Idaho Batholith Near Pierce and Bungalow Clearwater County, Idaho

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By ANNA HIETANEN

METAMORPHIC AND IGNEOUS ROCKS ALONG THE NORTHWEST BORDER ZONE OF THE IDAHO BATHOLITH

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Petrologic study of igneous rocks in the northwestern corner of the Idaho batholith

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IDAHO BATHOLITH NEAR PIERCE AND BUNGALOW, CLEARWATER COUNTY, IDAHO

By Anna Hietanen

ABSTRACT

The northwestern part of the Idaho batholith consists of several intrusive bodies of differing composition, separated by belts of metasedimentary rocks, by dike rocks, or by fault zones. On the basis of chemical analyses and thin-section studies, the intrusive rocks can be grouped into two suites: a quartz dioritic suite poor in potassium and a quartz monzonitic suite rich in potassium. In the quartz dioritic suite, quartz diorite is most common and forms bodies as large as 200 square miles (about 600 sq. km) in land-surface area; other members of the suite—hornblendite, gabbro, and tonalite—form small sill-like bodies. Among the rocks of the quartz monzonitic suite, quartz monzonite and granite occur in large bodies, 50–100 square miles (100–250 square km in land-surface area); the mafic varieties are in small bodies, dikes, and inclusions. Both suites are represented also by pegmatites and hypabyssal dike rocks.

Field relations, structures, and textures indicate that the quartz diorite and related rocks were emplaced earlier than the rocks of the quartz monzonitic suite. According to lead-alpha age determinations, both suites are of Early Cretaceous age (Larsen and others, 1958) and were thus emplaced during a relatively short time interval. Because the quartz diorite and related rocks are in the western part of the area and the quartz monzonite and granite are in the eastern part, it is evident that magmatic activity started in the west with the intrusion of rocks poor in potassium and later moved toward the east as the magmas became enriched in potassium.

Variation diagrams indicate a close compositional relationship between the rocks of both suites. Notable differences occur only in the distribution of potassium, calcium, and vanadium. Two possibilities of origin are considered: either the quartz dioritic rocks are early differentiates of the quartz monzonitic magma, or both magmas were formed directly through melting or parts of the crust. The latter mode of origin postulates that the difference in the chemical compositions of the two rock suites is due to the differences in material from which the magmas were formed, or that the differentiation took place during the formation of the magmas rather than during their crystallization.

INTRODUCTION

This work is a petrologic and structural study of the igneous and metamorphic rocks in the northernmost part of the Idaho batholith. Metamorphic rocks are discussed only briefly because similar rocks have been described in detail in earlier papers (Hietanen, 1962, 1963a, b). A petrographic description of quartz monzonite and related rocks in a stocklike mass just north of the area studied is included in this report for comparison with the quartz monzonite in the southern part of the area.

During the present study, it became evident that much of the area shown on earlier geologic maps as the northwestern part of the Idaho batholith (Anderson, 1930; Ross and Forrester, 1947), is actually underlain partly by prebatholitic metamorphic rocks and partly by small satellitic bodies of intrusive rocks, the composition of which has a rather wide range. It was necessary to map this area in considerable detail in order to establish accurately the north boundary of the batholith, to establish the relations between the prebatholitic metasedimentary rocks and the igneous rocks, and to examine the sequence of intrusion.

Chemical petrology is used to determine the magmatic relations between the various intrusions of the Idaho batholith and its outliers. Study of the effects of the intrusive bodies on the metasedimentary country rocks throws light on the physico-chemical conditions of the intrusion.

The area studied lies in the south-central part of Clearwater County in the southern part of the Idaho "panhandle". It joins the areas described in earlier reports (fig. 1). The Orofino, Dent, and Big Island areas, and the Headquarters quadrangle (Hietanen, 1962) adjoin the area of this report in the west; the Boehls Butte quadrangle (Hietanen, 1963a) and the Elk River-Clarkia area (Hietanen, 1963b) lie to the northwest. The northeastern part of the area (pl. 1) comprises about 300 square miles around Bungalow Ranger station and is called the Bungalow area in this report. It is bounded by long 115°25′ and 115°45′ W. and lat 46°30′ and 46°45′ N. The area adjoining the Bungalow area and the Headquarters quadrangle on the south is called the Pierce area (pl. 2). It includes two small logging towns, Weippe and Pierce, and is bounded by long 115°35′ and 116°00′ W. and lat 46°17′ and 46°30′ N.; it covers an area of about 200 square miles. Quartz monzonite just north of the Bungalow area covers an area of about 27 square miles and is well exposed along Beaver Creek (pl. 3).

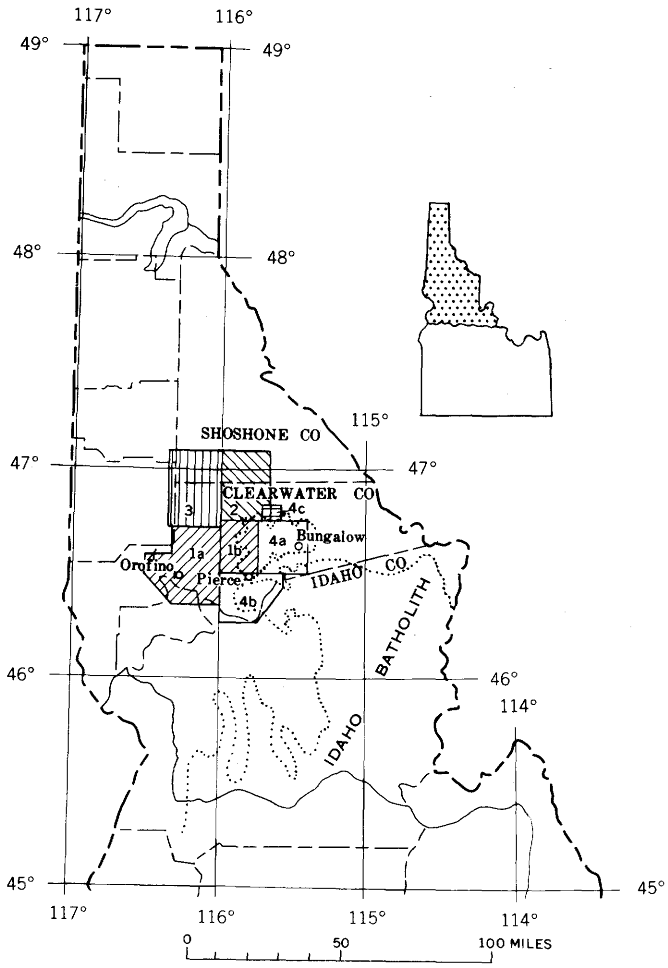

FIGURE 1.—Index map of northern Idaho: 1a, Orofino, Dent, and Big Island areas commbined; 1b, Headquarters quadrangle; 2, Boehls Butte quadrangle and vicinity; 3, Elk River-Clarkia area; 4a, Bungalow area; 4b, Pierce area; 4c, Beaver Creek area. The dotted line shows the outline of the northern part of the Idaho batholith.

The western part of the Pierce area (pl. 2) lies along the east margin of the Columbia River Plateau, which here is about 3,000 feet above sea level. The plateau is cut deeply by two large streams, Lolo and Orofino Creeks, the bottoms of which are about 1,200 feet above sea level.

The North Fork of the Clearwater River flows through the northeastern corner of the Bungalow area, where it turns from west to north and, farther downstream, to northeast. Most of the creeks are tributaries of this river. The southwestern part of the Pierce area is drained to the South Fork of the Clearwater River by Orofino, Jim Ford, and Lolo Creeks and their tributaries.

Part of the Columbia River Plateau in the mapped area is farming land and part is covered by a heavy growth of timber, which includes white and yellow pine, fir, cedar, hemlock, spruce, and larch. The forested mountain area is logged for white and yellow pine and cedar.

Most of the roads (pls. 1, 2) are gravel or dirt, but the road from Pierce and Weippe to Orofino and points west is paved. The gravel road from Pierce to Bungalow Ranger station is good, and many new logging roads have been constructed during recent years. These roads make the area easily accessible during the dry summer season, which usually lasts from the beginning of July to the end of August.

The field work on which this report is based was done intermittently during the summers of 1952, 1957, and 1958. In 1952, the author was assisted by Dorothy Rainsford and Cynthia Wilkin. The canyon of the swift North Fork of the Clearwater River north of Bungalow was mapped with the aid of a rubber raft.

LOCALITY AND SPECIMEN NUMBERS

Specimen numbers are used as locality numbers and are shown on plates 1 to 3. The following index gives the section, township, and range for each locality mentioned in the text:

No.	*Township*	*Range*	*Sec.*	*No.*	*Township*	*Range*	*Sec.*
574	40 N.	7 E.	5	1081	39 N.	7 E.	6
578	40 N.	6 E.	24	1085	39 N.	7 E.	18
719	39 N.	6 E.	21	1121	36 N.	7 E.	20
758	38 N.	8 E.	20	1125	36 N.	7 E.	19
818	35 N.	5 E.	23	1126	36 N.	7 E.	19
827	35 N.	6 E.	20	1139	38 N.	7 E.	33
830	35 N.	6 E.	5	1143	37 N.	6 E.	22
831	36 N.	6 E.	32	1171	38 N.	8 E.	22
848	39 N.	8 E.	6	1539	35 N.	5 E.	21
1063	40 N.	6 E.	26	1880	34 N.	9 E.	[1]5
1064	40 N.	6 E.	26	1944	38 N.	7 E.	35
1065	40 N.	6 E.	26	1976	35 N.	6 E.	7
1072	40 N.	7 E.	7	1983	38 N.	6 E.	31
1073	40 N.	7 E.	7	1988	36 N.	6 E.	7
1079	40 N.	7 E.	31				

[1] East of the area of plate 2.

Localities 20, 32, 42, 43, 180, 190, 213, 292, 301, 322 and 379 are west of areas of plates 1 and 2 and are shown on the maps of Headquarters quadrangle and of Orofino, Dent, and Big Island areas (Hietanen, (1962).

MAJOR GEOLOGIC UNITS

The major geologic units (fig. 2), in the order of decreasing age are the Belt series (Precambrian), rocks of the Idaho batholith (Cretaceous), and the Columbia River basalt (Miocene and Pliocene(?)).

The Belt series is a thick sequence of sediments metamorphosed to diopside and biotite gneiss, schist, and quartzite. Equivalents to the Prichard, Revett, and St. Regis formations are exposed in various parts

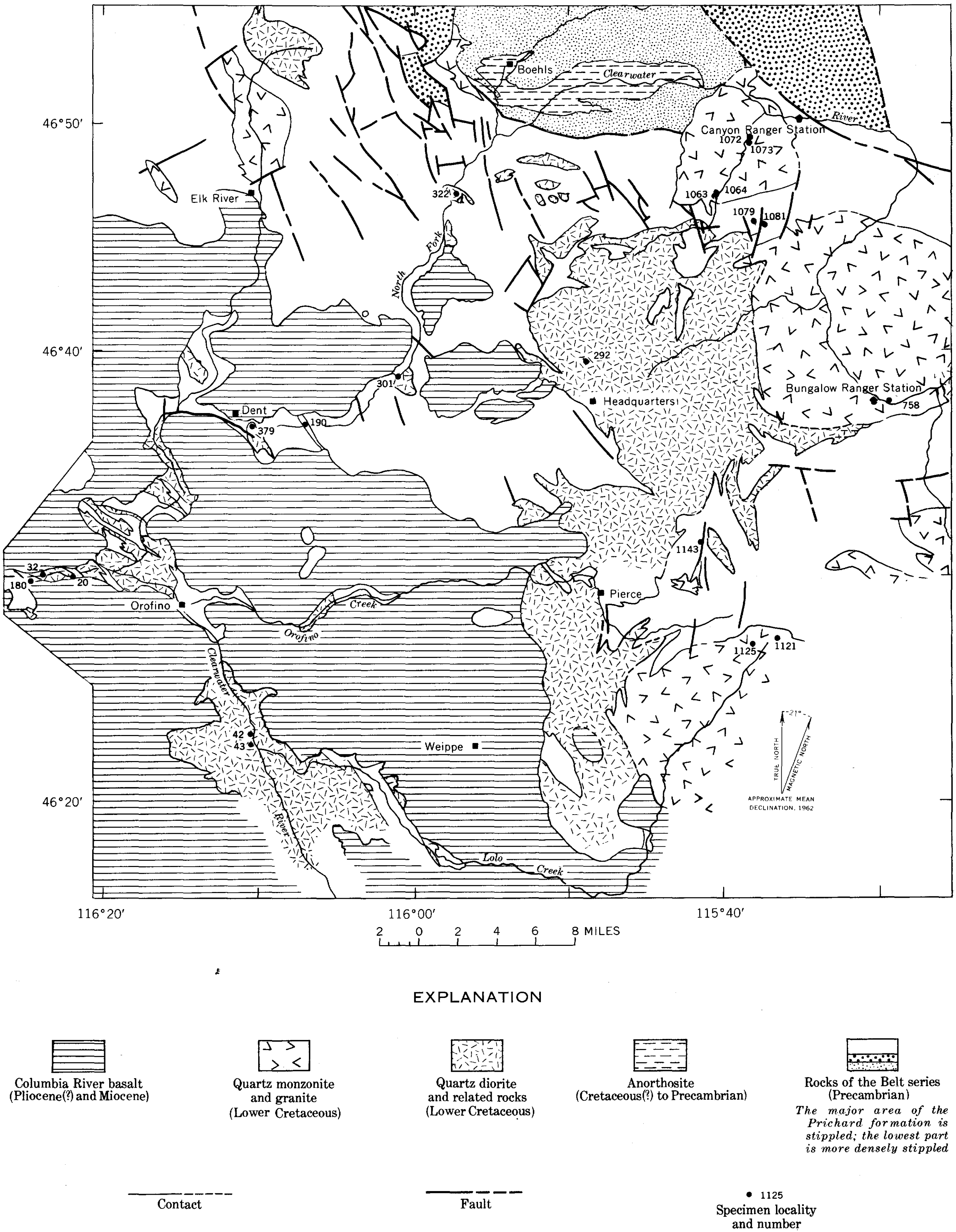

FIGURE 2.—A geologic sketch map showing the distribution of the igneous rocks along the northwest border zone of the Idaho batholith.

of the area (pls. 1, 2) but most of the rocks in the area are equivalent to the Wallace formation.

In the area mapped, the Idaho batholith is a composite batholith consisting of two larger and several small bodies of petrologically different plutonic rocks. These bodies are separated from each other by rocks of the Belt series, by dike rocks, or by sheared contact zones. The southernmost body, which is the largest, extends at least 150 miles south of the present area and consists of coarse-grained quartz monzonite. Quartz diorite forms one large and several small bodies. The largest body extends west of the mapped area and covers about 200 square miles. A large stocklike intrusion of granite covers the northeastern part of the area. Another stocklike mass occurs north of the area and consists of fine- to medium-grained quartz monzonite (pl. 3).

ANORTHOSITE, ITS COUNTRY ROCKS, AND THE OROFINO SERIES OF ANDERSON (1930)

The biotite gneiss exposed low on the Canyon walls of Lolo Creek in the southwestern part of the Pierce area is similar to the medium-grained biotite gneiss exposed 16 miles to the northwest, near Orofino and described in an earlier report (Hietanen, 1962).

The anorthosite shown on the western part of plate 3 and its country rocks have been described and discussed in an earlier report (Hietanen, 1963a). Description of metamorphic rocks in the eastern part of this plate will be included in a later report.

BELT SERIES

DISTRIBUTION

The northern contact of the intrusive rocks follows closely the north boundary of the Bungalow area (pl. 1), leaving only a narrow strip of metamorphic rocks in the northwestern corner. Most of the rocks of the Belt series are exposed south of Bungalow (pl. 1) and continue to the northeastern part of the Pierce area (pl. 2). Most of this terrane was formerly mapped as the Idaho batholith (Ross and Forrester, 1947). In addition to these occurrences several inclusions of rocks of the Belt series, ranging from ½ to 3 miles in length, are within the intrusive masses in the western and southern parts of the mapped area.

LITHOLOGY AND CORRELATION

Most of the rocks of the Belt series consist of diopside and biotite gneiss, interbedded with garnet-mica schist that locally contains abundant sillimanite. Pure quartzite beds are rare.

Comparison of the lithology and stratigraphic sequence of the metamorphic rocks with those of the Belt series northwest of the mapped area indicates that parts of the formations are equivalent to the Prichard, Revett, St. Regis, and Wallace formations. The Burke formation, which occurs between the Prichard formation and the Revett quartzite in Shoshone County, was not identified with certainty. The uppermost beds of the Prichard formation as herein mapped probably are equivalent to the Burke formation.

Coarse-grained fairly pure quartzite occurs along the northern boundary of the Bungalow area (pl. 1) and in the northern part of the Pierce area (pl. 2), east of Pierce. The quartzite in the Bungalow area continues northward into the Boehls Butte quadrangle, where it has been mapped as the Revett quartzite (Hietanen, 1963*a*). The quartzite south of Hemlock Butte and southwest of Dan Lee Lookout (southeast of Pierce) is petrographically and structurally similar to the Revett quartzite and occupies a corresponding stratigraphic position under a thick sequence of interbedded schist and gneiss and is therefore also mapped as Revett. A layer of schist that overlies the Revett quartzite is considered to be equivalent to the schist of the St. Regis formation near Elk River (Hietanen, 1963*b*). Between Hemlock Butte and Dan Lee Lookout (pl. 2) a layer of schist just north of the quartz monzonite body dips under the Revett quartzite and is mapped as the Prichard formation. The Burke formation, which in Shoshone County is transitional between the Prichard formation and the Revett quartzite and thus should underline the Revett quartzite, is not identified; either its equivalent was not deposited in the Pierce area or equivalent beds are here included with the adjacent formations. The contact between the Revett quartzite and the underlying schist (Prichard formation) is fairly sharp.

A thick sequence of diopside gneiss, biotite gneiss, and interbedded schist overlies the St. Regis formation; it is mapped as the Wallace formation, which elsewhere rests on the St. Regis formation. In this area the stratigraphic sequence within the Wallace is difficult to establish because of faulting and discontinuous exposures. The attitude of beds north of Hemlock Butte indicates that the lowest beds consist of thin-bedded biotite gneiss and diopside-plagioclase gneiss. This lower gneiss unit, which may be as much as 1800 feet thick, is overlain by a sillimanite-garnet-biotite schist with interbedded quartz-rich layers. The thickness of the schist unit could not be measured but is estimated to be about the same as that of the gneiss unit. Another unit of diopside-plagioclase gneiss crops out north of the schist and is in turn overlain by a second schist unit. This sequence is similar to that of the Wallace formation in the Headquarters quadrangle

(Hietanen, 1962) and near Elk River (Hietanen, 1963b).

Outcrops along French Creek show that the gneiss units consist of rock types that are similar to those of the quartzite-gneiss units near Elk River, about 30 miles to the northwest. At French Creek layers of thin-bedded biotite gneiss alternate with layers of banded diopside-plagioclase gneiss, which is the major rock type. In some layers, beds of biotite quartzite, 1 to 2 cm thick, are interbedded with diopside-plagioclase gneiss. A number of thin fairly pure quartzite layers that contain only a few mica flakes are interbedded with biotite gneiss and also with thin-bedded diopside-plagioclase gneiss.

PETROGRAPHY

PRICHARD FORMATION

The coarse-grained mica schist that dips under the Revett quartzite between Hemlock Butte and Dan Lee Lookout is mapped as the Prichard formation. This schist is poorly exposed along the south slope of a wooded ridge. The outcrops on the western end of the ridge south of Orofino Creek consist of bedded biotite gneiss and biotite-muscovite schist containing garnet and sillimanite. The beds of biotite gneiss range from 2 to 5 cm in thickness, are medium grained and consist of quartz, plagioclase, biotite, and some muscovite. The schist layers are coarse grained and rich in both micas. The amount of garnet and sillimanite ranges from 0 to about 10 weight percent. The southern part of this schist is granitized and grades into a coarse-grained quartz monzonitic rock which includes remnants of schist and gneiss.

REVETT QUARTZITE

The Revett quartzite along the northern boundary of the Bungalow area is well exposed along logging roads. Most of it is coarse grained and light bluish. The individual beds, 1 to 30 cm thick, are separated by paper-thin laminae of mica. About 85 to 95 percent of the rock is quartz; the rest is plagioclase, microcline, biotite, and muscovite. The quartz grains range from 0.5 to 2 mm in diameter, are strained, and have interlocking boundaries. Feldspars occur as isolated grains. The micas, especially muscovite, tend to form paper-thin laminae that separate thick layers of pure quartz. Laminae south of Sheep Mountain Creek have abundant sillimanite prisms, 3 to 10 mm long, whereas numerous small needles of sillimanite with nearly square cross sections and a few flakes of biotite and muscovite are scattered in the quartzose layers. In some beds biotite flakes, 1 to 2 mm long, are scattered throughout the rock.

Many of the pure quartzite beds near the northern boundary of the Bungalow area consist of polygonal grains from 0.01 to 0.04 mm in diameter. A few larger grains, about 0.2 mm in diameter, occur among the small grains, and some of these large grains have a relict mosaic structure, which suggests that large grains grew at the expense of small ones during recrystallization.

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The Revett quartzite on Dan Lee Ridge southeast of Pierce is poorly exposed and was traced mainly by float. Most of the float is very pure coarse-grained quartzite with very little if any mica. Sillimanite is abundant about a mile west-southwest of Hemlock Butte. The outcrops south of Orofino Creek contain some biotite; those north and west of Dan Lee consist of bluish to white coarse-grained quartzite containing about 10 percent feldspar and about 2 percent biotite; all minor constituents occur in scattered grains.

ST. REGIS FORMATION

Schist overlying the Revett quartzite is considered to be equivalent to the St. Regis formation. This schist is thin bedded or laminated and contains layers of thin-bedded biotite quartzite and biotite gneiss. The major constituents are quartz, plagioclase, biotite, sillimanite, garnet, and muscovite. In the laminated schist, layers (2 to 3 mm thick) of quartz, plagioclase, and small flakes of biotite, are separated by paper-thin micaceous laminae. The amount of biotite exceeds that of muscovite, and in many layers, biotite is the only micaceous mineral. Sillimanite and garnet range from 0 to about 15 percent. In the layers of thin-bedded biotite quartzite and biotite gneiss, paper-thin biotite laminae separate the individual beds, which are 2 mm to 2 cm thick and rich in quartz or in quartz and oligoclase. Pegmatitic veins are common in the vicinity of Hemlock Butte and Dan Lee Lookout. These veins range in thickness from 1 to 50 cm and locally form as much as 60 percent of the rock. The composition and origin of these veins is dicussed in the chapter on the contacts of plutonic rocks.

WALLACE FORMATION

Most of the metamorphic rocks in the area are similar to the rock types mapped as the Wallace formation in the Headquarters quadrangle (Hietanen, 1962). The equivalent of this formation in the present area consists of at least two fairly thick units of diopside gneiss and schist. In each unit, layers of quartzite and biotite gneiss are interbedded.

SCHIST UNITS

The schist units consist mainly of biotite-garnet-sillimanite schist with interbedded layers of biotite gneiss. The schist is coarse grained and many outcrops contain abundant pegmatitic veins. The major constituents are quartz, plagioclase (An_{24}), and biotite. Garnet, sillimanite, and muscovite are in places abundant but can be sparse or lacking. Magnetite and zircon are the common accessories. The amount of quartz is usually much larger than that of oligoclase, but in some outcrops, especially in those near tonalitic bodies, the amount of oligoclase ranges from 40 to 50 percent. The amount of biotite exceeds that of muscovite or the biotite is the sole micaceous mineral. Garnet crystals range from a fraction of a millimeter to about 1 cm in diameter; the maximum amount is about 5 percent. Sillimanite, though commonly sparse or lacking, is as much as 15 percent in such outcrops as those along Hook Creek (sec. 35, T. 38 N., R. 7 E.), others about 1½ miles northeast of Hemlock Butte, and still others along Lolo Creek. Muscovite is sparse in the sillimanite-rich schist.

The biotite gneiss interbedded with the schist is medium grained and contains more oligoclase and less biotite than the schist. Garnet occurs sparingly and sillimanite only in micaceous laminae. Most of the gneiss is thin bedded and resembles the biotite gneiss of the St. Regis formation.

GNEISS UNITS

At least two units consisting of a fairly heterogeneous sequence of diopside-plagioclase gneiss, biotite gneiss, and quartzite are interbedded with the schist of the Wallace formation. Most of the gneiss and quartzite is thin bedded and the mineral content of the individual beds varies considerably. A few thick beds are of more homogeneous diopside-plagioclase gneiss.

In typical gneiss along Orogrande Creek, light-green diopside-bearing layers, 1 to 5 cm thick, are separated by biotite-bearing laminae or are interbedded with layers of plagioclase quartzite. The individual beds in plagioclase quartzite are 2 to 5 cm thick and are separated by thinner biotite-bearing or diopside-bearing layers. Megascopically this gneiss is very similar to parts of the quartzite-gneiss units near Elk River (Hietanen, 1963b), except that the grain size tends to be larger and pegmatitic veinlets are more common.

Thick beds of diopside-plagioclase gneiss are exposed in many localities along French and Orofino Creeks. These layers resemble thick beds of diopside-plagioclase gneiss in the Headquarters quadrangle (Hietanen, 1962). The major constituents, quartz, plagioclase (An_{29-30}), and diopside, occur about in equal amounts. Sphene and magnetite are the common accessories. Quartz and plagioclase occur as irregular-shaped grains with rounded corners. The size of the quartz grains in a common variety of diopside gneiss ranges from ¼ to 1 mm in diameter and that of the plagioclase grains from ½ to 2 mm. Diopside is light green with $\alpha = 1.684 \pm 0.001$, $\beta = 1.691 \pm 0.001$ and $\gamma = 1.709 \pm 0.001$. It occurs in subhedral grains that generally measure 1 to 2 mm in diameter. In some outcrops, as for instance in locality 1988, about 2 miles east of Pierce, euhedral prisms, up to 5 cm long, are embedded in a coarse-grained matrix of quartz and plagioclase (An_{29}).

In most specimens microcline is sparse and appears in the form of small square antiperthitic inclusions in plagioclase. In specimen 1944, however, several layers, 2 to 3 mm thick, contain plagioclase and microcline in equal amounts. This specimen was collected along Hook Creek, 3 miles southwest of Bungalow, just south of the contact of diopside gneiss with quartz diorite. Plagioclase (An_{22}) in this rock is more sodic than that usually found in the diopside gneiss. Diopside is altered to antigorite along the cracks and cleavage planes, and very light green hornblende instead of diopside occurs in many layers, especially in those that contain microcline. Microcline occurs as polygonal grains with the plagioclase.

Actinolite with $\alpha = 1.612 \pm 0.001$, $\beta = 1.625 \pm 0.001$, $\gamma = 1.640 \pm 0.001$ and $Z \wedge c = 25°$ occurs in several layers in diopside-plagioclase gneiss along Orofino and Orogrande Creeks. The actinolite is darker green than the diopside and can be easily identified in the outcrops.

Layers of biotite gneiss that are interbedded with diopside-bearing gneisses are thin bedded, medium grained, and consist of quartz, oligoclase, and biotite. Muscovite is usually absent. Microcline occurs in some layers, especially in those that contain granitic veinlets. The very thin bedded biotite gneiss 1½ miles southwest of Musselshell and that just north of Musselshell (loc. 827) are examples of this type. In these rocks, paper-thin biotite laminae separate the light-colored layers that consists of quartz, oligoclase, and some microcline. More potassium feldspar occurs in the medium-grained granite-pegmatitic veinlets which are 0.5 to 1 cm wide and parallel the bedding. Grains in the gneiss range from 0.2 to 1 mm in diameter whereas those in the veinlets are 1 to 2 mm long. These veinlets are common near the contacts of the coarse-grained quartz monzonite and their origin is discussed later.

Beds of light bluish-gray, fairly pure quartzite are exposed in sections 10 and 22 of T. 37 N., R. 6 E. in the vicinity of Orogrande Creek. These beds range from 5 to 20 cm in thickness and are separated by micaceous laminae or by layers, about 1 cm thick, of biotite quartzite. Scattered grains of oligoclase constitute 5 to 15 percent of most layers. The quartz grains are rounded with interlocking borders. The texture and mineralogy of these beds resemble those of the white granular quartzite in the Elk River-Clarkia area (Hietanen, 1963b) even though the beds under discussion are more completely recrystallized and quartz is of translucent variety giving a glassy appearance to many beds.

STRUCTURE OF THE BELT SERIES

The metamorphic rocks trend mainly eastward, thus deviating considerably from the regional northwesterly trends common in the rocks of the Belt series to the northwest. Northwesterly trends can be recognized only in the extreme northwestern part of the Bungalow area (pl. 1). Local deviations from easterly trend occur east of Pierce where the strike of the Wallace formation swings north (pls. 1 and 2). The northerly trend seems to be localized in a zone about 4 miles wide extending northward through the quartz diorite in the western part of the Bungalow area where it is defined by a swarm of northward-trending dikes and inclusions. Farther toward the north several large faults occur in this zone, indicating that it had been a zone of weakness during deformation.

Attitudes of the beds and stratigraphic relations show that folding is isoclinal, with local overturning to the south. Dips between 45° and 85° are most common; beds are flat only on the crests of folds. In the zone of north-south trends east of Pierce the beds dip eastward, which indicates overturning to the west.

The axes of folds plunge mainly east or southeast, although some in the northwestern part of the Bungalow area and in the vicinity of Hemlock Butte plunge northwestward.

Lineation appears as a fine wrinkling and parallel orientation of elongated mica flakes along the flanks of the folds. It either is parallel to the fold axis or intersects it at an angle of 60° to 80°. Very strong lineation with local small-scale folding on it occurs in some outcrops near Hemlock Butte. This lineation plunges 60° to 65° north-northeast and makes an angle of about 50° with the northwestward-plunging fold axis.

The relation of the lineation to the fold axis is similar to that observed in the areas to the northwest (Hietanen 1961, 1962) and may be attributed to two acts of folding. The axes of the major folds trend mainly in an easterly or southeasterly direction, and those of the minor and somewhat later folds, in a northeasterly direction.

Generally the foliation in the schists and the gneisses is parallel to the bedding. A weak transecting foliation was observed at only a few localities in the quartzitic layers, as near the mouth of Crystal Creek, in the southwestern part of the Bungalow area. Strong fracturing parallel to a fault system is seen in the outcrops of Revett quartzite along Deadhorse Creek and west of Swanson Creek, near the north boundary of plate 1. The lack of mineral development along these fractures indicates that they are late. Their formation is probably related to the intrusion of the granite, as discussed later.

Several northward- or northwestward-trending and a few eastward-trending faults transect the metamorphic rocks or occur along their contacts with the igneous rocks. Most faults are steeply dipping with only minor displacement, mainly vertical; but a few normal faults such as those along Sheep Mountain Creek in the northwestern part of the Bungalow area also interrupt the stratigraphic sequence. These faults are parallel to the regional fault system; specifically, the northward-trending faults form the south end of a fault zone that is one of the major breaks in the area north of the Bungalow area (Hietanen, 1961, and 1963a).

METAMORPHISM

The development of sillimanite, garnet, biotite, and some muscovite in the metamorphosed equivalents of the shaly layers and diopside, actinolite, and plagioclase (An_{20-85}) in the calcareous layers of the Belt series indicates *P-T* conditions of the sillimanite-muscovite subfacies of the amphibolite facies during recrystallization. The orientation of the micaceous minerals, sillimanite, and actinolite parallel to the bedding, which was the dominant plane of slip during the folding, indicates that recrystallization took place contemporaneously with deformation.

In some diopside gneiss, secondary hornblende is developed. These hornblende crystals are larger than the other mineral grains and are oriented at random, many across the bedding. They are similar to the secondary hornblende described earlier from the Headquarters quadrangle (Hietanen, 1962). Their development is thought to be connected with the emplacement of the plutonic rocks.

In many outcrops east of Pierce, pegmatitic veins and secondary feldspars are abundant in the biotite gneiss and schist. Most of the veins are parallel to the bedding; only a few are transecting. As a rule the total amount of feldspars increases toward the intrusive rocks. In many places along Orofino Creek and near Dan Lee Lookout, there is complete gradation from metamorphic rocks to those with a plutonic appearance. All feldspathization is therefore thought to be connected with the emplacement of the plutonic rocks, discussed later.

PLUTONIC ROCKS

DISTRIBUTION AND CLASSIFICATION

Each petrologically different rock type forms one or several intrusive bodies, which are bordered by metamorphic rocks, dike rocks, or other plutonic rocks. The western part of the Bungalow area (pl. 1) and the central part of the Pierce area (pl. 2) are occupied by quartz diorite so coarse grained that the major constituents—plagioclase, quartz, hornblende, and biotite—are obvious. Tongues from this large body extend into the country rocks southwest of Bungalow Ranger Station and along Orogrande and French Creeks. Small bodies of similar quartz diorite crop out 2 miles northeast of French Mountain, 4 miles east of Bungalow, and along the north boundary of the Bungalow area.

About 200 square miles are underlain by quartz diorite; about 140 square miles are exposed in the mapped area, and 60 square miles in the Headquarters quadrangle to the west. Larsen and Schmidt (1958, p. 4) estimated the area of quartz diorite to be 1,000 square miles, assuming that considerable quartz diorite underlies the Columbia River basalt around Weippe. However, all outcrops of prebasaltic rocks in that vicinity are of metasedimentary rocks. Metasedimentary rocks are also exposed along the southern tributaries of Lolo Creek. Accordingly it is here assumed that only a few tens of square miles of quartz diorite is covered by basalt. The platy structure along the western border zone of the quartz diorite dips about 45° eastward (Hietanen, 1962); therefore it is not likely that this intrusion would extend farther to the west and be covered by only a thin layer of metasedimentary rocks.

Rocks that have a chemical composition intermediate between quartz diorite and trondhjemite are called tonalite in this report. The tonalite is more silicic and finer grained than the quartz diorite. Biotite is the only dark-colored constituent, and plagioclase is more sodic than the plagioclase of the quartz diorite. Tonalite occurs as small lenticular bodies next to the quartz diorite, or as separate dikes and other small intrusive bodies in the metamorphic rocks.

The quartz monzonite in the southeastern part of the mapped area is a light-gray, coarse-grained rock in which biotite is the only dark constituent and in which a part of the orthoclase occurs as phenocrysts. In the eastern part of the Pierce area the northern border zone of this quartz monzonite consists of light-gray medium-grained rock that megascopically appears very similar to the tonalite. About a mile south of the north boundary abundant large orthoclase crystals are embedded in this light-gray medium-grained rock, which with an increase in the number of orthoclase phenocrysts grades to a normal coarse-grained quartz monzonite. The light-gray medium-grained rock and the "groundmass" between the large orthoclase crystals have a composition which is intermediate between the tonalite and the main body of the quartz monzonite and is therefore called monzotonalite in this report. The common occurrence of porphyritic dikes of monzotonalitic composition in the country rocks prove that magma of this intermediate composition also existed. Coarse-grained quartz monzonite with anhedral to subhedral phenocrysts is a common variety along the south border of Clearwater County and forms a major rock type in the body that continues southward from the county line and covers about 2,000 square miles in Idaho County (fig. 1).

Coarse-grained true granite with about equal amounts of sodic plagioclase, quartz, and orthoclase forms a fairly large rectangular body of about 110 square miles in the northeastern part of the Bungalow area. It is accompanied by granophyric dikes of the same composition.

A few small occurrences of ultramafic rocks (not shown on the maps) and of hornblende gabbro were found within and near the plutonic rocks.

Pegmatitic veins and dikes [2] are common in all rock types. The pegmatites related to the quartz diorite are plagioclase-biotite pegmatites, but those related to the quartz monzonite and the granite contain abundant potassium feldspar.

STRUCTURE

The structural elements and their orientation in each individual body of plutonic rocks differ markedly from those of the other bodies. These differences are most striking between the quartz diorite and the granite. Tonalitic bodies exhibit two structural varieties; in one variety, structures are similar to those in quartz diorite, and in the other, similar to those in quartz monzonite.

SHAPE OF THE BODIES

The quartz diorite mass is elongate from north to south. Its exposed length is 32 miles and its width is 4 to 10 miles. The direction of elongation parallels a prominent fault zone, north of the Bungalow area, that is the locus of a stocklike intrusion of quartz monzonite (pl. 3).

The western contact of the quartz diorite as exposed in the Headquarters quadrangle (Hietanen, 1962) dips from 40° to 50° E. and generally parallels the bedding of the rocks of the Belt series. The eastern contact dips 50° to 60° E. or is nearly vertical. Thus the quartz diorite mass is a dikelike body, dipping eastward and intruded parallel to a fault zone.

Reconnaissance mapping in Idaho County indicates that the three occurrences of quartz monzonite along the southern border of Clearwater County probably

[2] Veins and dikes are used as descriptive terms, veins referring to thinner irregular bodies, and dikes to thicker crosscutting sheetlike bodies.

belong to a large body of quartz monzonite that extends 15 miles southeastward to the vicinity of Lochsa River where it curves southward and continues at least 30 miles farther.

Reconnaissance mapping east of the Bungalow area shows that the outline of the granite mass at Bungalow is rectangular with rounded corners. The dimension in the easterly direction is 13 miles and that in the northerly direction 11 miles. The contacts of the mass are steep and irregular, typical of a pluglike intrusion. The western contact lines up with a northward-trending fault that extends northward from Deadhorse Mountain.

CONTACTS

The quartz diorite, the tonalite, and the quartz monzonite have both discordant and concordant contacts with the metamorphic rocks. Both types of contacts are sharp or gradational, but the latter are more common. The width of the gradational zone varies from a few centimeters to hundreds of meters, and along the discordant contacts the plutonic rock sends tonguelike extensions into the country rock. This type of tonguing relation is more common where the intrusive rock is in contact with schist or biotite gneiss than with diopside gneiss.

The contact rock between the intrusive rock and the schist or gneiss is medium-grained biotite gneiss in which bedding is far less distinct than in the metamorphic rock. The grain size and the amount of plagioclase increase toward the intrusive rock. Tonalitic veins and masses are common in the biotite gneiss and schist near the quartz diorite and tonalite exposed along Orofino Creek southeast of Pierce. In this vicinity abundant oligoclase has crystallized in metamorphic rocks along a mile-wide contact zone, changing about 40 percent of the biotite gneiss and schist to a medium-grained rock that has tonalitic composition but contains ghostlike remnants of metamorphic rocks. The schist north of this zone (northwest of Rosebud Creek) also contains plagioclase-rich portions, small masses of inhomogeneous tonalitic rock, and numerous pegmatitic veins.

Migmatite is exposed 2½ miles southeast of Hemlock Butte along a road leading to Weitas Ranger Station. The older rock in this vicinity is thin-bedded biotite gneiss with quartzitic layers, and the nearby intrusive rocks are quartz monzonite. The migmatite contains two types of quartzofeldspathic layerlike masses and veins: medium-grained tonalitic veins, 1 to 3 cm thick, and coarse-grained pegmatite veins, 2 to 10 cm thick. The tonalitic veins, consisting of quartz, plagioclase (An_{26}), and some small flakes of biotite, are separated by gneiss layers that range from 1 to 3 mm in thickness and are rich in biotite. The texture of the tonalitic veins is granoblastic, and there is every gradation from these veins to the pegmatitic veins that have orthoclase in addition to quartz and plagioclase. The grain size increases from 1 to 2 mm in the tonalitic veins to about 3 to 10 mm, or even more, in the pegmatitic veins. The tonalitic veins and most of the pegmatitic veins parallel the bedding, but some pegmatitic veins cut the bedding. Because the mineralogy of the tonalitic veins is similar to that of the quartzofeldspathic layers in the biotite gneiss, although the grain size is larger, it is believed that these veins crystallized at the expense of sedimentary material. The occurrence of orthoclase in the pegmatites, however, proves that at least a part of the material (potassium and perhaps some other elements) in them was introduced because the country rock does not contain potassium feldspar. The source of the introduced material was most likely the nearby quartz monzonite. This migmatite represents a typical contact migmatite in which the minerals of the parent rock recrystallized and differentiated sufficiently to increase the amount of vein material.

Parts of the north border zone of the large quartz monzonite body are exposed between Weitas Ranger Station and Lean-to Ridge lookout and also along Hemlock Creek. This border zone is heterogeneous, containing abundant pegmatite and remnants of older metasedimentary rocks. The outcrops along the road north of Lean-to Ridge as well as those south of Weitas Ranger Station indicate that the border zone here consists of 50 to 70 percent pegmatite, about 20 percent rocks of the Belt series, and about 20 to 30 percent hypabyssal dike rocks. The rocks of the Belt series are mainly biotite gneiss and diopside gneiss with less biotite quartzite and schist. There is every gradation of these rocks to feldspathized gneiss and to quartz monzonitic gneiss in which ghostlike remnants of metasedimentary rocks are common. The orientation of relict bedding in the remnants of the metasedimentary rocks indicates that the position of these remnants was not changed during the emplacement of the igneous rocks.

The quartz monzonite along Hemlock Creek is part of a tonguelike extension. The northern part contains abundant pegmatite and the southern part and the core are fairly homogeneous coarse- to medium-grained quartz monzonite.

The contact zone of the granite stock near Bungalow Ranger Station differs strikingly from that of the coarse-grained quartz monzonite. The contacts with the country rocks—quartz diorite and the rocks of the Belt series—are discordant. In many places, granite porphyry occurs between the coarse-grained granite and its country rock. In most localities, the granite porphyry intrudes the granite or is in fault contact with it. However, along the northern contact zone, between Deadhorse Lookout and the North Fork of the Clearwater River, the rock grades from granite porphyry through coarse-grained porphyritic granite to coarse-grained granite. The porphyritic granite is mineralogically and chemically similar to the coarse-grained granite. In the porphyritic variety, the euhedral to subhedral crystals of quartz and feldspars are embedded in a medium-grained groundmass consisting of quartz, plagioclase, orthoclase, and biotite. Granophyric intergrowth of quartz and feldspars is common around the large perthitic orthoclase crystals (fig. 3*A*).

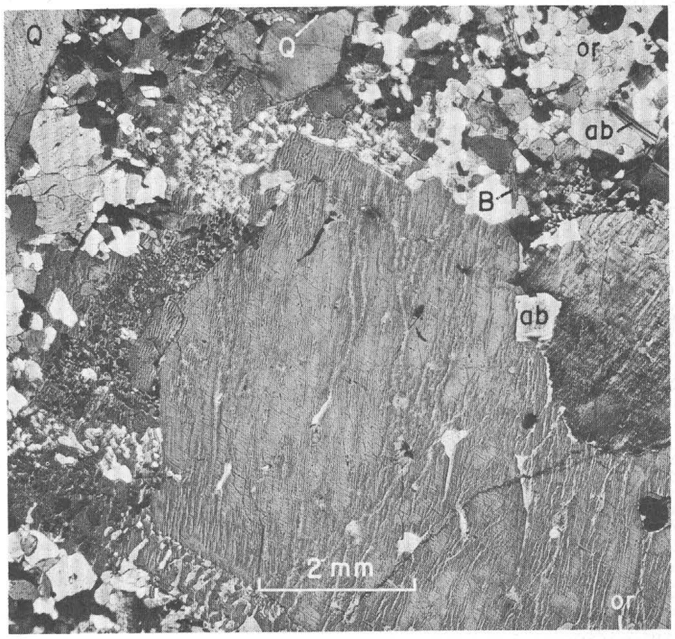
The porphyritic granite is well exposed along the North Fork of the Clearwater River half a mile northeast of the mouth of Governor Creek, where it grades to a coarse-grained granite toward the south and to a fine-grained granophyric granite (fig. 3*B*) toward the north, near the contact with the rocks of the Belt series. A similar granophyre occurs as a border facies of the granite porphyry west of Deadhorse Lookout.

Along the southern contact west of Bighorn Point, granite porphyry separates the coarse-grained granite from the rocks of the Belt series. This mass, lacking outcrops but mapped on the basis of float, is probably fairly thick; many dikelike bodies ranging from a few meters to about 30 meters in width occur elsewhere along this southern contact zone.

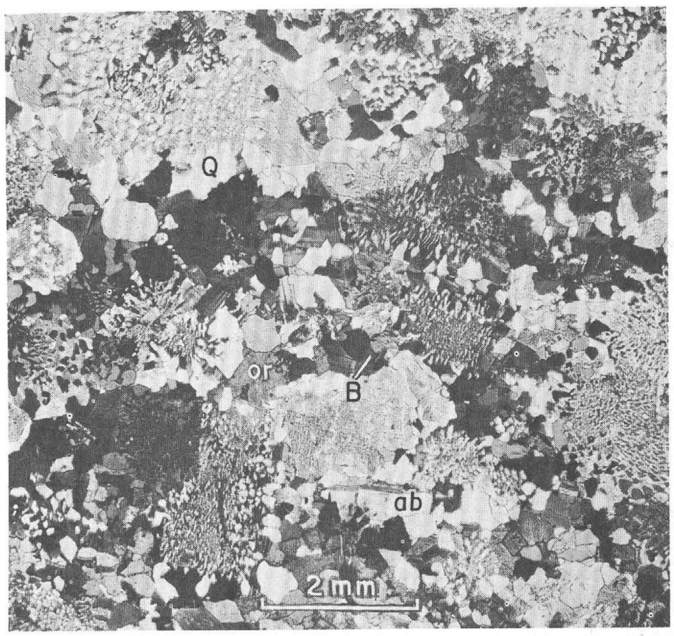
Near the mouth of Fischer Creek, 6 miles northeast of the mouth of Weitas Creek (east of the Bungalow area), granite porphyry occurs between coarse-grained granite and quartz diorite to the south. The western end of this quartz diorite mass is exposed along the North Fork of Clearwater River east of the mouth of Weitas Creek (pl. 1). Along Fischer Creek the granite itself, the quartz diorite, and also a gneissic medium-grained granite south of the quartz diorite are cut by many dikes of quartz porphyry.

Medium-grained equigranular pink granite forms a border facies of the coarse-grained granite west of Deadhorse Mountain. This granite is similar to a small mass of pink equigranular granite in the schist about 9 miles southwest of Deadhorse Mountain. The contact between the pink granite and the coarse-grained granite is not exposed. The two granites may well be separated by a fault that extends northward from Deadhorse Mountain.

Along Orogrande Creek about 1½ miles south of Bungalow, coarse-grained granite is in contact with gneissic quartz diorite. On a small scale, the contact



A, A porphyritic granite with large phenocrysts of perthitic orthoclase (or) and small subhedral phenocrysts of quartz (Q, only a part shown). Granophyric intergrowth of quartz and feldspar forms lacy rims around the orthoclase crystals; groundmass consists of quartz, orthoclase (or), ablite (ab), and a few small flakes of biotite (B). Locality 848, along the North Fork of the Clearwater River near the northern contact of the granite. Crossed nicols.



B, Fine-grained granophyric granite north of locality 848, along the river. Granophyre consists of quartz and orthoclase; quartz (Q), orthoclase (or), albite (ab), and biotite (B), are the constituents in the portion with a granitoid texture. Crossed nicols.

FIGURE 3.—PHOTOMICROGRAPHS OF THE BORDER ZONE OF THE GRANITE.

is discordant and the gray quartz diorite changes to a reddish orthoclase-rich medium-grained rock along the contact. The altered zone is about 1 meter thick and contains about 15 percent dark minerals. Thin sections show that the amounts of orthoclase, oligoclase, and quartz are about equal and that dark-brown biotite is the main dark constituent. Some hornblende is found with the biotite; and magnetite, apatite, and zircon are the accessories.

PLATY AND LINEAR STRUCTURES

Platy and linear structures are common in quartz diorite and related rocks, but rare in the rocks of the quartz monzonite series. Fairly well developed platy and linear structures occur in the border zone of the quartz diorite and in adjacent tonalite. Farther from the contact only the linear structure is visible; in the central parts of large bodies the minerals are oriented at random.

The foliation is due mainly to parallel orientation of biotite, but some of the hornblende is also oriented similarly. In places, both of these dark constituents form elongated clusters. The foliation is parallel to the contacts, which are parallel to the bedding of the country rocks. The linear structure is, as a rule, parallel to the fold axes of the metasedimentary rocks.

In contrast to the structures of quartz diorite and related tonalite, almost all the quartz monzonite and granite is massive. A weakly developed parallel orientation of biotite occurs rarely in the coarse-grained quartz monzonite. Minerals in the groundmass of the porphyritic quartz monzonite are oriented at random.

INCLUSIONS

Inclusions are common in quartz diorite, tonalite, and quartz monzonite but not in the granite near the Bungalow Ranger Station. Most inclusions are of rocks of the Belt series, and many, especially those consisting of schist and biotite gneiss, are feldspathized and migmatized.

A few gabbroic inclusions occur in quartz diorite. Minerals in these inclusions are the same as those in the quartz diorite except that plagioclase is more calcic and the amount of hornblende is 60 percent or more. Only large inclusions are shown on the maps and most of them consist of gneissic layers of the Wallace formation with a minor amount of schist. Many inclusions are elongate parallel to the bedding. Those which are not, as for instance those north and west of Browns Rock (pl. 1), occur on a ridgetop and their shape in plan is modified by erosion. Schist and some of the biotite gneiss in the inclusions contain abundant quartzofeldspathic veins and scattered grains of feldspar. The amount of quartzofeldspathic material in many inclusions is from 40 to 60 percent. Some parts of each inclusion, however, consist of unaltered rock that can be easily identified.

The secondary feldspar in the inclusions in the quartz diorite is mainly plagioclase (An_{22-28}). Potassium feldspar occurs only in the veins and in the pegmatitic dikes cutting the inclusions near contacts with quartz monzonite. The large elongate inclusion 2 miles west of Musselshell belongs to this group. This inclusion consists of very thin bedded biotite gneiss and schist similar to many layers in the Wallace formation. The schist contains numerous round plagioclase (An_{28}) grains which range from 3 to 6 mm in diameter. The gneiss contains two types of veins, fine-grained veins parallel to the bedding and medium- to coarse-grained ones which either parallel the bedding or cut across it. The fine-grained veins consist of quartz and oligoclase with very little biotite and occasionally some potassium feldspar. The medium- to coarse-grained veins are rich in orthoclase (about 45 percent) and contain about 20 percent oligoclase, 30 percent quartz, and as much as 5 percent biotite. Similar coarse-grained pegmatitic veins occur also in the schist. Large subhedral orthoclase crystals, similar to those in the quartz monzonite, appear in the schist next to a coarse-grained pegmatite (30 cm wide) about half a mile north of Musselshell Creek. The schist in this locality also contains abundant round plagioclase grains and is rich in biotite.

A small body of coarse-grained hornblende gabbro occurs in the center of this inclusion (loc. 818) and a fine- to medium-grained equigranular gray tonalite dike cuts the schist discordantly just south of the gabbro body . The gabbro consists of plagioclose (An_{55}), hornblende, and a little biotite.

Most of the inclusions in the quartz monzonite consists of thin-bedded biotite gneiss and diopside gneiss. These inclusions are migmatized and contain potassium feldspar and plagioclase in scattered grains, in rows of grains, and in quartzofeldspathic veins. A part of the potassium feldspar—especially small granoblastic grains in the thin-bedded biotite gneiss—is microcline, as shown by microscopic grid structure and by X-ray diffraction. The potassium feldspar in many veins is orthoclase, as indicated by X-ray diffraction. Large scattered grains show transition from orthoclase to microcline; X-ray diffraction of these crystals indicate a triclinicity of about 0.75 when determined by the method of Goldsmith and Laves (1954).

The granoblastic grains of medium size that occur with quartz and oligoclase are, in their mode of occurrence, similar to the potassium feldspar in the thin-bedded gneiss of the Wallace formation near Elk River and Clarkia. They most likely crystallized at the expense of sedimentary material. The orthoclase of the veins and the large scattered grains of potassium feldspar are secondary and crystallized from material supplied by the nearby igneous rock.

The diopside gneiss of the inclusions is much less granitized and migmatized than the schist and biotite gneiss. Common contact phenomena are alteration of diopside to green hornblende and development of secondary feldspar. Quartzofeldspathic veins and pegmatites are common but not as abundant as in the biotite gneiss and the schist.

JOINTS

Joints are prominent in the granite near Bungalow but are only locally developed in the other intrusive rocks.

The joint system in the granite is especially noticeable in the outcrops near Buckingham Point, where rugged peaks are bounded by northward-trending joints that dip about 70°W. This northward-trending joint system is also prominent north of the Bungalow Ranger Station, in the outcrops on the steep slopes of the North Fork of the Clearwater River. Westward-trending steeply dipping joints appear in several localities, but they are not as well developed as the northward-trending joints. In the northern part of the river valley the steeply dipping joints strike northwest; in places a northeastward-trending joint set is also present.

Nearly horizontal joints that are about perpendicular to the steeply dipping joints are prominent in the steep cliffs along the river, but are more difficult to detect elsewhere. Where measurement was possible, the dips range from 0° to 25°, those from 5° to 20° being most common.

The northwestward-trending steeply dipping joint system continues to the northwest border of the granite mass. Strong fracturing of the same trend affects the Revett quartzite to the northwest.

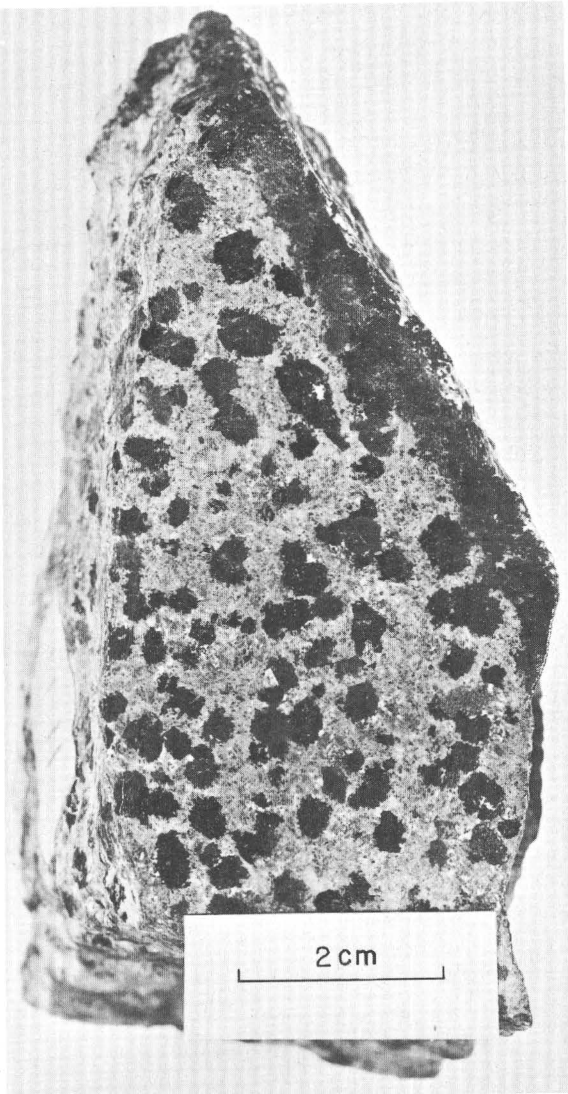
PETROGRAPHIC DESCRIPTION

ULTRAMAFIC ROCKS

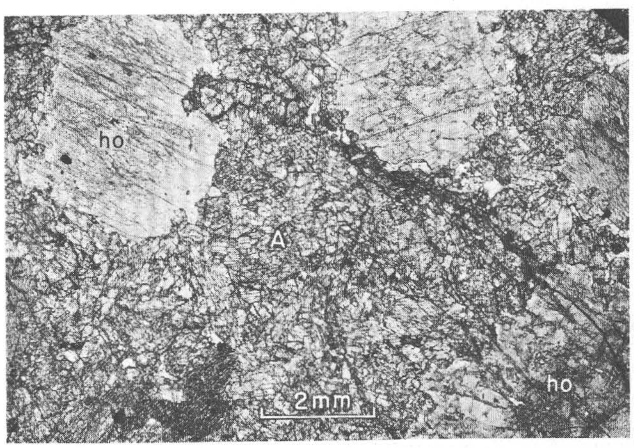
A hornblendite mass, a few meters thick, is included in quartz diorite about 2 miles east of logging camp 57. About 96 percent of this rock is hornblende, which appears dark in the hand specimen and pale green under the microscope. Most of the rest is greenish-brown biotite partly altered to chlorite. Small grains of magnetite occur as inclusions in hornblende.

Two sill-like bodies of pyroxenite crop out in the area. One is exposed on a road cut along Weitas Creek 1½ miles south of the creek mouth (loc. 1171). Large boulders from the other lie along the road 2 miles northwest of Brown Creek Lookout (loc. 1539).

Augite constitutes 60 to 70 percent of both masses. In the pyroxenite along Weitas Creek, dark round grains of hornblende ranging from 2 to 5 mm in diameter are embedded in grayish-green augite (fig. 4*A*).



A, Hornblende (dark)-bearing pyroxenite along Weitas Creek (loc. 1171).



B, Photomicrograph of the rock shown in *A*. Large round hornblende (ho) grains are embedded in medium-grained rock consisting of augite (A). Plane-polarized light.

FIGURE 4.—PHOTOGRAPH AND PHOTOMICROGRAPH OF PYROXENITE WITH HORNBLENDE CRYSTALS.

The augite is in grains 1 to 2 mm long that contain small patches of green hornblende (fig. 4*B*). The large hornblende grains are brownish green and have green borders. The rock also has small interstitial grains of untwinned plagioclase and magnetite.

In the mass northwest of Brown Creek Lookout, the hornblende grains are small and irregular. They are browner than those in the sill along Weitas Creek. The rock has 2 percent of interstitial quartz, rather than plagioclase.

HORNBLENDE GABBRO AND AMPHIBOLITE

Small bodies of hornblende gabbro—most from 100 to 600 m long—crop out within and near the quartz diorite. Only the largest of these are shown on plate 1; two are near Crystal Creek in section 34 of T. 38 N., R. 6 E.

Most of the gabbros are medium- to coarse-grained rocks, in which the minerals are the same as those in the quartz diorite, except that there is more hornblende and less quartz. Some of them, however, are very coarse grained and contain more plagioclase than the medium-grained variety.

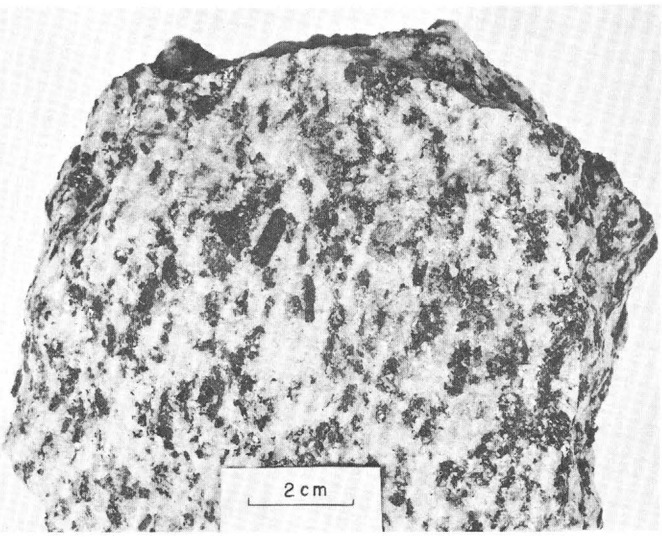
A few small bodies of medium-grained gneissic hornblende-plagioclase rock occur in the metamorphic rocks northwest of Hemlock Butte (pl. 2) and southeast of Larch Butte (pl. 1). The mineralogy of these amphibolites is similar to that of the hornblende gabbro and they may be old gabbroic intrusions that were deformed during the folding of the enclosing metasedimentary rocks.

The body of amphibolite that is about a mile north-northwest of Hemlock Butte is coarse grained and contains about 40 percent hornblende, 25 percent plagioclase (An_{65}), 20 percent quartz, and 15 percent garnet. The garnet crystals are rounded and range from 3 mm to 1 cm in diameter; many contain small quartz inclusions. Ilmenite-magnetite, in skeletonlike crystals and in groups of small elongate grains with round ends, constitutes 1 to 3 percent of this rock. Brown biotite is abundant in the border zone of this mass but sparse in the center. Other accessories are apatite, sphene, and zircon.

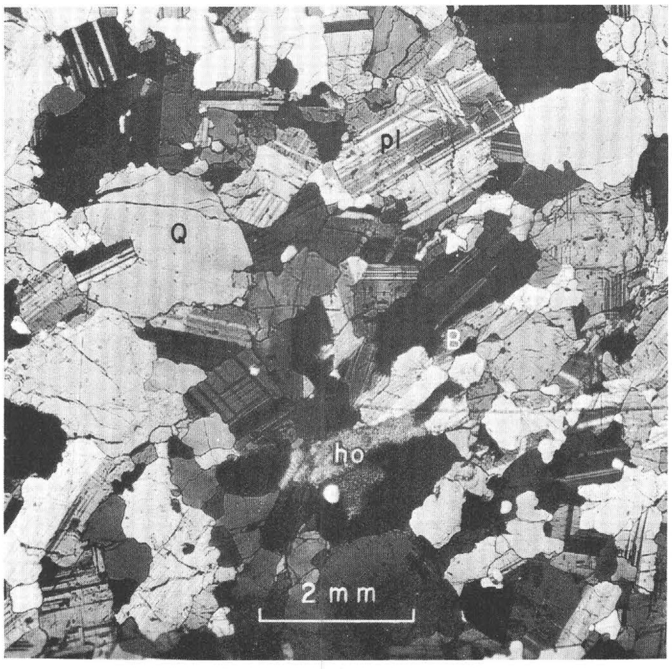
The mineralogy and mode of occurrence of the garnet amphibolite are similar to those of the garnet amphibolite near the anorthosite bodies in Boehls Butte quadrangle (Hietanen, 1963a), except that the amount of ilmenite-magnetite is larger near Hemlock Butte.

QUARTZ DIORITE

The quartz diorite is a coarse-grained rock in which the dark constituents, hornblende and biotite, are strongly contrasted against the light-colored mixture of quartz and plagioclase (fig. 5*A*). Part of the hornblende is in stubby prisms 5 to 15 mm long; smaller grains form clusters with biotite. Some of the central part of the largest body is somewhat coarser, with less biotite and less mineral orientation than the common variety. In many places near the contacts, variation in the distribution of biotite produces dark- and light-



A, A common type of quartz diorite a mile west of logging camp 57. The dark minerals, hornblende and biotite, show a parallel orientation. The light-colored constituents are quartz and plagioclase (loc. 1983).



B, Photomicrograph of the rock (no. 1983) shown in *A*. Unzoned plagioclase (An_{34}) occurs in elongated grains that show parallel orientation and complex twinning (pl). Quartz grains (Q) are anhedral and strained. Hornblende (ho) and biotite (B) are the dark constituents. Crossed nicols.

FIGURE 5.—PHOTOGRAPH AND PHOTOMICROGRAPH OF QUARTZ DIORITE.

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colored portions. In a few localities, the quartz diorite grades to a light-gray gneissic tonalite in which biotite is the only dark constituent and the plagioclase is more sodic than that in the quartz diorite. Magnetite, apatite, and zircon are the common accessories.

The texture of the quartz diorite is hypidiomorphic granular (fig. 5*B*); hornblende and plagioclase are subhedral, whereas quartz fills the interstices. The grains of plagioclase (An_{36}–38) are 2 to 6 mm long. The rounded interstitial grains of quartz have diameters of 0.5 to 5 mm. The dark constituents are clustered; the individual grains in most common types are 3 to 10 mm long.

Biotite is reddish brown, strongly pleochroic, and has $\gamma=1.651\pm0.002$; hornblende has α (pale green)$=1.660\pm0.002$; β (green)$=1.679\pm0.002$, and γ (blue green)$=1.683\pm0.001$ measured in a specimen taken about a mile west of Camp 57 in the southwest part of the Bungalow area. Larsen and Schmidt (1958, table 9, nos. 2 and 3) give chemical analyses of biotite and hornblende in quartz diorite collected about 2 miles southeast of Camp 57. Calculation of the formula for this biotite gives the following result: $(K_{1.68}Na_{.09}Ca_{.19})_{\Sigma=1.96}$ $(Mg_{2.57}Fe_{2.24}Mn_{.02}Ti_{.46}P_{.02}Fe_{.25}Al_{.27})_{\Sigma=5.83}$ $(Al_{2.29}Si_{5.71})_{\Sigma=8.0}$ $(OH_{1.50}O_{22.50})_{\Sigma=24.0}$, in which Mg/Fe=1.

The formula calculated for the hornblende in the same rock is as follows: $(Na_{.28}K_{.14}Ca_{1.92})_{\Sigma=2.34}$ $(Mg_{2.29}Fe_{1.64}Mn_{.04}Ti_{.16}P_{.02}Fe_{.37}Al_{.61})_{\Sigma=5.13}(Al_{1.34}Si_{6.66})_{\Sigma=8.0}(OH_{1.46}O_{22.54})_{\Sigma=24.0}$ and Mg/Fe=1.4 (42 percent iron end member).

TONALITE

Two types of tonalite are distinguished in the area, gneissic and massive. The gneissic variety occurs in small lens-shaped bodies in the metasedimentary rocks and as a border facies of quartz diorite. The massive variety is in dikes transecting the metasedimentary rocks near the contacts of quartz diorite. The same types appear also west of the Bungalow area (Hietanen, 1962).

The major constituents of both varieties are plagioclase An_{30-34}, quartz, and biotite. The gneissic tonalite is medium grained, light to medium gray, and banded in an irregular manner. The banding is due to an irregular distribution of biotite, the amount of which ranges from 5 to 15 percent. The tonalite southeast of Pierce grades northward to feldspathized schist and gneiss by a gradual decrease in the amount of plagioclase and increase in the amount of biotite. Southward the tonalite grades to quartz diorite, and thus is a contact rock between the quartz diorite and metasedimentary rocks. Specimen L 227 of Larsen and Schmidt (1958) was collected from such a contact zone. Small bodies of similar gneissic tonalite are surrounded by metasedimentary rocks.

The massive tonalite is light bluish gray and fine to medium grained with a hypidiomorphic granular texture. In its mode of occurrence and mineralogy, it is similar to the intrusive tonalite near Dent (Hietanen, 1962).

QUARTZ MONZONITE AND RELATED ROCKS

Small exposures of quartz monzonite along the southeastern border of the Bungalow and Pierce areas are probably northward extensions of a large body. The westernmost occurrence contains in places large euhedral orthoclase phenocrysts. A stocklike body of quartz monzonite is exposed along Beaver Creek (pl. 3) just north of the Bungalow area.

STOCK AT BEAVER CREEK

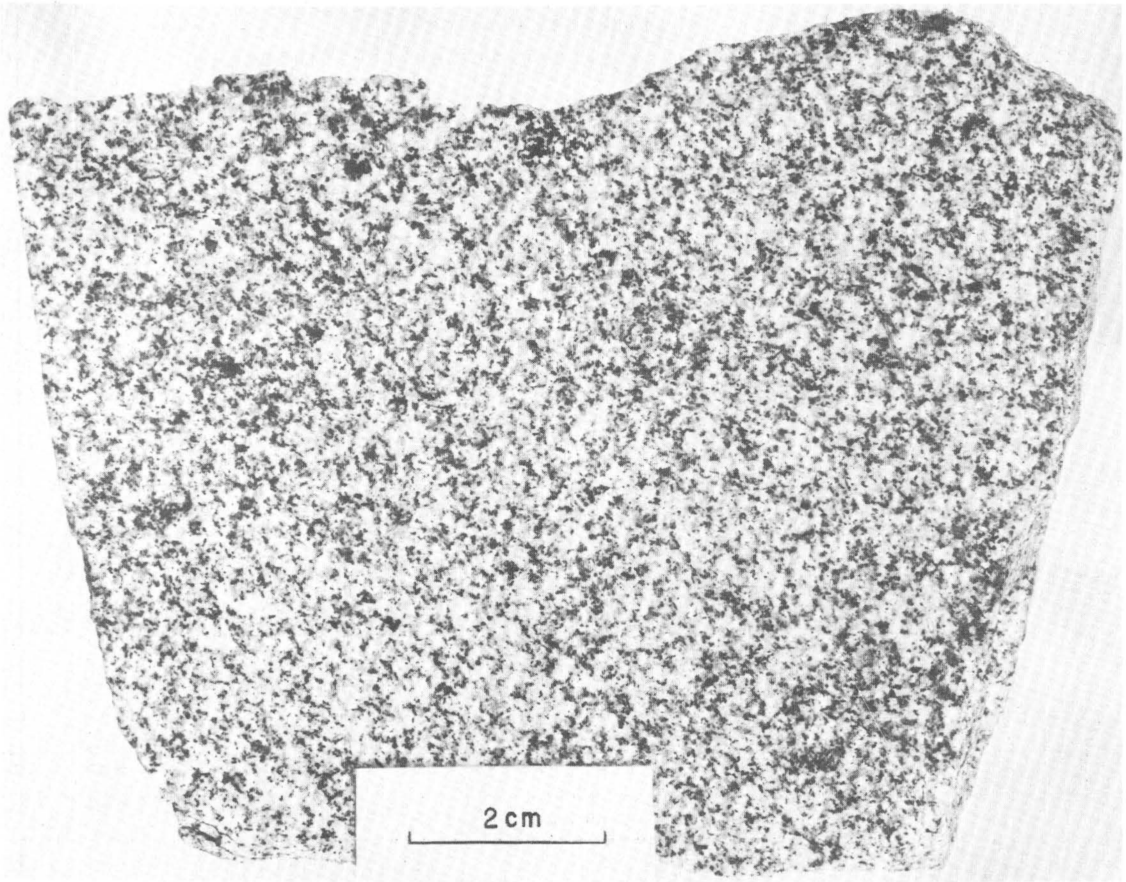
The main rock type in the outlier at Beaver Creek is light-gray or light-brownish-gray fine- to medium-grained quartz monzonite in which minerals are oriented at random (fig. 6*A*). It includes a few small lens-shaped bodies of olivine gabbro and several bodies of pyroxene gabbro, hornblende gabbro, and diorite.

Texture of the main rock type is typical of quartz monzonite; small euhedral to subhedral, strongly zoned and twinned plagioclase (An_{26-28}) crystals are included in large anhedral grains of quartz and orthoclase (fig. 6*B*). Plagioclase (An_{26-28}) grains of medium size occur with quartz between the large poikilitic quartz and orthoclase crystals. Near the northern border of the stock, along the North Fork of the Clearwater River, large anhedral zoned phenocrysts of plagioclase are embedded in the fairly fine grained quartz monzonite.

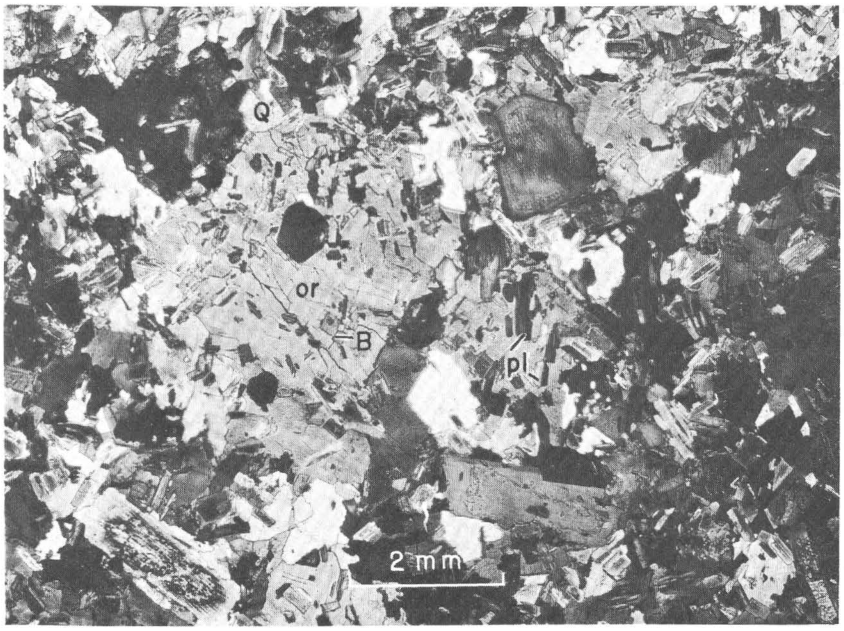
Biotite ($\gamma=1.648\pm0.002$) is the main dark constituent; in addition, most of the rock has a little chlorite. Tiny muscovite laths are next to the biotite and in the centers of some plagioclase crystals. Small grains of magnetite, apatite, allanite, and zircon are the accessories. Much of the zircon is included in biotite. The pleochroic haloes around zircon crystals are darker and wider than those in other rocks of this area.

In places, quartz and orthoclase are granophyrically intergrown around subhedral orthoclase grains. The occurrence of numerous small lath-shaped zoned plagioclase crystals and the granophyric texture indicate fairly rapid cooling of the magma.

Chemical analyses (No. 1064 on table 1) shows that the quartz monzonite is rich in silicon and potassium. It is chemically close to a granite except that the amount of calcium is higher due to a higher anorthite content.



A, Fine-grained quartz monzonite along Beaver Creek (loc. 1064). Minerals are oriented at random.



B, Photomicrograph of the rock shown in *A*. Small plagioclase laths (pl) and biotite flakes (B) are included in anhedral grains of orthoclase (or) and quartz (Q). Crossed nicols.

FIGURE 6.—PHOTOGRAPH AND PHOTOMICROGRAPH OF QUARTZ MONZONITE ALONG BEAVER CREEK.

TABLE 1.—*Chemical composition in weight and ionic percentage, molecular norms, and modes of the plutonic rocks and dike rocks near Pierce and Bungalow*

[Analyses by the U.S. Geological Survey. Analysts: Lois D. Trumbull, Nos. 1063, 1064, 1073, 1072, 1079, 1081; Paula Montalto, Nos. 1121, 1125, 1143; Ruth H. Stokes, No. 758; Dorothy F. Powers, No. 1880]

	1063	1073	1072	1079	1143	1125	1121	1081	1064	1880	758	L 219
Rock type	Olivine gabbro	Pyroxene gabbro	Gabbro	Gabbroic dike	Monzotonalitic dike	Coarse-grained monzotonalitic groundmass	Monzotonalite	Quartz monzonitic dike	Quartz monzonite	Coarse-grained quartz monzonite	Granite	Granite
Locality	Beaver Creek 1.5 miles north of Camp 14	1.5 miles south of mouth of Beaver Creek	1.2 miles south of mouth of Beaver Creek	2.5 miles east of Camp 14	2 miles northeast of French Mountain	1.7 miles south of Hemlock Butte	2 miles southeast of Hemlock Butte	2.5 miles east of Camp 14	Beaver Creek 1.5 miles north of Camp 14	Lochsa River	1 mile east of Bungalow (Hietanen, 1962)	1 mile east of Bungalow (Larsen and Schmidt 1958)
Weight percent												
SiO_2	46.57	50.60	52.72	50.37	65.75	66.62	67.69	66.14	70.36	71.37	77.43	75.28
Al_2O_3	11.59	18.17	18.06	17.34	16.47	17.35	17.09	15.33	15.14	15.56	12.47	13.14
Fe_2O_3	1.28	1.60	1.65	3.04	.60	1.05	1.13	1.45	.51	.68	.22	.89
FeO	9.20	8.17	5.93	7.50	2.61	1.71	1.49	3.42	1.80	.92	.84	1.47
MnO	.15	.15	.12	.16	.05	.07	.04	.07	.04	.04	.04	.07
MgO	21.77	6.59	5.49	5.17	2.09	1.08	.85	.93	.93	.45	13	.27
CaO	5.09	8.20	8.70	7.41	4.08	3.05	3.37	2.82	2.55	1.91	.51	.89
Na_2O	1.39	3.09	3.18	3.80	4.15	5.24	4.82	3.60	3.38	4.41	3.77	3.50
K_2O	.66	.94	1.12	1.04	2.36	2.16	2.19	3.80	4.08	3.63	4.37	4.47
BaO	--	--	.07	.04	--	--	--	.12	.09	--	--	.01
TiO_2	.34	1.39	1.31	1.79	.55	.33	.40	.77	.39	.25	.06	.14
P_2O_5	.10	.24	.49	.37	.15	.26	.14	.25	.14	.05	.04	.03
CO_2	.02	--	--	--	.24	.01	.12	.01	--	.02	.01	--
H_2O+	1.63	.47	.91	1.37	.69	.67	.46	.78	.32	.32	.19	.08
H_2O-	.10	.14	.06	.32	.06	.25	.03	.25	.06	.07	.03	.07
Total	99.89	99.75	99.81	99.72	99.85	99.85	99.82	99.74	99.79	99.68	100.11	100.31
Cation percent												
SiO_2	42.04	47.20	49.36	47.75	61.31	61.91	62.94	62.80	66.10	66.59	72.55	70.54
$AlO_{3/2}$	12.33	19.97	19.92	19.37	18.10	19.00	18.72	17.15	16.76	17.11	13.77	14.51
$FeO_{3/2}$	.87	1.12	1.16	2.17	.43	.74	.79	1.04	.36	.48	.16	.63
FeO	6.94	6.37	4.64	5.94	2.03	1.33	1.16	2.74	1.42	.72	.66	1.15
MnO	.11	.12	.09	.13	.04	.06	.03	.06	.03	.04	.03	.06
MgO	29.27	9.15	7.66	7.30	2.90	1.49	1.18	1.32	1.30	.63	.18	.38
CaO	4.92	8.19	8.72	7.52	4.07	3.04	3.36	2.87	2.57	1.91	.51	.89
$NaO_{1/2}$	2.43	5.59	5.77	6.98	7.49	9.43	8.68	6.62	6.15	7.98	6.84	6.36
$KO_{1/2}$	.76	1.12	1.34	1.25	2.81	2.56	2.60	4.60	4.89	4.32	5.22	5.35
BaO	--	--	.03	.02	--	--	--	.04	03	--	--	.01
TiO_2	.23	.98	.92	1.27	.39	.23	.28	.55	.28	.17	.04	.10
$PO_{5/2}$	.08	.19	.39	.30	.12	.20	.11	.20	.11	.03	.03	.02
CO_2	.02	--	--	--	.31	.01	.15	.01	--	.02	.01	--
H_2O	(4.91)	(1.46)	(2.84)	(4.33)	(2.14)	(2.08)	(1.42)	(2.47)	(1.00)	(1.00)	(.60)	(.23)
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
O	142.51	154.19	155.02	151.79	164.17	163.60	166.23	164.67	168.59	168.45	172.97	171.89
OH	9.82	2.92	5.68	8.66	4.28	4.16	2.84	4.94	2.00	2.00	1.20	1.00
Total anions	152.33	157.11	160.70	160.45	168.45	167.76	169.07	169.61	170.59	170.45	174.17	172.89
Molecular norm												
Q	--	--	2.64	--	18.93	18.26	21.34	20.95	25.85	25.03	34.72	32.48
Or	3.80	5.60	6.70	6.25	14.05	12.80	13.00	23.00	24.45	21.60	26.10	26.80
Ab	12.15	27.95	28.85	34.90	37.45	47.15	43.40	33.10	30.75	39.90	34.20	31.80
An	22.85	33.15	32.03	27.85	17.80	13.50	15.15	12.85	12.10	9.20	2.25	4.30
C	--	--	--	--	.68	1.61	1.38	.79	.88	1.13	.81	1.07
Wo	0.40	2.48	3.38	2.94	--	--	--	--	--	--	--	--
En	17.44	14.32	15.32	13.08	5.80	2.98	2.36	2.64	2.60	1.26	.36	.76
Fs	3.80	7.76	6.46	6.68	2.92	1.58	1.04	3.46	1.98	.70	1.14	1.60
Fo	30.82	2.99	--	1.14	--	--	--	--	--	--	--	--
Fa	6.72	1.60	--	.57	--	--	--	--	--	--	--	--
Ap	.21	.51	1.04	.80	.32	.53	.29	.53	.29	.08	.08	.05
Il	.46	1.96	1.84	2.54	.78	.46	.56	1.10	.56	.34	.08	.20
Mt	1.31	1.68	1.74	3.25	.65	1.11	1.18	1.56	.54	.72	.24	.94
Cc	.04	--	--	--	.62	.02	.30	.02	--	.04	.02	--
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 1.—Continued

	Measured mode [1]			Calculated molecular mode [2]								
Quartz			0.5	3.65	21.50	20.16	22.53	21.73	28.02	26.00	35.15	
Plagioclase	27.04	57.3	58.3	49.10	53.05	59.95	58.25	42.85	41.90	48.75	36.30	
(An content)	(60–65)	(47)	(45)	(29)	(29–30)	(22)	(26)	(23)	(27)	(18)	(6)	
Orthoclase					7.50	8.15	7.95	19.40	20.25	18.20	24.50	
Biotite	8.2	7.0	4.7	12.49	12.93	9.39	9.79	7.40	9.60	5.19	3.40	
Muscovite						1.80	1.35		.10	2.24	.90	
Hornblende	16.0	15.0	31.1	33.39	6.52			8.54				
Augite	19.2	19.2	3.8									
Olivine	29.0											
Allanite									.16			
Apatite			.8	.80	.33	.53	.29	.53	.30	.08	.08	
Magnetite	.2	1.5	.8	3.00		.96	.40	.78	.20	.36	.12	
Ilmenite				1.90		.26	.20	.32	.10	.14		
Rutile									.18			
Sphene							.15	.60				
Stilbite							.05					
Calcite										.04		
Total	100.0	100.0	100.0	104.33	101.83	101.20	100.96	102.15	100.81	.101.00	100.45	
Less calcium								.70				
Total								101.45				

[1] The presence of several ferromagnesian minerals (augite, hornblende, biotite, and olivine) makes calculating the mode for the gabbros impossible.

[2] The mode was calculated from molecular norm by regrouping the oxides. In calculation the formulas for biotite and hornblende were modified from those determined from the analyses by Larsen and Schmidt (1958, table 9, nos. 2 and 3) for these minerals in tonalites of this area. The magnesium and the remaining part of iron, after forming ilmenite and magnetite, were divided between biotite and hornblende using arithmetic equations. The rest of the potassium and aluminum will determine the amount of orthoclase if no muscovite is present.

In many localities west of Beaver Creek, the quartz monzonite contains evenly scattered dark spots 1 to 2 cm in diameter. The centers of these spots are cordierite, which is altered to yellowish-green pinite and light-grayish-green chlorite along the cracks and borders (fig. 7). More chlorite borders the cordierite.

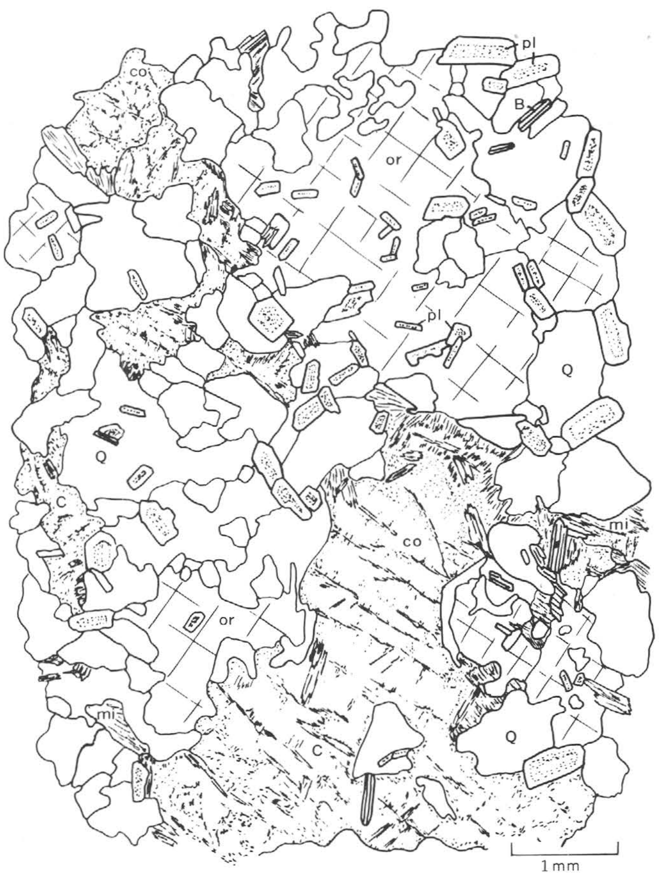


FIGURE 7.—Camera lucida drawing of partly altered cordierite (co) in the quartz monzonite along Beaver Creek (loc. 578). Orthoclase (or); quartz (Q); plagioclase (pl); muscovite (mi); biotite (B).

Many grains of cordierite are completely altered to pinite in which the cracks are filled by chlorite. Chlorite that surrounds the grains of pinite forms radiating aggregates. Along the edges of these aggregates, brown biotite has crystallized at the expense of chlorite. The sequence of recrystallization is cordierite⟶pinite⟶chlorite⟶biotite. West of Beaver Creek, all cordierite is altered to pinite and chlorite or to fine-grained aggregates of chlorite and muscovite (fig. 8). These aggregates have irregular outlines and contain relict cracks filled by chlorite just as do the cordierite and pinite. The presence of every step of alteration of cordierite indicates that the cordierite is a relict mineral and not in equilibrium in this quartz monzonite.

As cordierite is abundant in the metasedimentary country rocks to the west, it is quite probable that the cordierite spots represent remnants of inclusions of these rocks; however, cordierite is not confined to certain zones which might represent relict bedding. Rather, the distribution is irregular and, together with the hypidiomorphic texture of the quartz monzonite, indicates that the magma that picked up the fragments of cordierite-bearing country rock was moving and hot enough to melt or digest all other minerals of the fragments except the cordierite. The small lath-shaped strongly zoned plagioclase crystals were floating in this magma. During the final cooling period, the large anhedral crystals of quartz and feldspars crystallized and enclosed the preexisting small laths of plagioclase. During this phase, the cordierite altered to pinite and chlorite because of lower temperature and the presence of more water (in the residual solution). The temperature was still high enough for the crystallization of biotite at the expense of chlorite derived from cordierite and of potassium present in the magma surrounding the inclusions.

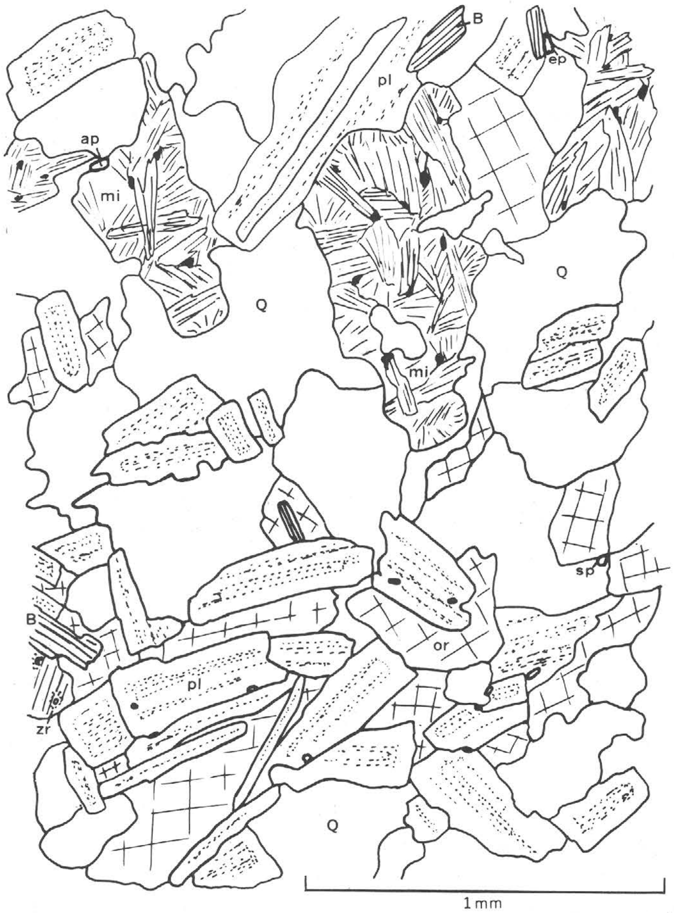


FIGURE 8.—Camera lucida drawing showing aggregates of muscovite and chlorite (mi), originally cordierite, in fine-grained quartz monzonite along Beaver Creek (loc. 1065). Quartz (Q); sphene (sp); epidote (ep); plagioclase (pl); orthoclase (or); biotite (B); apatite (ap); black, magnetite; zircon (zr).

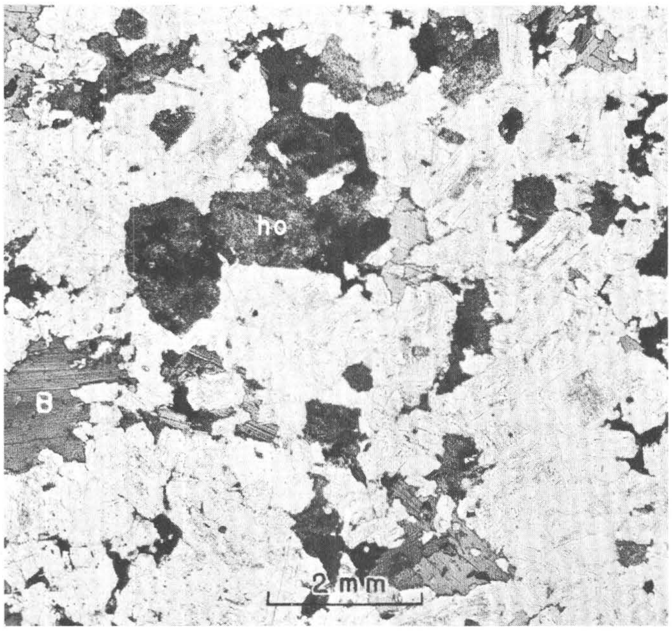
Dioritic rocks along the northern border zone of the stock are medium-grained dark-gray hornblende-biotite-plagioclase rocks with interstitial quartz. Plagioclase is subhedral, twinned, and strongly zoned, with centers An_{40-42}, and borders An_{27}. Sphene, magnetite, apatite, and zircon are the accessories. Small bodies of similar diorite crop out along the contacts of the stock (fig. 9*A*, *B*).

Road cuts in dioritic rocks along Beaver Creek expose a number of dark- to brownish-gray inclusions of coarse-grained olivine gabbro and pyroxene-hornblende gabbro. The inclusions of olivine gabbro range from 30 cm to 1 m in length and from 20 to 50 cm in thickness. They consist of about 30 percent plagioclase, 20 percent enstatite-hypersthene, 30 percent olivine, 14 percent hornblende, 6 percent biotite and a little pyrrhotite. Plagioclase (An_{60-65}) occurs as subhedral lath-shaped crystals which range from 1 to 3 mm in length, show complex twinning, and are oriented at random. Enstatite-hypersthene, brown hornblende, and biotite form large anhedral crystals, 3 to 5 mm in diameter and include round olivine crystals that range from 0.5 to 2 mm in diameter (fig. 10).

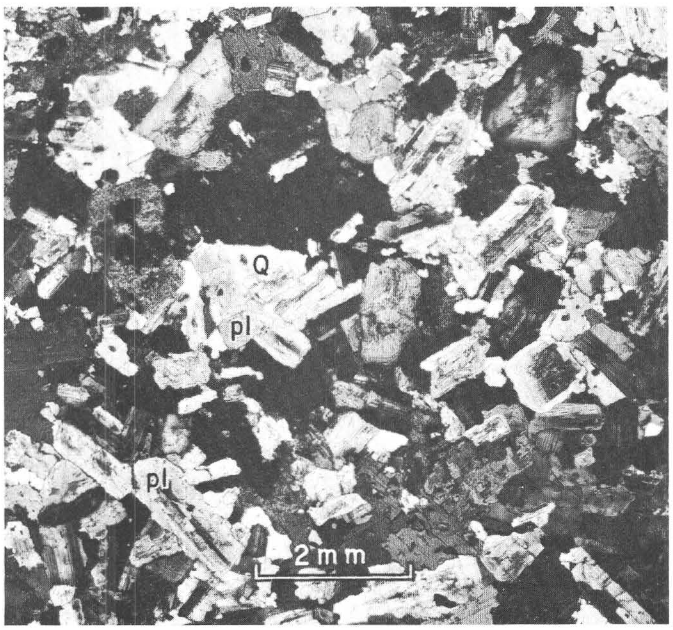
The olivine crystals are chrysolite with $\alpha=1.678\pm0.001$, $\beta=1.696\pm0.001$, $\gamma=1.717\pm0.002$. Enstatite-hypersthene has $\alpha=1.673\pm0.001$,$\gamma=1.691\pm0.001$; and $-2V$, large; it contains about 20 percent of the iron end member. Most of the hornblende is brown and shows $\gamma=1.677\pm0.002$; and $\gamma\wedge c=20°$; but parts of some grains are grayish green. Biotite is strongly pleochroic with γ=reddish brown and α=pale yellow. The optical properties, $\gamma=1.601\pm0.001$ and $-2V$=small, indicate that it is eastonite rich in magnesium. A chemical analysis of the olivine gabbro is given in table 1, No. 1063.

Loose blocks of fine- to medium-grained dark pyroxene gabbro occur for 1 mile along Beaver Creek in sec. 7, T. 40 N., R. 7 E. Light-gray quartz monzonite is exposed to the north and to the south of the gabbro. The minerals in the gabbro are plagioclase (An_{47}), hypersthene, clinohypersthene, hornblende, biotite, magnetite, and apatite. The texture of the gabbro is hypidiomorphic (fig. 9*C*, *D*). Plagioclase occurs in stubby laths, which range from 1 to 2 mm in length and are oriented at random. Dark constituents form anhedral grains that have irregular borders. Most pyroxene grains are surrounded by hornblende, and spots of hornblende are common in pyroxene. Clinohypersthene contains abundant small ilmenite lamellae oriented parallel to the cleavages. Biotite flakes, 0.5 to 1 mm in diameter, are clustered with other dark constituents and include rounded magnetite grains.

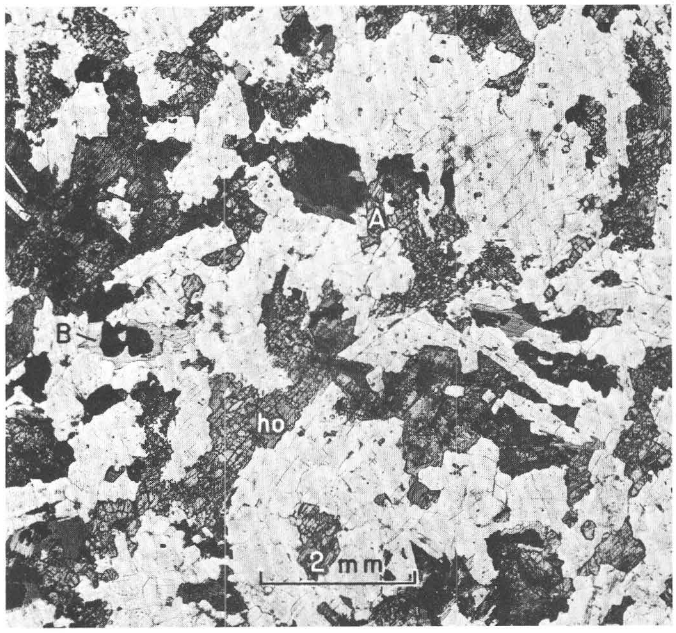
Hypersthene is pleochronic with α=reddish tan, β=pale tan, γ=light bluish green, and $-2V$=large. The indices of refraction, $\alpha=1.696\pm0.002$, $\gamma=1.771\pm0.002$, indicate that it contains about 37 percent iron end member (Winchell and Winchell, 1951, p. 406). Clinohypersthene shows $\gamma\wedge c=31°$, $+2V$ about 65°, and $\alpha=1.689\pm0.002$, $\gamma=1.709\pm0.002$—values which indicate according to Winchell's curves about 32 percent iron end member. Hornblende is brownish gren and the indices of refraction $\alpha=1.668\pm0.002$, $\gamma=1.690\pm0.002$, and $\gamma\wedge c=17°$ indicate it to be richer in iron than the hornblende in the olivine gabbro. Biotite is dark brown, with $\gamma=1.648\pm0.002$. Some of the gabbro is coarser grained and lighter in color (spec. 1072) than the common variety (spec. 1073). The lighter colored variety has a few small quartz grains between the plagioclase laths, and most of the dark minerals are green hornblende. All the pyroxene is surrounded by hornblende and shows spotty alteration to this mineral. Tiny inclusions of magnetite are common in hornblende. Chemical analyses of a common gabbro (spec. 1073)



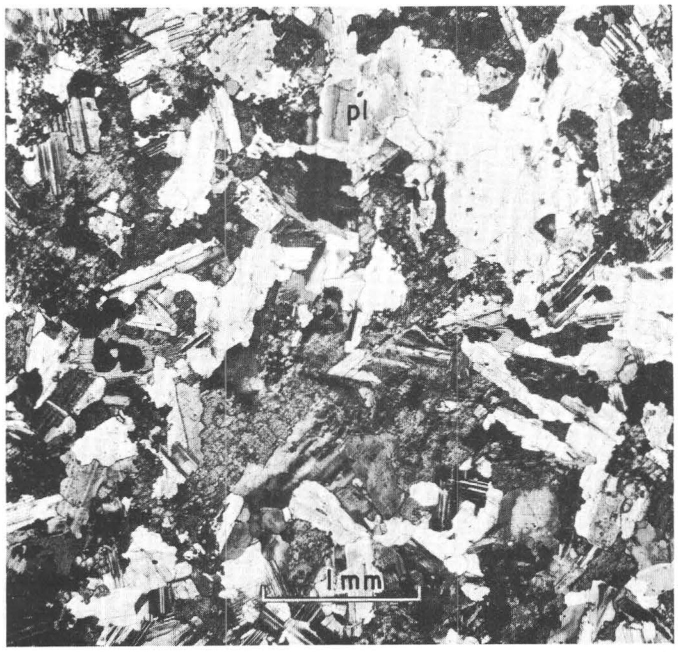
A, Quartz diorite along Beaver Creek (loc. 574). Dark minerals are hornblende (ho) and biotite (Bi). Plane-polarized light.



B, The field of figure *A* with crossed nicols. Plagioclase (pl) occurs in lath-shaped crystals that are twinned and zoned. Quartz (Q) is interstitial.



C, Gabbro along Beaver Creek (loc. 1073). The main dark constituents are pyroxene (A) and hornblende (ho). Biotite (Bi) and magnetite (black) occur in small quantities. Plane-polarized light.



D, The field of figure *C* with crossed nicols. Plagioclase (pl) is subhedral, shows complex twinning, and is zoned.

FIGURE 9*A*–*D*.—PHOTOMICROGRAPHS OF QUARTZ DIORITE AND GABBRO OF THE QUARTZ MONZONITE SERIES.

and of a light-colored variety (spec. 1072) are reported on table 1. The light-colored variety is slightly more silicic and contains less iron and magnesium than the common variety.

FIGURE 10.—Camera lucida drawing of olivine gabbro. From an inclusion in quartz monzonite along Beaver Creek (loc. 1063). Olivine (ol); augite (A); hornblende (ho); plagioclase (pl); chlorite (chl); biotite (B).

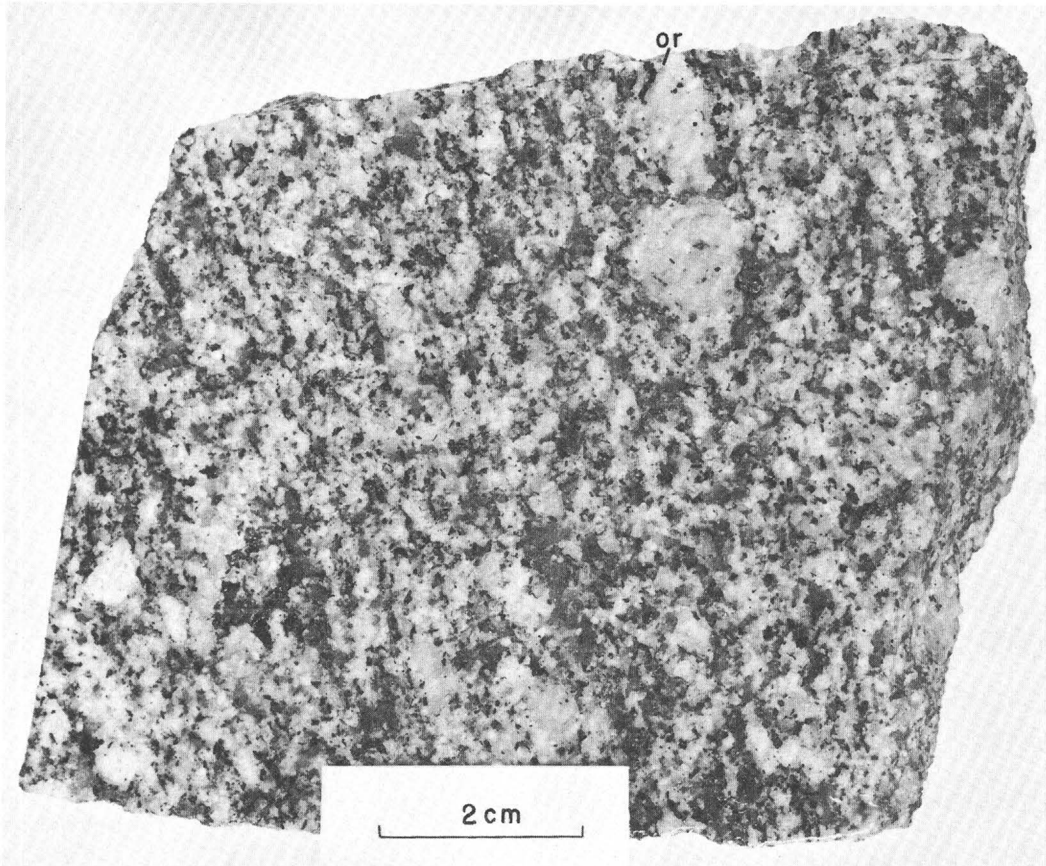
COARSE-GRAINED QUARTZ MONZONITE AND MONZOTONALITE

Most of the quartz monzonite in the southern part of the Pierce area is light gray, coarse to medium grained and contains orthoclase crystals that are larger in size than the other mineral grains (fig. 11*A*). The size, shape, and number of the large orthoclase crystals vary, so that the rock is rather inhomogenous. This inhomogeneity is increased by variation in the amount of interstitial orthoclase in the groundmass. At most places, the orthoclase crystals are anhedral to subhedral and range from 0.5 to 2 cm in diameter, but in a few localities euhedral phenocrysts as much as 5 cm in diameter abound. These large phenocrysts show well-developed (001), (010), (110), and (201) faces. They are more resistant to weathering than the rest of the rock, and can be picked by hand from decomposed outcrops, as for instance along Musselshell Creek (loc. 830), 2 miles south of Hemlock Butte (loc. 1126), and along Swede Creek (loc. 1976) near the western border of the mass. The average grain size of the groundmass ranges from 0.5 to 3 mm. In a few outcrops, however, the groundmass is coarse grained; many plagioclase grains range from 0.5 to 2 cm in diameter. The amount of orthoclase in the groundmass is about 10 to 25 percent. The amount of quartz is generally less than that of plagioclase (An_{26-28}) and the amount of biotite is 3 to 6 percent.

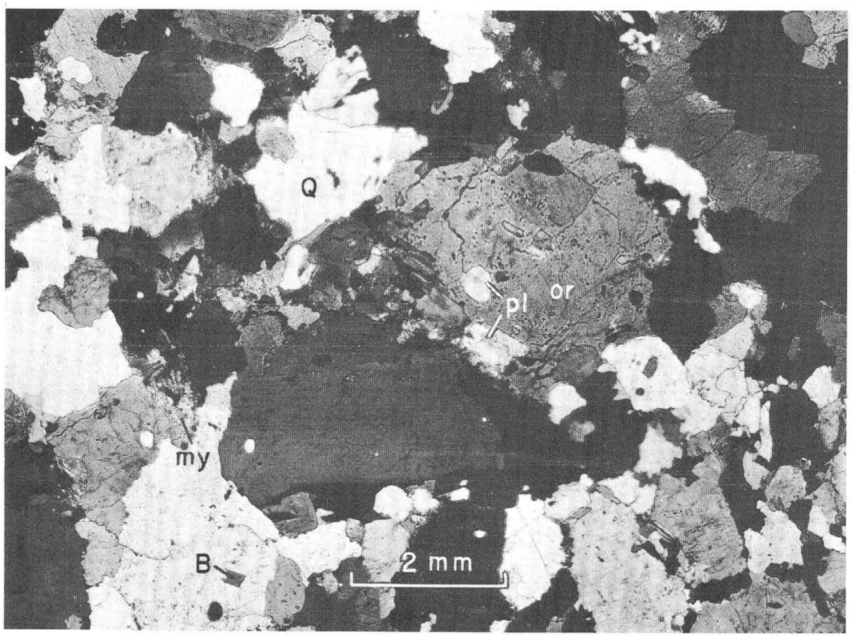
The texture of the quartz monzonite with orthoclase phenocrysts is very different from the texture of the quartz monzonite along Beaver Creek. The texture of the groundmass (fig. 11*B*) is similar to that found in the massive tonalite. Some of the plagioclase grains are subhedral and zoned, whereas others are anhedral and form granoblastic texture with irregularly shaped or rounded grains of quartz and flakes of biotite (fig. 12). The subhedral grains of plagioclase tend to be larger than the anhedral ones; they range from 3 to 4 mm in diameter, whereas the anhedral grains plagioclase are about 1 to 3 mm in diameter, as are the quartz grains. A few small grains of quartz are interstitial. Rarely, myrmekite grains appear, with rounded borders against orthoclase. Some rodlike inclusions of quartz in the myrmekite extend over the border into the orthoclase; some of the myrmekite was probably replaced by orthoclase in the latest episode of crystallization.

Biotite is the only dark constituent. It occurs in flakes, 1 to 2 mm long, between the quartz and plagioclase grains and has a subparallel orientation giving weak gneissic structure to some outcrops. The index of refraction $\gamma = 1.649 \pm 0.002$ indicates that this biotite is similar to that in the quartz monzonite along Beaver Creek. These biotites are richer in iron than the biotite in the quartz diorite. A small amount of muscovite occurs with biotite and magnetite; apatite and zircon are the accessory minerals.

The orthoclase phenocrysts in a fine- to medium-grained light-gray groundmass are perthitic and contain only a few small inclusions of biotite, quartz, plagioclase (An_{28}), and zircon. The indices of refraction are $\alpha = 1.520 \pm 0.001$, $\beta = 1.523 \pm 0.001$, $\gamma = 1.527 \pm 0.001$, and X-ray study shows a good orthoclase pattern. Some orthoclase phenocrysts in a fairly fine grained rock about 2 miles south of Hemlock Butte were separated by means of heavy liquids and analyzed chemically (table 2). They contain 16.77 molecular percent albite, 5.85 molecular percent barium feldspar, and only a small amount of anorthite. The high content of barium shows that orthoclase is a chief carrier of barium in the porphyritic quartz monzonite. This high content of barium makes it difficult to compare the com-



A, Medium-grained light-gray quartz monzonite with a few larger grains of orthoclase (or). Note crude parallel orientation of biotite.



B, Photomicrograph of the rock shown in figure *A*. Orthoclase (or) includes a few small plagioclase (pl) grains; some myrmekite (my) occurs between the orthoclase and bordering plagioclase. Quartz (Q); biotite (B).

FIGURE 11.—PHOTOGRAPH AND PHOTOMICROGRAPH OF QUARTZ MONZONITE ALONG MUSSELSHELL CREEK (loc. 831).

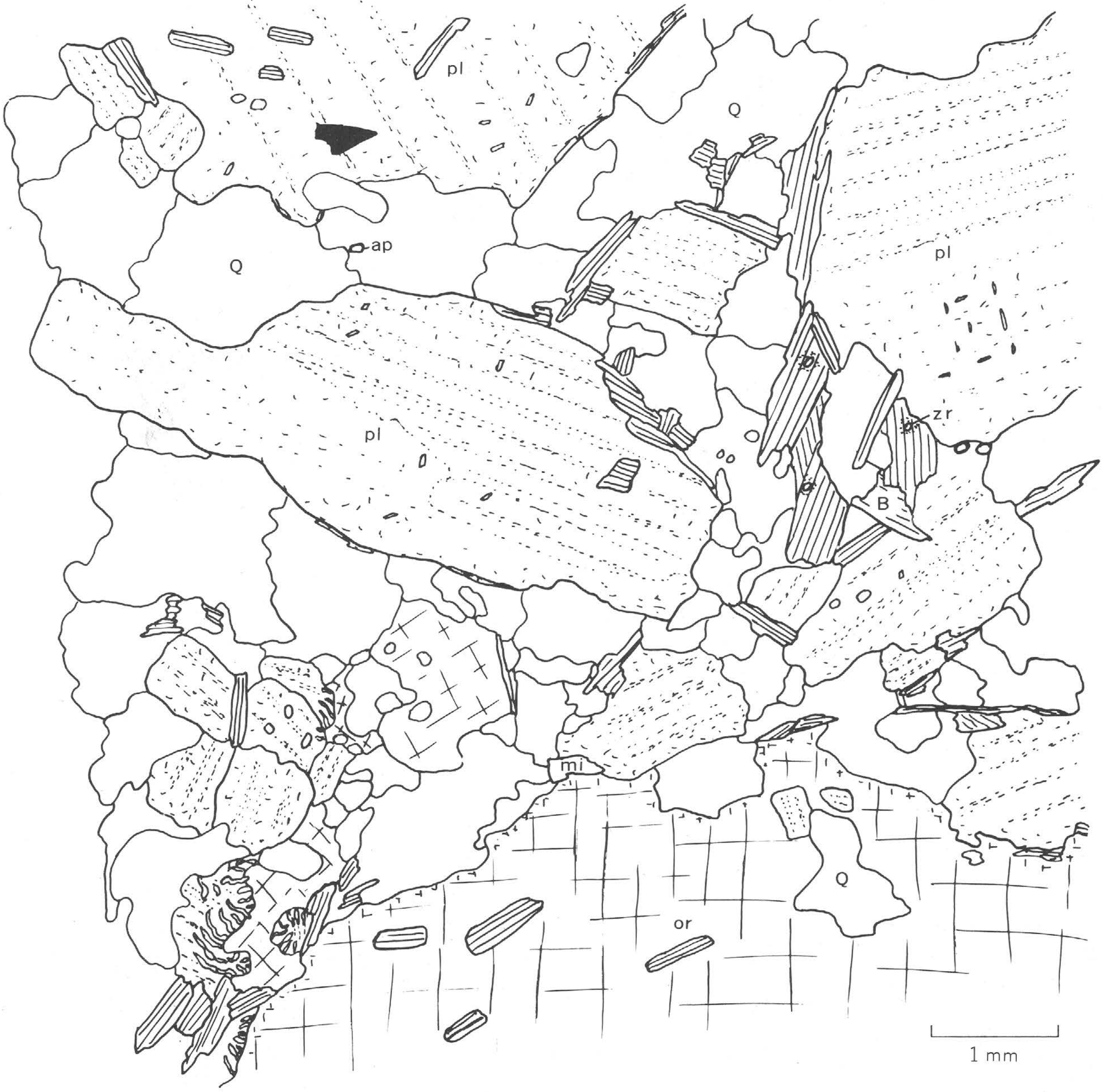


FIGURE 12.—Camera lucida drawing of coarse-grained quartz monzonite south of Hemlock Butte (loc. 1125). Quartz (Q); plagioclase (pl); orthoclase (or); biotite (B); apatite (ap); zircon (zr); black, magnetite; muscovite (mi).

position of these phenocrysts with the compositions used in the experimental work by Tuttle and Bowen (1958). The orthoclase-albite ratio of this analysis, together with the general amount of perthite as determined under the microscope, indicates that the quartz monzonite in the northern part of the Idaho batholith is type B of the subsolvus granites in the classification of Tuttle and Bowen.

Some specimens have scattered small interstitial groups of radiating crystals with low indices of refraction, negative elongation, and small extinction angle, probably stilbite.

The "groundmass" of the coarse-grained quartz monzonite (table 1, No. 1125) has a chemical composition between that of quartz monzonite and the tonalites analyzed earlier from the Dent area, about 20 miles west-northwest of Pierce (Hietanen, 1962, table 10). The total composition of this groundmass plus the phenocrysts has the composition of quartz monzonite. The origin of the phenocrysts and the sequence of crystallization are discussed in a later section.

The northern border zone south of Hemlock Butte consists of medium-grained, light-gray rock with only a small amount of interstitial orthoclase (fig. 13).

TABLE 2.—*Chemical composition of orthoclase phenocrysts from quartz monzonite 1.5 miles south of Hemlock Butte*

[Analyst: Dorothy F. Powers, U.S. Geol. Survey]

	Weight percent	Inclusions			Feldspar after subtraction of inclusions		Molecular proportions	Minerals (molecular percent)
		Biotite	Kaolinite	Quartz	a	b = a, calculated to 100		
SiO_2	63.77	0.16	0.74	0.82	62.05	64.02	10654	Orthoclase 76.81
TiO_2	.01	.01						Albite 16.77
Al_2O_3	19.04	.07	.63		18.34	18.92	1856	Celsian 5.83
Fe_2O_3	.01	.01						Anorthite .59
FeO	.05	.05						
MnO	.00							
MgO	.03	.03						
CaO	.06				.06	.06	11	
BaO	1.61				1.61	1.66	108	
Na_2O	1.87				1.87	1.93	311	
K_2O	13.03	.03			13.00	13.41	1424	
P_2O_5	.01	.01						
H_2O+	.10	.01	.11					
H_2O-	.02							
Total	99.61	.38	1.48	.82	96.93	100.00		100.00

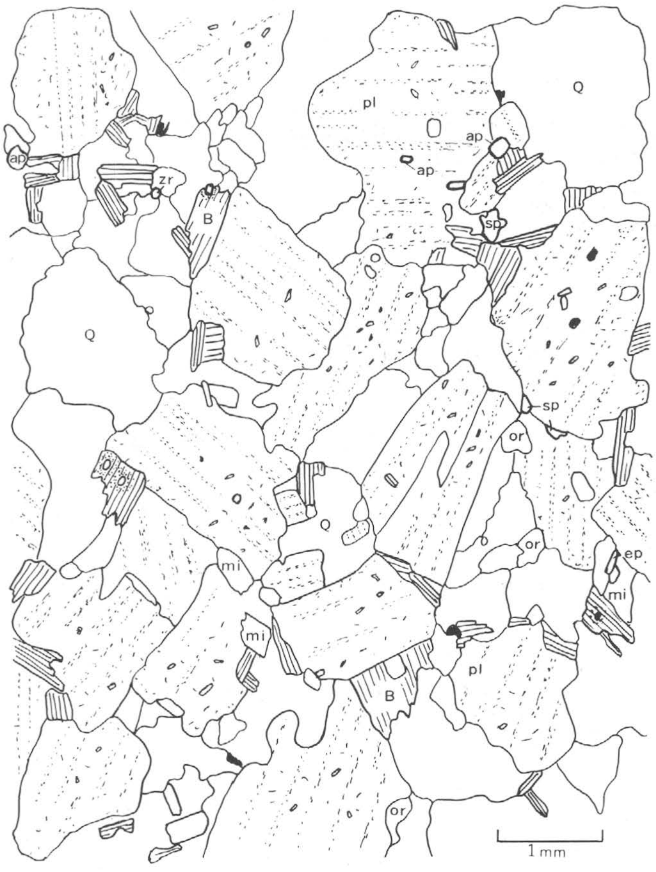


FIGURE 13.—Camera lucida drawing of the potassium-poor border zone of quartz monzonite south of Hemlock Butte (loc. 1121). Quartz (Q); plagioclase (pl); biotite (B); muscovite (mi); orthoclase (or); zircon (zr); sphene (sp); epidote (ep); apatite (ap); black, magnetite.

Chemical analysis of this rock (table 1, No. 1121) shows that it contains more calcium and sodium and less silicon and potassium than the main part of the quartz monzonite. In its mineral content and composition this border facies is between quartz monzonite and the intrusive tonalite and is therefore called monzotonalite. The transition from the potassium-poor border zone into normal quartz monzonite takes place over about a hundred meters. In this transitional zone, large orthoclase crystals are embedded in a fine-grained groundmass, the composition of which is similar to that of the border facies. Southward, more interstitial orthoclase appears and phenocrysts there are smaller and less euhedral.

The quartz monzonite in the southern part of the Bungalow area is light gray, coarse grained, and slightly gneissic. The grains of orthoclase are somewhat larger than those of plagioclase, quartz, and biotite. The amount of orthoclase in specimens from south of Larch Butte is about 10 percent. Many outcrops elsewhere contain large subhedral orthoclase crystals, which together with the monzotonalitic groundmass give the average composition of common quartz monzonite. Most of the rocks mapped as quartz monzonite in the easternmost part of the Bungalow area are very coarse grained and grade to a pegmatitic quartz-feldspar rock with some muscovite.

GRANITE

The granite near Bungalow Ranger Station is a very light gray coarse-grained homogeneous rock in which the major constituents—quarts, feldspars, and biotite—are easily recognized (fig. 14*A*). The grains of quartz and orthoclase are 2 to 3 mm in diameter, whereas those of plagioclase are 0.5 to 2 mm long. Orthoclase is twinned according to the Carlsbad law, and contains perthite and tiny dustlike inclusions of an opaque mineral, probably hematite. Biotite, partly altered to chlorite, is in small dark-brown flakes or groups of

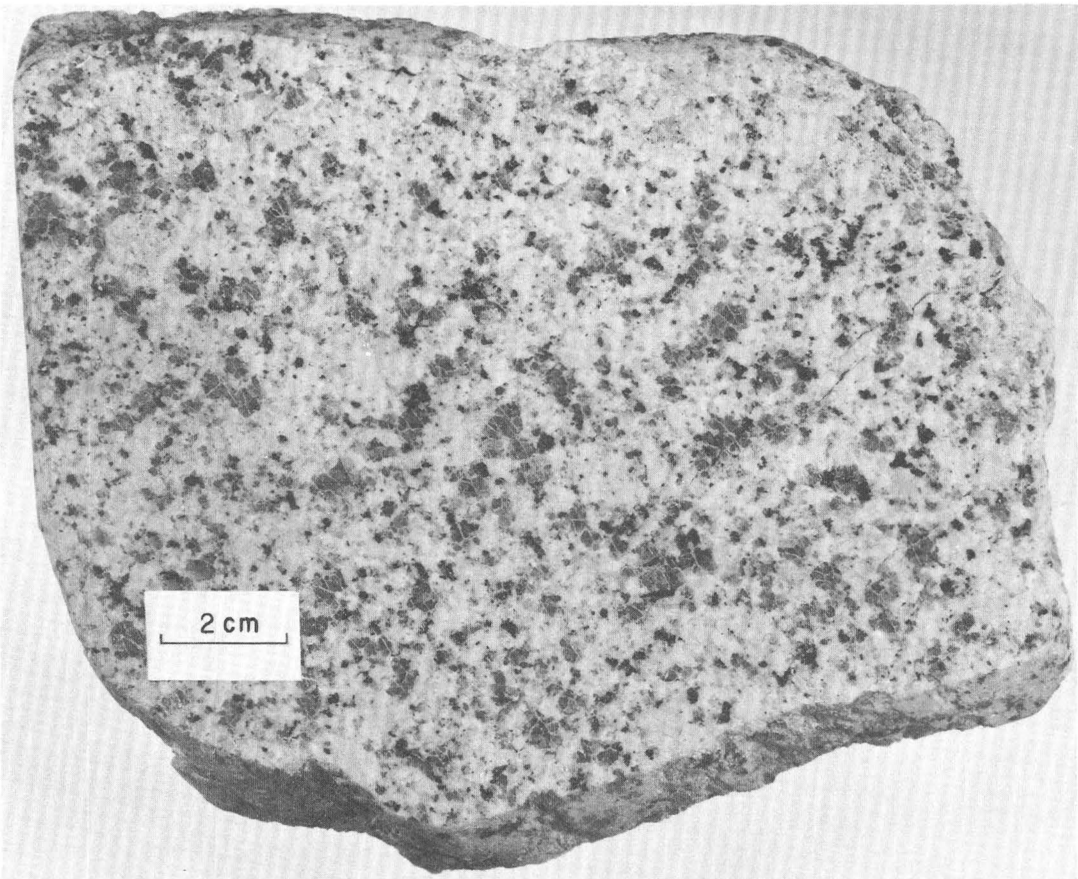


FIGURE 14A, Photograph of granite near Bungalow (loc. 758).
Coarse-grained granite in which quartz grains (gray) and biotite flakes (black) are easily seen.

flakes. A few grains of allanite and abundant tiny crystals of zircon with strongly pleochroic halos are included in biotite. Some muscovite occurs next to the biotite.

Two chemical analyses of this granite have been published and are shown in table 1 as Nos. 758 (Hietanen, 1962) and L 219 (Larsen and Schmidt, 1958) for comparison with the analyses of quartz monzonite. Both analyses of granite are much alike and show that the amounts of potassium and sodium are larger and those of calcium and magnesium smaller than the amounts of these elements in the quartz monzonites.

The outcrops just east of the Bungalow area between Pot Mountain and Bar Point are porphyritic coarse-grained granite with quartz and feldspar phenocrysts, 1 to 2 cm in diameter, embedded in a medium-grained groundmass of quartz, feldspar, and biotite.

The granite northeast of the mouth of Governor Creek and west of Deadhorse Lookout is coarse grained and porphyritic. It contains abundant euhedral to subhedral phenocrysts of orthoclase, 1 to 2 cm in diameter, and subhedral grains of quartz, about 1 cm in diameter. The phenocrysts of orthoclase contain about 20 percent albite as perthitic stringers and are surrounded by narrow lacy rims of granophyrically intergrown orthoclase and quartz (fig. 3*A*). All orthoclase in the rims is perthitic and has the same optical orientation as the host orthoclase. The groundmass is medium grained and consists of quartz, albitic plagioclase, orthoclase, and small flakes and needles of biotite. Some quartz occurs in small subhedral or round crystals included in plagioclase and orthoclase. Tiny prisms or apatite and small crystals of zircon with pleochroic halos are the accessories.

The pink medium-grained granite west of Deadhorse Mountain consists of about 60 percent orthoclase, 10 percent plagioclase, and 30 percent quartz, with a little biotite and magnetite. The orthoclase crystals are 1 to 2 mm long, subhedral, and include only about 1 percent perthitic stringers of albite. Many grains have Carlsbad twinning and all are clouded by tiny dustlike inclusions, similar to those in the coarse-grained granite and in the porphyritic variety.

FIGURE 14*B*, Photomicrograph of the specimen of figure 14*A*. Orthoclase (or) is perthitic, includes a few grains of plagioclase (pl), and is clouded by tiny inclusions of hematite. Quartz (Q) is subhedral. Crossed nicols.

PEGMATITES

Two petrologically different types of pegmatite, plagioclase pegmatite and granite pegmatite, are common in the area. The major difference between them is in the amount of potassium-bearing minerals; the plagioclase pegmatite contains little or no potassium feldspar and muscovite, whereas the granite pegmatite is rich in these minerals.

PLAGIOCLASE PEGMATITE

Plagioclase pegmatite is common in the metamorphic rocks, in the quartz diorite, and in its tonalitic border facies, but is lacking in the quartz monzonite and granite. In the metamorphic rocks, pegmatite occurs in veins a few millimeters to a meter wide. The narrow veins are parallel to the bedding or more rarely parallel to the foliation, whereas the wide ones follow fractures and joints.

The mineralogy is fairly simple; either plagioclase (An_{25}) and quartz occur in equal amounts or the amount of plagioclase is larger (as much as 60 percent). Biotite is the only dark constituent in most of the pegmatite in the metamorphic rocks, whereas many dikes transecting the quartz diorite have hornblende also. Small amounts of muscovite, chlorite, sphene, zircon, and apatite are common.

Plagioclase pegmatite is especially common along the contact zones of the quartz diorite and its border facies, the gneissic tonalite. For instance, along Orofino Creek southeast of Pierce, much of the rocks mapped as tonalite consists of plagioclase pegmatite and there is every gradation from an equigranular homogeneous tonalite to an inhomogeneous coarse-grained plagioclase-quartz rock in which biotite occurs either as schlieren or as large plates, 0.5 to 2 cm in diameter.

The mode of occurrence of the plagioclase pegmatite indicates that it is a result of accumulation of quartzofeldspathic material along the contact zones, shear planes, joints, and other structural planes. Their mineralogy indicates that they are genetically connected with the formation of gneissic tonalite, which is considered to be a result of feldspathization of the country rocks near and along the contacts of quartz diorite. The processes leading to this feldspathization have been discussed earlier (Hietanen, 1962). Metamorphic differentiation in biotite gneiss can alone produce veinlets of plagioclase pegmatitic composition with little or no biotite.

GRANITE PEGMATITE

Granite pegmatite is more common near and in quartz monzonite and granite than in other settings. Most of these pegmatites are discordant, but concordant masses of varied thicknesses occur in the metamorphic rocks next to the coarse-grained quartz monzonite in the southeastern part of the Bungalow area. Large pegmatitic masses occur along many contacts of the coarse-grained quartz monzonite; this mode of occurrence is very similar to that of the plagioclase pegmatite along the contacts of quartz diorite. Every gradation from the pegmatite to a coarse-grained quartz monzonite occurs along Weitas Creek and in the area west of it. Pegmatite also occupies the contact between the quartz monzonite and the quartz diorite along Weaver Creek.

Pegmatite dikes, 10 to 20 cm wide, and masses up to 50 cm in diameter are common in the northeastern part of the granite pluton northeast of Bungalow. The metamorphic rocks near the quartz monzonite bodies have been migmatized and contain abundant veinlets, 1 to 10 mm thick, of granitic-pegmatitic composition. In addition to these rather fine grained narrow veinlets that parallel the bedding, there are veins and dikes, 20 cm to 1 mm thick, parallel to the bedding and the joint systems.

The minerals in fine- to medium-grained veinlets are quartz, plagioclase (An_{20}), orthoclase, and a few small flakes of biotite and muscovite. The granitic veins in the migmatized biotite gneiss are mineralogically similar to the light-colored layers of the thinly laminated biotite gneisses of the Wallace formation, except that the borders of the veins tend to be more irregular than the bedding planes of the laminated rocks. However, there is every gradation from a laminated rock to a migmatite, and it is often impossible to tell on the basis of field study whether the veins were formed by recrystallization of sedimentary material, or by introduction of granitic material, or perhaps by introduction only of potassium. Study of textures and mineralogy is helpful but not conclusive.

Since the composition and crystal structure of potassium feldspar depends on the temperature of crystallization, it might be possible in some cases to distinguish between the metamorphic and igneous feldspar either by determining the amount of albite in orthoclase (Tuttle and Bowen, 1958, p. 128–129) or by determining the triclinicity, that is the "degree of order" of Al and Si atoms in the potassium feldspar as suggested by Goldsmith and Laves (1954). The disordered (monoclinic) form crystallizes at high temperatures and the ordered (triclinic) form at low temperatures. In the intermediate types the triclinicity is a function of temperature of crystallization.

The X-ray powder diffraction data shows that the potassium feldspar in quartz monzonite in the area studied is orthoclase, but in the quartzofeldspathic laminae of the metasedimentary rocks it is microcline. The triclinicity should therefore offer means to distinguish between the igneous and metamorphic potassium feldspar in the veins. Several samples were examined; some appeared to contain orthoclase but many showed triclinicity of 60 to 70 percent. These intermediate types were further examined under the microscope and compared with those that contain only orthoclase or only microcline. Results of this study are as folows:

All veins near the plutonic rocks contain orthoclase. Most of these veins are medium- to coarse-grained pegmatite, but some resemble the quartzofeldspathic laminae. The latter are fine to medium grained and have granoblastic texture, as do the laminae; they can be distinguished from the laminae, however, because of their reddish color and more irregular shape. Many intermediate types also occur and it seems possible that heating of the sedimentary material to magmatic temperatures changed the triclinic metamorphic feldspar to monoclinic form.

All potassium feldspar farther from the immediate contact zone of plutonic rocks tends to be triclinic. For instance, large orthoclase crystals with Carlsbad twinning in schist next to a granite pegmatite show triclinicity of 70 percent. Components to form this orthoclase were introduced from the nearby pegmatite, which in turn represents the last crystallizing part of quartz monzonite magma. The high degree of triclinicity apparently is due to the low temperature of crystallization. This raises the question: Did all potassium feldspar with trinclinicity of 60 to 70 percent come from igneous sources and thus are most of the veins of igneous origin?

The presence or absence of perthitic lamellae offers additional evidence for the origin of potassium feldspar. All orthoclase in the quartz monzonite is perthitic, contains tiny inclusions of sericite, and is clouded by dustlike inclusions of opaque minerals. The orthoclase in the pegmatitic dikes and in the large veins consists of similar perthite, but the microcline in the gneissic layers of the Wallace formation farther from the batholith is nonperthitic and free of inclusions.

X-ray study of some of this nonperthitic clear potassium feldspar shows a good orthoclase pattern, and it seems possible that this orthoclase crystallized from the sedimentary material in magmatic temperatures. On the other hand, the perthitic clouded orthoclase next to the igneous bodies with similar orthoclase probably crystallized from material introduced from igneous sources.

HYPABYSSAL ROCKS

Hypabyssal dikes and sills transect all rocks of the other types except the Columbia River basalt. They are especially common along fault zones and along the contacts between the plutonic and metamorphic rocks or between two types of plutonic rocks, or they traverse the host rocks at random. Some dikes are cut by plutonic rocks, but many occur parallel to the joints in the plutonic rocks. In composition they range from gabbro through diorite to quartz monzonite and to granite. These structural relations suggest that some dikes may be older than the plutonic rocks but most are younger.

GRANOPHYRIC AND PORPHYRITIC DIKES OF GRANITIC COMPOSITION

Many of the dikes and sills are light- to medium-gray porphyritic rocks with easily recognized light-gray phenocrysts of quartz and white phenocrysts of feldspars. The number of phenocrysts and the ratio between quartz and feldspars among them vary widely. Some dikes have far more quartz than feldspar phenocrysts, whereas others have more feldspar phenocrysts. In some dikes most of the feldspar phenocrysts are orthoclase; in others, plagioclase. Where the orthoclase phenocrysts are more numerous, they are larger than the plagioclase phenocrysts; however, where the amounts of orthoclase and plagioclase phenocrysts are about equal, their sizes also tend to be equal. The phenocrysts commonly range from 1 mm to 1 cm in diameter.

The groundmass is fine to medium grained, 0.1 to 0.5 mm, and consists of quartz, orthoclase, plagioclase, and biotite. Granophyric intergrowth of quartz and feldspars is common in the groundmass, and also around the quartz phenocrysts (fig. 15*A*). In these granaphyric rims the orientation of a part of the quartz is parallel to the host phenocryst but another part forms groups belonging to small individual crystals. Biotite is in small flakes, more rarely as needlelike crystals. Magnetite and zircon are the accessories.

About a mile east of Browns Rock, this common type of granite porphyry grades to a fine-grained spherulitic rock with albite spherules, 0.5 to 1 cm in diameter, in a fine-grained groundmass of tiny polygonal grains of quartz, albite, and orthoclase, flakes of biotite, and small spherules of albite. The grains in this groundmass range from 0.1 to 0.2 mm in diameter.

Several of the granitic dikes along Swanson Creek are medium grained and almost equigranular. Plagioclase crystals are subhedral and smaller than the anhedral grains of quartz and orthoclase. Some quartz occurs in small round grains, many of which are included in orthoclase. Small flakes of biotite occur as the dark constituent. Some of these equigranular dikes have granite porphyry in their center, others are cut by porphyritic dikes.

Near Deadhorse Lookout, the common type of granite porphyry grades to a variety with as much as 60 percent of large phenocrysts. The phenocrysts, 0.5 to 1 cm in diameter, are quartz, orthoclase, and albite. The groundmass, medium- to fine-grained, consists of polygonal grains of quartz, orthoclase, albite, and biotite. Granophyric intergrowth of quartz and feldspars is common around the phenocrysts (fig. 15*B*). This coarse-grained granite porphyry is mineralogically similar to the porphyritic granite border facies of the coarse-grained granite between Deadhorse Lookout and the North Fork of the Clearwater River. Thus there seems to be a complete gradation from coarse-grained granite through porphyritic granite to granite porphyry and further to the spherulitic rock. The field relations and the similarity of composition and mineralogy indicate that all these granitic intrusive rocks solidified from the same magma, the different textures being due mainly to the rate of cooling.

Many of the joints in the coarse-grained granite at Bungalow are filled by dikes of fine- to medium-grained gray rock with scattered drusy vugs. The walls of the dikes are straight, contacts are sharp, and their grains are smaller toward the walls. The vugs are lined by euhedral crystals, 3 to 5 mm long, of smoky quartz and white slightly perthitic orthoclase. The quartz crystals have well-developed prism and rhomb faces. The orthoclase contains abundant small opaque inclusions similar to those in the main part of the granite.

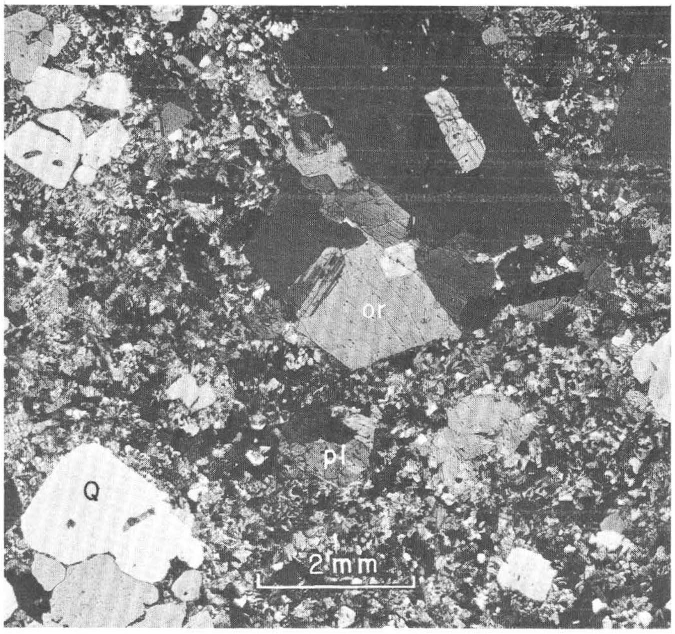
The minerals in these dikes are the same as those in the host granite, but the texture is different. A part of the quartz, plagioclase (An_8), and orthoclase occurs as subhedral or, occasionally, euhedral, crystals in a granophyric groundmass. Both plagioclase and orthoclase are intergrown with quartz in this groundmass. Some of the granophyre has crystallized around euhedral plagioclase and orthoclase grains. The central plagioclase crystals show square cross sections and polysynthetic twinning. Granophyre next to the central feldspar grains is finer grained than that between the grains. All the orthoclase is heavily clouded by tiny dustlike inclusions of opaque iron oxide similar to that in the orthoclase of the coarse-grained granite.

Greenish-brown biotite and chlorite, in amounts usually less than 3 percent, are the dark constituents. Most of them occur as long slender needlelike flakes; only a few small flakes are equidimensional. All the biotite flakes are symplectically intergrown with quartz. Zircon with dark pleochroic halos is included in biotite. The chlorite is deuterically altered biotite.

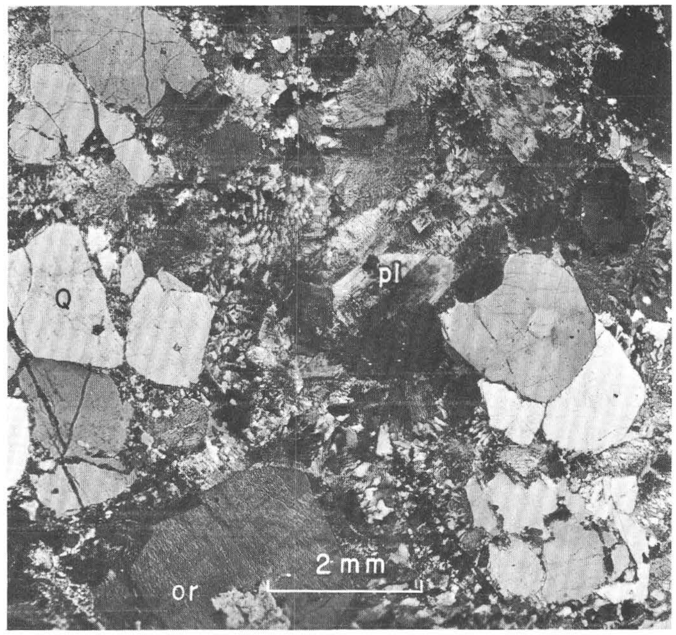
It is noteworthy that all the granitic dike rocks have perthitic orthoclase heavily clouded by tiny opaque inclusions. The orthoclase of the dikes has more perthitic albite and more dustlike inclusions than the orthoclase of the coarse-grained quartz monzonite. These foreign elements were originally in solid solution and their large amount indicates rapid crystallization at high magmatic temperature followed by exsolution. The granophyric groundmass indicates that the final solidification took place near the eutectic temperature, which, according to Tuttle and Bowen (1958, p. 122), is about 650°C at a depth of about 13 km, but higher if closer to the surface.

PORPHYRITIC DIKES OF QUARTZ MONZONITIC AND MONZOTONALITIC COMPOSITION

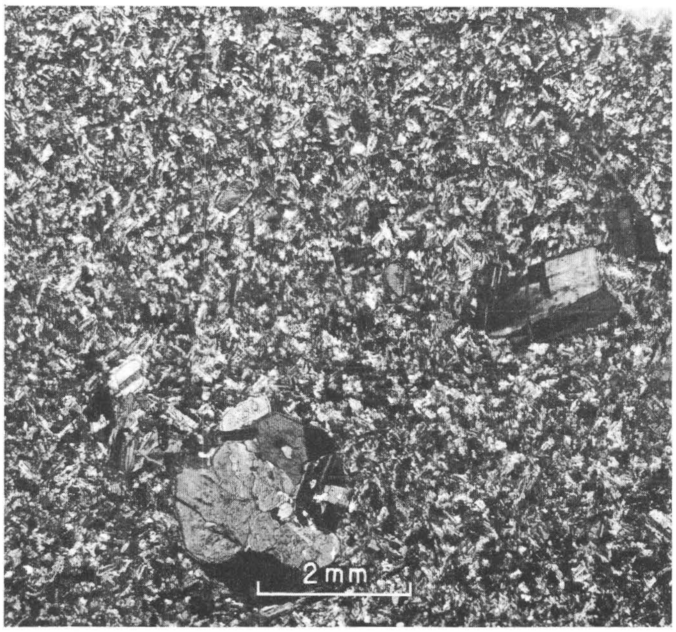
Dikes of intermediate composition vary extensively in their appearance and type of phenocrysts. Most quartz monzonitic dikes have small phenocrysts of plagioclase embedded in fine- to medium-grained dark or medium-gray groundmass of quartz, plagioclase, orthoclase, and biotite (fig. 15*C*). Some dikes, however, are fine grained and equigranular. In the dikes along Sheep Mountain Creek (loc. 1081) light-colored phenocrysts of plagioclase range from 0.5 to 2 mm in diameter, and the fine-grained dark-gray groundmass consists of



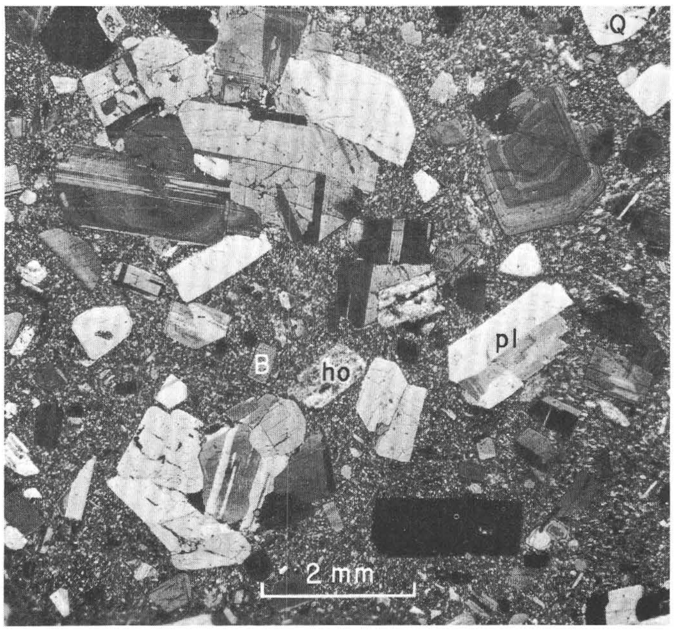
A, A common type of granite porphyry just east of Browns Rock (loc. 719). Phenocrysts are quartz (Q), orthoclase (or), and plagioclase (pl); the groundmass, which consists of these minerals plus a small amount of biotite, is fine to medium grained. Narrow rims of granophyric intergrowth of quartz and orthoclase are common around the quartz phenocrysts.



B, A coarse-grained granite porphyry near Deadhorse Lookout (loc. 1085). Larger phenocrysts are quartz (Q) and orthoclase (or). Plagioclase (pl) forms phenocrysts of medium size. Groundmass is granophyric and contains small flakes of biotite.



C, Quartz monzonitic dike 1½ miles north of Deadhorse Mountain (loc. 1081. Phenocrysts are plagioclase that occurs in tabular crystals or groups of crystals. Groundmass is fine grained and consists of lath-shaped crystals of twinned plagioclase and interstitial quartz, orthoclase, biotite, and hornblende.



D, Monzotonalitic dike 2 miles northeast of French Mountain (loc. 1143). Phenocrysts are plagioclase (pl), quartz (Q), biotite (B), and hornblende (ho). Groundmass is fine grained and contains orthoclase in addition to the minerals that occur as phenocrysts.

FIGURE 15.—PHOTOMICROGRAPHS OF HYPABYSSAL ROCKS.

tiny laths of plagioclase and intersititial grains of quartz, orthoclase, hornblende, and biotite. Sphene and magnetite are the accessory minerals. The chemical composition of these dikes is similar to that of the fine-grained quartz monzonite (table 1, No. 1081).

Dikes that have quartz as well as plagioclase phenocrysts (fig.15*D*) are common; they are similar to the granite porphyry dikes except that the number of quartz phenocrysts is smaller, orthoclase occurs only in the groundmass, the amount of plagioclase is more than 50 percent, and hornblende is common in addition to biotite. The chemical composition of these dikes is intermediate between that of the quartz monzonite and the tonalite (table 1, No. 1143); they contain more calcium and less potassium than the quartz monzonitic dikes and considerably less silicon and potassium than the normal granitic dikes. Because of their intermediate composition, these dikes are called monzotonalitic in this report.

The monzotonalitic dikes east and south of French Mountain are light to medium gray and coarse to medium grained. The phenocrysts, which make up 10 to 40 percent of the rock, consist of about 60 percent plagioclase, 10 percent quartz, 20 percent biotite, and 10 percent hornblende. The plagioclase is strongly zoned and twinned and many "phenocrysts" are made of groups of crystals 1 to 3 mm long. Biotite phenocrysts have hexagonal or rounded outlines and range from 0.2 to 1 mm in diameter. The groundmass is fine grained, granoblastic and makes up about 50 percent of the rock. Some of the biotite is altered to chlorite; sphene and magnetite are accessories. In certain much-altered dikes, abundant calcite fills the centers of hornblende crystals, and leucoxene and rutile are included in altered biotite flakes. A chemical analysis, No. 1143 in table 1, shows that the composition of typical monzotonalitic dike rock is close to that of the medium-grained monzotonalitic border zone of the coarse-grained quartz monzonite.

DIORITIC DIKES

Most dioritic dikes are fine grained, dark to medium gray and equigranular. The major constituents are plagioclase and hornblende; biotite and interstitial quartz occur in small quantities; and sphene, magnetite, and epidote are the accessories. Plagioclase occurs either in small lath-shaped crystals, as along Orogrande Creek (loc. 1139), or as equidimensional grains. The hornblende prisms are dark green, 0.1 to 1 mm long, and unoriented.

A medium-gray fine- to medium-grained dioritic dike cuts quartz diorite just east of the granite stock at Bungalow. About 60 percent of this rock is albite in equidimensional subhedral grains, 0.1 to 0.2 mm in diameter, that contain tiny inclusions of sericite and epidote minerals. Hornblende, which constitutes about 15 percent of the rock, is dark to blue green, and some of the grains have augite in their centers. The amount of quartz is about 15 percent. About 4 percent of the rock is orthoclase, both as small grains and in granophyric intergrowth. Biotite, chlorite, and magnetite occur in small quantities.

GABBROIC DIKES

The gabbroic dikes are fine grained and dark gray, resembling the dioritic dikes. The major constituents are plagioclase (45–55 percent), hornblende (15–35 percent), augite (10–20 percent), biotite (2–15 percent), and magnetite. Plagioclase (An_{44}) is in unoriented lath-shaped crystals in which cracks are filled by green hornblende. Most of the augite is altered to green hornblende that includes small grains and lamellae of ilmenite-magnetite. Hornblende is light green and occurs in aggregates and small prisms. Biotite is reddish brown and contains tiny inclusions of magnetite. Many small flakes are included in the aggregates of hornblende. Small grains of magnetite, irregular in shape, occur with hornblende and biotite. A chemical analysis of a gabbroic dike along Sheep Mountain Creek is No. 1079 in table 1; this dike rock is chemically and mineralogically similar to the gabbro along Beaver Creek and probably is genetically related to it.

GEOCHEMISTRY OF THE IGNEOUS ROCKS

The plutonic and dike rocks range from ultramafic pyroxenite and hornblendite through olivine gabbro, pyroxene and hornblende gabbro, diorite, and quartz diorite to tonalite, quartz monzonite, and granite. The field relations, mineralogy, and chemical composition suggest that there are two separate suites of intrusive rocks: a quartz dioritic suite that includes pyroxenite, hornblendite, hornblende gabbro, quartz diorite, and tonalite; and a quartz monzonitic suite that includes olivine and pyroxene gabbro, diorite, quartz monzonite, and granite. Minerals such as olivine, pyroxene, and orthoclase indicate that the rocks of the quartz monzonitic suite crystallized from a dry magma whereas the minerals of the rocks of the quartz dioritic suite indicate a wet environment in which hornblende and biotite crystallized instead of pyroxenes and orthoclase. Comparison of the chemical composition of the rocks and distribution of the minor elements within each series should help resolve the problem of origin and differentiation of the magmas. Did the two rock series crystallize from the same parent magma or were two separate magmas formed at different places and times?

VARIATION IN THE MAJOR AND MINOR ELEMENTS

Ten new analyses of the rocks belonging to the quartz monzonite series are given in table 1, along with two analyses published earlier (No. 758, Hietanen, 1962; No. L 219, Larsen and Schmidt, 1958) of the granite at Bungalow. Results of spectrographic analysis of minor elements in the same specimens are presented in table 3. Silica variation diagrams (fig. 16–20) are based on the data in these two tables (1, 3) and on the data published earlier on intrusive rocks just northwest of the present area (Hietanen, 1962, tables 1, 10, 15, 26, and 27). The major elements are plotted in ionic percentages. The minor elements are plotted in both weight percent, on the right, and in number of ions, corresponding to the ionic percentage of major elements, on the left.

Fairly smooth curves can be drawn by inspection through the plots for most elements. Some points, however, are considerably above or below the curves, so that two branches could have been drawn. Most of the plots for the rocks of the quartz diorite series fall along the same curves as those for the quartz monzonite series; in a few instances, the curves are notably different.

TABLE 3.—*Quantitative spectrographic analyses, in parts per million, of minor elements in the igneous rocks in the northwestern part of the Idaho batholith* [1]

[Analyst: Paul R. Barnett, U.S. Geological Survey]

Sample No.	Rock name	Ni	Co	Cr	Cu	V	Ga	Sc	Ba	Sr	Be	Y	Yb	La	Zr	B	Pb	Nb	Sn
Gabbroic rocks																			
1063	Olivine gabbro	600	100	300	50	100	6	6	500	600	0	0	0	0	30	0	0	0	0
1073	Pyroxene gabbro	90	50	200	80	100	20	20	1000	1000	0	80	4	0	100	0	0	0	0
1072	Gabbro	60	40	90	40	100	10	30	1000	2000	0	90	3	0	200	0	0	0	0
1079	Gabbroic dike	90	50	70	50	100	20	30	1000	1000	0	90	5	0	200	0	0	0	0
Mean		80	47	120	57	100	17	26	1000	1333	0	87	4	0	166	0	0	0	0
Monzotonalitic rocks																			
1143	Monzotonalitic dike	16	11	48	15	56	20	10	700	400	---	20	2	<100	110	<20	0	0	0
1125	Monzotonalite	4	4	14	3	68	20	10	540	660	---	30	3	<100	140	<20	0	0	0
1121	Monzotonalite	2	4	4	3	43	20	10	980	760	---	20	2	100	180	<20	0	0	0
Mean		7	6	33	7	56	20	10	740	606	---	23	2	100	143	20	0	0	0
Quartz monzonitic rocks																			
1081	Quartz monzonitic dike	0	10	3	10	40	10	10	2000	500	2	80	3	200	300	0	0	0	0
1064	Quartz monzonite	7	5	20	10	30	10	6	1000	400	2	50	1	100	200	0	20	0	0
1880	Quartz monzonite	0	0	0	2	20	22	0	1400	700	0	0	0	0	180	0	0	0	0
Mean		2	5	8	7	30	14	5	1467	533	1	43	1	100	227	0	7	0	0
758	Granite	0	0	1	4	5	10	2	50	10	9	100	10	0	200	0	40	20	10
Average of 3 tonalites (190, 379, 43 from tables 26 and 27 in Hietanen, 1962)		2	3	3	4	30	20	0	466	1000	---	0	0	0	123	-----	0	0	0
Average of 4 quartz diorites (180, 42, 292, 322 from tables 26 and 27 in Hietanen, 1962)		44	17	57	21	112	22	9	415	975	---	10	0	0	140	2	0	0	0

[1] Looked for but not found: Ag, As, Au, Bi, Cd, Ge, In, Mo, Pt, Sb, Ta, Th, Tl, U, V, W.

SODIUM, POTASSIUM, AND BARIUM

Variation curves for sodium, potassium, and barium are combined in figure 16. The amount of sodium increases steadily up to about 61 percent silicon, drops between 61 and 65 percent silicon and stays fairly constant at the silicic end. The amount of potassium is 1 to 1.5 percent at the mafic end, increases rapidly from 1.5 to 5 percent between 61 and 65 percent silicon, and at the silicic end, is again constant at about 5 percent.

A considerable scattering of the sodium and potassium points between 61 and 65 percent silicon reflects the branching of parental magmas into two series, one rich in potassium and the other poor in potassium and exceptionally rich in sodium. The latter series includes the tonalitic rocks (Nos. 42, 190, 379, 43) and the potassium-poor border zone of the quartz monzonitic batholith (Nos. 1125, 1121). Representatives of the potassium-rich rocks within this interval are dike rocks (Nos. 1143, 301, 1081) that may represent the composition of the quartz-monzonitic parent magma. The question arises whether or not the tonalites could be products of crystallization differentiation of the quartz

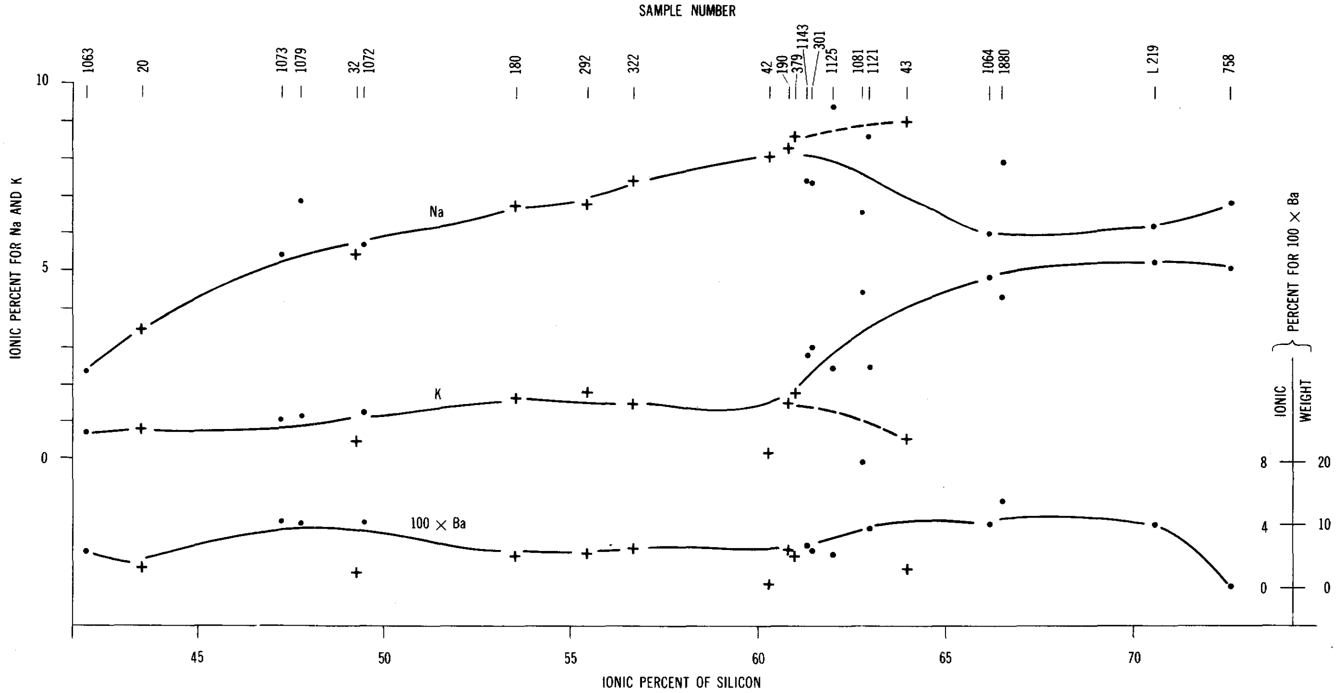


FIGURE 16.—Variation of sodium, potassium, and barium in the rocks of the Idaho batholith. Nos. 1063, 1073, 1072, 1079, 1143, 1125, 1121, 1081, 1064, 1880, and 758 are from tables 1 and 3. No. L 219 is from Larsen and Schmidt (1958). Added for comparison are igneous rocks from the area to the west (fig. 2; and Hietanen, 1962, tables 1, 10, 15, 26, and 27) as follows: No. 20 is hornblendite: No. 32 hornblende gabbro; Nos. 180, 292, 322, and 42, quartz diorite; Nos. 379, 190, and 43, tonalite; No. 301 is monzotonalitic dike rock called "granite porphyry" earlier. Localities for these specimens are shown on figure 2. Dots refer to the rocks of the quartz monzonite series and crosses to those of the quartz diorite series.

monzonitic magma, formed in a manner similar to that of the potassium-poor border zone. This question is considered later.

The barium curve is shaped like the potassium curve except that the content of barium drops abruptly at the extreme silicic end. According to Sen, Nockolds, and Allen (1959) potassium feldspar and biotite are the chief carriers of barium in the Southern California batholith. In Idaho, the amount of potassium feldspar stays constant in rocks that have more than 65 ionic percent of silicon and the amount of biotite in the most silicic member is only slightly less than in the intermediate rocks. It seems, therefore, that the barium entered the crystal structure early and that the residual magma from which the granite crystallized was depleted in this element.

CALCIUM AND STRONTIUM

The amount of calcium decreases steadily from hornblendite and gabbro to granite (fig. 17). A considerable drop occurs at the extreme mafic end between pyroxene gabbro and more mafic olivine-bearing gabbro in which the calcium content is about the same as in the quartz diorites. There is no systematic difference between the distribution of calcium in the quartz monzonite series and in the quartz diorite series.

The curve for strontium is similar to that for calcium. The amount increases from olivine gabbro to gabbro and then decreases steadily toward the silicic end. The ratio $Sr \times 100/Ca$ increases from about 0.8 at the basic end to about 1 at the silicic end. The rocks of the Idaho batholith have more strontium than comparable rocks of the Southern California batholith (Nockolds and Allen, 1953) but the ratio $Sr \times 100/Ca$ is approximately equal.

IRON, MAGNESIUM, NICKEL, COBALT, VANADIUM, SCANDIUM, AND CHROMIUM

Iron and magnesium increase steadily from the silicic end to the mafic end, the increase in magnesium, however, is much greater (fig. 18). No difference can be seen in the distribution of these elements between the rocks of the quartz monzonite and those of the quartz diorite series. The shape of the variation curve for cobalt is much like that for iron; the ratio $Co \times 1000/Fe$ decreases slightly from the mafic end toward the silicic end where the amount of cobalt is below the analytical limit. The amount of nickel increases with increasing magnesium content; olivine in the most mafic member has the ratio $Ni \times 1000/Mg = 2$. The same ratio in gabbros is about 1, and in tonalites and quartz monzonites about 0.5.

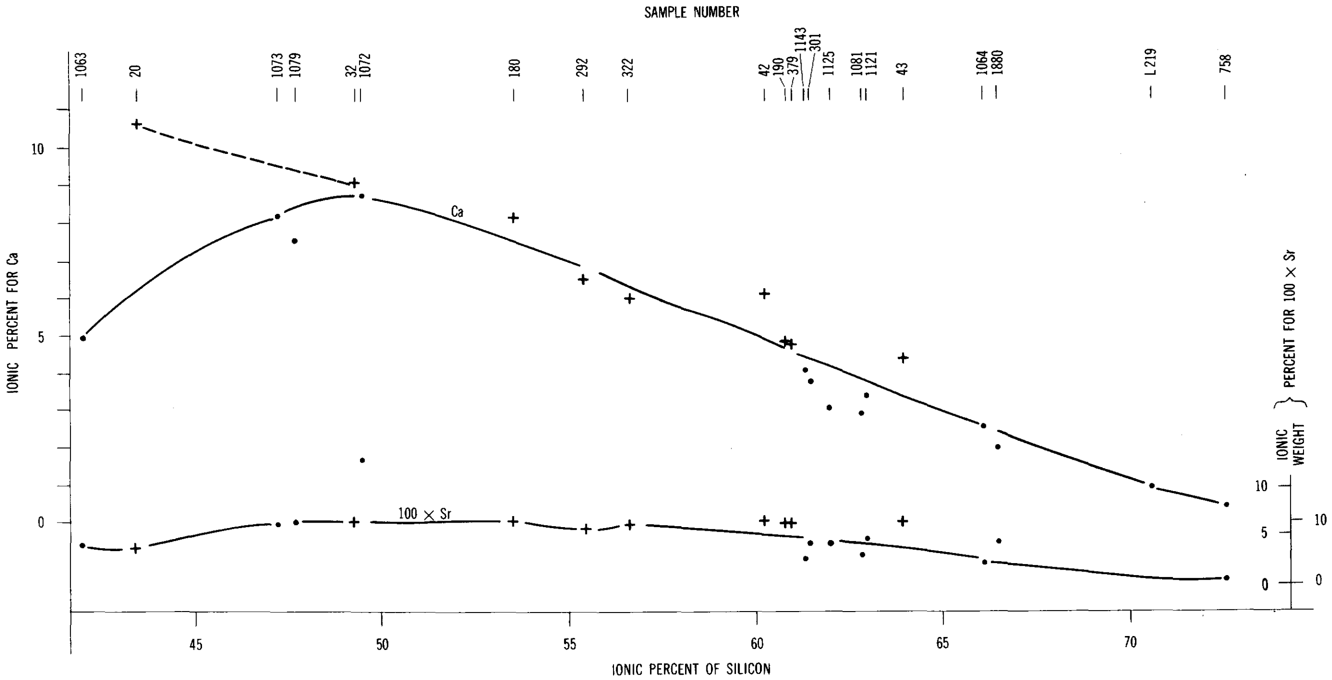


FIGURE 17.—Variation of calcium and strontium in the rocks of the Idaho batholith. Numbers refer to the same analyses as those in figure 16. Dots refer to rocks of the quartz monzonite series and crosses to rocks of the quartz diorite series.

The mafic members of the quartz diorite series, especially the hornblendite, have more vanadium than the rocks of the quartz monzonite series. In general, the amount of vanadium increases with increasing content of magnesium but drops abruptly at the extreme mafic end. Most of the vanadium in the Southern California batholith (Sen, Nockolds, and Allen, 1959) is in magnetite, augite, hornblende, and biotite, whereas in olivine the amount of vanadium is below the analytical limit. The olivine gabbro in Idaho similarly has little vanadium. Hornblendite (No. 20) has an extraordinarily high content of vanadium even though it contains only one percent ilmenite-magnetite (Hietanen, in 1962, table 15). The hornblende gabbro (No. 32) contains considerably more vanadium than the pyroxene gabbros (Nos. 1072, 1073, 1079). It seems, therefore, that hornblende is the chief carrier of vanadium in the rocks of the Idaho batholith.

The shape of the variation curve for scandium is similar to that for vanadium; the highest content is also in the hornblendite (No. 20). With the exception of this rock the points for scandium in the quartz monzonite series and in the quartz diorite series fall along the same curve.

The content of chromium and ferric iron increase toward the mafic end where the amount of ferric iron suddenly drops but that of chromium increases. Magnetite is the chief carrier of these elements and according to Sen, Nockolds, and Allen (1959) this mineral is richer in chromium when in mafic rocks.

ALUMINUM AND GALLIUM

The ionic percentage of aluminum increases rapidly from the mafic end to a silicon content of 47 percent (fig. 19). It stays constant between 47 and 61 percent of silicon and decreases toward the silicic end. The aluminum curves are similar for rocks of both series. The content of gallium increases slightly from the very mafic end to hornblendite, stays constantly low for most silicon contents, and declines toward the silicic end to approach there a value that is as low as that at the mafic end.

YTTRIUM AND ZIRCONIUM

In general the amounts of yttrium and zirconium are fairly small but variable; the points for zirconium especially are notably scattered around the curve (fig. 20); some of the gabbros and dike rocks contain considerably more of these elements than other rocks with about the same silicon content. The quartz diorite No. 322 and the tonalite No. 190 are rich in zirconium whereas the gabbro No. 32 and the quartz diorite No. 42 are poor in it. The average content of yttrium in the quartz diorite series is lower than that in the quartz monzonite series.

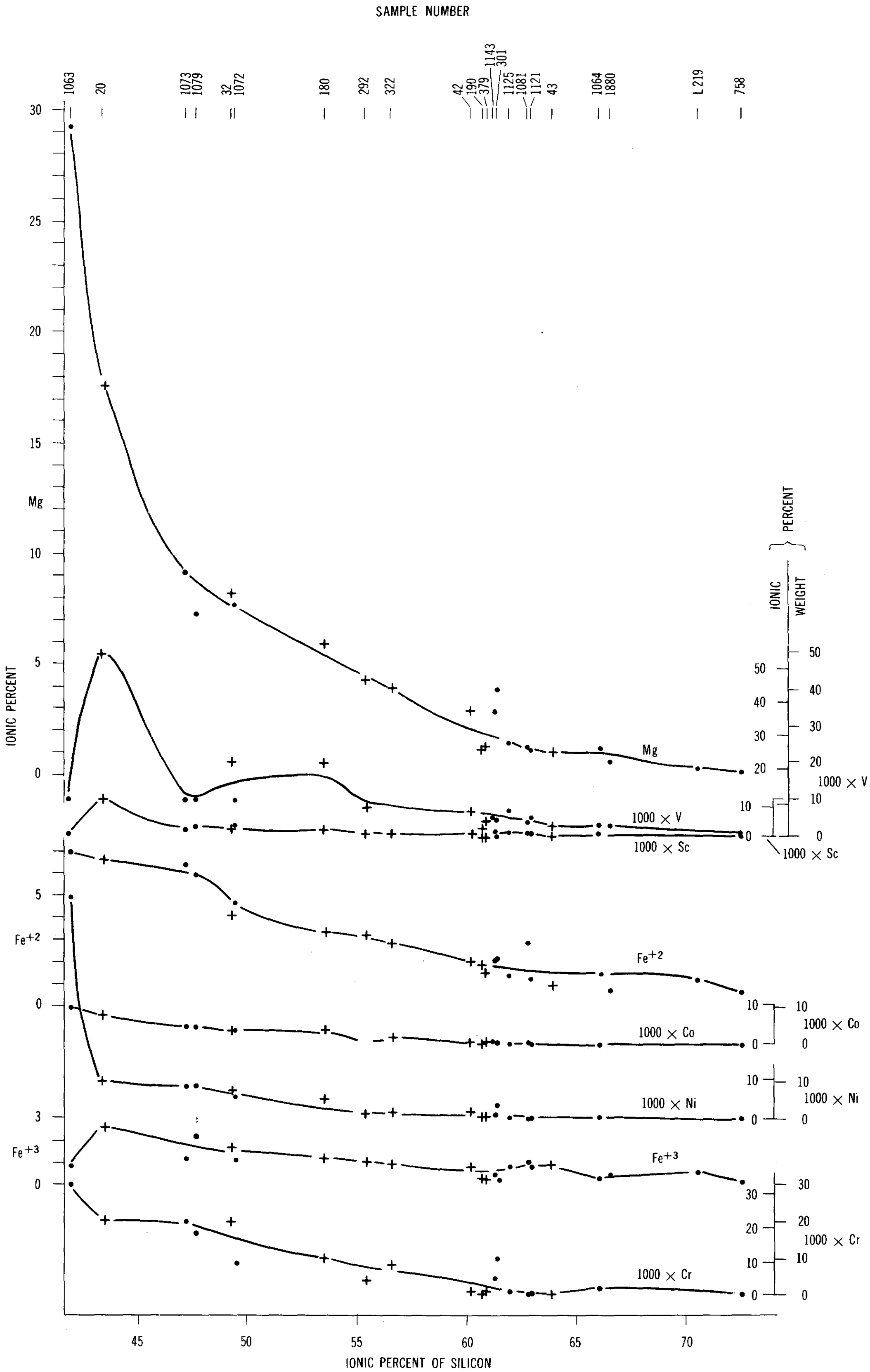


Figure 18.—Variation of iron, magnesium, nickel, cobalt, vanadium, scandium, and chromium in the rocks of the Idaho batholith. Numbers refer to the same analyses as those in figure 16. Dots refer to rocks of the quartz monzonite series and crosses to those of the quartz diorite series.

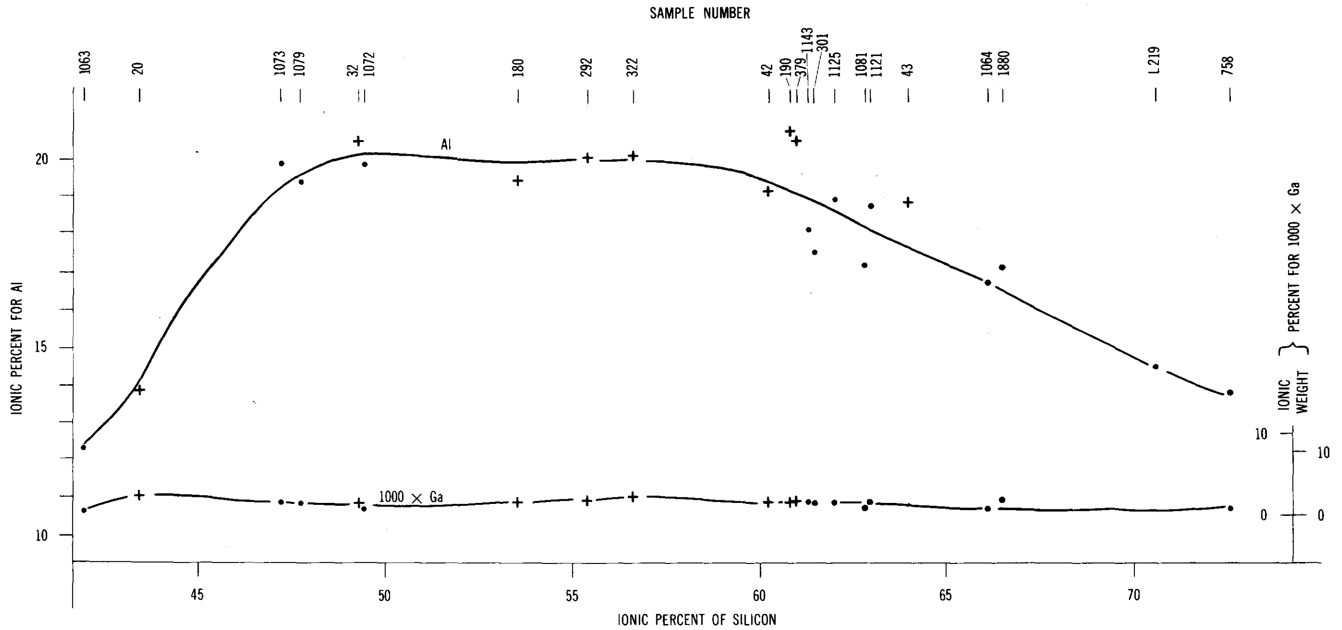


Figure 19.—Variation of aluminum and gallium in the rocks of the Idaho batholith. Numbers refer to the same analyses as those in figure 16. Dots refer to rocks of the quartz monzonite series and crosses to rocks of the quartz diorite series.

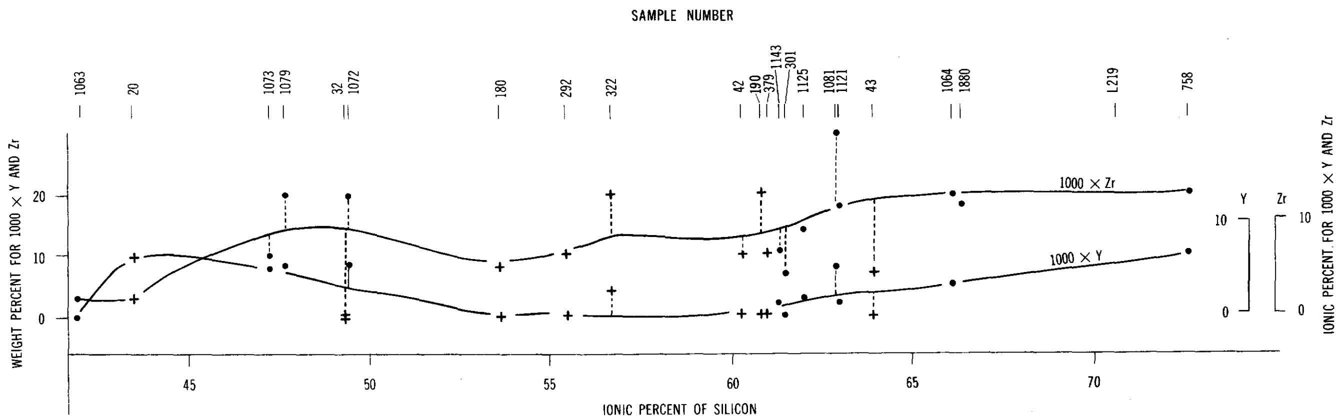


Figure 20.—Variation of yttrium and zirconium in the rocks of the Idaho batholith. Numbers refer to the same analyses as those in figure 16. Dots refer to rocks of the quartz monzonite series and crosses to rocks of the quartz diorite series.

MOLECULAR NORMS AND CLASSIFICATION OF IGNEOUS ROCKS

Molecular norms have been calculated by regrouping the ionic percentage following the method by Barth (1952). The ternary diagrams of figures 21 to 23 are based on these molecular norms.

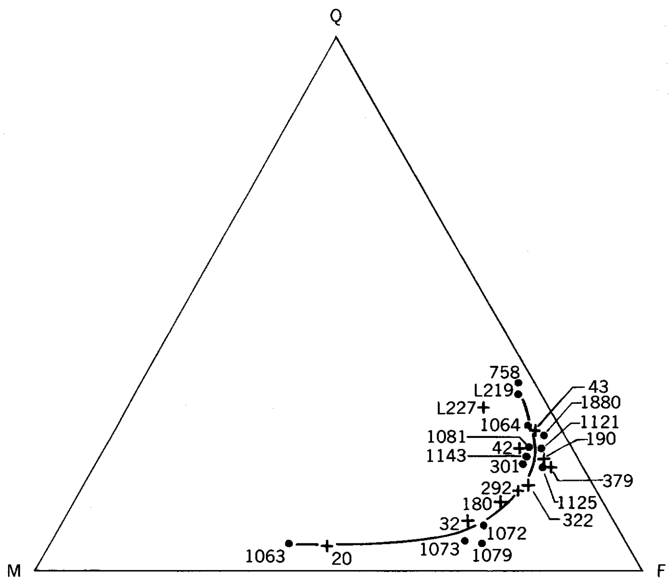


FIGURE 21.—MFQ diagram for the igneous rocks. F, total amount of feldspars in the molecular norm; M, total of iron and magnesium calculated as orthosilicates to which is added corundum and magnetite, all from molecular norm; Q, molecular norm of quartz after calculation of M. Q+M+F=100. Nos. 1063, 1073, 1072, 1079, 1143, 1125, 1121, 1081, 1064, 1880, 758, and L 219 are from table 1. No. L 227 is tonalite between Pierce and Bungalow (Larsen and Schmidt, 1958). Added for comparison are igneous rocks from the area to the west (fig. 2, and Hietanen, 1962, tables 1, 10, and 15) as follows: No. 20, hornblendite; No. 32, hornblende gabbro; Nos. 180, 292, 322, and 42 are quartz diorite; Nos. 379, 190, and 43, tonalite. No. 301 is monzotonalitic dike rock called "granite porphyry" earlier (Hietanen, 1962). Dots refer to rocks of the quartz monzonite series and crosses to those of the quartz diorite series.

The plots for rocks of the quartz diorite series in an area west of the Bungalow area are added for comparison. These analyses were made from rock types similar to those in the western part of the area under discussion (Hietanen, 1962).

In the MFQ diagram (fig. 21), F is the total amount of normative feldspar. M is the combined iron and magnesium calculated as orthosilicates, forsterite and fayalite, to which corundum or wollastonite and magnetite are added. Q is the amount of normative quartz after calculating M and Q+F+M=100. The plots for most analyses are alined along a curve close to the F corner; only one point, L 227, falls very far from this curve. According to the description by Larsen and Schmidt (1958), L 227 was collected from quartz diorite northeast of Pierce along the road leading to Bungalow, apparently near the contact with biotite

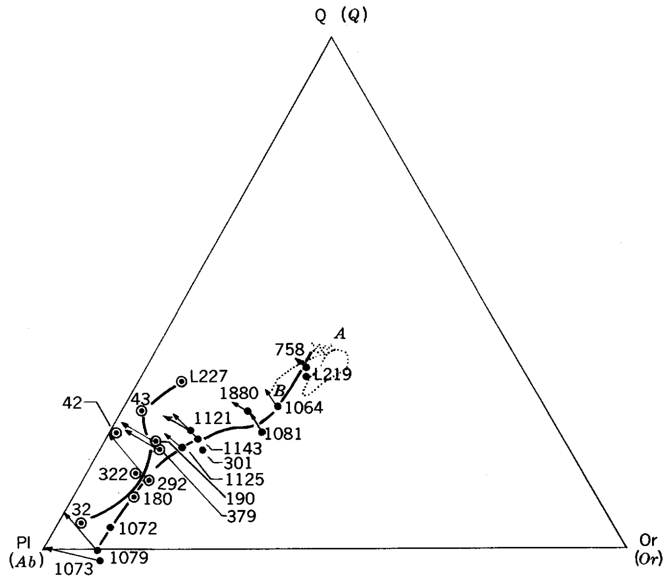


FIGURE 22.—Pl–Or–Q diagram from the igneous rocks. Molecular norms for plagioclase (Pl), orthoclase (Or), and quartz (Q) are recalculated to 100 and plotted (dots). The rocks that are deficient in Q are plotted under the Pl–Or line. The numbers refer to the same analyses as those in figure 21. The dots for the rocks of the quartz diorite **series are encircled. The trend line for the rocks of the quartz diorite** series (at left) and that for the rocks of the quartz monzonite series **are drawn by inspection. Molecular modes for 9 rocks of the quartz** monzonite series and for 3 rocks of the quartz diorite series, 2 tonalites (190 and 379), and 1 quartz diorite (292) are shown by the arrowheads connected with the dots that represent the molecular norm for the same rock. Superimposed with a stippled closed line is the area of highest concentration of granites and the positions of the "ternary" minimum for mixtures of Ab, Or, Q at various pressures of water vapor, 500 kg/cm² at A to 4000 kg/cm² at B after Tuttle and Bowen (1958, p. 75). The weight norms of two granites, Nos. 758 and L 219, are shown by stippled crosses that also are connected with the corresponding molecular norms. All stippled values refer to weight norm.

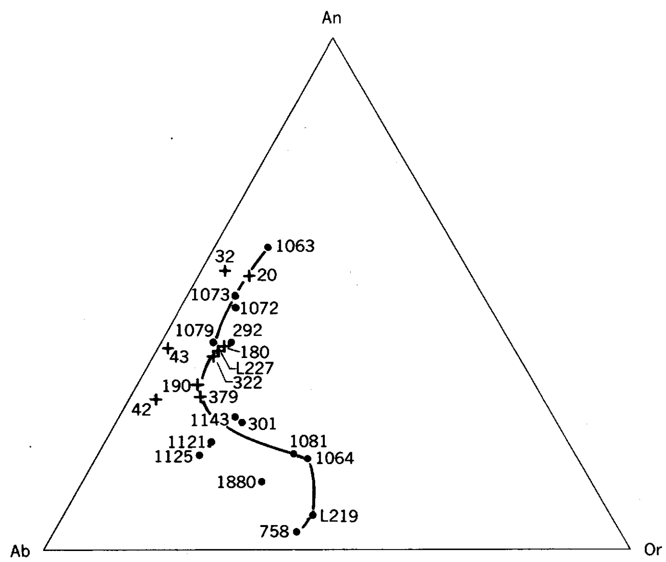


FIGURE 23.—Ab–Or–An diagram for the igneous rocks. Molecular norms for orthoclase (Or), albite (Ab), and anorthite (An) are recalculated to 100 and plotted on this ternary diagram. The numbers, dots, and crosses refer to the same analyses as those in figure 21.

quartzite of the Wallace formation. The large amount of quartz in this specimen as compared with the normal quartz diorite (No. 292) is probably due to digestion of metasedimentary country rocks rich in quartz.

Molecular norms and modes of quartz, plagioclase, and orthoclase are recalculated to 100 and plotted in figure 22. The plots for the rocks of the quartz diorite series (circled dots) are closer to the plagioclase corner than those for the rocks of the quartz monzonite series. A trend line drawn by inspection through them stays close to the Pl–Q side of the triangle. The dots for the rocks of the quartz monzonite series are scattered around a trend line that extends from the center of the diagram toward the plagioclase corner. The plots for the two granites (Nos. 758 and L 219) at the end of this trend line are in the minimum melting trough as determined by Tuttle and Bowen (1958). Plots for quartz monzonites are a short distance from the granite toward the plagioclase corner. The monzotonalites and monzotonalitic dikes form a distinct group between the quartz monzonites and tonalites. Plots for two typical quartz diorites, Nos. 292 and 180, are along the trend line for the quartz monzonite series, whereas at the basic and silicic ends the trend lines for these two rock series deviate considerably.

The composition of the normative feldspar is shown in figure 23, which was prepared by recalculating the sum of molecular norms Or, Ab, and An to 100. In this Ab–Or–An diagram, the plots for various different rock types are grouped along a zone that curves from near the center of Or–Ab line to near the center of Ab–An line. In the granite (Nos. 758 and L 219) the amount of An is less than 10 percent and the amounts of Or and Ab are about equal. In the quartz monzonite An is considerably larger (15–20 percent), and in the tonalites, An is larger and Or smaller than the corresponding values for quartz monzonite. The relative amount of An increases further in the quartz diorite, gabbro, and ultrabasic rocks.

The parameters shown in figures 21 and 23 provide the basis for a simple and easy classification of intrusive rocks. The MFQ diagram gives the values for M and Q in the various petrologic groups and the Ab–Or–An diagram defines the relationship of the feldspars. Some standard rock groups are defined on the basis of molecular norms in table 4, which also shows examples of each group, and the range of the amount of normative feldspars. The plots for the normative feldspar (fig. 23) in the border facies of the coarse-grained quartz monzonite (Nos. 1121 and 1125) are between the plots for the quartz monzonites and the tonalites. The common occurrence of porphyritic dikes of the same composition (Nos. 1143 and 301) proves that this composition existed as a magma and should be considered as a separate petrologic type. The name monzotonalite is used for these rocks because of their intermediate character between quartz monzonites and tonalites. The amounts of dark constituents and quartz in the analyzed examples of the three groups—quartz monzonite, monzotonalite, and tonalite—are about equal (M, 5–10; Q, 18–30), but the differences are in the proportions of orthoclase, albite, and anorthite. The rocks of the monzotonalite group have little orthoclase, whereas the quartz monzonite is rich in this mineral. The dike rocks of monzotonalitic composition resemble many porphyritic granite dikes but lack orthoclase phenocrysts and have much less normative orthoclase than the granitic dikes. No porphyritic dikes of tonalitic composition were found.

The intrusive tonalite looks like the fine-grained monzotonalitic border facies of the coarse-grained quartz monzonite batholith, but these rocks differ chemically and mineralogically. The tonalite contains less potassium and a little more calcium and therefore less orthoclase and more plagioclase (table 4).

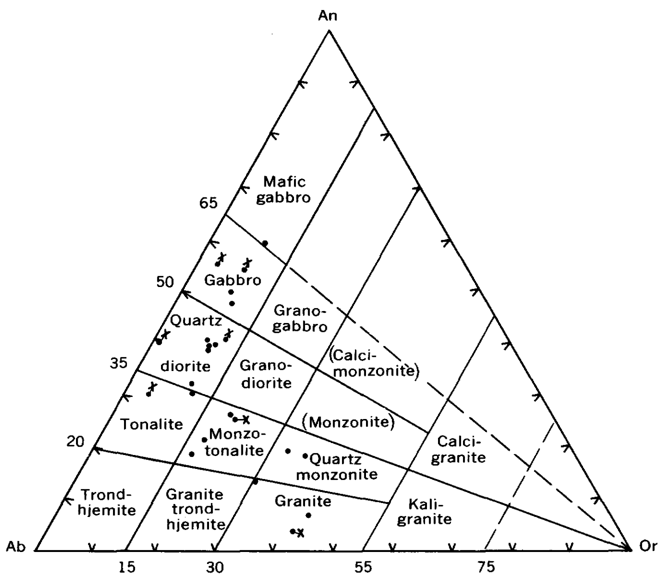
The intrusive tonalites are chemically and mineralogically similar to the medium-grained gneissic border facies of the quartz diorite and also similar to the small occurrences of gneissic tonalite formed through metasomatic processes (Hietanen, 1962); they may represent mobilized parts of such occurrences. The tonalites contain less femic constituents and more quartz than the quartz diorite, and the plagioclase in the tonalite is more albitic (table 4). Thus the rocks that are called tonalite in this report are intermediate between quartz diorite and the most silicic member of the potassium-poor intrusive rock series, the trondhjemite (Goldschmidt, 1916).

The gabbro associated with the quartz diorite contains only hornblende and biotite as dark constituents, whereas most gabbro belonging to the quartz monzonite series contains pyroxene as well. Olivine appears only in a few small mafic inclusions in the quartz monzonite. The hornblende and pyroxene gabbro commonly have a few grains of quartz. After all femic constituents are calculated as olivine, the amount of quartz in the molecular norm is 5 to 10 in the gabbros, and about 5 in the mafic gabbros. The normative amount of anorthite increases toward the mafic end of the series, but the amount of normative orthoclase stays around 10 percent of the total amount of feldspars.

Several of the subdivisions shown in table 4 are based mainly on the relative amounts of orthoclase, albite, and anorthite; therefore the Ab–Or–An diagram is best suited for the illustration of this classification. Figure 24 was prepared on the basis of figure 23 by dividing

TABLE 4.—*Classification of igneous rocks on basis of their molecular norms*

	Granite	Quartz monzonite	Monzotonalite	Tonalite	Quartz diorite	Gabbro	Mafic gabbro
Range of M and Q from figure 21							
M	5	5–10	5–10	4–10	8–20	20–40	40
Q	30–35	23–30	18–23	18–28	10–18	5–10	5
Normative feldspar content from figure 23							
Or	30–55	30–55	15–30	0–15	0–15	0–15	0–15
$\frac{An}{Ab+An}$	0–20	20–35	20–35	20–35	35–50	50–65	65
Examples of various groups and the range of their Or, Ab, and An in table 1							
	758 L 219	1064 1081	1143, 301 1121, 1125	190, 379 43	322, 292, 180 L 227, 42	32, 1072 1073, 1079	20, 1063
Or	25–30	20–25	12–15	3–10	1–10	3–7	3–4
Ab	30–35	30–35	35–47	40–45	34–40	27–35	12–17
An	2–5	10–15	13–18	20–25	27–30	28–36	22–24
Ratios between Or, Ab, and An in the rocks of table 1							
	Or>3 An Or≤Ab Ab>4 An	An<Or<3 An Or<Ab Ab>2 An	Or<An Or<½ Ab Ab>2 An	Or<½ An Or<¼ Ab Ab≃2 An	Or<⅓ An Or<¼ Ab Ab>An	Or<¼ An Or<¼ Ab Ab<An	Or<⅙ An Or<⅓ Ab Ab≃½ An



	Q	M
Granite	30-35	<5
Quartz monzonite	20-30	5-10
Monzotonalite	20-25	5-10
Tonalite	20-30	5-10
Quartz diorite	10-20	10-20
Gabbro	5-10	20-40
Mafic gabbro	<5	> 40

FIGURE 24.—Classification of coarse-grained calc-alkalic igneous rocks on the basis of their normative feldspar content. Ab, Or, and An refer to the molecular norms of albite, orthoclase, and anorthite. The plots for the weight norm would fall a short distance farther from the Ab corner, as shown by crosses for 2 gabbros, 2 quartz diorites, a tonalite, a monzotonalite, and a granite.

the field occupied by the intrusive rocks into subfields in such a manner that each subfield contains plots for a certain rock type. The composition of plagioclase along each tie line that joins a point along the Ab–An line to the orthoclase corner is constant. Thus the range of the anorthite content of the plagioclase in the rocks between two tie lines, such as trondhjemite, granite-trondhjemite, and granite, stays the same and only the amount of orthoclase increases from left to right.

For the next group—the tonalite, monzotonalite, and the quartz monzonite—the tie lines are drawn through An_{20} and An_{35}. Two of the analyzed tonalites are close to the upper line because they contain considerable epidote. The composition of plagioclase in most tonalites ranges from An_{28} to An_{34}. The dividing lines parallel to the Ab–An side give the range of normative orthoclase in the various rock types. Because some potassium is in biotite, the relative amount of potassium feldspar appearing in the rock is smaller than that shown in this diagram. For example, normal trondhjemites, tonalites, quartz diorites, and gabbros have less than 5 percent modal orthoclase. Granite trondhjemite, monzotonalite, and granodiorite are intermediate rocks that contain less orthoclase than normal granite, quartz monzonite, and monzonite. The amount of normative quartz in the trondhjemites and granites is about 35 percent; in the tonalite, monzotonalite, and quartz monzonite it is usually 20 to 25 percent, and decreases steadily through quartz diorite and gabbro to mafic gabbro. In an Ab–Or–An–Q tetrahedron, figure 24 would thus be close to a section that cuts the Ab–Or–Q face along the line 35 percent quartz, and it is tilted toward the An corner where it approaches the Ab–Or–An plane. The amount of mafic constituents increases from less than 5 percent in the granite to about 45 percent in the mafic gabbro and is constant in the groups of equal anorthite content, such as tonalite, monzotonalite, and quartz monzonite.

It appears that this norm classification is better suited to the present suite of rocks than a modal classification. In the modal classification, the tonalite and quartz diorite would fall into the same subdivision because a part of the calcium in the quartz diorite is combined with iron and magnesium to form hornblende, the amount of which is not shown in the Ab–Or–An diagram. All differences between these two rock types would thus be eliminated in a classification based on the modal composition of feldspars. This lack of difference in the modal feldspar content may be the reason why these two rock types are usually considered synonymous. The norm classification usefully brings out the considerably higher content of calcium, iron, and magnesium in the quartz diorite as compared with the tonalite.

SEQUENCE OF CRYSTALLIZATION IN IGNEOUS ROCKS

The textures of the igneous rocks indicate that the order of crystallization of the major constituents varied considerably. Typical examples can be found among the silicic rock types of the quartz monzonite series. In the medium-grained quartz monzonite along Beaver Creek, numerous small euhedral and lath-shaped plagioclase crystals are included in and apparently are older than large anhedral orthoclase crystals. In the dikes of the same composition, plagioclase forms phenocrysts and the groundmass is thus richer in quartz and orthoclase than is the total rock. In the Pl–Or–Q diagram, a plot for the groundmass would be toward the ternary eutectic from the plot for the dike rock No. 1081 (fig. 22), a normal crystallization trend for this magma type as experimentally demonstrated by Tuttle and Bowen (1958).

In the granite at Bunglow (No. 758) the quartz grains have better crystal forms than the feldspar grains. In dikes of the same composition, euhedral quartz phenocrysts abound and tend to be larger than the feldspar phenocrysts. Crystallization apparently started with quartz, and after the magma reached the eutectic composition, quartz, orthoclase, and plagioclase crystallized simultaneously. Composition of the phenocrysts plus the groundmass would lie toward the quartz corner from the eutectic.

In the monzotonalitic dikes plagioclase and quartz occur as phenocrysts; the plagioclase is more abundant and the orthoclase is only in the groundmass. Crystallization started with plagioclase, and continued by separation of plagioclase and quartz, enriching the residual magma, the groundmass, in the components of orthoclase. The plots for the groundmass would lie toward the eutectic (minimum melting trough) from the plots for the total composition of these dikes (fig. 22, Nos. 1143 and 301).

The cooling history of the coarse-grained quartz monzonite with large orthoclase phenocrysts is not as easy to follow. If the orthoclase crystals are true phenocrysts formed at an early stage in a liquid magma, the magma should have been rich in potassium; accordingly, the plots for this rock should lie toward the Or corner from the eutectic area of the Pl–Or–Q diagram. However, the plots for all quartz monzonites fall toward the Pl corner, which indicates that the magma was rich in sodium and calcium rather than in potassium. In such magma, crystallization should have started by separation of plagioclase as it did in the quartz monzonite along Beaver Creek. The textures in the two masses of quartz monzonite differ markedly; many euhedral plagioclase crystals are included in anhedral orthoclase along Beaver Creek, whereas the inclusions of plagioclase in large euhedral to subhedral orthoclase phenocrysts of the coarse-grained quartz monzonite are few and small. The "groundmass" between the large orthoclase phenocrysts contains only a small amount of interstitial orthoclase and is compositionally close to monzotonalite. Thus the relation between the composition of groundmass and that of the total rock is contrary to the normal sequence of crystallization, and the orthoclase crystals can scarcely be true phenocrysts. Two explanations are worth considering:

1. That crystallization started with separation of plagioclase, and was followed by quartz, and these two minerals continued to crystallize until the composition of the liquid part of the magma reached the eutectic region where orthoclase also was crystallizing. Slow cooling permitted partial recrystallization and rearrangement of material, so that the orthoclase crystals attained a large size, and the quartz and plagioclase formed a granoblastic groundmass.

2. That crystallization started with separation of plagioclase (An_{28}), was followed by quartz, and these two minerals continued to crystallize until the phase boundary of orthoclase plus quartz was reached. There the orthoclase phenocrysts formed fast and the composition of the remaining liquid moved along the boundary

line toward the eutectic. In the eutectic region, the rest of the quartz, plagioclase (An_{26}), and orthoclase crystallized.

In the first possibility, partial recrystallization during the very latest phase of crystallization would be responsible for the formation of large euhedral orthoclase crystals. In the second case, the separation of quartz and plagioclase would continue until the remaining magma would be enriched in orthoclase to such an extent that it would behave like a potassium-rich magma. The orthoclase crystals would thus be late phenocrysts, but formed in a liquid, not in solid rock.

The equal distribution of the orthoclase in the groundmass indicates that the phenocrysts did not grow in a solid or almost solid rock. Comparison with the textures common in the porphyritic rocks throws light on the order of crystallization of the porphyritic quartz monzonite. Late crystallizing minerals usually take the elements needed for their growth from the surrounding groundmass. This is well demonstrated in many metamorphic rocks in which ferromagnesian porphyroblasts rob iron from their surroundings. Staining of a specimen from the Cathedral Peak granite, Sierra Nevada, brings out a similar relation between feldspars. Subhedral phenocrysts of orthoclase in this specimen are surrounded by a zone about 1 to 2 cm wide almost devoid of orthoclase even though interstitial orthoclase is abundant elsewhere in the rock. These phenocrysts completed their growth during a late stage, when the other constituents—quartz, plagioclase, and biotite—were solid, and took from their surroundings all the potassium that would normally go to form interstitial orthoclase. The width of the potassium-free zone around each phenocryst—1 to 2 cm—gives the maximum distance of migration of potassium atoms during this late phase of crystallization.

The orthoclase phenocrysts in the coarse-grained quartz monzonite in Idaho are similar to those in the granite just described, but there is no potassium-free zone around them. This is most likely due to a slight difference in the order of crystallization. The crystallization of the normal porphyritic rock in Idaho may have proceeded as follows: The few small plagioclase crystals that are included in the orthoclase phenocrysts were first to crystallize. The orthoclase phenocrysts started to crystallize when the plagioclase grains were 1 to 2 mm long and continued to the end of the crystallization period, using most of the potassium. They did not, however, continue to grow after the rock was almost solid because they did not rob potassium from their surroundings. Rather, enough potassium remained in the melt to permit orthoclase to crystallize interstitially.

Crystallization of an exceptionally large amount of euhedral orthoclase phenocrysts in some outcrops about a mile from the border and the formation of the border zone poor in potassium are most likely results of crystallization differentiation of the quartz monzonitic magma. Perhaps crystallization started by separation of plagioclase, quartz, and biotite; the border zone, where cooling was fastest, solidified first. The crystals were attached to the border, and the potassium that remained in the liquid moved toward the center ahead of the solidifying border. In this way, a solid border zone poor in potassium was formed and the liquid magma next to it was enriched in potassium. As the temperature continued to drop, large euedral crystals of orthoclase started to form in this potassium-rich inner zone. In places the magma became undercooled and supersaturated in potassium, so that crystallization was rapid and a great number of large euhedral crystals were formed.

SEQUENCE AND MODE OF EMPLACEMENT OF PLUTONIC ROCKS

The sequence of emplacement of various igneous bodies can be determined on the basis of their contact relations, structure, and texture. The conformable bodies which show platy and linear structures parallel to the corresponding structures in the folded country rocks are considered to be earlier than the massive bodies with discordant contacts. The sequence is as follows: hornblende gabbro and amphibolite, quartz diorite, tonalite, plagioclase pegmatite, coarse-grained quartz monzonite, medium-grained quartz monzonite, granite, and granite pegmatite. The small occurrences of pyroxene-bearing gabbro and diorite that represent early differentiates of the quartz monzonite magma may have been emplaced shortly after the intrusion of quartz diorite.

The earliest members of the intrusive series are synkinematic and the latest ones postkinematic. Small bodies of mafic rocks, which were emplaced before the folding of the metasedimentary rocks, occur west of the Bungalow area. Some of the plutonic rocks of metasomatic origin have contact relations, structures, and textures similar to those of the early intrusive bodies. But they also have enough relict structures and textures to reveal their origin. All major intrusive bodies in the mapped area have contact relations and textures typical of true igneous rocks; they were at one time, at least in part, liquid. Some intrusive rocks, such as the quartz diorite, may have been derived from large quantities of country rocks, the influence of which is seen in the variable chemical composition, especially in the exceptionally large amount of quartz in those parts of the quartz diorite bodies near quartzite country rocks (for example, Nos. L227 and 43).

The contacts between the igneous rocks and the metasedimentary country rocks are in part conformable and in part discordant. They show that the magmas chose the easiest ways parallel to the preexisting structures—the bedding or fault zones—but also had enough force to break locally across the structures of the country rocks. The extent of migmatization and metasomatic alteration of the country rocks varies and gives some information about the change of physicochemical conditions during the intrusion period. The metasomatic alteration of local portions of country rocks west of the quartz diorite around Pierce has been described in an earlier paper (Hietanen, 1962) and attributed to the introduction mainly of calcium, iron, and magnesium, and removal of silicon and potassium from local parts of the contact aureole, which is 15 to 20 miles wide. Structural studies show that this metasomatic exchange of elements took place under the quartz diorite mass, which is 5 to 15 miles thick and is tilted about 45° to the east. Probably the hot solutions were trapped for a long time under the magma, which may have extended farther to the west above the present erosion surface.

The coarse-grained quartz monzonite in the southern part of the area (pl. 2) is bordered by a zone of contact migmatites about a mile wide. Feldspathization of the metasedimentary country rocks there is common, but where the contact is between quartz diorite and quartz monzonite, the composition of quartz diorite is little affected.

In contrast to these contact effects, the medium-grained quartz monzonite along Beaver Creek and the granite around Bungalow have fairly narrow contact aureoles. Contact migmatites are lacking and the feldspathized zone is usually only a few meters wide. This difference in the chemical activity around the igneous bodies is probably closely connected with the time of intrusion and the depth of burial during the intrusion. The porphyritic border facies of the granite at Bungalow indicates that this youngest body was emplaced at shallow depths, not very far from those of the hypabyssal dikes, and cooled rapidly. The quartz diorite, however, must have cooled more slowly to make the extensive migration of elements possible. The slower cooling indicates a thicker cover, which in turn accords with the idea that the quartz diorite was intruded well before the granite.

AGE OF THE ROCKS OF THE BATHOLITH

No absolute age determinations have been made of any of the intrusive bodies of this area. According to Larsen and others (1958) the average age of tonalites (including quartz diorites) of other parts of the Idaho batholith is 108 million years and that of quartz monzonites 102 million years. The relative ages fit the sequence of emplacement of the quartz diorite and quartz monzonite in the area under discussion. The period of intrusion, of course, started earlier and lasted longer than indicated by these two averages. Absolute age determinations of the oldest plutonic rock in the area, the quartz diorite in small bodies to the west, and of the youngest, the granite at Bungalow, would answer the question of range in age.

ORIGIN OF THE MAGMAS

As pointed out earlier, the igneous rocks can be grouped into two series, an older one poor in potassium and a younger one rich in potassium. Each series has representatives among the mafic, intermediate, and silicic rocks, even though the intermediate members are most common and form larger bodies than the mafic and silicic members. The following questions arise: What was the composition of the parent magma of each differentiation series? Could potassium-poor and potassium-rich magma types have been derived from the same parent magma, or must they have originated in separate magma chambers at different levels or different places in the crust?

The textures and structures of the quartz diorite indicate that this rock crystallized from a magma that was liquid at least in part. The gabbroic rocks associated with the quartz diorite consist of the same kind of minerals as the quartz diorite, but in different proportions. The hornblendite and gabbro inclusions in quartz diorite were formed during an early stage of crystallization. Small masses of hornblendite in the metasedimentary rocks near the quartz diorite are most likely products of introduction of iron and magnesium into the country rocks (Hietanen, 1962). Some of the quartz diorite and all of the gneissic tonalites are products of feldspathization of the country rocks along and near the contacts of the quartz diorite. The intrusive tonalite contains more silicon and sodium, and less calcium, iron, and magnesium than the quartz diorite. This tonalite can be either a silicic magmatic differentiate of the quartz dioritic magma or it may represent mobilized parts of gneissic (metasomatic) tonalite. Quartz diorite forms a major part of the rocks of this series, and it seems safe to assume that the magma from which most of the intrusive rocks of the quartz diorite series crystallized had a composition close to quartz diorite.

The rocks of the quartz monzonite series are more varied in composition than those of the quartz diorite series, and two of the rock types, quartz monzonite and granite, are found as fairly large bodies. That granite is an end member of the series fits its theoretical position in the area of minimum melting in the Pl–Or–Q diagram. The composition and textures indicate that the granite and quartz monzonite are derivatives of one magma, with a composition that may have been the mean composition of all rocks belonging to this series. To find this mean composition, the area of the Idaho batholith should be carefully mapped, the amount of each rock type estimated on the assumption that all the rock masses have depths proportional to their area, and the average composition computed. Larson and Schmidt (1958, table 7) made an estimation of this average composition on the basis of their reconnaissance work. Their result is close to the composition of the quartz monzonitic dikes in the present area (comp. table 1 No. 1081) except for a somewhat higher content of CaO and Na_2O and a lower content of K_2O in the mean. These differences become insignificant if it is considered that the area of quartz diorite around Pierce is about 200 square miles and not 1,000 square miles as was estimated by Larsen. A reasonable position is that some of the dikes crystallized from an undifferentiated magma and that these dikes represent the composition of the parent magma. Some of the stocklike bodies, such as those along Beaver Creek, include small bodies of more mafic differentiates. The computed mean composition of all intrusive rocks within and near the stock is close to the composition of the quartz monzonite dikes. This shows that the quartz monzonite and associated rocks along Beaver Creek are most likely offshoots of the same magma that formed the larger bodies of the batholith farther south. According to Ross (1936) this southern part is remarkably uniform in composition, consisting of somewhat calcic quartz monzonite.

The quartz monzonite in the stock along Beaver Creek has a fairly uniform composition. The amounts of major constituents—plagioclase, orthoclase, quartz, and biotite—are nearly constant throughout. In contrast, the amounts of the major constituents of the large body of quartz monzonite in the southern part of the area vary considerably. Along some of the border zones, the amount of orthoclase is very small, yet some of the outcrops about a mile form the contact contain numerous large euhedral orthoclase phenocrysts, which increase the amount of potassium to about 5 or 6 percent, compared with only 4 percent in the main part of the body.

The presence of the potassium-poor border zone of the quartz monzonite batholith (samples Nos. 1121, and 1125) shows that a rock poor in potassium feldspar can be formed by crystallization differentiation from a quartz monzonitic magma. It is possible that the rocks of the quartz diorite series were formed in a similar way and represent early crystallization differentiates of the quartz monzonitic magma. Moreover, only one set of variation diagrams can be drawn for most of the major and minor elements. Some of the curves branch, however, which indicates different behavior of certain elements in some parts of the series. Such elements are calcium and vanadium, which are enriched in the mafic members of the quartz diorite series, and potassium, which is considerably enriched in the silicic rocks of the quartz monzonite series. The general similarity of distribution of elements certainly indicates a close relationship, if not a common origin, of both series.

The field relations show that the large body of quartz diorite around Pierce and some small bodies of tonalite to the northwest were crystallized from mobile magmas. If these rocks crystallized from a quartz monzonitic magma, all of the residual liquid rich in potassium was removed before the final solidification. The largest body of quartz diorite could represent a potassium-poor border facies of the quartz monzonitic batholith but the dikes and sill-like bodies of tonalite indicate that a magma poor in potassium existed and that potassium separated from it before intrusion. One of the possible processes leading to such a separation would be early crystallization and accumulation of plagioclase, quartz, hornblende, and biotite to form a quartz dioritic or tonalitic rock, and later partial remelting of this rock to form a quartz dioritic or tonalitic magma. If a quartz dioritic magma was formed it would be capable of limited crystallization differentiation to produce hornblende gabbro, quartz diorite, and tonalite.

An alternative possibility is that the quartz dioritic magma formed directly through melting of a part of the local crust. If it is assumed that rocks of the Belt series, or older strata below it, were folded down to a temperature level above the melting point of quartz monzonite, first a granitic and then a quartz monzonitic melt would start to form. The first melt would contain the material necessary to crystallize quartz, potassium feldspar, plagioclase, and biotite in eutectic ratios. The composition of the later melt would be similar to that of the quartz monzonitic dikes (No. 1081). As the Belt series along the northwestern border zone of the Idaho batholith is composed of a sequence of common type of garnet-mica schist, biotite gneiss, diopside gneiss with occasional silicated dolomite, quartzite, and other products of metamorphism of normal miogeosynclinal sediments, the chemistry of the formation of magmas can be illustrated by using the average rock of the Belt series as an example of a possible source rock. It has been shown earlier (Hietanen, 1962) that the average rock of the Belt series along the northwestern border zone of the Idaho batholith is richer in calcium, magnesium, and iron, and poorer in potassium than the granitic and quartz monzonitic melt assumed to be forming at depth. At this stage, the rocks next to the reservoir of melt would therefore be enriched in the elements left behind as the melt was forming, such as calcium, magnesium, and iron, and impoverished in potassium and silicon, which were needed for the formation of the quartz monzonitic melt. Thus a zone of enrichment of basic components would envelop the area where the eutectic melt was forming. As shown earlier, the average composition of the basified zone in Headquarters quadrangle and farther west (Hietanen, 1962), is very close to that of the quartz diorite. Thus if the temperature was raised, or pressure released, the basified zone capping the melt may have melted partially and formed a quartz dioritic magma, which was squeezed up along a zone of weakness ahead of the major intrusion of quartz monzonite. This latter alternative would require only one more or less continuous major rise in the temperature, whereas the former alternative postulates a period of cooling and crystallization of quartz dioritic rock before a second heating, during which the quartz dioritic rock would have been remelted and intruded into the country rocks.

A general similarity of composition and distribution of minor elements could be a result of common origin of the magmas as remelted parts of the same formations, perhaps with added material from a basaltic magma. The few differences in the distribution of elements between the two rock series could be due to selective solution at temperatures close to 650°C and above. Because at the beginning of melting, the elements enter solution in eutectic ratios, the country rock must then have been enriched in elements not needed and impoverished in elements needed to form eutectic melt, the granitic magma. Thus the differentiation into two rock series, one rich in potassium and the other poor, could have occurred during the formation of the magmas rather than during their crystallization. During the cooling period, each type of magma may have formed a more or less complete crystallization differentiation series.

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