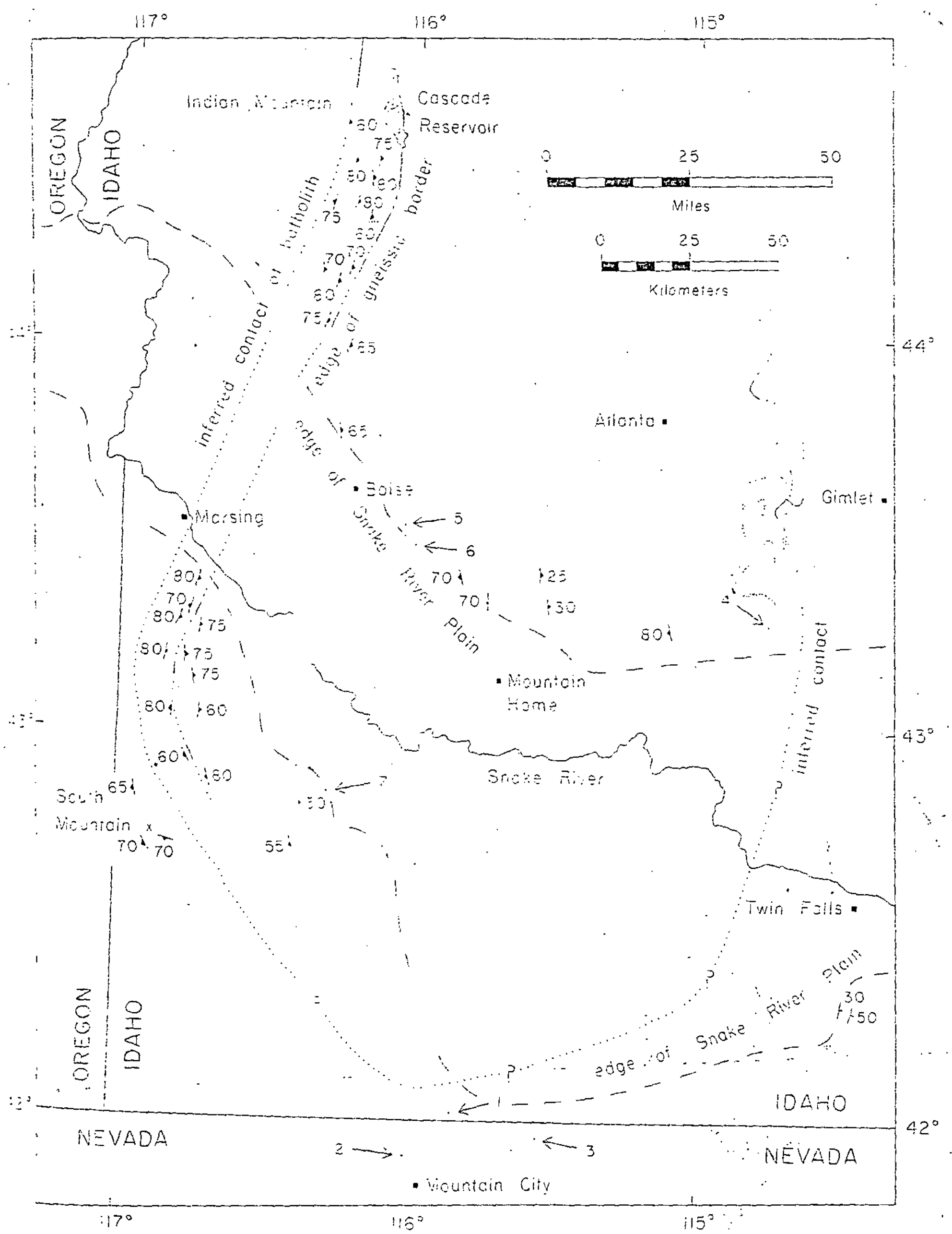

Figure 1. Map showing inferred contacts of Idaho batholith, structural trends, and locations (dots) of numbered localities discussed in text.

almost immediate importance, for example, in facilitating the radiometric investigations of geochronologists.

Modal data (Tables 1 and 2) for granitic rocks in the area between the Cascade Reservoir (Fig. 1) and the Snake River Plain illustrate that the petrography and the distribution of rock types within the batholith are more complex that implied by published statements. This part of the batholith was studied by semireconnaissance methods that involved observations restricted mostly to localities not

TABLE 1. MODES OF ROCKS FROM GNEISSIC BORDER NEAR NORTH SIDE OF SNAKE RIVER PLAIN*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio-clase	Biotite	Muscovite	Horn-blende	Accessories Opaque	Accessories Nonopaque
122	0.1	25.5	50.8	19.7	2.0	0.0	0.4	1.5
123	0.0	26.1	54.7	14.5	0.8	2.6	0.5	0.8
124	0.1	25.9	59.4	13.6	0.4	0.2	0.0	0.4
125	0.0	27.6	57.5	13.6	0.7	0.2	0.0	0.4
126	0.0	26.7	58.2	14.2	0.4	0.1	0.0	0.4
127	0.1	29.2	55.9	13.8	0.4	0.1	0.1	0.4
128	2.4	30.8	53.4	11.9	0.9	0.0	0.3	0.3
129	0.1	28.7	55.9	14.1	1.0	0.0	0.0	0.2
130	3.5	31.8	54.0	9.8	0.8	0.0	0.0	0.1
131	10.6	32.4	45.9	10.0	0.7	0.0	0.3	0.1
132	4.7	32.2	51.7	11.3	0.0	0.0	0.0	0.1
177	0.0	22.1	59.7	10.6	0.1	5.8	1.0	0.7
251	0.2	27.8	53.3	16.1	1.7	0.3	0.2	0.4
252	0.1	32.1	55.5	10.1	1.7	0.0	0.2	0.3
253	0.0	32.8	57.2	9.0	0.1	0.0	0.0	0.9†

*Each modal analysis is the average of two thin sections.
†[illegible]

TABLE 2. MODES OF ROCKS FROM INTERIOR OF BATHOLITH NEAR NORTH SIDE OF SNAKE RIVER PLAIN*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio-clase	Biotite	Muscovite	Horn-blende	Accessories

	[illegible]	[illegible]	45.9	10.0	0.7	0.0	0.3	0.1
132	4.7	32.2	51.7	11.3	0.0	0.0	0.0	0.1
177	0.0	22.1	59.7	10.6	0.1	5.8	1.0	0.7
251	0.2	27.8	53.3	16.1	1.7	0.3	0.2	0.4
252	0.1	32.1	55.5	10.1	1.7	0.0	0.2	0.3
253	0.0	32.8	57.2	9.0	0.1	0.0	0.0	0.9+

*Each modal analysis is the average of two thin sections.
+[illegible] 0.7 percent garnet

TABLE 2. MODES OF ROCKS FROM INTERIOR OF BATHOLITH NEAR NORTH SIDE OF SNAKE RIVER PLAIN*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio-clase	Biotite	Muscovite	Horne-blende	Accessories Opaque	Accessories Nonopaque
178	11.2	26.9	51.8	8.5	0.6	0.0	0.3	0.7
287	8.2	28.9	50.8	10.9	0.4	0.0	0.2	0.6
176	0.0	5.9	69.2	2.6	0.0	20.2	1.0	1.1
179	4.1	23.5	55.2	13.7	0.0	1.9	0.2	1.4
180	8.5	28.6	48.3	12.4	0.0	0.2	0.1	1.9
242	6.7	26.1	55.5	10.1	0.3	0.0	0.3	1.0
243	10.1	26.4	50.2	11.4	0.1	0.4	0.2	1.2
244	3.6	28.8	57.2	8.7	0.1	0.0	0.1	1.5
236	21.9	29.0	42.5	5.6	0.6	0.0	0.2	0.2
237	11.6	27.6	51.9	8.0	0.6	0.0	0.1	0.2
240	10.4	36.8	47.3	3.5	1.9	0.0	0.0	0.1
241	8.5	32.1	54.3	4.1	1.0	0.0	0.0	0.0

*Data for specimens 178, 287, and 237 are averages of five thin sections each; specimens 236, 240, and 241 are averages of seven thin sections each; other specimens are averages of two thin sections each.

more than 0.5 mi from roads. The batholith in this region is not amenable to easy investigation because of much timber and brush, as well as a heavy coating of lichens on most rocks in the more open country at the lower elevations near the Snake River Plain. The following discussion of rocks to the east of the inferred contact (Fig. 1) of the batholith includes no mention of relationships between different rock types because the critical relationships are unknown.

Rocks of the foliated border zone within 25 mi of the Snake River Plain are mostly quartz diorite that is characterized by a comparatively large amount of biotite, minor muscovite, and little or no hornblende. Rocks more than 25 mi north of the plain commonly contain garnet. The general absence of phenocrysts of potassium feldspar is a distinctive feature of the foliated rocks. Modal data for typical border rocks are given in Table 1. Except for a higher percent of biotite, the rocks are more closely related mineralogically to trondhjemite (Goldschmidt, 1916, p. 77), than to quartz diorite.

A porphyritic granodiorite with phenocrysts of potassium feldspar occurs east of the gneissic shell of the batholith. To the north, this rock was called the "granodiorite near Cascade" by Larsen and Schmidt (1958, p. 6). A modal analysis given by Larsen and Schmidt (1958, Table 3, column 8) for a specimen of this granodiorite collected about 30 mi north of the Snake River Plain compares very closely with modal analyses of two porphyritic granodiorites (Table 2, specimens 178, 287) from near the plain.

Within 30 mi of the Snake River Plain, any west to east traverse through porphyritic granodiorite will pass within about 5 mi, or less, into a northerly trending belt of more mafic rocks that apparently are mostly hornblende-bearing nonporphyritic granodiorite and quartz diorite with minor diorite. This elongated belt of relatively mafic granitic rocks extends northward to within about 20 mi of Cascade Reservoir; the width of the belt is probably not more than 7 mi. Table 2 contains modes for six specimens (176, 179, 180, 242, 243, 244).

Porphyritic granodiorite without hornblende occurs east of the zone of relatively mafic rocks. Specimens 236 and 237 (Table 2) were collected several miles to the east, whereas leucocratic specimens 240 and 241 are from typical exposures about 7 mi to the east. The porphyritic granodiorite east of the zone of mafic rocks is more felsic (Table 2) than the porphyritic granodiorite that extends south-southwest from Cascade Reservoir to the Snake River Plain.

In summary, modal data in Tables 1 and 2 support the conclusion that the petrography and over-all distribution of rocks within the Idaho batholith are more complex than is apparent from published descriptions.

Schmidt (1964, p. 8) concluded from reconnaissance petrographic studies in Adams and Valley Counties in west-central Idaho that the "bedrock systematically and gradationally changes from schist and gneiss to directionless granitic rock" in 35-mi west to east traverses across the border and interior of the batholith. Schists and metasedimentary gneisses are present, primarily to the west, but most rocks in the area described by Schmidt (1964) are part of igneous plutons which commonly have at least some well-defined intrusive contacts. Figure 2 is a reconnaissance map of the most pertinent part of the area considered by Schmidt (1964). The rocks are discussed from west to east.

The quartz diorites of Council Mountain and Deserette are satellites of the batholith and are the most westerly pre-Tertiary rocks in the region. Both masses are of igneous origin. The Council Mountain pluton exhibits intrusive relationships to adjacent country rocks. Although contacts of the Deserette pluton with bordering country rocks are concealed beneath Columbia River Basalt, xenoliths within the pluton show evidence of transportation and intrusion. Most exposures of the plutons are good to excellent, but poor exposures within 100 ft of their mutual contact prevented a determination of their relative ages. Both quartz diorites have gneissoid to gneissic borders that grade inward to rocks with a more nearly directionless fabric. Although the quartz diorite of Council Mountain is exposed in two areas (Fig. 2), all exposures may be part of one large pluton concealed mostly by Columbia River Basalt. Likewise, a continuous mass of the quartz diorite of Deserette may underlie the Columbia River Basalt in the area between the main exposures of the rock and the small outcrops about 1 mi to the north (Fig. 2).

Modal analyses of the quartz diorites of Council Mountain and Deserette are given in Tables 3 and 4. As one of two specimens of the quartz diorite of Deserette from the restricted northern exposure (Fig. 2) has the composition of a granodiorite, part of the concealed rock

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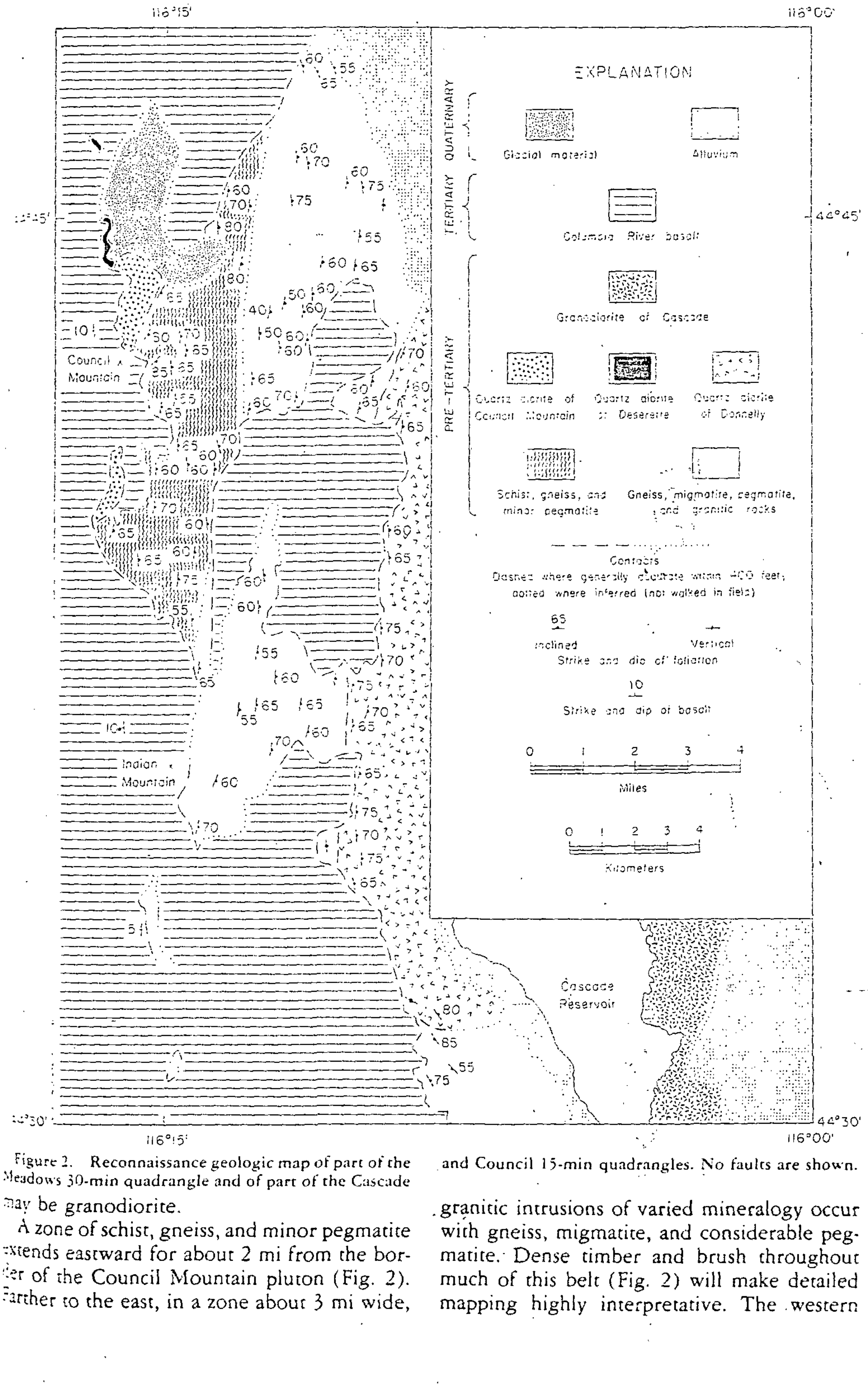

Figure 2. Reconnaissance geologic map of part of the Meadows 30-min quadrangle and of part of the Cascade and Council 15-min quadrangles. No faults are shown.

may be granodiorite.

A zone of schist, gneiss, and minor pegmatite extends eastward for about 2 mi from the border of the Council Mountain pluton (Fig. 2). Farther to the east, in a zone about 3 mi wide, granitic intrusions of varied mineralogy occur with gneiss, migmatite, and considerable pegmatite. Dense timber and brush throughout much of this belt (Fig. 2) will make detailed mapping highly interpretative. The western

TABLE 3. MODES OF QUARTZ DIORITE OF COUNCIL MOUNTAIN*

(in volume percent)

Specimen number	133	134	135	137	142
Potassium feldspar	2.4	0.0	0.0	0.0	0.0
Quartz	18.4	13.8	14.6	20.3	8.2
Plagioclase	52.2	55.9	53.5	52.2	59.4
Biotite	9.2	10.6	8.2	13.6	8.2
Hornblende	12.5	15.6	18.7	9.9	21.8
Epidote	4.2	2.9	3.6	3.3	1.2
Opaque accessories	0.1	0.1	0.1	0.0	0.5
Nonopaque accessories	1.0	1.1	1.3	0.7	0.7

*Each modal analysis is the average of two thin sections.

limit of lens-shaped (?) igneous intrusions is selected arbitrarily as the western border of the Idaho batholith. No two geologists will place the "contact" in the same location. The percent of igneous rocks varies in a north-south direction with mostly hornblende-bearing types (Table 5, specimens 136, 139) in the north, in contrast to the common occurrence of garnet-bearing types (Table 5, specimens 154, 155, 156, 161) in the south.

The quartz diorite of Donnelly, the major unit of the batholith to the west of the Cascade Reservoir, intrudes the east side of the 3-mi-wide zone of mixed igneous and metamorphic rocks (Fig. 2). The simplest and most clean-cut contact of the Donnelly intrusion is about 4 mi east-northeast of Indian Mountain (Fig. 2) where a marked color contrast occurs between relatively mafic quartz diorite and adjacent leucocratic country rocks.

The quartz diorite of Donnelly is an elongated pluton that extends northward for many miles, to a large extent beneath the surficial deposits of Long Valley. The east contact of the pluton in the vicinity of Figure 2 must lie beneath Cascade Reservoir, because the granodiorite of Cascade occurs along the east shore of the reservoir. Therefore, the Donnelly pluton is less than 6 mi wide in the vicinity of the map area (Fig. 2). Presumably the granodiorite of Cascade intrudes the Donnelly pluton beneath the reservoir in the same manner that an interior-type granodiorite (or quartz monzonite) intrudes a gneissic quartz diorite that resembles the Donnelly unit near the section line between sections 3 and 10 in T. 19 N., R. 4 E., some 32 mi north-northeast of Indian Mountain.

Although the quartz diorite of Donnelly generally is gneissic near contacts, planar structure is less strongly defined inward. In contrast to the distinct planar structure of the Donnelly pluton, planar structure in the granodiorite of Cascade is weak or absent.

In summary, field relationships and rock distribution within the area of Figure 2 necessitate a rejection of the conclusion that in west to east traverses, the "bedrock systematically and gradationally changes from schist and gneiss to directionless granitic rock" (Schmidt, 1964, p. 8). Moreover, the modal data for quartz diorites (Tables 3, 4, 5, and 6) show that no systematic mafic to felsic change occurs in west to east traverses across the area.

Cenozoic deformation within the batholith also is more complex and widespread than some generalizers have implied. For example the batholith is visualized by Hamilton and Myers (1966, p. 540-542) as a resistant mass that defied internal deformation during the Ce-

UNCIL MOUNTAIN*

	137	142	14
	0.0	0.0	0.
	20.3	8.2	21.
	52.2	59.4	53.
	13.6	8.2	13.
	9.9	21.8	4.
	3.3	1.2	5.
	0.0	0.5	0.
	0.7	0.7	0.

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ade intrudes the Donnelly pluton reservoir in the same manner that pe granodiorite (or quartz monzo- es a gneissic quartz diorite that e Donnelly unit near the section sections 3 and 10 in T. 19 N., R. 32 mi north-northeast of India

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TABLE 4. MODES OF QUARTZ DIORITE OF DESERETTE*

(in volume percent)

Specimen number	143	149	150	151	152	153	172
Potassium feldspar	0.8	1.7	0.6	2.5	1.3	10.1	1.2
Quartz	30.8	30.4	27.2	30.6	25.2	30.6	33.4
Plagioclase	62.4	60.8	64.3	59.7	65.3	52.0	52.0
Biotite	4.4	5.0	6.1	5.1	6.1	5.4	9.4
Muscovite	0.7	0.8	0.6	0.4	0.6	0.5	1.2
Epidote	0.7	0.9	0.8	1.3	0.7	0.8	2.4
Opaque accessories	0.2	0.2	0.2	0.0	0.2	0.3	0.3
Nonopaque accessories	0.0	0.2	0.2	0.4	0.6	0.3	0.1

*Each modal analysis is the average of two thin sections.

zoic evolution of western North America. According to Hamilton and Myers (1966, p. 542), "young fault blocks lie north, west, and east of the batholith, but none of consequence break it." In a brief discussion of a major belt of north-trending faults in western Idaho, Hamilton (1962, p. 513) stated that "the average throw on each of the long faults is about 1000 or 1500 ft." Contrary to Hamilton and Myers (1966, p. 542), the belt of north-trending faults discussed by Hamilton (1962) extends eastward into the interior of the batholith.

About 25 mi north of Boise (Fig. 1), a small remnant of downdropped Columbia River Basalt at an elevation of 2800 ft dips about 20° W. on the east side of a prominent fault reported by Anderson (1934a, p. 17). Three mi to the west, at an elevation of 4000 ft near the crest of the uplifted block, Lindgren's (1898) cross-section shows an extensive cap of Columbia River Basalt dipping about 10° W. This fault qualifies as a major break in the Idaho batholith. The fault is about 6 mi east of the edge of the gneissic border (Fig. 1) of the batholith.

About 25 mi north-northeast of Boise, Anderson (1947, p. 170) recognized a major fault that trends slightly northeast along the west side of Boise Basin. On Hawley Mountain, the fault escarpment at an elevation of 7000 ft is capped by Columbia River Basalt that dips about 15° W. About 2.5 mi to the east, on the downdropped side of the fault, a remnant of Columbia River Basalt is at an elevation of 5400 ft. In the vicinity of Hawley Mountain, the fault displacement is at least 2000 ft. The fault is about 15 mi east of the edge of the gneissic border (Fig. 1) of the batholith. No attempt was made to trace this important fault northward, but the impressive alignment of hot springs (Stearns and others, 1937, p. 138-139) that trends slightly northeast about 45 mi is an indication of the probable location of the fault, or one of its branches.

No veneer of Columbia River Basalt is available as a horizon marker for determination of post-Miocene displacement along faults elsewhere in the interior of the batholith, but major northerly trending faults have been reported. The Montezuma fault (Anderson, 1939, p. 17; Reid, 1963, p. 11) near Atlanta (Fig. 1), probably is one of the best documented. This fault forms the west boundary of the Sawtooth Mountain fault block. Anderson (1939, p. 17) suggested a vertical displacement of as much as 2000 ft; a cross section by Reid (1963, Fig. 19) indicates a similar displacement.

Northwest drift of the Idaho batholith *as an unbroken plate* is a basic part of the Hamilton and Myers (1966) concept of Cenozoic tensional

TABLE 5. MODES OF QUARTZ DIORITE WEST OF DONNELLY PLUTON*

(in volume percent)

Specimen number	136	139	154	155	156	161
Potassium feldspar	0.0	0.3	0.3	0.7	0.3	0.[illegible]
Quartz	21.4	25.0	22.3	22.9	29.9	33.[illegible]
Plagioclase	62.9	59.4	63.3	64.5	58.4	59.[illegible]
Biotite	8.8	10.9	10.4	11.3	10.4	6.[illegible]
Hornblende	5.7	3.2	1.0	0.0	0.0	0.[illegible]
Muscovite	0.0	0.0	0.1	0.1	0.4	0.[illegible]
Garnet	0.0	0.0	2.0	0.1	0.2	0.[illegible]
Opaque accessories	0.5	0.3	0.0	0.0	0.0	0.[illegible]
Nonopaque accessories	0.7	0.9	0.6	0.4	0.4	0.[illegible]

*Each modal analysis is the average of two thin sections.

rifting and oroclinal bending in the Pacific Northwest. Appraisal[1] of the entire concept requires an extended discussion of relationships throughout the Pacific Northwest, but the major fault blocks mentioned in the three preceding paragraphs invalidate the basic premise that "young fault blocks lie north, west, and east of the batholith, but none of consequence break it" (Hamilton and Myers, 1966, p. 542).

SATELLITES WEST OF THE IDAHO BATHOLITH

From the standpoint of the regional distribution of plutonic rocks in western Idaho, several petrographic relationships involving satellites of the batholith require comment as background for interpretations and conclusions regarding the location of the contact of the batholith south of the Snake River Plain.

The occurrence of discrete crystals of epidote, as much as 3.0 mm across and commonly associated with unaltered biotite and hornblende, is a notable feature of satellites which are near (generally within 15 mi) the batholith. Insofar as the writer knows, discrete crystals of megascopic epidote occur in the granitic rocks of eastern Oregon, southeastern Washington, and western Idaho only in plutons and small igneous bodies that border the Idaho batholith. Rocks that contain the conspicuous crystals of epidote range in composition from mafic quartz diorite to leucocratic trondhjemite and granodiorite. Some rocks contain as much as 6 percent epidote. The quartz diorites of Council Mountain and Deserette (Fig. 2) are excellent examples of the epidote-bearing rocks which occur northward in satellites for at least 125 mi. The unique epidote-bearing rocks occur as plutons of trondhjemite (Hamilton, 1963) in the 30-min Riggins quadrangle, some 25 to 55 mi north of Council Mountain. Farther to the north, the rocks are conspicuous about 6 to 10 mi south of Grangeville[2] in plutons surrounded areally by Columbia River Basalt.

[1] Paleomagnetic data for Columbia River Basalt in southern Washington and the over-all trend of basalt dikes in western Idaho, northeast Oregon, and southeast Washington indicate that little or no post-Miocene oroclinal bending has occurred in these regions (Taubeneck, 1970, p. 92-95). It is emphasized that possible pre-Miocene rotation is irrelevant to a tectonic model (Hamilton and Myers, 1966) in which normal faulting in the Basin and Range structural province is supposedly accompanied by oroclinal bending in the Pacific Northwest.

[2] Grangeville is about 84 mi N. 5° E. from Council Mountain.

ONNELLY PLUTON*

155	156	161
0.7	0.3	0.:
22.9	29.9	33.:
64.5	58.4	59.:
11.3	10.4	6.:
0.0	0.0	0.:
0.1	0.4	0.:
0.1	0.2	0.:
0.0	0.0	0.:
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TABLE 6. MODES OF QUARTZ DIORITE OF DONNELLY*

(in volume percent)

Specimen number	157	158	159	160	162	173
Potassium feldspar	1.0	1.0	2.3	0.1	0.7	0.0
Quartz	19.9	20.3	22.4	18.7	21.3	17.9
Plagioclase	45.5	42.9	44.6	52.4	49.5	48.7
Biotite	17.6	17.3	16.1	14.9	14.4	15.9
Hornblende	14.4	17.9	12.4	13.4	13.1	17.1
Augite	0.8	0.3	2.0	0.0	0.0	0.1
Opaque accessories	0.0	0.0	0.0	0.0	0.0	0.0
Nonopaque accessories	0.8	0.3	0.2	0.5	1.0	0.3

*Each modal analysis is the average of two thin sections.

About 5 to 9 mi east-southeast of Grangeville, the large crystals of epidote occur in a trondhjemite bordered by basalt on the west. Exposures of pre-Tertiary rocks are not common north of Grangeville. Nevertheless, megascopic crystals of epidote in a tonalite about 27 mi due north of Grangeville indicate that the belt of epidote-bearing rocks extends northward beneath the Columbia River Basalt. Hietanen (1962, p. 55) described large crystals of epidote in tonalite about 40 mi north of Grangeville; the belt of epidote-bearing rocks probably continues further northward. South of the quartz diorite of Council Mountain, Columbia River Basalt prevents any determination of the distribution of epidote in concealed satellites that undoubtedly occur between Indian Mountain (Fig. 1) and the Snake River Plain.

The distribution of interstitial zeolites (Taubeneck, 1967, p. 17-19) in the granitic rocks of western Idaho also is significant because zeolites apparently occur only in satellites of the batholith. The zeolites (mostly heulandite) comprise less than 0.05 percent by volume of the rocks. Accordingly, the careful examination of hundreds of thin sections will be necessary to document the distribution of interstitial zeolites in the granitic rocks of western Idaho. The absence of interstitial zeolites in thin sections of 71 rocks from the batholith and the presence of zeolites in sections from 21 of 59 rocks from satellites, however, seem to justify the conclusion that zeolites characterize granitic rocks of satellites rather than those of the batholith. Interstitial zeolites occur near Council Mountain (Fig. 2) in the Deserette pluton and in satellites northward for 110 mi, which is near the northern limit of sampling.

The common occurrence of gabbroic rocks in western Idaho near the batholith is another relationship that can be used as an indication of the approximate location of the contact of the batholith south of the Snake River Plain. The gabbroic rocks generally include hypersthene-bearing varieties. Near the northwest part of the batholith, gabbro and norite in the vicinity of Ahsahka occur in close proximity to hornblendite (Hietanen, 1962, p. 52). About 43 mi to the south-southeast, gabbro and norite are present near Harpster (Myers, 1968, p. 118). Some 30 mi south of Ahsahka, gabbroic rocks near Ferdinand include gabbro, hornblende melagabbro, and hypersthene gabbro. In the Cuddy Mountains, about 25 mi west of Council Mountain (Fig. 2), gabbro and norite are present in an area of plutonic and low-grade metamorphic rocks that is surrounded by Columbia River Basalt. The distribution of gabbroic rocks in each of the four areas cannot be determined because of the widespread flows of Columbia River Basalt that cover much of the pre-Tertiary basement near the west contact of the batholith.

STRUCTURAL TRENDS NEAR THE WEST CONTACT OF THE BATHOLITH

The west border of the Idaho batholith near the Snake River Plain is exposed in greatest detail in the area (Fig. 2) west of Cascade Reservoir. North of the area of Figure 2 for about 10 mi, the border rocks are concealed by Columbia River Basalt and the Quaternary deposits of Long Valley. Southwest of the Cascade Reservoir, much of the gneissic shell of the batholith is covered by Columbia River Basalt. Accordingly, the area of Figure 2 merits special consideration in documenting structural trends near the west contact of the batholith.

Over-all structural trends in the area west of Cascade Reservoir are north-south (Fig. 2). Most deviations more than 15° from north-south in trends of country rocks are attributable to disruption by forceful emplacement of plutons such as the Council Mountain and Donnelly bodies. Trends in plutons closely parallel wall rocks and are essentially north-south, except along contacts that turn appreciably to the east or west. Within 10 mi to the south of Cascade Reservoir, structural trends swing from north-south to about S. 20° W.—a trend that persists (Fig. 1) southward to the Snake River Plain.

Near the south end of Cascade Reservoir, the width of the foliated zone within the batholith is about 10 mi (Fig. 1). Although the "contact" of the batholith is concealed by Columbia River Basalt south of Indian Mountain (Fig. 1), foliated rocks of the border zone are exposed almost continuously southward to within 8 mi of the Snake River Plain. The inferred location of the contact of the batholith south of Indian Mountain is arbitrarily drawn (Fig. 1) about 10 mi west of the east margin of the foliated border rocks. The line denoting the east margin of the foliated border rocks should be accurate to within 0.5 mi, although the location of the line south of Cascade Reservoir is based on only five traverses across the border zone. A general accuracy of 0.5 mi is probable because the intensity of foliation diminishes rapidly near the eastern margin of the foliated border zone. Faint to good planar structure does occur, however, in some rocks east of the foliated border zone.

STRUCTURAL TRENDS IN GRANITIC ROCKS NEAR THE SNAKE RIVER PLAIN

The southern limit of the Idaho batholith traditionally has been placed near the north edge of the Snake River Plain, although younger rocks everywhere overlie the batholith along this boundary. Larsen and Schmidt (1958, p. 3) noted that the batholith "may extend southward for many miles beneath this cover." Planar structures trending roughly north-south in granitic rocks near the plain strongly suggest that the batholith does continue southward beneath the Cenozoic rocks. If the batholith terminated near the plain, structures in the granitic rocks just north of the plain should be more nearly east-west in close parallelism to a concealed contact along or near the northern edge of the plain. In six areas of granitic rocks that were examined eastward from the vicinity of Boise, planar structure was not detected in two areas, but northward-striking planar structure was observed in the following four areas.

About 10 mi north-northwest of Boise (Fig. 1), faint planar structure in granitic rocks near the Snake River Plain trends about N. 5° W. and dips 65° NE. Although the structure is weak, the trends are consistent with a southward continuation of the batholith under the Cenozoic cover.

About 20 mi north-northwest of Mountain Home (Fig. 1), excellent planar structure in rocks bordering the plain trends about N. 15° W. with 70° dips to the west. About 14 mi north of Mountain Home, rocks bordering the plain trend mostly between N. 10° E. and N. 10° W.; dips are generally 70° W. Trends in the areas north and north-northwest of Mountain Home indicate that the batholith extends south under the Cenozoic rocks of the plain.

Some 32 miles east-northeast of Mountain Home, good planar structure in granitic rocks near the county line between Elmore and Camas Counties has an average trend of N. 15° W. with dips 80° SW. Planar structure in this vicinity also implies a continuation of the batholith to the south.

General absence of gneissic rocks in the batholith along the north edge of the Snake River Plain also supports the conclusion that the batholith continues south beneath the plain. If the south contact of the batholith was near the north edge of the plai
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north edge of the plain, gneissic border rocks trending more or less east-west should occur along the southernmost exposures of the batholith. Gneissic rocks do occur in one area, but trends are not parallel to the margin of the plain. About 16 mi northeast of Mountain Home, gneissic granitic rocks near the northern edge of the plain occur with intensely metamorphosed country rocks in an area of at least 15 sq mi. One traverse across this gneissic terrane indicates that trends are mostly within 15° of north-south; dips are generally less than 45° E.

SOUTHERN EXTENSION OF THE BATHOLITH IN SOUTHWEST IDAHO

Most of southwest Idaho is characterized by Cenozoic volcanic formations, but many isolated outcrops of granitic rocks southward 40 mi from the Snake River (Fig. 1) permit important conclusions regarding petrographic and structural relationships of pre-Tertiary rocks throughout an area of about 1000 sq mi. Farther to the south, toward the southwest corner of Idaho, no pre-Tertiary rocks are exposed. Uncertainties regarding the characteristics of concealed pre-Tertiary rocks near the southwest corner of Idaho are increased by the cover of Cenozoic volcanic rocks in adjoining parts of Oregon and Nevada.

Granitic rocks of southwest Idaho are correlated with the Idaho batholith primarily by the location and trend of gneissic border rocks on either side of the Snake River Plain. The trend of S. 20° W. in the gneissic border zone of the Idaho batholith on the north side of the Snake River Plain is duplicated 40 to 55 mi farther south-southwest where gneissic granitic rocks reappear in the westernmost exposures of pre-Tertiary rocks on the south side of the Snake River (Fig. 1). Furthermore, the intensity of planar structure in the westernmost granitic rocks south of the Snake River rapidly diminishes to the east, in the same manner as in the westernmost granitic rocks north of the plain. Coinciding structural relationships in granitic rocks on either side of the plain, strengthened by similar mineralogical characteristics, warrant the conclusion that the granitic rocks near the south side of the Snake River in southwest Idaho are a southern continuation of the Idaho batholith.

Gross mineralogical relationships of granitic rocks south of the Snake River resemble the relationships in the west part of the batholith on the north side of the Snake River Plain. Potassium feldspar is less abundant in the gneissic border rocks than in nongneissic granitic rocks to the east. Although phenocrysts of potassium feldspar occur in several areas within the gneissic border zone, many granitic rocks contain no phenocrysts and only small amounts of potassium feldspar. In contrast, phenocrysts of potassium feldspar are characteristic of the nongneissic granitic rocks to the east of the border zone. As is true just north of the Snake River Plain (Table 1), biotite is more abundant in the gneissic border rocks, whereas hornblende is confined either to the border rocks or to rocks a short distance to the east. Modal data in Table 7 provide a general approximation of the mineral proportions in the exposed parts of the batholith in southwest Idaho. Specimens 116, 117, 118, 249, and 256 are from the gneissic border zone; the remaining specimens are representative of interior rocks.

Location of the gradational contact (Fig. 1) in southwest Idaho between gneissic and nongneissic granitic rocks of the batholith poses few problems in comparison with uncertainities regarding the location of the "contact" of the batholith. Most of the westernmost exposures of gneissic granitic rocks south of the Snake River generally cannot be traced continuously eastward into nongneissic granitic rocks. Nevertheless, exposures are adequate in most places to permit a confident location of the east margin of the gneissic border rocks within a distance of 2 mi or less (Fig. 1). No exposures of pre-Tertiary rocks occur in southwest Idaho west of the inferred "contact" (Fig. 1) of the batholith, except in the vicinity of South Mountain. Pre-Tertiary rocks exposed throughout an area of about 25 sq mi near South Mountain are neither part of the Idaho batholith nor part of a roof pendant, as was verified by six days of reconnaissance supplemented by unpublished mapping of R. L. Krueger, north of the mountain. Metamorphic rocks composed mostly of quartzite, schist, and marble (Sorenson, 1927, p. 11) are intruded by small granitic bodies and, on the south, by a gabbroic complex. East and northeast of South Mountain, scattered areas of gneissic and nongneissic granitic rocks within the batholith permit the location of the "contact" of the batholith with a maximum error of not more than about 5 mi. The inferred width of the gneissic border zone northeast of South Mountain is maintained arbitrarily in extending the "contact" of the batholith north-

TABLE 7. MODES OF ROCKS FROM SOUTHWESTERN IDAHO*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio- clase	Biotite	Muscovite	Horn- blende	Accessories Opaque	Accessories Nonopaque
116	2.7	28.0	57.3	11.6	0.3	0.0	0.0	0.1
117	1.8	30.5	51.9	14.9	0.9	0.0	0.0	0.0
118	3.1	18.3	57.8	14.6	0.0	4.8	0.0	1.4
249	0.0	30.8	58.6	9.4	1.0	0.0	0.0	0.2
256	3.6	32.9	49.1	13.5	0.8	0.0	0.0	0.1
204	19.2	27.5	45.0	7.8	0.4	0.0	0.0	0.1
245	11.3	30.5	50.9	4.5	2.7	0.0	0.1	0.0
257	14.5	32.2	46.2	4.9	1.9	0.0	0.0	0.3
326	10.7	27.6	52.5	8.3	0.7	0.0	0.0	0.2

*Data for specimens 204, 245, 257, and 326 are averages of four thin sections each; other specimens are averages of two thin sections each.

ward to the Snake River. The abundance of gneissic granitic rocks in eastern Oregon in conglomerates[3] in Cenozoic formations west of Marsing (Fig. 1) suggests that the gneissic border zone is at least as wide as is shown in Figure 1. Gravity data (Bonini, 1963) are consistent with the general location of the inferred "contact" of the batholith throughout the 55-mi interval from east of South Mountain northward to the Snake River; the correlation seems best within 25 mi of South Mountain.

Mineralogical and structural features of the igneous masses near South Mountain confirm that the bodies are satellites of the Idaho batholith. Gneissoid quartz diorites characterized by discrete crystals of epidote occur as lens-shaped intrusions in schist along a ridge almost 1 mi west of the lookout tower on South Mountain. The small igneous bodies have a considerable range of color index, as shown by modal data (Table 8, nos. 259, 261, 264) for rocks from three intrusions. The large amount of epidote (average content 2.7 percent) in the three rocks is typical of many satellites of the batholith on the north side of the Snake River Plain. However, as most epidote in the granitic rocks west of the lookout is less than 0.5 mm across, the crystals are not as conspicuous as in the satellites of west-central Idaho.

The largest granitic intrusion in the vicinity of South Mountain is a zoned stock about 6 sq mi in outcrop area. This intrusion is north of the mountain. Four specimens (Table 8, nos. 265, 266, 267, 268) from within 0.35 mi of the contacts of the mass are quartz diorites, whereas two specimens (nos. 269, 270) from near the center of the pluton are granodiorites. All rocks carry hornblende, but they are structureless, unlike hornblende-bearing rocks of the border zone of the batholith.

Gabbroic complexes that occur as satellites of the batholith on the north side of the Snake River Plain have a counterpart near South Mountain that supports the conclusion that the contact of the batholith lies to the east. On the south and southeast sides of South Mountain, a gabbroic complex extends for 5 mi along an overlapping contact of Tertiary volcanic rocks. About 4 sq mi of the complex are exposed; dominant rocks apparently are hornblende gabbro, hornblende melagabbro, and coarse hornblendite. Hornblende-augite norite and amphibolitized inclusions of country rocks also are part of the complex. Locally, the gabbroic rocks are intruded by quartz diorite.

Data summarized in Figure 1 indicate that southwest structural trends in granitic rocks near the Snake River commence a swing to the southeast in an area about 25 mi due south of Marsing. Farther to the south, trends within the batholith in the most westerly rocks are about S. 20° E. for 28 mi, beyond which the batholith is concealed by Tertiary volcanic rocks. Granitic rocks are exposed for a total of only 10 mi along the 28-mi interval, but the general S. 20° E. trend suggests that a similar southeast trend characterizes the intervening parts of the batholith that are overlain by volcanic rocks. Furthermore, structural trends in the metamorphic rocks near South Mountain are also to the southeast; dips are to the southwest. Trends of schistose inclusions within the gabbroic complex, as well as local banding in the gabbroic rocks, are also to the southeast. Accordingly, structural trends in the pre-Tertiary wall rocks near South Mountain are similar to the southeast trends in the Idaho batholith to the east and northeast. The southeast trends within and outside of the batholith prevail throughout an area of sufficient size to conclude that a significant change in structural direction occurs in southwest Idaho in the region near South Mountain.

CONTACT OF BATHOLITH NEAR IDAHO-NEVADA BOUNDARY

The Idaho batholith cannot be traced southward from the exposures (Fig. 1) east of South Mountain by means of surface geology because of a widespread cover of Tertiary volcanic rocks. The nearest known pre-Tertiary rock to the south is a granodiorite (Fig. 1, loc. 1) that crops out for several miles along Cottonwood Creek near the headwaters of this stream. This granodiorite, surrounded areally by Tertiary volcanic rocks, is exposed on either side of the Idaho-Nevada state line. Paleozoic strata, intruded by small granitic plutons, occur from 3 to 10 mi south of the state line. The pre-Tertiary rocks in Nevada suggest that the granodiorite along Cottonwood Creek is either part of the border of the Idaho batholith or part of a satellitic stock of the batholith.

Structural and mineralogical features of the

[3] The conglomerates also contain nonfoliated clasts of the typical muscovite-bearing granodiorite (Table 7) of the interior of the batholith. The common occurrence of quartz-feldspathic gneisses in the conglomerates, as well as many clasts of gneissic granitic rocks, indicates that the source area includes a larger region near the border of the batholith than present exposures of pre-Tertiary rocks represent.

*Data for specimens 204, 245, 257, and 326 are averages of four thin sections each; other specimens are averages of two thin sections each.

TABLE 8. MODES OF ROCKS FROM SATELLITES SOUTH OF SNAKE RIVER*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio-clase	Biotite	Horn-blende	Epidote	Accessories Opaque	Accessories Nonopaque
259	0.2	8.9	36.2	19.3	29.6	4.2	0.1	1.5
261	0.0	14.7	62.4	15.9	3.7	2.7	0.1	0.5
264	0.1	32.0	57.9	8.0	0.0	1.3	0.1	0.6
265	2.1	18.2	61.5	11.2	6.8	0.0	0.0	0.2
266	4.9	22.3	54.7	13.2	4.8	0.0	0.0	0.1
267	6.7	18.9	55.4	12.1	6.7	0.0	0.1	0.1
268	4.6	20.4	57.1	10.8	6.9	0.0	0.1	0.1
269	13.5	25.5	49.8	8.7	2.3	0.0	0.0	0.2
270	10.8	24.2	56.5	7.3	0.7	0.0	0.0	0.5
315	11.4	28.4	47.1	10.1	0.0	1.9	0.1	1.0
316	12.8	27.5	49.1	8.0	0.7	1.1	0.1	0.7
317	9.2	26.4	48.8	10.4	1.5	2.5	0.2	1.0
307	7.5	26.5	50.7	9.0	4.8	0.4	0.3	0.8
308	11.6	25.4	50.6	6.8	4.3	0.3	0.3	0.7
310	11.0	26.4	51.5	6.0	3.4	0.8	0.2	0.7
311	9.1	23.4	54.3	7.5	4.1	0.3	0.3	1.0

*Each modal analysis is the average of three thin sections.

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granodiorite along Cottonwood Creek favor the interpretation that the granodiorite is part of a satellite of the batholith. Most granitic rocks along Cottonwood Creek are without planar structure. Absence of planar structure is atypical of border rocks of the batholith and suggests, instead, that the rocks are part of a satellite. The rather high percentage of potassium feldspar in three specimens (Table 8, nos. 315, 316, 317) also is not typical of border rocks of the batholith. Furthermore, megascopic crystals of epidote (average content 1.8 percent) are characteristic of satellites rather than border rocks of the batholith. Also, the three rocks contain about 0.1 percent of interstitial zeolites (Taubeneck, 1967, p. 17-19), which have been observed in Idaho only in rocks satellitic to the batholith.

South of the southernmost granodiorite along Cottonwood Creek, 4 to 5 mi, four specimens from the elongated Hicks Mountain stock (Coats and others, 1965) were collected for comparison with granitic rocks of Cottonwood Creek. The specimens (Table 8, nos. 307, 308, 310, 311) contain megascopic epidote (rather small crystals and not abundant) and about 0.1 percent of interstitial zeolites—minerals that commonly distinguish rocks of the satellites of the Idaho batholith.

A few hundred yards south of the drainage divide between Cottonwood Creek and Little Salmon Creek, thermally metamorphosed gabbroic rocks several miles north of the Hicks Mountain stock are overlain by Tertiary volcanic rocks. Together with cited features of the Hicks Mountain and Cottonwood Creek granodiorites, the presence of gabbroic rocks near the headwaters of Cottonwood Creek in northernmost Nevada can be used as an argument that the south contact of the Idaho batholith is not far to the north.

The east to east-northeast trends of Paleozoic rocks in the 15-min Mountain City and Rowland quadrangles of northernmost Nevada are compatible with the possibility that the south contact of the Idaho batholith is not far north of the Nevada-Idaho state line. Paleozoic strata are exposed almost continuously between locations 2 and 3, Figure 1. Over-all trends in the Mountain City quadrangle are nearly east-west (R. R. Coats, 1967, oral comm.) although farther east in the adjoining Rowland quadrangle, trends are east-northeast (Bushnell, 1967, Pl. 1). Where pre-Tertiary strata occur farther south in Nevada, the regional trend is north-northeast to northeast. Trends of country rocks generally are more or less concordant with contacts of bordering batholiths. Therefore, the anomalous deviation of the north-northeast regional trend of the pre-Tertiary rocks of northern Nevada to east-west in the Mountain City quadrangle and to east-northeast in the Rowland quadrangle may reflect the nearness of the south contact of the Idaho batholith.

EAST CONTACT OF BATHOLITH NEAR SNAKE RIVER PLAIN

The inferred location of the east contact (Fig. 1) of the batholith near the north side of the Snake River Plain is influenced by the character of poor exposures of granitic rocks that are surrounded near location 4 by Cenozoic formations (Malde and others, 1963). The granitic rock near location 4 is a porphyritic granodiorite or quartz monzonite of a type that characterizes the interior of the batholith. Therefore, the contact of the batholith is east of location 4. About 12 mi to the north-northeast of location 4, in an area partly covered by volcanic rocks, the contact of the batholith can be located to within a few miles. From this vicinity the contact is arbitrarily extended almost due south to pass about 6 mi east of location 4.

The location of the east contact of the batholith on the south side of the Snake River Plain involves by far the greatest uncertainty in the attempt (Fig. 1) to define the approximate boundaries of the southern part of the Idaho batholith. Two small areas of Ordovician sedimentary rocks (Youngquist and Haegele, 1956, p. 10-11; Crosthwaite, 1969, p. 10) about 18 mi south of Twin Falls (Fig. 1) imply by their unmetamorphosed condition that the nearest contact of any large batholith is many miles away. As other Paleozoic strata also surrounded by Cenozoic volcanic rocks occur within 12 mi to the southeast of the Ordovician sediments, the east contact of the Idaho batholith must be west of the Ordovician rocks. Exposures of the Ordovician strata are sufficiently good, especially in the larger area to the west, to assure that trends shown in Figure 1 are representative throughout an area of at least several square miles.. As a general parallelism between the trend of the Ordovician sediments and the contact of the batholith is a reasonable assumption, the postulated configuration of the batholith, as suggested in Figure 1, is consistent with the attitude of the Ordovician rocks.

SIERRA NEVADA BATHOLITH

Many comprehensive investigations during the past 20 yrs by members of the U.S. Geological Survey have made the Sierra Nevada batholith the best known Mesozoic batholith of the circum-Pacific belt. The most fundamental relationship from the standpoint of this paper is that the axis of the Sierra Nevada batholith does not parallel the Sierra Nevada Mountains, which trend north-northwest. The axis of the batholith trends northerly across the Sierra Nevada at an acute angle and continues northward into Nevada (Bateman and Wahrhaftig, 1966, p. 107).

Willden (1963, p. 6) reported that the Jackson Mountains of northwest Nevada "lie just east of what might be considered the east margin of the Sierra Nevada batholith." The presence of the batholith in northwest Nevada was established by chemical and radiometric studies of the granitic rocks in western Pershing County by Tatlock and Marvin (1967) of the U.S. Geological Survey and by reconnaissance mapping of Willden (1964) in Humboldt County. On a generalized geological map that showed the configuration of the Sierra Nevada batholith, Bateman and Eaton (1967, Fig. 1) extended the east border of the batholith as far north as the Nevada-Oregon state line. Moore (1969, Fig. 5) also extended the east limit of the batholith northward to the Nevada-Oregon boundary.

A recent analysis of radiometric age data for granitic rocks of California and western Nevada revealed that the Sierra Nevada batholith is composed of five belts of rock ranging in age from Middle and Late Triassic to Late Cretaceous (Evernden and Kistler, 1970). The belt of Middle and Late Triassic age, not well defined in the western United States, will be ignored in this discussion. The four remaining belts in the batholith are combined into a Jurassic belt and a Cretaceous belt, to permit summary statements of age relationships of granitic rocks in areas to the north of the central Sierra Nevada. The Cretaceous belt of granitic rocks in the batholith extends northward across the Sierra Nevada and into Nevada. The Jurassic belt of granitic rocks diverges north-northwest from the Yosemite region of the batholith and extends into the Klamath Mountains of northern California and southwest Oregon (Lanphere and others, 1968). Traditionally, the belt of Jurassic plutons has dominated concepts regarding the location and trend of the major zone of Mesozoic granitic rocks in the western United States. In any modern synthesis of the Mesozoic evolution of western North America, however, the northward divergence (Kistler, 1970, p. 597) of the Jurassic and Cretaceous belts of granitic rocks from the general region of Yosemite National Park must be evaluated.

SIERRA NEVADA BATHOLITH IN HUMBOLDT COUNTY, NORTHWEST NEVADA

Knowledge of the granitic rocks of western Humboldt County in northernmost Nevada is desirable as background for any attempt to evaluate the possibility of a connection between the Idaho and Sierra Nevada batholiths. Accordingly, reconnaissance studies were made of the plutonic rocks in Humboldt County that are within 45 mi of the Nevada-Oregon boundary.

The approximate location of the east border of the Sierra Nevada batholith[4] in northwest Humboldt County is shown by the dashed line in Figure 3. This line represents the east margin of a belt in which granitic rock is more abundant than stratified rock in scattered areas of pre-Tertiary terrane. Widespread Tertiary volcanic rocks and Quaternary alluvium necessitate that the dashed line be a generalized line with a possible error of as much as 5 mi. The west margin of the batholith cannot be delineated with assurance because Cenozoic formations extend continuously for scores of miles to the west of the granitic plutons (Fig. 3). However, Denio may be near the west border because only a few small granitic intrusions occur in the pre-Tertiary rocks to the west and north of this small community (Fig. 3). Low grade metamorphism of greenschist facies in the pre-Tertiary rocks to the west and north of Denio

[4] The belt of granitic rocks that extends from Baja California on the south, northward through the Sierra Nevada, and into western and northwest Nevada customarily is subdivided into individual batholiths, but "a single name, such as Cordilleran batholith, could be applied" (Bateman and others, 1963, p. 2) to these plutonic rocks. Sierra Nevada batholith, however, is the name used in this paper for the belt of granitic rocks in western and northwest Nevada, as well as for the granitic rocks of the High Sierra in California.

The granitic rocks of northwest Humboldt County might be subdivided into several batholiths in a detailed petrologic investigation because continuity is uncertain (Fig. 3). Rather than introduce one or more new names for the mass or masses of granitic rocks, Sierra Nevada batholith is used for convenience, but the writer emphasizes that the major zone of granitic rocks in Humboldt County could be a discontinuous belt of small batholiths.

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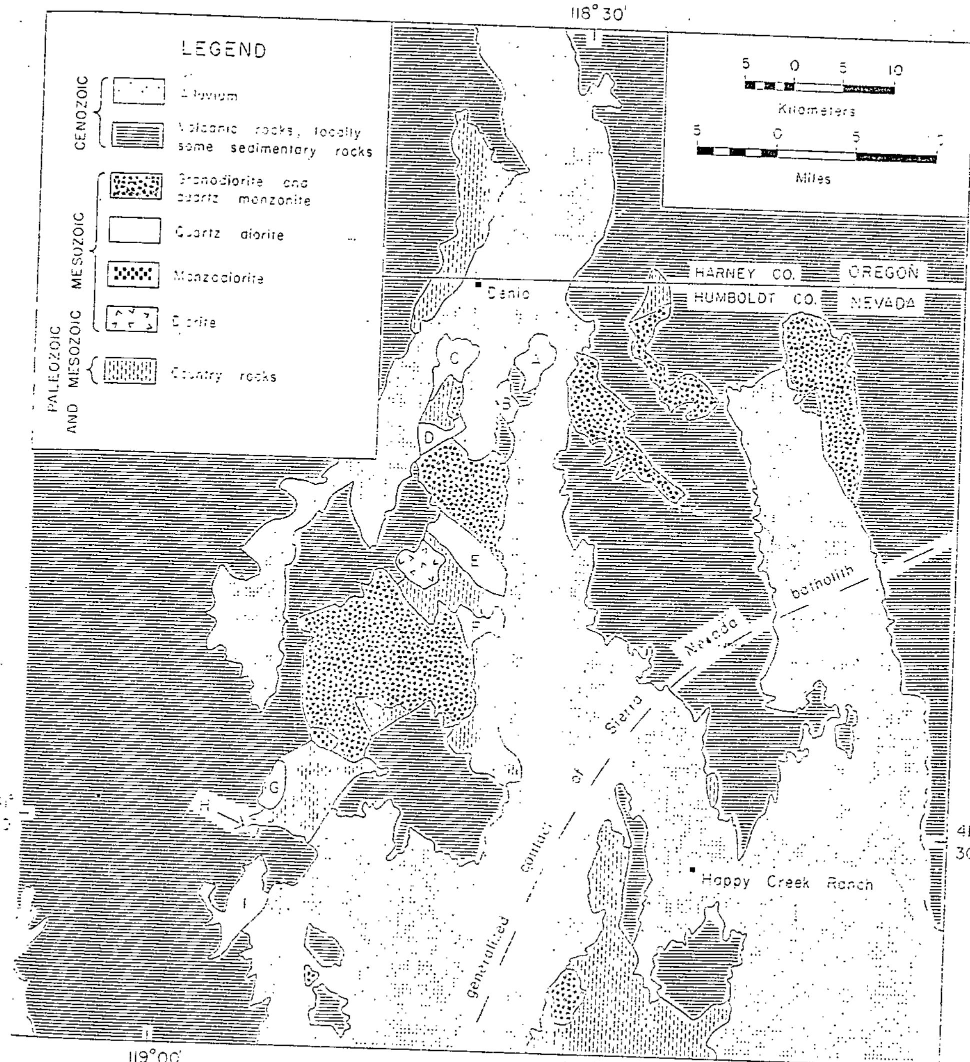

Figure 3. Semireconnaissance map showing generalized subdivisions of batholithic rocks of northern Humboldt County, Nevada. Map is modified slightly from Willden (1964) and from Walker and Repenning (1965). Capital letters indicate plutons dominantly of quartz diorite.

suggests that the rocks are not part of a large screen or roof pendant of a batholith which includes concealed granitic rocks a few miles to the west. Therefore, the pre-Tertiary rocks near Denio probably are a short distance west of the border of the Sierra Nevada batholith. Satellitic plutons may lie beneath the Cenozoic volcanic formations for scores of miles to the west, as granitic clasts partly verify, which occur in a conglomerate near the base of the Warner Mountain fault block about 9 mi west of the California-Nevada boundary.

Plutons with mesozonal attributes in northern Humboldt County imply that the dashed line (Fig. 3) representing the east border of the batholith cannot be invalidated by the possibility that inadequate erosion has exposed only the upper part of a much larger batholith that underlies country rocks to the east. The gneissic to gneissoid texture of most of the quartz diorite, as well as some granodiorite, characterizes mesozonal and catazonal plutons, rather than plutons of the epizone (Buddington, 1959). The regional metamorphism of the greenschist facies (Willden, 1963, p. 17), however, is indicative of the mesozone rather than the catazone (Buddington, 1959, p. 714). Moreover, the schistose structure in country rocks bordering the plutons and the absence of granophyre confirm a mesozonal classification for the plutons. Mesozonal plutons provide an adequate depth of erosion to permit an accurate assessment of the approximate location of the east border of the batholith.

In comparing Figure 3 with the reconnaissance map of Humboldt County by Willden (1964), students of Nevada geology will note minor differences. For example, granitic rocks are not shown in Figure 3 in the Pueblo Mountains to the west and southwest of Denio because only two small intrusions were observed in traverses across the pre-Tertiary part of this range. Another difference in the maps is that Figure 3 omits a dioritic pluton in the pre-Tertiary rocks west of the Happy Creek Ranch. This pluton, unlike the diorite and monzodiorite plutons shown in Figure 3, was subjected to the greenschist-facies regional metamorphism (Willden, 1963, p. 16) that preceded emplacement of the batholithic rocks.

In the barren mountain ranges of northwest Humboldt County, distinct color differences in the plutonic rocks as seen from a distance of many miles permit a rough subdivision between dark-colored bodies on the west that include much quartz diorite, as opposed to leucocratic intrusions on the east that are composed of granodiorite and quartz monzonite. Because few contacts were walked, detailed field studies will necessitate changes in the configuration of most bodies shown in Figure 3. Moreover, as at least some of the intrusions are composite, a subsequent subdivision of several bodies will be possible. Enough samples were collected, however, to confirm the abundance of quartz diorite in the designated plutons. Except for pluton B (Fig. 3), modal analyses of rocks from intrusions that are dominantly of quartz diorite are given in Table 9. Additional samples from pluton E may disclose that granodiorite comprises part of this body, as suggested by specimen 41. Diorite and gabbroic rocks are associated with some masses of quartz diorite, as in pluton C. The diorite body west of pluton E, as judged by thin sections from four samples, contains an estimated 1 to 6 percent of quartz and from 0 to 4 percent of potassium feldspar. Several dioritic rocks from pluton C are of similar composition. Thin sections of four specimens from the monzodiorite northeast of pluton G contain an estimated 2 to 9 percent of quartz and from 6 to 12 percent of potassium feldspar.

The distribution and composition of the plutonic rocks of northwest Humboldt County suggest that the quartz diorite boundary line of Moore (1959) may trend northeast to Denio, although Moore (1959, p. 199) placed this boundary about 160 mi west of Denio. Location of the line in this part of the United States is uncertain because of widespread Cenozoic formations in northeast California, northwest Nevada, and southern Oregon. Moreover, modal data for granitic rocks in northwest Nevada were not available in 1959. Ralph J. Roberts has informally suggested in recent years that the quartz diorite boundary line is near Denio, approximately parallel with boundaries (Roberts, 1966, Fig. 3) farther east for facies belts in the Cordilleran geosyncline. Modal data in Table 9 strengthen the suggestion of Roberts that the quartz diorite boundary line is near Denio.

A relocation of the quartz diorite boundary line is supported by the occurrence of boulders (as much as 5 ft across) of quartz diorite among the plutonic and metamorphic clasts in a conglomerate in the Warner Mountains, about 90 mi west-southwest of Denio. Clasts in the conglomerate provide the only indication of the character of the pre-Tertiary basement throughout an area of more than 10,000 sq mi. Additional justification for a relocation of the quartz diorite boundary line is the occurrence of boulders of quartz diorite and epidote-bearing trondhjemitic rocks (closely akin to the trondhjemite of west-central Idaho) in a basal conglomerate of Cenozoic age about 5 mi north of Denio. If the boundary line is moved about 160 mi eastward to Denio, the line should trend northeast through southeast Oregon to the vicinity of South Mountain before swinging north-northeast along the western margin of the Idaho batholith. Southwest of Denio a relocated line apparently should trend about S. 45° W. to the northernmost part of the Sierra Nevada Mountains, where Diller (1908, p. 89) reported that granitic rocks in the Taylorsville region are "generally quartz diorite, but locally the orthoclase may increase and the rock passes into granodiorite." If modern petrographic studies confirm a large proportion of quartz diorite among the granitic rocks in the Taylorsville region, the boundary line in northern California and southern Oregon should be moved

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The probability that the quartz diorite boundary line is near Denio is another factor that favors the supposition that Denio approximately marks the west border of the batholith. The quartz diorite boundary line in east-central California is in the west margin of the Sierra Nevada batholith, and the line in west-central Idaho is in the west part of the Idaho batholith (Moore, 1959, p. 199). Accordingly, it can be argued by analogy that the location of the line in northwest Nevada coincides with the west border of the batholith in Nevada. If so, the batholith in northwest Humboldt County is only about 40 percent as wide as in the central Sierra Nevada Mountains. A much narrower batholith in northwest Nevada is reasonable because the batholith does not include the large plutonic belt of Jurassic age that contributes to its mass in the region of Yosemite National Park.

It does not follow from the northward divergence (Kistler, 1970, p. 597) of the Jurassic and Cretaceous plutonic belts from the central Sierra Nevada that all granitic rocks in western Humboldt County are of Cretaceous age. Randomly distributed plutons of Jurassic age are present east of the batholith in north-central Nevada (McKee and Silberman, 1970, p. 613), and they also may occur in western Humboldt County as small intrusive units that are early in the emplacement sequence. Moreover, pre-Cretaceous granitic rocks definitely occur in the region as is demonstrated by clasts of metamorphosed granodiorite and quartz monzonite in a basal Cenozoic conglomerate about 5 mi north of Denio, by small bodies of regionally metamorphosed granitic rocks in the southern Pueblo Mountains near Denio, and by restricted exposures of metamorphosed granodiorite and quartz monzonite about 55 mi south-southwest of Denio. The metamorphosed granitic rocks are characterized by finely disseminated grains of epidote. Small flakes of recrystallized biotite are common, and some rocks are highly fractured. Perhaps the metamorphosed granitic rocks belong to the Lee Vining (Evernden and Kistler, 1970, p. 19) intrusive sequence of Middle and Late Triassic age. Regardless of the age or ages of the metamorphosed granitic rocks, their restricted distribution is in harmony with the conclusion that the Cretaceous plutonic belt dominates the Sierra Nevada batholith in northwest Nevada.

POSSIBLE CONNECTION BETWEEN IDAHO AND SIERRA NEVADA BATHOLITHS

Many earth scientists during the last quarter century speculated on the continuity of Mesozoic granitic rocks between the Idaho batholith in central Idaho and the Sierra Nevada batholith in the High Sierra of California. If the batholiths are connected, granitic rocks of the connecting link must occur beneath the Cenozoic volcanic rocks of southeast Oregon, southwest Idaho, and northernmost Nevada.

Structural data (Fig. 1) from exposures of pre-Tertiary rocks in southwest Idaho weaken the possibility of a connection between the Idaho and Sierra Nevada batholiths. If the batholiths are connected, the Idaho batholith southeast of South Mountain must veer sharply west beneath the Cenozoic volcanic formations and reach the Idaho-Nevada boundary between long 116° and long 117° (Fig. 4). Between long 117°30′ and long 117°45′, however, Mesozoic metasedimentary rocks in the Santa Rosa Range (Compton, 1960) extend northward to within 15 mi of the Nevada-Oregon boundary (Willden, 1964). Accordingly, if the two batholiths are connected, granitic rocks of the connecting link must be confined to a relatively narrow belt (Fig. 4) that extends east-northeast for about 75 mi near lat 42° N.

The distribution of granitic rocks in northern Humboldt County indicates that the Sierra Nevada batholith does swing eastward near lat 42° N. As shown by Moore (1969, Fig. 5), the east contact of the batholith swings through an arc of about 40° (Fig. 3) before it is covered by Tertiary volcanic rocks.

Structural trends in gneissic and schistose country rocks about 11 mi east of Denio are consonant with an eastward swing in the axis of the batholith near the Nevada-Oregon boundary. The highly metamorphosed rocks are exposed in an area of slightly more than 2 sq mi (Fig. 3) on the north side of a pluton of granodiorite. The intricate contact has a general trend of about N. 60° E. (Fig. 3). Trends in the country rocks vary within a range of N. 20° E. to S. 75° E.; the average of 27 determinations is N. 59° E. The average trend is much more easterly than the over-all trend of the Sierra Nevada batholith in Nevada. Exposures are inadequate to determine whether the intensely metamorphosed country rocks east of Denio are along the northern border of the batholith or are part of a screen between two

TABLE 9. MODES OF ROCKS FROM THE SIERRA NEVADA BATHOLITH IN NORTHWESTERN NEVADA*

(in volume percent)

Specimen number	Potassium feldspar	Quartz	Plagio-clase	Horn-blende	Biotite	Augite	Accessories Opaque	Accessories Nonopaque
Pluton A								
17	4.6	18.4	54.9	6.4	15.2	0.0	0.1	0.4
19	4.7	10.7	56.0	12.1	15.3	0.0	0.4	0.8
40	0.9	9.3	51.7	19.4	16.2	0.2	0.1	2.2
101	0.0	0.7	58.3	23.3	16.8	0.0	0.1	0.8
Pluton C								
20	10.6	11.6	49.7	11.1	15.8	0.1	0.3	0.8
21	3.2	8.7	54.0	19.9	11.2	0.2	1.1	1.7
84	6.8	12.3	56.1	13.8	10.0	0.0	0.3	0.7
85	1.4	8.6	53.5	19.4	15.4	0.6	0.2	0.9
86	4.3	10.6	58.9	9.3	14.9	0.0	0.4	1.6
Pluton D								
79	8.1	9.4	52.3	14.6	12.9	1.7	0.5	0.5
80	4.3	10.2	53.2	16.3	14.8	0.4	0.4	0.4
81	3.5	10.1	55.6	16.5	12.9	0.0	0.3	1.1
82	1.1	9.9	63.3	9.5	14.9	0.2	0.6	0.5
83	3.4	10.1	55.1	18.2	9.0	0.7	0.2	3.3
Pluton E								
41	9.2	17.9	54.2	6.3	10.7	0.0	1.0	0.7
42	4.8	9.6	56.5	12.5	14.6	0.1	0.6	1.3
88	0.0	2.1	60.0	24.9	11.6	0.0	0.5	0.9
89	6.3	12.8	58.8	10.8	9.6	0.0	0.8	0.9
90	6.7	15.7	55.8	11.7	8.4	0.0	0.5	1.2
91	3.8	15.0	58.3	12.5	7.7	0.0	0.7	2.0
92	3.4	13.4	57.0	13.0	11.7	0.0	0.7	0.8
Pluton F								
78	0.0	12.6	52.6	23.9	8.8	0.0	1.5	0.6
93	0.0	13.8	47.7	26.3	9.9	0.0	1.4	0.9
94	0.0	15.9	59.3	12.0	11.1	0.1	0.9	0.7
95	0.0	15.1	52.0	23.3	9.4	0.0	0.1	0.1
102	0.0	13.6	52.3	24.4	8.5	0.0	1.2	0.0
[illegible]	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Pluton E								
41	9.2	17.9	54.2	6.3	10.7	0.0	1.0	0.7
42	4.8	9.6	56.5	12.5	14.6	0.1	0.6	1.3
88	0.0	2.1	60.0	24.9	11.6	0.0	0.5	0.9
89	6.3	12.8	58.8	10.8	9.6	0.0	0.8	0.9
90	6.7	15.7	55.8	11.7	8.4	0.0	0.5	1.2
91	3.8	15.0	58.3	12.5	7.7	0.0	0.7	2.0
92	3.4	13.4	57.0	13.0	11.7	0.0	0.7	0.8
Pluton F								
78	0.0	12.6	52.6	23.9	8.8	0.0	1.5	0.6
93	0.0	13.8	47.7	26.3	9.9	0.0	1.4	0.9
94	0.0	15.9	59.3	12.0	11.1	0.1	0.9	0.7
95	0.0	15.1	52.0	23.3	9.4	0.0	0.1	0.1
102	0.0	13.6	52.3	24.4	8.5	0.0	1.2	0.0
103	0.0	19.2	54.0	15.2	10.6	0.0	0.8	0.2
104	0.0	20.1	52.8	14.7	9.9	0.0	0.6	1.9
105	0.0	13.4	58.9	22.4	4.0	0.0	1.0	0.3
106	0.0	24.0	52.5	9.1	12.5	0.0	0.8	1.1
107	0.0	12.5	55.8	19.9	10.0	0.0	1.0	0.8
Pluton G								
72	5.6	12.1	63.1	10.7	6.5	0.0	0.8	1.2
73	6.0	15.7	60.9	8.9	6.8	0.0	0.9	0.8
74	4.0	14.2	63.6	7.8	8.7	0.0	1.0	0.7
Pluton H								
69	6.2	8.5	56.2	8.9	15.1	3.8	1.0	0.3
70	5.5	11.4	56.0	4.0	16.5	5.4	0.7	0.5
71	6.6	11.3	50.0	14.3	15.8	1.2	0.5	0.3
Pluton I								
63	4.0	10.2	52.1	14.8	15.9	2.0	0.4	0.6
64	7.6	13.6	51.7	14.6	11.9	0.3	0.1	0.2
66	3.7	14.5	53.8	14.2	12.5	0.6	0.4	0.3
68	7.4	12.8	58.3	8.7	11.3	0.1	0.4	1.0
97	3.5	11.3	55.2	15.7	12.2	0.5	0.8	0.8
98	6.0	16.9	51.5	6.2	15.3	3.3	0.6	0.2
99	4.7	9.5	54.0	11.2	15.6	3.4	1.1	0.5
100	4.0	11.3	56.0	13.7	13.1	0.8	0.6	0.5

*Each modal analysis is the average of two thin sections.

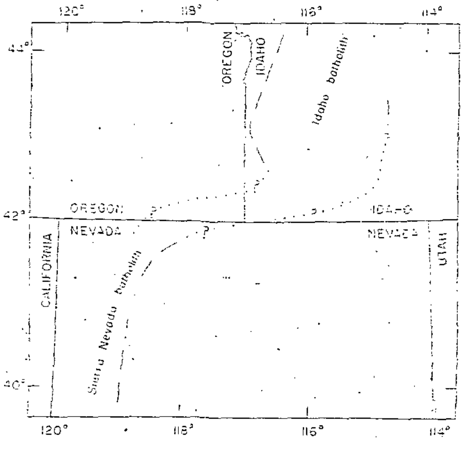

Figure 4. Map showing possible connection between the Sierra Nevada batholith and the Idaho batholith.

plutons. Either possibility is consistent with an eastward swing of the batholith because screens commonly strike parallel to the axis of a batholith. The country rocks probably are part of a screen, as suggested by the intense metamorphism and by the geometry (Fig. 3) of the plutons near the Oregon-Nevada boundary.

Structural trends in the large area of pre-Tertiary rocks west and north of Denio are compatible with an eastward swing of the batholith, although more easterly trends in the rocks would provide stronger confirmation of a change in direction of the batholith. The average trend of pre-Tertiary rocks west and southwest of Denio is N. 42° E., as judged by observations at 14 localities in an area of 3 sq mi. Massive volcanic rocks north of Denio in the northern part of the region of pre-Tertiary rocks (Fig. 3) provided little evidence of structural trends during two traverses across the area. However, isolated exposures of pre-Tertiary rocks that are not shown in Figure 3, about 13 mi north of Denio, include a nearly vertical greenstone that trends about N. 40° E.

In summary, relations in northernmost Nevada indicate that the Sierra Nevada batholith may extend eastward near lat 42° N. to connect with the Idaho batholith in the manner suggested in Figure 4. This possibility is favored by the virtual continuity of the Cretaceous plutonic belt, wherever pre-Tertiary rocks are exposed, northward from the central Sierra Nevada Mountains to the Oregon-Nevada boundary. Logic suggests that the belt of granitic rocks does not terminate beneath the Cenozoic volcanic formations east-northeast of Denio, although continuity in the strict sense may not persist for each mile of the concealed interval between the two batholiths.

POST-OLIGOCENE DISPLACEMENT OF IDAHO AND SIERRA NEVADA BATHOLITHS

The Idaho and Sierra Nevada batholiths were more nearly in a north-south alignment before post-Oligocene deformation in the Basin and Range structural province produced an estimated east-west change of as much as 50 mi in the relative position of the two batholiths. A positional change of such a magnitude is consistent with the combined displacements from normal faulting, dike intrusion, and right-lateral faulting, which are features of the Basin and Range structural province.

Interpretations of the Cenozoic evolution of the western United States in terms of plate tectonics must emphasize the tectonic significance of the intersection of the North America plate with the crest of the East Pacific Rise in late Oligocene time. Annihilation of the easternmost sector of the rise with concomitant initiation of the northern portion of the San Andreas fault system is closely related to collision of the North American and Pacific plates (Atwater and Menard, 1970, p. 449). Extensional Basin and Range faulting throughout much of the western United States commonly is regarded as a consequence of the subsequent interaction of the two plates.

Extension in the Basin and Range structural province must be a major factor in the east-west change in alignment of the Idaho and Sierra Nevada batholiths. Available radiometric ages of dikes in the western United States suggest an age of about 25 m.y. for the inception of important normal faulting of the Basin and Range structural province (Taubeneck, 1970, p. 88). Accordingly, Basin and Range extension is classified as post-Oligocene. The close agreement is noteworthy between the 27 m.y. date (Atwater and Menard, 1970, p. 449) when the North American continent impinged on the crest of the East Pacific Rise and the beginning of Basin and Range faulting as determined by radiometric ages of dikes.

The Sierra Nevada batholith in the vicinity, about lat 36°45′ N., of Fresno, California, is west of the Basin and Range structural province; the Idaho batholith is mostly east of the normal faults of the structural province. Regional relationships can be visualized from a

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map of Basin and Range faults (Gilluly, 1963, p. 158). In addition to faults shown by Gilluly, the writer includes (*see also* Schmidt and Mackin, 1970, p. 4) within the structural province the north-south faults of western Idaho (Anderson, 1934b, p. 23-26). Many of the larger faults, mostly near the west side of the Idaho batholith, were shown on a sketch map by Hamilton (1962, p. 512). The major fault apparently has at least 9000 ft of displacement as judged from gravity interpretations of valley fill in the Long Valley graben (Kinoshita, 1962, p. 6). Farther south, on the southwest side of the Snake River Plain, a detailed map by Kittleman and others (1967) shows the abundance of north-south normal faults near the Idaho-Oregon state line.

The effect of Basin and Range faulting on the position of the Sierra Nevada and Idaho batholiths is readily seen from a map[5] by Gilluly (1970, p. 61) that shows the percentage of distention across the width of the structural province. If an extension of 50 mi is assumed across northern Utah, northern Nevada, and northeast California, the distribution of faults in the structural province implies roughly 30 mi of post-Oligocene east-west change in the relative position of the Sierra Nevada and Idaho batholiths.

Part of the east-west flexure near lat 42° N. in the possible connection (Fig. 4) between the Idaho and Sierra Nevada batholiths can be explained by differential extension on either side of the Idaho-Nevada state line. The rather abrupt change in fault density (Gilluly, 1963, p. 158) in passing northward from northern Nevada into southern Idaho would accentuate an original flexure in the belt of plutonic rocks.

Post-Oligocene dikes and dike swarms of the Basin and Range structural province (Taubeneck, 1969) also have contributed to the change in position of the Idaho and Sierra Nevada batholiths, but the magnitude of the change is uncertain, partly because many of the dikes are so poorly exposed that they commonly escape detection (Taubeneck, 1970, p. 74, 78). Basaltic dikes that cut pre-Tertiary rocks generally are characterized by negative relief; the dikes are not easily seen unless bedrock is well exposed. Even in Tertiary volcanic rocks, in contrast to textbook concepts and mental images, many dikes do not exhibit positive relief. For example, most dikes of a basaltic swarm near Lakeview, Oregon, not far from the northwest corner of Nevada, would remain unknown without roadcuts. A 75-ft-wide dike in Warner Canyon, exposed only in a roadcut along highway 140, is an excellent example of a large dike that would not be noticed without man-made excavations. The writer has found at least some dikes in nearly every mountain range in southeast Oregon, western Idaho, and northern Nevada. Published and unpublished data of many workers indicate that dikes occur in most parts of the Basin and Range structural province. Although dike swarms occur north of the Snake River Plain in the Idaho batholith, they apparently are absent in that portion of the Basin and Range province that is east of the batholith. Considering the distribution of dikes of all compositions, rhyolitic as well as basaltic, dike intrusion in the structural province probably produced from 3 to 5 mi of east-west change in the over-all position of the Sierra Nevada and Idaho batholiths.

Westward displacement of much of the Sierra Nevada batholith (mostly the part in California) during right-lateral faulting in the western Great Basin also is a factor that must be evaluated in reconstructing the late Oligocene position of the two batholiths. Major northwest-trending structural zones that require consideration are the Las Vegas-Walker Lane and Death Valley-Furnace Creek systems. Data summarized by Stewart and others (1968, p. 1411) indicate about 30 to 35 mi of right-lateral displacement (rotational drag as well as fault slip) along the Las Vegas shear zone. Bending and faulting along the Las Vegas shear zone are post-Oligocene according to Fleck (1970, p. 333). Nielsen (1965, p. 1305) reported about 12 mi of aggregate right-lateral displacement in the Soda Springs region of the Walker Lane, some 240 mi northwest of Las Vegas. Lateral faulting in the Soda Springs region probably began after middle Miocene time (Nielsen, 1965, p. 1305, 1306). Estimates of the amount of right-lateral displacement along the Death Valley-Furnace Creek fault system vary from 50 mi (Stewart, 1967, p. 133) to between 10 and 20 mi (Wright and Troxel, 1970, p. 2173) to even less in the southern

[5]The map was compiled from the tectonic map of the United States by considering each 10-mi-long normal fault segment. As pointed out by Gilluly (1970, p. 59-60), no consideration was given to fault segments shorter than 10 mi, nor does the map provide for the many miles of normal faults concealed beneath the alluvium of the intermontane basins. Accordingly, actual distention is greater than indicated by the map.

Death Valley region (Wright and Troxel, 1967, p. 947). McKee (1968, p. 512) suggested 30 mi of right-lateral displacement along the northern part of the Death Valley-Furnace Creek fault zone. Faults along the Death Valley-Furnace Creek zone have been active in late Tertiary and Holocene time, but present evidence does not warrant a conclusion that all strike-slip displacement is post-Oligocene. Appraisal of data for right-lateral faulting in the western Great Basin, primarily along the Las Vegas-Walker Lane and Death Valley-Furnace Creek systems, permits a tentative suggestion of as much as 10 to 15 mi of post-Oligocene east-west change in the relative position of the Sierra Nevada and Idaho batholiths.

The possibility that sigmoidal bending in western Nevada and eastern California is responsible for about 100 mi of horizontal displacement (Albers, 1967, Fig. 4) must be considered in any attempt to determine the original relative position of the two batholiths. Between lats 37° N. and 39° N., some 40 to 185 mi south-southeast of Reno, a generalized map by Albers (1967, Fig. 4) suggests that sigmoidal bending has displaced Paleozoic and Mesozoic rocks about 100 mi westward. Although Albers (1967, p. 151) concluded that most of the postulated sigmoidal bending occurred before Miocene time, the effect of a horizontal displacement of as much as 100 mi on the position of the Sierra Nevada batholith justifies consideration regardless of whether or not most of the suggested displacement is pre-Miocene.

The east border (Moore, 1969, Fig. 5) of the Sierra Nevada batholith between lats 37° N. and 39° N. trends without deviation through the west-central part of the area of suggested sigmoidal bending. The border of the batholith as shown by Moore (1969, Fig. 5) is a generalized boundary, rather than a contact, between mostly granitic rock on the west and country rock on the east, but the state maps of Nevada and California indicate that the border of the batholith between lats 37° N. and 39° N. can be drawn with an accuracy of about 5 mi. The absence of distortion along the east border of the batholith suggests that post-batholith oroclinal bending has not occurred. This conclusion is strengthened by the N. 10° W. alignment (Evernden and Kistler, 1970, Pl. 1) of the eastern margin of the Lee Vining intrusive sequence. Rocks of this sequence occur in eastern California and western Nevada in a belt about 115 mi long between lats 37°12′ N. and 38°52′ N. Geochronologic data indicate that the Lee Vining intrusive epoch is of Middle to Late Triassic age. The trend of N. 10° W. of the east margin of the Lee Vining rocks is in the same region where 100 mi of bending involving Jurassic formations (Albers, 1967, p. 151) is postulated. Accordingly, westward displacement of the Sierra Nevada batholith by sigmoidal bending between lats 37° N. and 39° N. is not substantiated by the distribution of granitic rocks in the eastern part of the batholith.

In conclusion, an appreciable change in the relative position of the Idaho and Sierra Nevada batholiths has occurred since Oligocene time. If the suggested magnitudes of displacement from normal faulting, dike intrusion, and right-lateral faulting are approximately correct, an east-west change of as much as 50 mi in the alignment of the batholiths has occurred since the North American continent intersected the easternmost sector of the crest of the East Pacific Rise.

CHARACTER OF EARTH'S CRUST IN SOUTHWEST IDAHO

Hamilton and Myers (1966, p. 539) cited interpretations of seismic refraction data in an abstract by Hill and Pakiser (1963, p. 890) as justification for the conclusion that "low-velocity ('granitic') continental crust is probably wholly lacking beneath at least the western part" of the Snake River Plain, "which has a thick but high-velocity ('basaltic') crust." The seismic data are for a north-south profile that extends approximately from Boise, Idaho, through Mountain City (Fig. 1), Nevada, to Eureka, Nevada. Along the line of the seismic profile, the Snake River Plain is considered by Hamilton and Myers (1966, Fig. 1) and by Hill and Pakiser (1967, p. 686) to extend southward into northernmost Nevada. These workers include a much larger area within the plain[6] than is shown in Figure 1.

[6] Physiographers (for example, Fenneman, 1931; Freeman and others, 1945; Hunt, 1967) commonly have differed by more than 35 mi regarding the location of the southern edge of the Snake River Plain, mostly because the region southwest and west-southwest of Twin Falls has no well-defined topographic boundaries. Fenneman and Johnson (1946) included much of southern Idaho and all of southwest Idaho within their Columbia Plateau province—an unfortunate decision that influenced some workers to include most, or all, of southwest Idaho in a western Snake River Plain subprovince of the Columbia Plateau. As pointed out by Malde (1965, p. 255), the Snake River Plain is not an appendage

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The preferred model of Hill and Pakiser (1967, p. 697) for crustal structure along the Idaho part of the seismic profile includes a 5.2-kps layer about 10 km thick above a 6.7-kps layer about 40 km thick. The model includes no granitic layer (6.0 kps) in Idaho; the granitic layer in Nevada pinches out northward near the Nevada-Idaho border. Hill and Pakiser (1967, p. 701) did note, however, that "It is not clear from the seismic refraction data if a 6.0 km/sec layer exists between the intermediate layer and the 5.2 km/sec layer under the Snake River Plain." Significantly, Pakiser (1968, written commun.) stated that the 5.2 kps layer in southwest Idaho and the uppermost part of the underlying intermediate (6.7 kps) layer *might* be granitic, making it permissible to extend the granitic layer under the Snake River Plain.

Surface geology in Idaho indicates that a granitic layer is present along at least part of the seismic profile. The Boise shot point (Fig. 1, loc. 5) was in the batholith at Lucky Peak Reservoir (Hill and Pakiser, 1967, p. 686). The batholith extends south from the shot point for about 2 mi (Lindgren, 1898) before the granitic rocks disappear beneath Cenozoic deposits. Poor exposures of the batholith occur at location 6 (Fig. 1), about 4 mi south-southeast of the shot point. Where granitic rocks crop out along and near the profile, as in the vicinity of the Boise shot point, the exclusion of a granitic layer from the crustal profile seems unrealistic. Mineralogical and structural features in the granitic rocks south and southeast of the shot point are consistent with the interpretation that the rocks continue southward beneath the Snake River Plain. Furthermore, as geophysical data (Hill, 1963, p. 5808) do not support the possibility of a "pull-apart" for about 18 mi south of the shot point, the granitic rocks south and southeast of the shot point can be inferred to continue southward beneath the plain for at least as far as the northern edge of a large gravity high which could coincide with a postulated "pull-apart."[7]

South of the Boise shot point, 104 mi, granitic rocks near location 1 (Fig. 1) in southernmost Idaho are several miles east of the line of the seismic profile. Available geological and geophysical data include no compelling evidence for eliminating a granitic layer from the seismic profile for at least 68 mi north of location 1. Farther north, the seismic profile crosses the central part of a prominent gravity high about 20 mi wide (Hill, 1963, p. 5808). The preferred model of Hill and others (1961, p. 250) for explaining the gravity high is a tabular body of basalt about 90 mi long, from 4 to 6 mi in width, and extending from about 5000 ft to 60,000 ft below sea level. According to this interpretation, a 4 to 6 mi "pull-apart" of the granitic layer would occur along the seismic profile in the vicinity of the gravity high.

Exposures of granitic rocks to the west of the seismic profile prove that a granitic layer roughly parallels the profile for at least 35 mi. Granitic rocks at location 7 (Fig. 1) are within 14 mi of the profile. Gravity data (Bonini, 1963; Hill, 1963) east and southeast of location 7 impose no restrictions on extending the granitic rocks eastward beneath the Cenozoic formations to the line of the seismic profile.

In summary, gravity and seismic data considered in terms of surface geology and the distribution of granitic rocks are consistent with the

of the Columbia Plateau. Descriptions by Malde and Powers (1962, p. 1200) and by Malde (1965, p. 255) suggest that these geologists visualize the western Snake River Plain more or less as shown in Figure 1. The Owyhee Mountains, south of Marsing (Fig. 1), form a natural boundary for the plain near the Idaho-Oregon line. Along the northern edge of the Snake River Plain, most workers agree on the boundary except in the area that is east of Mountain Home (Fig. 1). In areas on either side of the Snake River where topography provides no unequivocal border for the plain, I selected boundaries (Fig. 1) that exclude pre-Tertiary rocks from the plain.

[7]The Snake River Plain is interpreted by Hamilton and Myers (1966, p. 535, 540) as a "lava-filled tensional rift formed in the lee of the northwestward drifting plate of the Idaho batholith" which supposedly is bounded on the north by the Osburn fault system. The batholith is visualized as drifting northwest accompanied by Basin and Range faulting on the east (Hamilton and Myers, 1966, p. 535). Tension was oblique in the northwest-trending western half of the Snake River Plain and direct in the northeast-trending half of the plain (Hamilton and Myers, 1966, p. 540). If so, a "pull-apart" more logically would occur in the eastern part of the plain rather than in the western part. The three *en echelon* gravity highs, however, are confined to the western half of the plain where strike-slip faulting is postulated (Hamilton and Myers, 1966, p. 540) rather than extensional thinning and normal faulting. In addition to the anomalous location of the gravity highs, the Hamilton and Myers (1966) model is weakened by the failure of geologists to recognize strike-slip displacement along the faults of the western Snake River Plain and, on the north, by lack of evidence for post-Miocene strike-slip displacement along the St. Joe fault (R. R. Reid, 1968, oral commun.), the Osburn fault (Hobbs and others, 1965, p. 128), and the Hope fault (King and others, 1970, p. 4).

interpretation that models of crustal structure should show a layer of low-velocity ("granitic") continental crust underlying most of the western Snake River Plain and nearly all of southwest Idaho. This conclusion is strengthened by the large volume and widespread distribution of arkose in Cenozoic formations in eastern Oregon, as well as by the distribution in Cenozoic formations in eastern Oregon of conglomerates that contain a more diverse suite of pre-Tertiary salic rocks than is represented among the present exposures of continental crust in southwest Idaho.

ACKNOWLEDGMENTS

The study of dikes in the Basin and Range structural province was facilitated by two grants from the General Research Fund of Oregon State University. A third grant from the same fund permitted the study of pre-Tertiary rocks near the Oregon-Nevada state line. L. R. Kittleman provided helpful information regarding locations in eastern Oregon of conglomerates that contain clasts of pre-Tertiary rocks. The writer is indebted to C. W. Hulbe for communications pertaining to the location of conglomerates in the Warner Mountains, northeast California.

REFERENCES CITED

Albers, J. P., 1967, Belt of sigmoidal bending and right-lateral faulting in the western Great Basin: Geol. Soc. America Bull., v. 78, p. 143-156.

Anderson, A. L., 1934a, Geology of the Pearl-Horseshoe Bend gold belt, Idaho: Idaho Bur. Mines and Geology Pamph. 41, 36 p.

—— 1934b, A preliminary report on recent block faulting in Idaho: Northwest Sci., v. 8, p. 17-28.

—— 1939, Geology and ore deposits of the Atlanta district, Elmore County, Idaho: Idaho Bur. Mines Geology Pamph. 49, 71 p.

—— 1947, Geology and ore deposits of Boise Basin, Idaho: U.S. Geol. Survey Bull. 944-C, p. 119-319.

Atwater, T., and Menard, H. W., 1970, Magnetic lineations in the Northeast Pacific: Earth and Planetary Sci. Letters, v. 7, p. 445-450.

Bateman, P. C., Clark, L. D., Huber, N. K., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith: A synthesis of recent work across the central part: U.S. Geol. Survey Prof. Paper 414-D, 46 p.

Bateman, P. C., and Eaton, J. P., 1967, Sierra Nevada batholith: Science, v. 158, p. 1407-1417.

Bateman, P. C., and Wahrhaftig, C., 1966, Geol of the Sierra Nevada: Calif. Div. Mines Geology Bull. 190, p. 107-172.

Bonini, W. E., 1963, Gravity anomalies in Id Idaho Bur. Mines and Geology Pamph. 1 p.

Buddington, A. F., 1959, Granite emplacement special reference to North America: Geol. America Bull., v. 70, p. 671-747.

Bushnell, K., 1967, Geology of the Rowland rangle, Elko County, Nevada: Nevada Mines Bull. 67, 38 p.

Coats, R. R., Marvin, R. F., and Stern, T. W., Reconnaissance of mineral ages of plut Elko County, Nevada, and vicinity: U.S. Survey Prof. Paper 525-D, p. 11-15.

Compton, R. R., 1960, Contact metamorph Santa Rosa Range, Nevada: Geol. Soc. Am Bull., v. 71, p. 1383-1416.

Crosthwaite, E. G., 1969, Water resources Salmon Falls Creek basin, Idaho-Nevada Geol. Survey Water-Supply Paper 1879 p.

Diller, J. S., 1908, Geology of the Taylorsvil gion, California: U.S. Geol. Survey Bull 128 p.

Evernden, J. F., and Kistler, R. W., Chronology of emplacement of Mesozoi olithic complexes in California and we Nevada: U.S. Geol. Survey Prof. Paper 6 p.

Fenneman, N. M., 1931, Physiography of the ern United States: New York, McGra Book Co., Inc., 534 p.

Fenneman, N. W., and Johnson, D. W., (with ographic Committee, U.S. Geol. Survey Physical divisions of the United States Geol. Survey Map, scale 1:7,000,000.

Fleck, R. J., 1970, Age and possible origin of Vegas Valley shear zone, Clark and Nye ties, Nevada Geol. Soc. America, Abs. wi grams (Ann. Mtg.), v. 2, no. 7, p. 55

Freeman, O. W., Forrester, J. D., and Lupher, 1945, Physiographic divisions of the C intermontane province: Assoc. Am. Ge phers Annals, v. 35, p. 53-75.

Gilluly, J., 1963, The tectonic evolution of the ern United States: Geol. Soc. London Jour., v. 119, p. 133-174.

—— 1970, Crustal deformation in the United States, p. 47-73 *in* Johnson Smith, B. L., *eds.*, The megatectonics nents and oceans: New Brunswick, New Rutgers Univ. Press, 282 p.

Goldschmidt, V. M., 1916, Ubersicht der E gesteine im Kaledonischen Gebirge zw Stavanger und Trondhjem: Kristiania skaps Skr., 1. Math.-Naturv. Klasse, no p.

Hamilton, W., 1962, Late Cenozoic stru west-central Idaho: Geol. Soc. America

C., and Wahrhaftig, C., 1966, Ge...
Sierra Nevada: Calif. Div. Mines ...
y Bull. 190, p. 107-172.
..., 1963, Gravity anomalies in Id...
ur. Mines and Geology Pamph. 13...

A. F., 1959, Granite emplacement ...
eference to North America: Geol. S...
Bull., v. 70, p. 671-747.
1967, Geology of the Rowland qu...
Elko County, Nevada: Nevada B...
ull. 67, 38 p.
Marvin, R. F., and Stern, T. W., ...
issance of mineral ages of pluton...
inty, Nevada, and vicinity: U.S. G...
rof. Paper 525-D, p. 11-15.
R., 1960, Contact metamorphism ...
ia Range, Nevada: Geol. Soc. Amer...
71, p. 1383-1416.
. G., 1969, Water resources of ...
alls Creek basin, Idaho-Nevada: U.S...
vey Water-Supply Paper 1879-D, ...

908, Geology of the Taylorsville ...
fornia: U.S. Geol. Survey Bull. 35...

F., and Kistler, R. W., 197...
y of emplacement of Mesozoic bat...
nplexes in California and wester...
.S. Geol. Survey Prof. Paper 623, ...

I., 1931, Physiography of the we...
l States: New York, McGraw-H...
Inc., 534 p.
/., and Johnson, D. W., (with Ph...
ommittee, U.S. Geol. Survey), 19...
visions of the United States: U...
y Map, scale 1:7,000,000.
), Age and possible origin of the L...
y shear zone, Clark and Nye Cou...
Geol. Soc. America, Abs. with Pr...
. Mtg.), v. 2, no. 7, p. 333.
Forrester, J. D., and Lupher, R. L...
ographic divisions of the Columbia...
e province: Assoc. Am. Geogra...
s, v. 35, p. 53-75.
The tectonic evolution of the wes...
States: Geol. Soc. London Quar...
, p. 133-174.
al deformation in the wester...
s, p. 47-73 *in* Johnson H., and ...
eds., The megatectonics of con...
ans: New Brunswick, New Jerse...
. Press, 282 p.
I., 1916, Ubersicht der Erup...
Kaledonischen Gebirge zwischen ...
d Trondhjem: Kristiania Vide...
Math.-Naturv. Klasse, no. 2, 14...

962, Late Cenozoic structure of ...
aho: Geol. Soc. America Bull., ...

73, p. 511-516.
—— 1963, Trondhjemite in the Riggins quadrangle, western Idaho: U.S. Geol. Survey Prof. Paper 450-E, p. 98-101.
Hamilton, W., and Myers, W. B., 1966, Cenozoic tectonics of the western United States: Rev. Geophysics, v. 4, p. 509-549.
Hietanen, A., 1962, Metasomatic metamorphism in western Clearwater County, Idaho: U.S. Geol. Survey Prof. Paper 344-A, 116 p.
Hill, D. P., 1963, Gravity and crustal structure in the western Snake River Plain, Idaho: Jour. Geophys. Research, v. 68, p. 5807-5819.
Hill, D. P., Baldwin, H. L., and Pakiser, L. C., 1961, Gravity, volcanism, and crustal deformation in the Snake River Plain, Idaho: U. S. Geol. Survey Prof. Paper 424-B, p. 248-250.
Hill, D. P., and Pakiser, L. C., 1963, Crustal structure from seismic refraction measurements between Eureka, Nevada, and Boise, Idaho [abs.]: Am. Geophys. Union, Trans., v. 44, p. 890.
Hill, D. P., and Pakiser, L. C., 1967, Seismic-refraction study of crustal structure between the Nevada Test Site and Boise, Idaho: Geol. Soc. America Bull., v. 78, p. 685-704.
Hobbs, S. W., Griggs, A. B., Wallace, R. E., and Campbell, A. B., 1965, Geology of the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geol. Survey Prof. Paper 478, 139 p.
Hunt, C. B., 1967, Physiography of the United States: New York, Freeman and Co., 480 p.
King, E. R., Harrison, J. E., and Griggs, A. B., 1970, Geologic implications of aeromagnetic data in the Pend Oreille area, Idaho and Montana: U.S. Geol. Survey Prof. Paper 646-D, 17 p.
Kinoshita, W. T., 1962, A gravity survey of part of the Long Valley district, Idaho: U.S. Geol. Survey open-file rept., 11 p.
Kistler, R. W., 1970, Fold orientations and intrusion loci in the central Sierra Nevada, California: Geol. Soc. America, Abs. with Programs (Ann. Mtg.) v. 2, no. 7, p. 597.
Kittleman, L. R., Green, A. R., Haddock, G. H., Hagood, A. R., Johnson, A. M., McMurray, J. M., Russel, R. G., and Weeden, D. A., 1967, Geologic map of the Owyhee region, Malheur County, Oregon: Univ. Oregon, Mus. Nat. Hist. Bull. 8.
Lanphere, M. A., Irwin, W. P., and Hotz, P. E., 1968, Isotopic age of the Nevadan orogeny and older plutonic and metamorphic events in the Klamath Mountains, California: Geol. Soc. America Bull., v. 79, p. 1027-1052.
Larsen, E. S., and Schmidt, R. G., 1958, A reconnaissance of the Idaho batholith and comparison with the southern California batholith: U.S. Geol. Survey Bull. 1070-A, 33 p.
Lindgren, W., 1898, Description of the Boise quadrangle, Idaho: U.S. Geol. Survey Geol. Atlas, Folio 45.
Malde, H. E., 1965, Snake River Plain, p. 255-263 *in* Wright, H. E., ed., The Quaternary of the United States: Princeton, New Jersey, Princeton Univ. Press, 922 p.
Malde, H. E., and Powers, H. A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 73, p. 1197-1220.
Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Invt. Map I-373.
McKee, E. H., 1968, Age and rate of movement of the northern part of the Death Valley-Furnace Creek fault zone, California: Geol. Soc. America Bull., v. 79, p. 509-512
McKee, E. H., and Silberman, M. L., 1970, Periods of plutonism in north-central Nevada: Geol. Soc. America, Abs. with Programs (Ann. Mtg.) v. 2, no. 7, p. 613-614.
Moore, J. G., 1959, The quartz diorite boundary line in the western United States: Jour. Geology, v. 67, p. 198-210.
—— 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bur. Mines Bull. 75, 45 p.
Myers, P. E., 1968, The geology of the Harpster quadrangle and vicinity, Idaho. [Ph.D. thesis]: Ann Arbor, Univ. Michigan, 267 p.
Nielsen, R. L., 1965, Right-lateral strike-slip faulting in the Walker Lane, west-central Nevada: Geol. Soc. America Bull., v. 76, p. 1301-1308.
Reid, R. R., 1963, Reconaissance geology of the Sawtooth Range: Idaho Bur. Mines and Geology Pamph. 129, 37 p.
Roberts, R. J., 1966, Metallogenic provinces and mineral belts in Nevada: Nevada Bur. Mines Rept. 13-A, p. 47-72.
Ross, C. P., 1936, Some features of the Idaho batholith: 16th Int. Geol. Congr., v. 1, p. 369-385.
—— 1963, Evolution of ideas relative to the Idaho batholith: Northwest Sci., v. 37, p. 45-60.
Russell, I. S., 1902, Geology and water resources of the Snake River Plains of Idaho: U.S. Geol. Survey Bull. 199, 192 p.
Schmidt, D. L., 1964, Reconnaissance petrographic cross section of the Idaho batholith in Adams and Valley Counties, Idaho: U.S Geol. Survey Bull. 1181-G, 50 p.
Schmidt, D. L., and Mackin, J. H., 1970, Quaternary geology of Long and Bear Valleys, west-central Idaho: U.S. Geol. Survey Bull. 1311-A, 22 p.
Sorenson, R. E., 1927, The geology and ore deposits of the South Mountain mining district, Owyhee County, Idaho: Idaho Bur. Mines and Geology Pamph. 22, 47 p.
Stearns, N. D., Stearns, H. T., and Waring, G. A., 1937, Thermal springs in the United States: U.S. Geol. Survey Water-Supply Paper 679-B, 206 p.
Stewart, J. H., 1967, Possible large right-lateral dis-

placement along fault and shear zones in the Death Valley-Las Vegas area, California and Nevada: Geol. Soc. America Bull., v. 78, p. 131-142.

Stewart, J. H., Albers, J. P., and Poole, F. G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: Geol. Soc. America Bull., v. 79, p. 1407-1414.

Taubeneck, W. H., 1967, Petrology of Cornucopia tonalite unit, Cornucopia stock, Wallowa Mountains, northeastern Oregon: Geol. Soc. America Spec. Paper 91, 56 p.

—— 1969, Post-Oligocene dikes and dike swarms of the Basin-Range structural province: Geol. Soc. America Abstracts for 1968, Spec. Paper 121, p. 293.

—— 1970, Dikes of Columbia River basalt in northeastern Oregon, western Idaho, and southeastern Washington, p. 73-96 *in* Gilmour, E. H., and Stradling, D., eds., Proceedings of the second Columbia River Basalt symposium: Cheney, Wash., Eastern Washington State College Press, 333 p.

U. S. Geological Survey, 1967, Northeast extension of Sierra Nevada granitic rocks; p. 86 *in* Geological Survey Research: U.S. Geol. Survey Prof. Paper 575-A, 377 p.

Walker, G. W., and Repenning, C. A., 1965, Reconnaissance geologic map of the Adel quadrang[le], Lake, Harney, and Malheur Counties, Oreg[on]: U.S. Geol. Survey Misc. Geol. Inv. Map I-...

Willden, R., 1963, General geology of the Jacks[on] Mountains, Humboldt County, Nevada: U.S. Geol. Survey Bull. 1141-D, 65 p.

—— 1964, Geology and mineral deposits of Humboldt County, Nevada: Nevada Bur. Mines Bull. 59, 154 p.

Wright, L. A., and Troxel, B. W., 1967, Limitations on right-lateral, strike-slip displacement, Death Valley and Furnace Creek fault zones, California: Geol. Soc. America Bull., v. 78, p. 93[3]-950.

—— 1970, Summary of regional evidence for right-lateral displacement in the western Great Basin: Discussion: Geol. Soc. America Bull., v. 81, p. 2167-2174.

Youngquist, W., and Haegele, J. R., 1956, Geological reconnaissance of the Cassia Mountains region, Twin Falls and Cassia Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 110, .. p.

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DAVID GOTTFRIED

Contrasting B... Differentiated ... Calc-Alkali...

ABSTRACT

Crystallization differen...
...gh-Al_2O_3 olivine thol...
...rnia) yields segregati...
...ndesite composition, an...
...asses of dacite and rhy...
..., and probably Nb, ...
...ched in segregation vei...
...lass by crystallization o...
...gite, and magnetite. P...
...sidual rhyolitic glass ...
...agnetite, ilmenite, and ...
... typical orogenic calc...
Mount Jefferson, Orego...
...pleted with increasin...
...ly minerals capable o...
..., Ti, and Nb with inc...
Fe-Ti oxides, amphibol...
There is no direct evide...
Mount Jefferson basalt ...
...re present in calc-alkali...
...d may occur at a s...
beneath Mount Jeffers...
Alternatively, mixing ...
basalt-andesite may acc...
...rson trend. By physic...
...th segregation veins ...
...asses, basaltic andes...
...agmas may segregat...
...k at depth, and mi...
...rface.

INTRODUCTION

Calc-alkaline magma...
...ntal evolution bec...
...ing continental ma...
However, chemical d...
...idual calc-alkaline ...
...m several causes—...
...ations for continen...
...es of chemical var...
... differentiation, ...

...gical Society of Amer...