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Plutonic and Hypabyssal Rocks of the Hailey 1°×2° Quadrangle, Idaho

U.S. Geological Survey Bulletin 2064-U

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Contents

Figures

Tables

Metric Conversion Factors

Multiply	By	To obtain
Miles	1.609	Kilometers
Feet	0.3048	Meters
Inches	2.54	Centimeters
Tons	1.016	Metric tons
Short tons	0.907	Metric tons
Troy ounces	31.103	Grams
Ounces	28.35	Grams

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Introduction

Much of the area of the Hailey 1°×2° quadrangle, Idaho, is underlain by Cretaceous plutonic rocks of the Atlanta lobe of the Idaho batholith (fig. l). The oldest phases of the Atlanta lobe consist of hornblende-bearing tonalite and granodiorite and minor pyroxene diorite. Younger phases include voluminous amounts of biotite granodiorite and lesser amounts of two-mica granite and leuococratic granite. Intrusive into these rocks are Eocene stocks and batholiths that range in composition from gabbro to younger granite. Cutting all of the plutonic rocks are swarms of Tertiary hypabyssal dikes that range in composition from rhyolite to andesite and include.

In the following rock descriptions, rock unit symbols refer to rock units of the Hailey 1°×2° geologic map by Worl and others (1991). A simplified version of that map, using different symbols, is shown in Worl and others (1991). Most geographic place names in the various descriptions are shown on the Hailey 1°×2° geologic map, and all place names are shown on the larger scale 7.5-minute topographic maps that were used as base maps in the geologic mapping of the region.

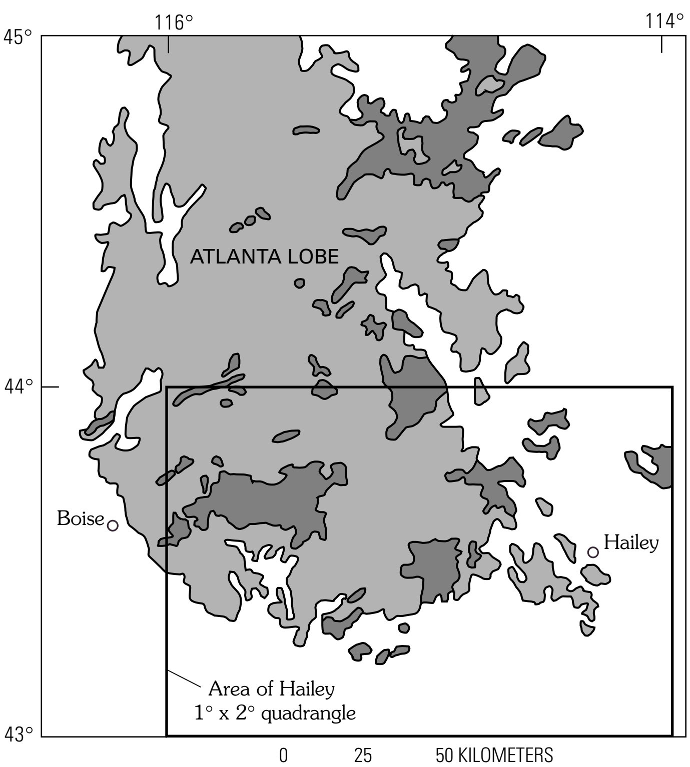


Figure 1. Index map of central Idaho showing location of the Hailey 1°×2° quadrangle, south-central Idaho, with respect to the Atlanta lobe of the Idaho batholith. Cretaceous plutonic rocks exposed in the region are light shaded; Eocene plutonic rocks are dark shaded.

Cretaceous Plutonic Rocks

Twelve rock units of Cretaceous age are shown on the Hailey 1°×2° geologic map (Worl and others, 1991). Figure 2 is a simplified geologic map showing the major plutonic phases. Most units cover large areas, on the order of 100 km^2. The biotite granodiorite unit is an immense mass of relatively homogeneous rock and is widely exposed in central Idaho. Individual zoned plutons have been mapped as outliers of the southeastern part of the batholith, but the main mass of the batholith is only crudely zoned. This zonation consists of a tonalitic western margin (west of the Hailey 1°×2° quadrangle) that is intruded in the more central part of the Atlanta lobe by biotite granodiorite and two-mica granite. In the southeastern part of the lobe are more mafic rocks that probably were emplaced at about the same time as the tonalitic phase on the west side.

Modes of representative samples from Cretaceous rock units are shown on figure 3. The various lithologies of Cretaceous plutonic rocks are described in the following sections.

Quartz Diorite of the Croesus Stock

The Croesus stock (fig. 2, unit kqd) is a northwest-trending body of quartz diorite grading to diorite that crops out in the hills west of Bellevue in the southeastern quarter of the quadrangle (Worl and others, 1991). At the Minnie Moore mine, the stock has an intrusive, sill-like relationship with the overlying Milligen Formation of Devonian age. Previous descriptions of the stock include those of Lindgren (1900), Hewett (1930), and Anderson and others (1950). Although separated from the main mass of the Atlanta lobe to the west, the Croesus stock as well as the Deer Creek and Rooks Creek stocks (fig. 2) (which differ in composition from the Croesus stock) are considered to be units of the Atlanta lobe.

The quartz diorite is dark gray, medium grained and equigranular and is characterized by subequal amounts of augite and vitreous biotite that together compose about 20 percent of the rock. Hypersthene is present in minor amounts, as is hornblende, which has replaced pyroxene. Andesine, the principle

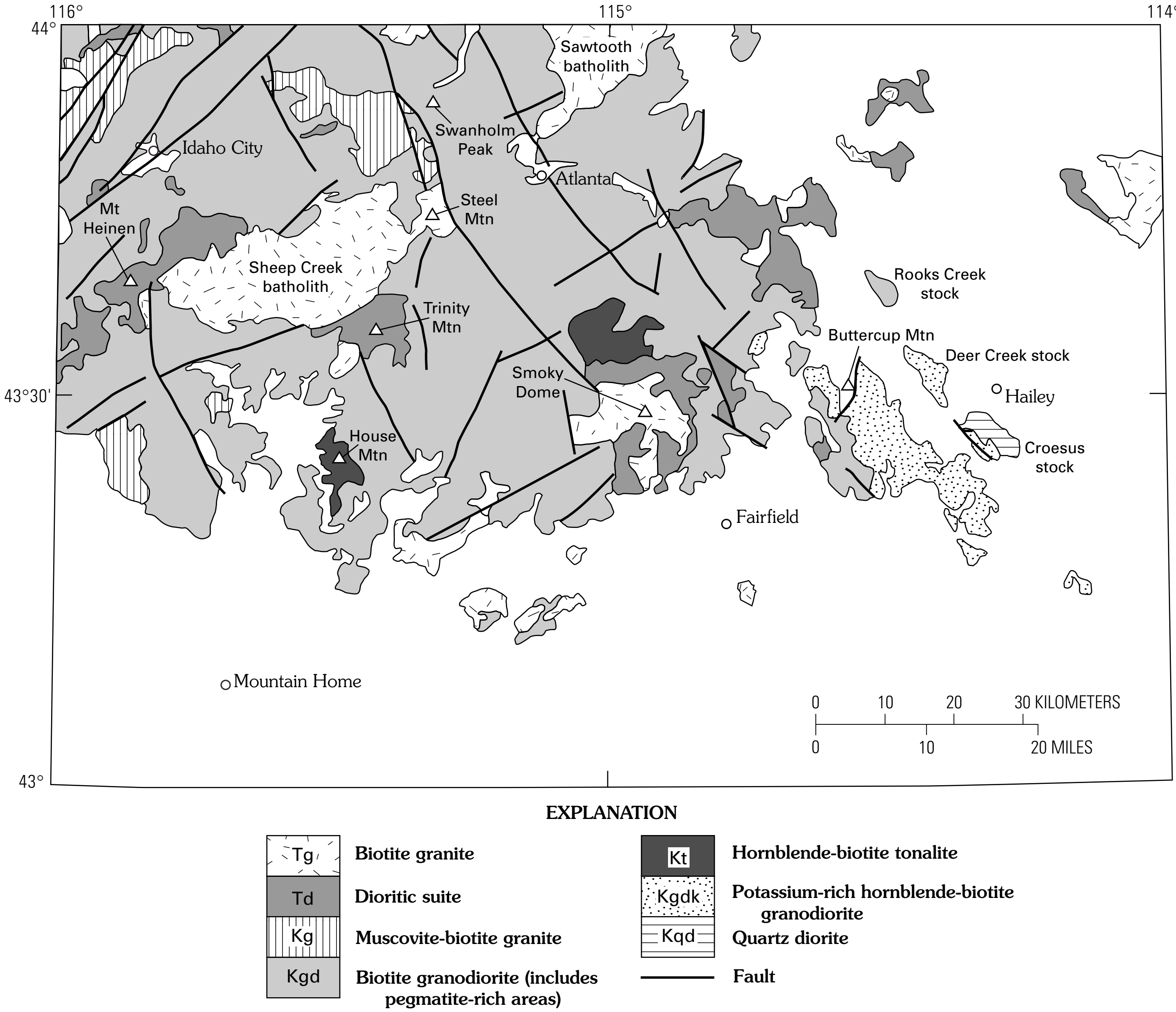


Figure 2. Simplified geologic map showing location of Cretaceous and Eocene plutonic rocks and associated major faults in the Hailey 1°×2° quadrangle.

constituent, is euhedral, commonly aligned, and slightly zoned. Quartz is interstitial and composes less than 15 percent of the rock; potassium feldspar is present in sparse amounts. Accessory minerals include sphene, apatite, magnetite, and ilmenite. Modal analyses are shown in figure 3*D*.

A unique feature of the stock is the abundance of silver-lead-zinc deposits that are peripheral to or within it (Hewett, 1930; Anderson and others, 1950). In this respect, the deposits appear to be closely associated with the quartz diorite of the stock.

The age of the Croesus stock has not been determined. Sericite from an alteration selvage at the Magdalena mine, northwest of Bellevue, yielded a $^{40}Ar/^{39}Ar$ plateau age of 85.6±0.6 Ma (L.W. Snee, unpub. data, 1992). The west side of the stock is intruded by hornblende-biotite granodiorite from which a sample, taken at the McCoy mine, yielded a K-Ar age on biotite of 83.8±2.5 Ma (recalculated from Berry and others, 1976). The quartz diorite, consequently, must be older than about 86 Ma.

Potassium-Rich Hornblende-Biotite Granodiorite

Hornblende-biotite granodiorite is widespread in the southeastern quarter of the quadrangle in the area northeast of Fairfield and southeast of Buttercup Mountain (Worl and others, 1991) (fig. 2, unit Kgdk). The unit grades from granodiorite to granite (fig. 3*D*) and is medium to dark gray, equigranular to porphyritic, and medium to coarse grained. It has a higher K_2O content for a given SiO_2 content than other Cretaceous units of the batholith (Lewis, 1989, 1990). The rock is characterized by

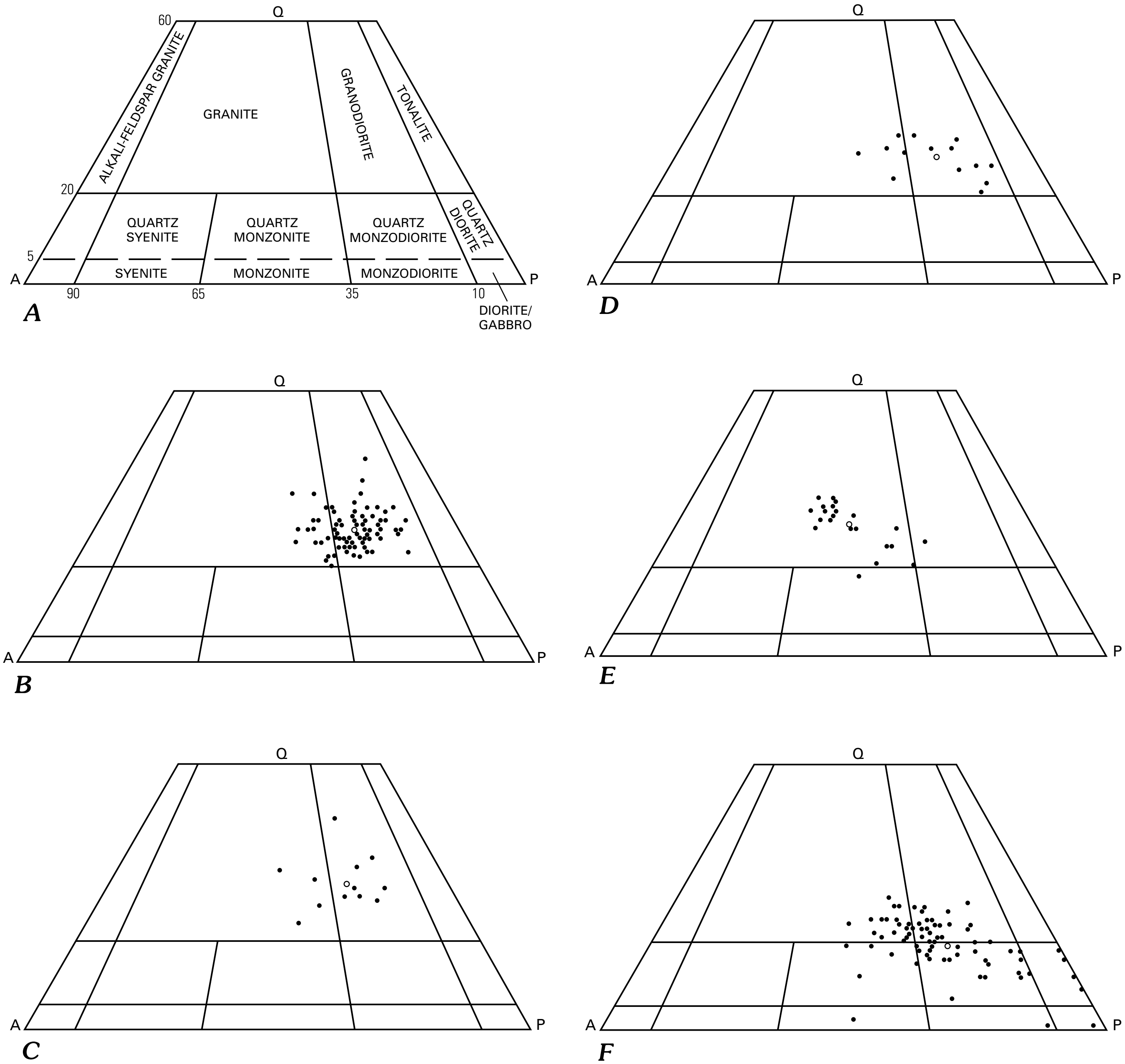


Figure 3. Modal analyses for samples of Cretaceous and Eocene plutonic rocks, Hailey 1°×2° quadrangle. Analyses normalized to 100 percent quartz (Q), alkali feldspar (A), and plagioclase (P). Closed circles indicate modal values; open circles indicate mean values. *A*, rock classification from Streckeisen (1973); *B*, Cretaceous biotite granodiorite (fig. 2, unit Kgd); *C*, muscovite-biotite (two-mica) granodiorite and granite (fig. 2, unit Kg); *D*, potassium-rich, hornblende-biotite granodiorite (fig. 2, unit Kgdk) and quartz diorite (fig. 2, unit Kqd); *E*, Eocene biotite granite (pink granite)(fig. 2, unit Tg); and *F*, dioritic suite (fig. 2, unit Td).

coarse books (as thick as 6 mm) of vitreous biotite that contrast with the small flakes of biotite in the widespread biotite granodiorite (unit Kgd). Subhedral crystals of hornblende range from 1 to 7 mm in length. The principal constituent is plagioclase, which ranges from oligoclase to andesine in composition and exhibits normal to oscillatory zoning. Quartz in the rock commonly forms polycrystalline aggregates as much as 10 mm across that locally contain needles of rutile. The potassium feldspar is pale pink microcline that displays poor to strongly developed grid twins and weak microperthitic texture. Accessory minerals include sphene and apatite and lesser quantities of allanite and zircon.

The western contact of potassium-rich hornblende-biotite granodiorite with the more extensive biotite granodiorite is not well exposed, and the age relationships of the two units were not determined by geologic mapping. Along the eastern contact, in the vicinity of the McCoy mine, the hornblende-biotite granodiorite intrudes the older quartz diorite.

Two K/Ar dates on biotite of 84.0 and 83.8 Ma (Lewis and others, 1987; Berry and others, 1976) are the best estimate of the age of the hornblende-biotite granodiorite unit.

Tonalite

Hornblende-biotite tonalite grading to granodiorite crops out along the western edge of the Challis 1°×2° quadrangle (Kiilsgaard and Lewis, 1985). Outcrops of similar rock are present west of the Hailey 1°×2° quadrangle but not in exposures of sufficient size to warrant mapping as individual units. In the central part of the quadrangle, tonalite grading to granodiorite was mapped along the western side of House Mountain and along both sides of the South Fork of the Boise River, from near the mouth of Beaver Creek east to near the junction of Big Smoky Creek and the South Fork of the Boise River (Worl and others, 1991) (fig. 2, unit Kt).

The tonalite is medium gray, equigranular, and medium grained. Biotite locally defines a weak foliation, and biotite-rich schlieren are present at a few localities. The unit is crosscut by numerous aplite and pegmatite dikes and, to a much lesser extent, by fine-grained granitic dikes that may be offshoots of the biotite granodiorite unit discussed in the following section. Although this dike relationship suggests that the tonalite predates the biotite granodiorite, several of the contact areas between the two units appear to be gradational, and the two units may be similar in age.

Plagioclase feldspar in the tonalite is normally zoned andesine and calcic oligoclase. Potassium feldspar lacks albite-pericline grid twins, and microperthitic textures are weakly developed or absent. Quartz is present as aggregates of small (0.5 mm) grains formed by recrystallization of larger strained grains. Subhedral biotite make up about 10 percent of the rock. Lesser amounts of green hornblende are present as stubby, subhedral crystals as long as 6 mm. Magnetite is the predominant opaque mineral. Apatite and sphene are conspicuous accessory minerals, and lesser amounts of allanite and zircon are also present.

An $^{40}Ar/^{39}Ar$ plateau age of 93.7±0.3 Ma on hornblende was obtained from tonalite along the South Fork of the Boise River (L.W. Snee, unpub. data, 1992).

Biotite Granodiorite

Biotite granodiorite is widespread over a vast area in central Idaho. It extends more than 130 km in an east-west dimension and more than 190 km in a north-south dimension (Fisher and others, 1983; Worl and others, 1991). Biotite granodiorite makes up most of the Idaho batholith in the Hailey 1°×2° quadrangle (fig. 2, unit Kgd) and the Challis 1°×2° quadrangle to the north. It is the principal granitic rock exposed along the various roads in that part of Idaho, such as north along State Highway 21 from the mouth of Grimes Creek, past Idaho City, to and beyond Lowman.

The biotite granodiorite is light gray, medium to coarse grained, and equigranular to porphyritic. Phenocrysts, where present, are potassium feldspar and are ±2 cm. Plagioclase (weakly zoned oligoclase) is the principal mineral in the rock, and quartz and potassium feldspar are also present (fig. 3*B*). Quartz commonly is present as large clots that are somewhat darkened and much like phenocrysts. Under the microscope, the clots are seen to be contiguous aggregates of crystals and not large single crystals. Biotite makes up 2-12 percent of the rock and commonly is partly altered to chlorite. Sericite, an alteration product of feldspar, is widespread throughout the rock, but primary muscovite is sparse to absent. Hornblende is not present in biotite granodiorite in the western part of the quadrangle but is locally present east of the Middle and South Forks of the Boise River. Accessory minerals include sphene, allanite, zircon, monazite, and opaque minerals.

The age of the biotite granodiorite is not well established, but the unit probably was intruded between about 85 and 70 Ma.

Altered Biotite Granodiorite

Altered biotite granodiorite (unit Kai of Worl and others, 1991) crops out at several localities in the western part of the quadrangle. It is conspicuous on the high ridge at the headwaters of California and Grayback Gulches, about 5 km south of Idaho City, and extending along the ridge to the southwest. Other exposures are on both sides of Mores Creek about 8 km southwest of Idaho City and west, south, and east of Mt. Heinen.

Altered biotite granodiorite is light gray, although commonly it is iron stained along or near fracture surfaces. The rock is medium- to coarse grained and equigranular to porphyritic. Feldspar in the rock is moderately to intensely altered to sericite and clay minerals. Commonly, feldspar phenocrysts are so altered that identification of the original mineral is uncertain. Biotite is altered to chlorite or to iron oxide minerals, which accounts for the reddish, rusty stain that is characteristic of the unit. Locally, the rock is moderately to intensely silicified, either by silica flooding of the matrix, or by countless veinlets of quartz, that commonly are 2 mm thick or less.

All mapped exposures of altered biotite granodiorite are near younger plutonic rocks of Eocene age that clearly intrude the older altered rocks. Field relationships and alteration features of the older rocks indicate that the alteration is the result of hydrothermal activity associated with the younger intrusive activity.

Biotite Granodiorite-Aplite and Pegmatite Complexes

Near the southern edge of the Idaho batholith, in the area between House Mountain and Smoky Dome, large exposures of biotite granodiorite are cut by so many aplite and pegmatite dikes (the dikes make up more than 50 percent of the exposed mass) that the rocks are identified as a separate unit (unit Kap of Worl and others, 1991). Locally, the dikes, which are considered to be Cretaceous in age, are so dominant that they give the host biotite granodiorite the appearance of being engulfed, ellipsoidal-shaped xenoliths (Bennett, in press). Northwest of Hill City, the biotite granodiorite-dike complex is foliated (unit Kfap of Worl and others, 1991), the biotite in the granodiorite marking the foliation. In the area around Anderson Ranch Reservoir, the granodiorite-dike complex contains pendants and xenoliths of schist, quartzite, and various calc-silicate rocks in such abundance that the rocks are identified as a mappable unit (unit Kapm of Worl and others, 1991).

The three biotite granodiorite-dike complex units mark the top or near top of the Idaho batholith. This conclusion is based on observations at roof pendants, both in the Hailey 1°×2° quadrangle and in the contiguous Challis 1°×2° quadrangle to the north (Kiilsgaard and Lewis, 1985).

Muscovite-Biotite (Two-Mica) Granite

A southwest-trending belt of muscovite-biotite (two-mica) granite grading to granodiorite extends across the northwestern corner of the quadrangle (fig. 2, unit Kg) (Worl and others, 1991). The rock also is exposed from the vicinity of Sunset Mountain southeast to the vicinity of Swanholm Creek and along the southern edge of the Idaho batholith in the areas north of Mayfield and west of Smith Prairie.

Laminated plates or books of primary muscovite, large enough to recognize in hand sample, were used as a field criterion in mapping muscovite-biotite granite. The rock is massive, light gray, medium to coarse grained, and equigranular to porphyritic and consists chiefly of oligoclase, quartz, and potassium feldspar. Muscovite makes up as much as 5 percent of the rock but averages about 2 percent. Biotite content averages less than 5 percent. Hornblende is not present in the two-mica granite. Red garnet is a common accessory. The average mode of samples of the rock from the Hailey 1°×2° quadrangle plots as granodiorite (fig. 3*C*), but in the Challis 1°×2° quadrangle to the north the average mode plotted as granite (Kiilsgaard and Lewis, 1985).

Except at fault contacts, the contact between muscovite-biotite granite and biotite granodiorite is gradational across widths of as much as 3 km or more. A K/Ar age determination of 67.2±2.5 Ma on biotite is interpreted as a minimum age of the two-mica unit. Similar muscovite-bearing granite in the Challis 1°×2° quadrangle has muscovite K/Ar ages of 76-69 Ma (Lewis and others, 1987).

Leucocratic Granite

Dikes and small stocks of leucocratic granite as large as 5 km in maximum dimension crop out in the north-central part of the quadrangle, northwest of Atlanta, in the vicinity of Johnson Creek and the North Fork of the Boise River (Kiilsgaard, 1983a) (unit Klg of Worl and others, 1991). Dikes of leucocratic granite are present, but less common, in the western part of the quadrangle.

The leucocratic granite is light gray to almost white and fine to medium grained and has a distinctive aplitic texture. The rock consists almost entirely of quartz, plagioclase, and potassium feldspar. Accessory minerals include biotite, magnetite, sphene, and allanite. Garnets as much as 3 mm across are common at some exposures. The plagioclase (An 26-30) is moderately altered to sericite, as is the potassium feldspar, which is chiefly perthitic microcline. Seventeen samples of the rock collected in the north-central part of the quadrangle and the area immediately to the north of the quadrangle have an average mode of 34 percent quartz, 32 percent potassium feldspar, and 34 percent plagioclase. Mafic mineral content, chiefly biotite, ranges from less than 1 percent to 3 percent but averages about 2 percent.

Distinguishing features of the rock are its fine to medium grain size and light color. The rock is resistant to erosion and tends to form high points of ridges. It weathers to irregular, resistant, rubbly scree that, on steep hillsides, gives the appearance of having been eroded from larger bodies, when, in fact, most rubbly scree is derived from dikes that are only about 2–4 m thick.

The leucocratic granite cuts sharply across all other plutonic rocks of the Idaho batholith. On the high ridges northeast of Goat Mountain it is intruded by Eocene biotite (pink) granite, and in upper reaches of Little Silver Creek, immediately to the north of the Hailey 1°×2° quadrangle, it is intruded by Eocene porphyritic biotite-hornblende granodiorite. K/Ar age determinations from leucocratic granite in the Challis 1°×2° quadrangle suggest an age of about 75–70 Ma (Lewis and others, 1987).

Pegmatite and Aplite Dikes

Pegmatite and aplite dikes commonly crosscut Cretaceous plutonic rocks in the Hailey 1°×2° quadrangle, but most of the dikes are small, only a few centimeters thick and a few meters long, and were not mapped. Locally, pegmatite dikes are 2-3 m thick but only ±10 m long. The larger pegmatite dikes are shown on the geologic map of Worl and others (1991). The dikes are most common along the crests of high ridges, and their resistance to erosion probably is a factor in the resistance of the ridges to erosion. In the south-central part of the quadrangle the dikes are so numerous that they form a complex of rocks described earlier as the aplite-pegmatite complex.

Aplite dikes rarely are more than 5-15 cm thick. The aplite has aphanitic texture and is composed chiefly of quartz and feldspar. The pegmatite is light, almost white in color, and is distinguished by the large grain size of the minerals. Sheets of muscovite, for example, commonly are as much as 15 cm in the maximum dimension. Quartz may be graphically intergrown with feldspar. The largest pegmatite dike crops out immediately north of the northern boundary of the Hailey 1°×2° quadrangle, near its northwestern corner. That dike, one of three in the area, is about 75 m long and 60 m wide. It has a graphic granite wall zone, a plagioclase-quartz-muscovite intermediate zone, and a quartz core. Columbite, samarskite, and monazite are in the intermediate zone. A 140 kg crystal that has a core of columbite and a rim of samarskite was reportedly found in the pegmatite (Fryklund, 1951). Also in the northwestern corner of the quadrangle, about 1.2 km upstream from the mouth of Swede Creek and at the stream bank, is a pegmatite about 2 m thick and 12 m long from which a few kilograms of colorless beryl and some topaz reportedly was mined in 1987.

Age determinations of the pegmatite and aplite dikes were not attempted, but field relationships indicate that they are associated with the Cretaceous plutonic rocks.

Geochronology

Although various age designations have been proposed for the Cretaceous plutonic rock units in the Hailey 1°×2° quadrangle, the ages of plutonic and hypabyssal rocks in the quadrangle are not well known. Most radiometric determinations were made using the K/Ar method, which records only the time since the rock cooled past the argon blocking temperature of the mineral dated. Also, in some areas, the Cretaceous plutonic rocks were reheated by Eocene plutonism, resulting in argon loss from the biotite and muscovite. A number of samples were collected along or near major faults, and hydrothermal activity along the faults also has caused argon loss. In some cases hornblende may have gained argon during reheating and the dates tend to be too old. Recent dating by the $^{40}Ar/^{39}Ar$ method (L.W. Snee, unpub. data, 1992) helps to define the effects of argon loss and gain and to obtain more reliable dates. Overall, however, age data for rocks of the Atlanta lobe of the batholith are sparse, and the K/Ar dates contain many uncertainties.

Age determinations of Cretaceous and Eocene rocks by the K/Ar method made during the course of the present study are presented in table 1. Field localities of known dated samples are shown in figure 4. Because of reasons discussed preceding, most of the age determinations of Cretaceous samples are considered to be too young. Nevertheless, a review of available data indicates that Cretaceous intrusive activity began about 95 Ma and continued until about 70-65 Ma (table 1) (Armstrong, 1975; Berry and others, 1976; Criss and others, 1982; Lewis and others, 1987; Lewis, 1990; Park, 1990; L.W. Snee, unpub. data, 1992).

Geochemistry

Mean values of major-element oxides and some trace elements for 90 samples comprising seven rock types are shown in table 2. Average SiO_2 content ranges from 57 to 75 percent, but the most common rock types contain between 66 and 74 percent. Average biotite granodiorite in the western part of the quadrangle differs in chemical content from that of petrographically similar biotite granodiorite in the eastern part of the quadrangle. The western biotite granodiorite is more enriched in SiO_2, Na_2O, and Ba but has a lower average content of iron oxides, MgO, CaO, TiO_2, P_2O_5, Y, and Zr. These chemical differences probably result from different magmatic source regions from west to east. The only field distinction between western and eastern biotite granodiorite is the local presence of hornblende in the eastern granodiorite. Chemically, granodiorite in the east contains less than about 70.5 percent SiO_2. The chemical and mineralogical changes occur across a poorly constrained northerly trending zone that passes through the vicinity of Atlanta (fig. 5) and appears to be gradational. East of this zone, biotite granodiorite contains less SiO_2 and Na_2O and more of MgO and CaO (fig. 5). Hornblende-biotite granodiorite, tonalite, and quartz diorite also contain less SiO_2 than does western granodiorite. Chemical differences are less apparent between eastern granodiorite and potassium-enriched hornblende-biotite granodiorite because only average values are reported. For a given SiO_2 content eastern granodiorite is depleted in K_2O and MgO and enriched in Na_2O, Ba, and Sr relative to hornblende-biotite granodiorite (Lewis, 1989, 1990).

Muscovite-biotite granite is similar chemically (table 2) and, except for muscovite, similar mineralogically to western

Table 1. Potassium-argon ages of Cretaceous and Eocene plutonic and hypabyssal rocks, determined from l979 to 1992, Hailey 1°×2° quadrangle, Idaho.

[Dated by R.F. Marvin and Jarel Van Essen, U.S. Geological Survey, except for samples IC-55 and IC-77, which were dated by Krueger Enterprises, Inc., Geochron Laboratories Division and the data donated by Lawrence F. Baum, of L.F. Baum and Associates. Rock units: Kgd, biotite granodiorite; Kg, muscovite-biotite granite; Tfgd, foliated hornblende-biotite granodiorite; Tqm, quartz monzodiorite; Tg, biotite granite; Tda, dacite. Listed ^{40}Ar radiometric (rad) values are 10^{-10} mole/gram]

Sample	Latitude (degrees north)	Longitude (degrees west)	Rock unit	Mineral	K_2O percent	^{40}Ar radio-metric	^{40}Ar percent	Age (Ma)
B8828501	43.59306	115.01000	Kgd	Hornblende	1.34	1.901	75	96.0 ± 3.5
RL-193	43.70000	115.99917	Kgd	Hornblende	1.29	1.980	85	104.0 ± 4.0
85-51K	43.90653	115.64500	Kg	Muscovite	10.20	10.06	80	67.2 ± 1.9
85-51K	43.90653	115.64500	Kg	Biotite	8.58	8.063	90	64.1 ± 2.3
84-34K	43.77597	115.92181	Tqm	Biotite	6.91	4.640	86	46.1 ± 1.7
85-301K	43.71000	115.80167	Tqm	Biotite	7.46	4.764	73	43.8 ± 1.6
85DS61	43.74167	114.72500	Tqm	Biotite	4.57	3.214	77	48.2 ± 1.7
IC-55	43.95235	115.99054	Kgd	Biotite	8.545	8.453	83	67.2 ± 2.5
IC-58	43.98057	115.90665	Tqm	Biotite	7.480	4.973	80	45.5 ± 1.8
P-87	43.55000	114.80000	Tfgd	Biotite	8.73	5.526	65	43.5 ± 1.3
P-147	43.60000	115.95000	Tqm	Biotite	8.73	5.271	76	41.5 ± 1.2
P-150-1	43.65000	115.78330	Tg	Biotite	8.85	5.309	51	41.2 ± 1.2
H-173	43.60500	114.7083	Tda	Hornblende	0.845	0.5849	42	47.2 ± 0.9

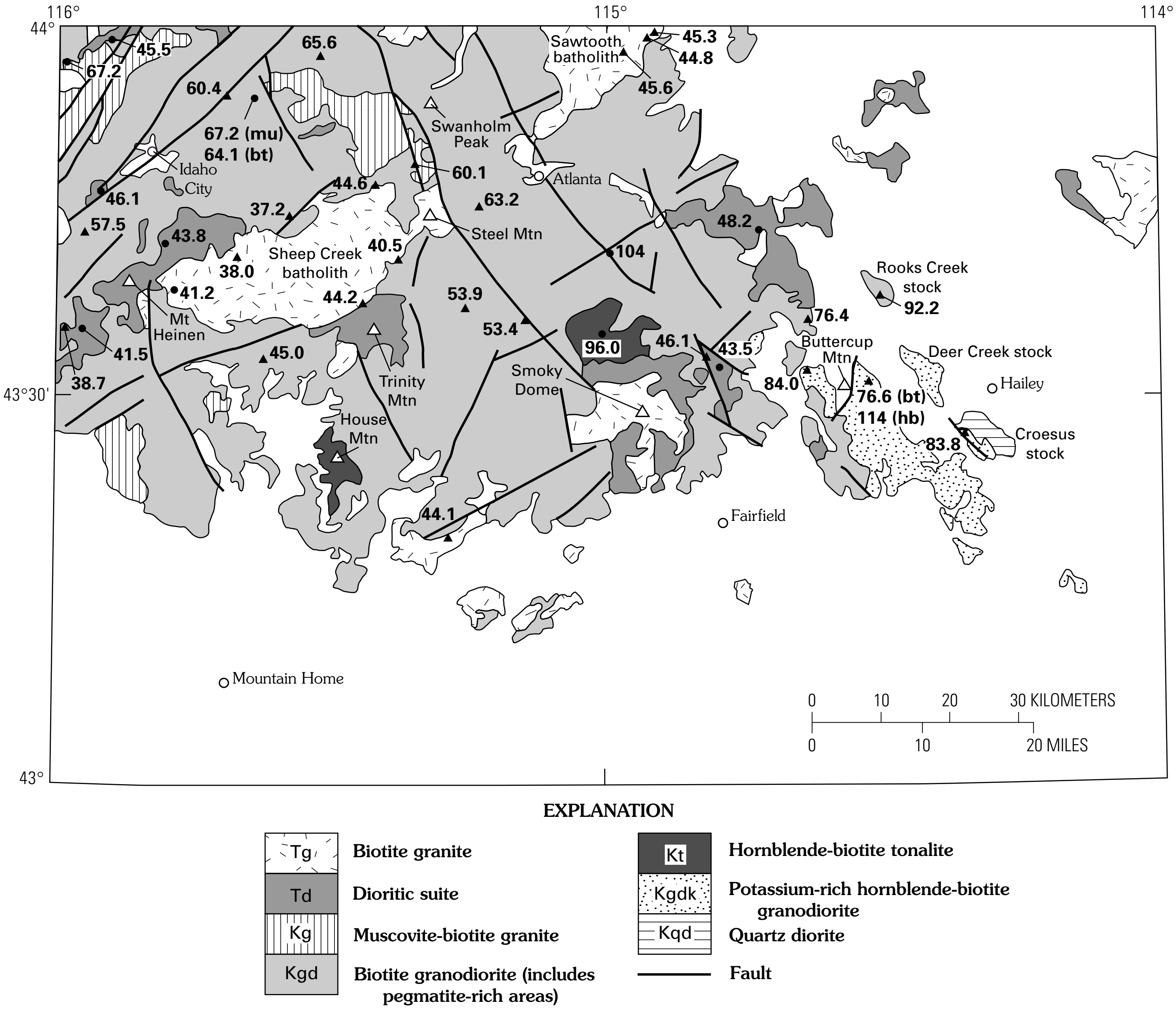


Figure 4. Simplified geologic map of Cretaceous and Eocene plutonic rocks and associated major faults in the Hailey 1°×2° quadrangle, showing K/Ar dates (in Ma) determined during the course the current study (solid circles), and those determined previously (triangles) (Criss and others, 1982). mu, muscovite; bt, biotite; hb, hornblende.

biotite granodiorite, as is leucocratic granite. Western biotite granodiorite, muscovite-biotite granite, and leucocratic granite are peraluminous (table 2, A/CNK ratios), whereas hornblende-bearing rocks (eastern biotite granodiorite, hornblende-biotite granodiorite, hornblende-biotite tonalite, and quartz diorite) that are east of the northerly trending zone near Atlanta are metaluminous to weakly peraluminous.

Eocene Plutonic Rocks

Large areas of the Hailey quadrangle previously thought to be underlain by Cretaceous plutonic rocks of the Idaho batholith are now known to be underlain by Eocene plutonic rocks (fig. 2) (Worl and others, 1991). Two categories of Eocene plutonic rocks are recognized: a dioritic suite that ranges from gabbro to granite in composition but is chiefly quartz monzodiorite, and biotite granite (commonly called pink granite). The designation “dioritic suite” is used herein as a means of showing the various intermediate to more mafic Eocene rocks as a single unit in figure 2 (unit Td). Rocks of the two categories are present as discrete stocks and epizonal batholiths that intrude the Cretaceous Idaho batholith as well as Paleozoic metasedimentary rocks in the eastern part of the quadrangle (Bennett, 1980a, b; Bennett and Knowles, 1985; Lewis and Kiilsgaard, 1991). Intrusive contacts with pre-Tertiary rocks commonly are sharp, and contact metamorphic effects are minimal. Rocks of the two categories commonly are in sharp contact with each other and have been intruded along similar northeast-trending structures (Fisher and others, 1983; Worl and others, 1991). At two localities, apophyses of biotite granite cut the dioritic rocks, and, elsewhere,

Table 2. Mean values of major oxides and trace elements, Cretaceous plutonic rocks, Hailey 1°×2° quadrangle, Idaho.

[Analytical determinations by X-ray fluorescence and optical spectroscopy. Analysts: T. Taggart A. Bartel, T. McCollom, P. Briggs, E. Brandt, C. Papp, C. Stone, S. Roof, L. Jackson, J. Christie, K. Stewart, D. Siems, K. Slaughter, N. Elsheimer, J. Evans, M. Malcolm, and S. Pribble, U.S. Geological Survey. Rock units: Kgd, biotite granodiorite; Kgdk, potassium-enriched hornblende-biotite granodiorite; Kt, tonalite; Kgd, quartz diorite; Kg, muscovite-biotite granite; and Klg, leucocratic granite. A/CNK, $Al_2O_3/(CaO+Na_2O+K_2O)$ molecular ratio]

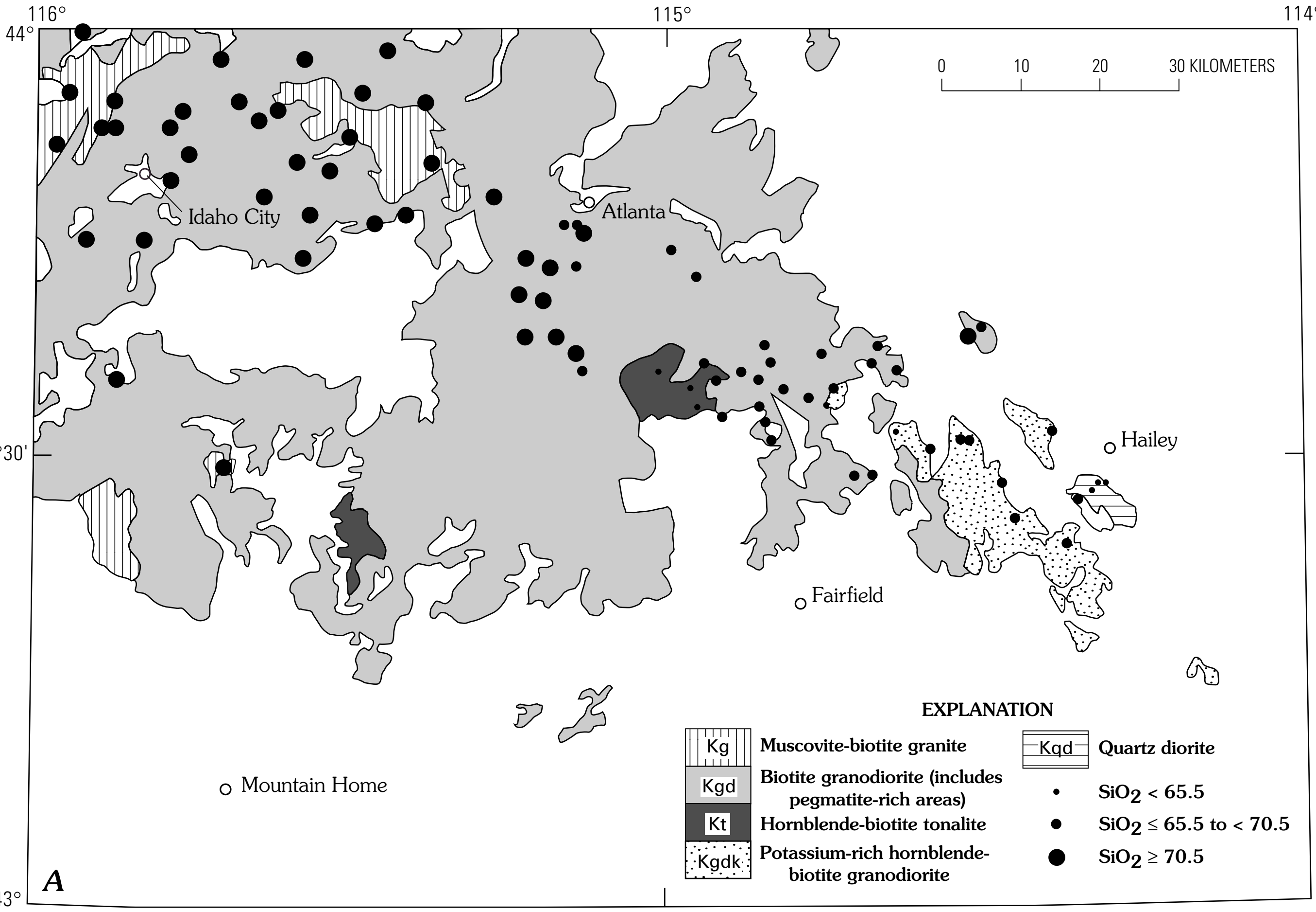
Rock unit	Kgd (west)	Kgd (east)	Kgdk	Kt	Kqd	Kg	Klg
No. of samples----------------	31	27	11	4	4	7	6
In Percent							
SiO_2	72.4	68.9	67.3	65.8	56.8	73.6	75.3
Al_2O_3	15.1	15.4	15.1	16.1	17.1	14.6	14.1
Fe_2O_3	0.35	1.19	1.26	1.43	1.61	0.49	0.30
FeO	0.77	1.55	2.10	2.25	4.62	0.52	0.42
MgO	0.28	0.90	1.68	1.49	4.06	0.24	0.17
CaO	1.67	3.07	3.54	3.95	6.99	1.53	0.85
Na_2O	4.40	3.64	3.27	4.04	3.47	4.16	4.17
K_2O	3.37	3.14	3.43	2.14	1.69	3.04	4.17
TiO_2	0.14	0.49	0.56	0.66	1.16	0.11	0.06
P_2O_5	0.04	0.16	0.18	0.22	0.40	0.05	0.05
MnO	0.03	0.04	0.06	0.06	0.10	0.03	0.02
A/CNK	1.09	1.00	0.98	1.00	0.84	1.13	1.09
In Parts Per Million							
Ba	1550	1310	910	1260	880	1460	1180
Sr	520	700	500	790	840	470	340
Y	6	12	13	14	20	9	5
Zr	90	210	170	220	180	80	20
Rb	80	100	120	80	50	80	80

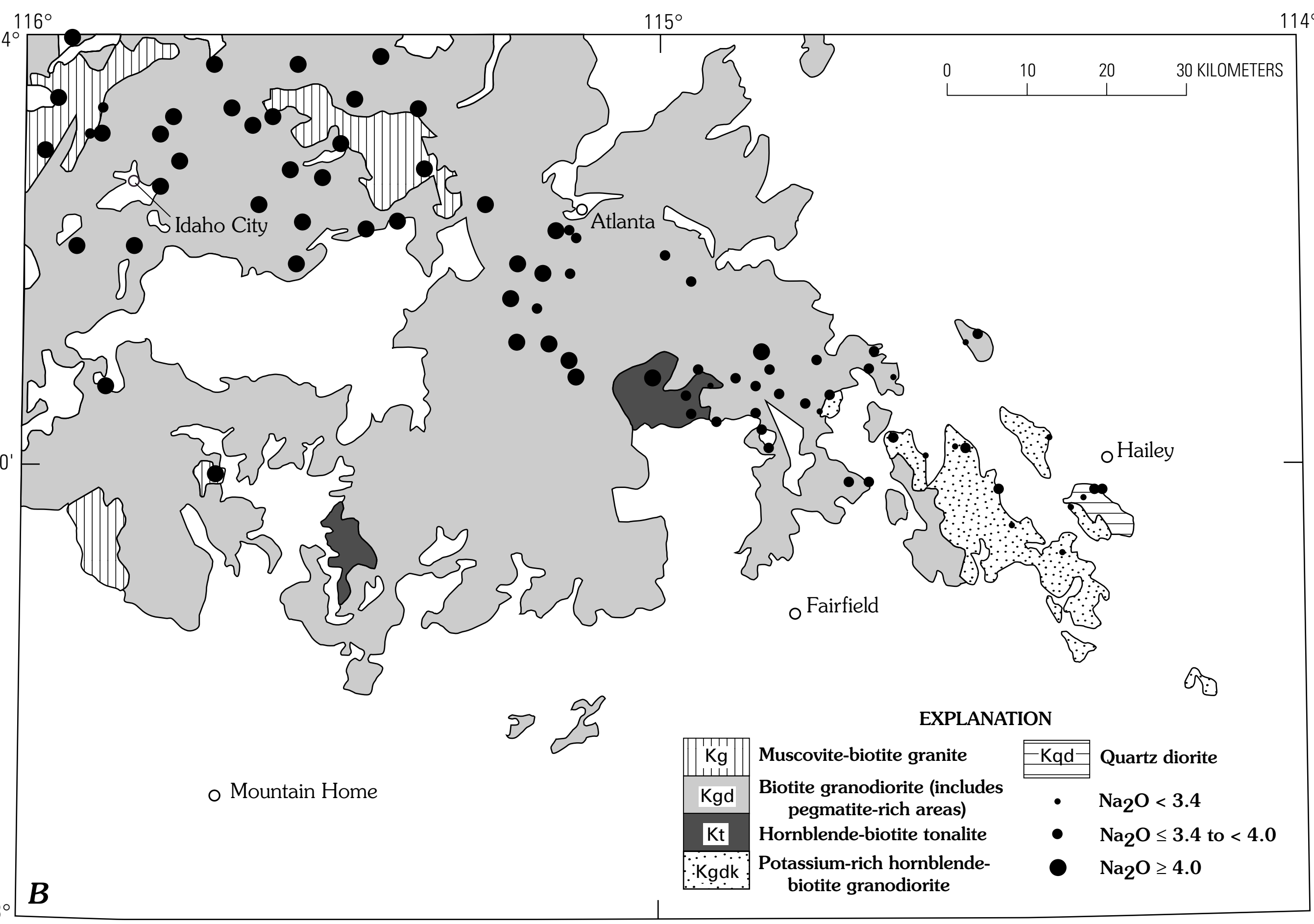
remnants of the dioritic rocks are present in the biotite granite. These field observations suggest that the dioritic rocks are older, a conclusion supported by age determinations of the rocks in the contiguous Challis 1°×2° quadrangle to the north (Bennett and Knowles, 1985).

New potassium-argon age determinations of Eocene plutonic rocks are shown in table 1. A summary of other age determinations is in Criss and others (1982). Locations of all known dated Eocene rocks for which sample determinations are considered reliable are shown in figure 4. In contrast to the problems associated with K/Ar dating of Cretaceous rocks, K/Ar age determinations of Eocene plutonic rocks are probably reasonably accurate. Most ages are between 48 and 40 Ma and are consistent with field relationships, which is probably a result of the epizonal emplacement levels and relatively rapid cooling rates of the Eocene rocks. Also, the area has not undergone major heating since Eocene time. Of the reported determinations, 11 samples of dioritic rocks show an age range from 48.4 Ma to 38.7 Ma and an average of 44.9 Ma, whereas 7 samples of biotite (pink) granite show an age range from 45.6 Ma to 37.2 Ma and an average of 43.0 Ma. The determinations indicate that, on average, the dioritic rocks are slightly older than the biotite granite, a relationship supported by field observations.

The close spatial relationship between the biotite granite and the dioritic suite was noted in the contiguous Challis 1°×2° quadrangle to the north (Fisher and others, 1983; Kiilsgaard, 1983a; Bennett and Knowles, 1985). In the Hailey 1°×2° quadrangle, the relationship is particularly evident along the northwest and southeast sides of the Sheep Creek batholith and along the periphery of much of the Smoky Dome stock. Although the close spatial relationship suggests a genetic link between the two types of rocks, isotopic and major- and trace-element geochemical data indicate that the two categories of rocks are not related through fractional crystallization (Lewis, 1984; Stewart, 1987; Lewis and Kiilsgaard, 1991; Stewart and others, in press). Rather, the respective magmas probably originated from different sources. The magmas could have been related to the same thermal event or to closely spaced events, and they could have been emplaced along the same zones of structural weakness (that is, the Trans-Challis fault system and related structures

Figure 5 (following pages). Simplified geologic map of the Hailey 1°×2° quadrangle showing Cretaceous plutonic rocks and ranges in major-element oxide percentages. All analyses by U.S. Geological Survey laboratories as part of current study except for eight samples of biotite granodiorite from the Cayuse Point area south of Atlanta (Slavik, 1987). *A*, SiO_2. *B*, Na_2O. *C*, MgO. *D*, CaO.


116°
115°
114°
44°
43°30'
43°
0 10 20 30 KILOMETERS
Idaho City
Atlanta
Hailey
Fairfield
Mountain Home
EXPLANATION
Kg Muscovite-biotite granite
Kgd Biotite granodiorite (includes pegmatite-rich areas)
Kt Hornblende-biotite tonalite
Kgdk Potassium-rich hornblende-biotite granodiorite
Kqd Quartz diorite
$SiO_2 < 65.5$
$SiO_2 \leq 65.5$ to < 70.5
$SiO_2 \geq 70.5$
A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Idaho City
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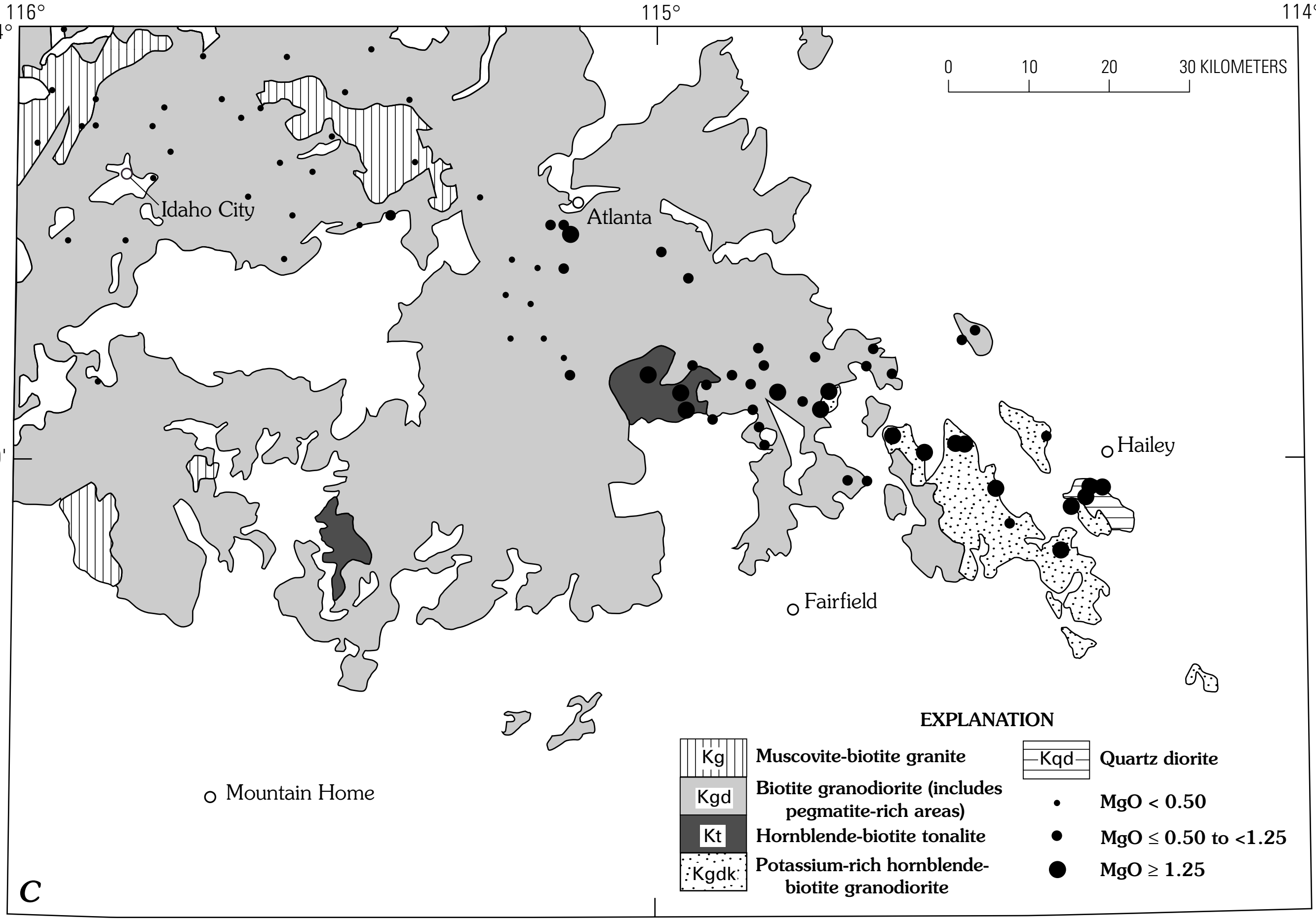
Kgdk Potassium-rich hornblende-biotite granodiorite
Kqd Quartz diorite
$Na_2O < 3.4$
$Na_2O \leq 3.4$ to < 4.0
$Na_2O \geq 4.0$
B


116°
115°
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0 10 20 30 KILOMETERS
Idaho City
Atlanta
Hailey
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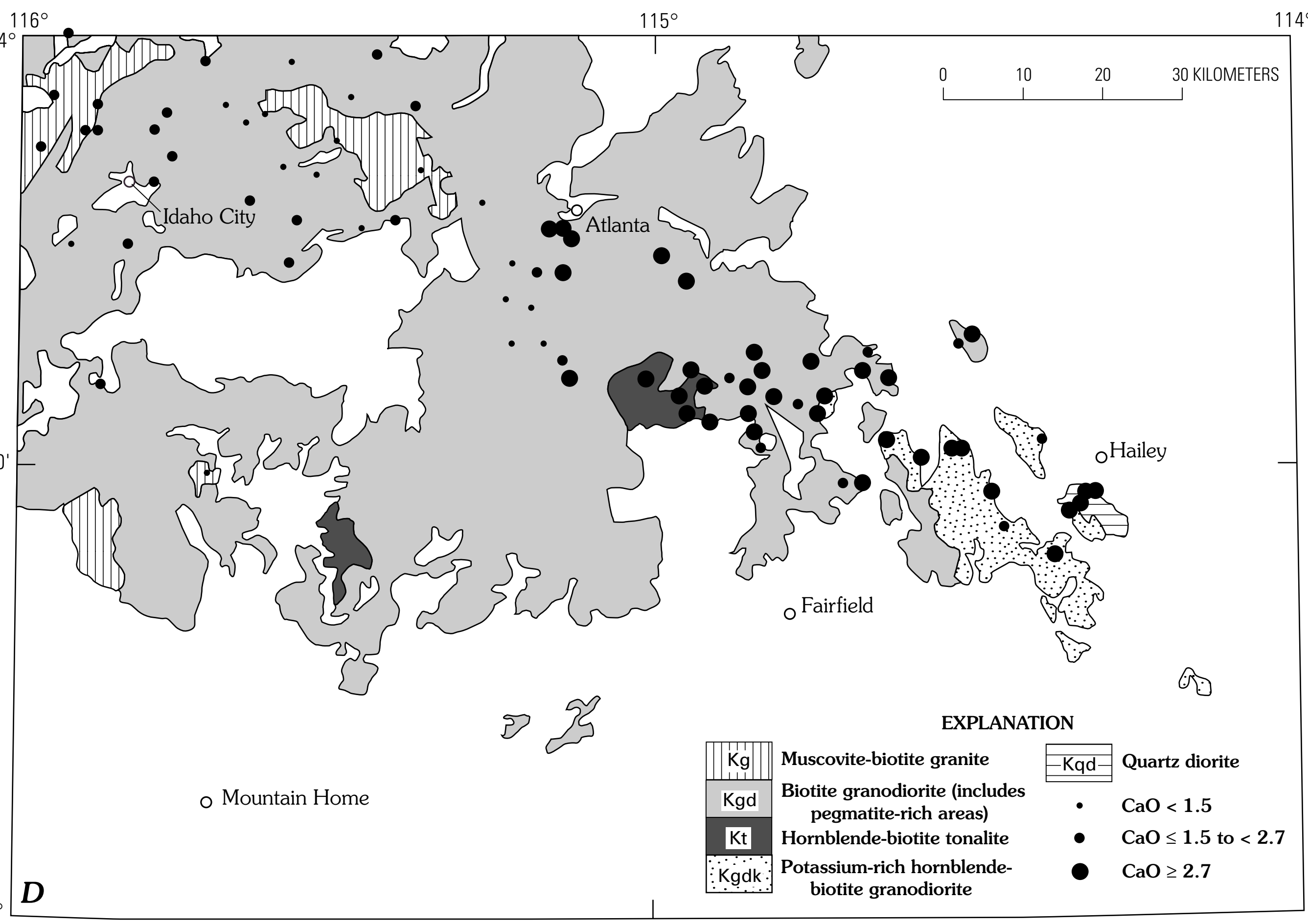
Mountain Home
EXPLANATION
Kg Muscovite-biotite granite
Kgd Biotite granodiorite (includes pegmatite-rich areas)
Kt Hornblende-biotite tonalite
Kgdk Potassium-rich hornblende-biotite granodiorite
Kqd Quartz diorite
MgO < 0.50
MgO ≤ 0.50 to <1.25
MgO ≥ 1.25
C


116°
115°
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0 10 20 30 KILOMETERS
Idaho City
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Fairfield
Mountain Home
EXPLANATION
Kg Muscovite-biotite granite
Kgd Biotite granodiorite (includes pegmatite-rich areas)
Kt Hornblende-biotite tonalite
Kgdk Potassium-rich hornblende-biotite granodiorite
Kqd Quartz diorite
CaO < 1.5
CaO ≤ 1.5 to < 2.7
CaO ≥ 2.7
D

Kiilsgaard and others, 1989), thereby resulting in the close spatial relationship. There are, however, alternative geologic processes that could have been involved in the formation of these two categories of rocks and these are discussed in a later section of this report that discusses the geochemistry of Eocene plutonic rocks.

Dioritic Suite

Rocks of the dioritic suite have many common characteristics and are widely exposed across the quadrangle (fig. 2, unit Td). The dioritic rocks are darker than the Cretaceous biotite granodiorite, and they weather to a reddish, even-granular soil that contrasts with the lighter soil derived from most Cretaceous plutonic rocks. They invariably contain hornblende and commonly contain augite. The plagioclase is chiefly andesine and is strongly and complexly zoned. Quartz tends to be interstitial. An unusual amount of magnetite is present, and several stocks are the source of magnetic highs on regional aeromagnetic maps. Textures of the dioritic rocks vary from equigranular to porphyritic, and from fine grained to coarse grained, but most rocks are medium grained and seriate. Dramatic variations in texture and composition can be present within a single stock, and contacts between some phases are gradational in some places but sharp in others. The more mafic rocks, particularly diorite, are more common at, but not restricted to, margins of the stocks. The compositional average of rocks of the suite is quartz monzodiorite (fig. 3*F*).

Gabbro

Several small stocks of gabbro crop out in two areas in the Hailey 1°×2° quadrangle. One area is in the central part of the quadrangle (unit Tgb of Worl and others, 1991), northwest of Fairfield, and the other is in the western part of the quadrangle (unit Td of Worl and others, 1991), on Thorn Creek ridge, about 4 km southwest of Thorn Creek Butte.

The rock on Thorn Creek ridge is dark gray, equigranular, and medium to fine grained. It is layered, the layers range from millimeters to centimeters in thickness and consist chiefly of cumulate aggregates of pyroxene, labradorite grading to andesine, and olivine. The plagioclase minerals are strongly altered to sericite. The quartz content is low, less than 1 percent. Magnetite, zircon, apatite, and sphene are common accessory minerals.

The gabbro northwest of Fairfield is rich in hornblende (about 50 percent). It is dark colored, equigranular, and medium to fine grained. The plagioclase is euhedral andesine that is highly altered to sericite and epidote. Relict clinopyroxene, potassium feldspar, and opaque minerals are minor constituents. Apatite is relatively abundant (about 1 percent).

Diorite

Diorite in the northwestern corner of the Hailey 1°×2° quadrangle was first recognized by Anderson (1947). Additional exposures of Eocene diorite mapped during this study include outcrops south of Wilson Peak, north of Idaho City, and southwest of Mt. Heinen (Scanlan, 1986) and a stock on the ridge west of Willow Creek in the eastern part of the quadrangle (unit Td of Worl and others, 1991). The diorite tends to crop out peripheral to or near quartz monzodiorite. It weathers readily and commonly is exposed as flat ridge tops or benches. Weathered diorite also forms a distinctive, fine-grained, dark-brown soil.

The diorite is dark gray, equigranular to somewhat porphyritic, and medium to fine grained. It commonly has a salt and pepper appearance resulting from lighter plagioclase crystals interstitial to darker mafic minerals. The plagioclase is andesine that is commonly strongly zoned. Hornblende is the principal mafic mineral, although biotite, augite, and hypersthene are common constituents. Potassium feldspar and quartz are rare. Magnetite, zircon, apatite, and sphene are common accessory minerals.

Foliated Hornblende-Biotite Granodiorite

Foliated hornblende-biotite granodiorite is well exposed in an upthrown fault block north of Fairfield (Lewis, 1990; unit Tfgd of Worl and others, 1991). It is resistant to erosion and forms steep canyon walls along Little Smoky Creek. The unit is heterogeneous, ranging from quartz diorite to granite in composition. The rocks vary from strongly foliated to massive; alternating centimeter- to decimeter-thick layers of mafic and subordinate felsic phases define the foliation. Foliation strikes northeast and typically dips steeply. The unit is intruded by nonfoliated rocks of the quartz monzodiorite unit described later.

Mafic rocks in the foliated hornblende-biotite granodiorite unit are medium to fine grained and equigranular. Plagioclase feldspar is euhedral to subhedral oligoclase-andesine. Zoning of plagioclase is pronounced; core compositions in one sample are about 20-25 percent higher in anarthite content than the rims. Hornblende and biotite are the predominant mafic minerals, and augite is present locally. Potassium feldspar and quartz are interstitial. Apatite, sphene, allanite, and zircon are present as accessory minerals.

Felsic rocks of the unit are fine-grained, equigranular biotite granodiorite and granite, some of which is aplitic. Quartz, oligoclase, and perthitic potassium feldspar are the predominant minerals. The mafic minerals are biotite and minor hornblende and opaque minerals. Apatite, sphene, allanite, and zircon are present in trace amounts.

Quartz Monzodiorite

Quartz monzodiorite ranging to hornblende-biotite granodiorite and hornblende-biotite granite (fig. 3*F*) is the most widespread Eocene plutonic rock in the Hailey 1°×2° quadrangle (unit Tqm of Worl and others, 1991). Anderson (1947) recognized this rock as Tertiary in age and described a belt of quartz-hornblende-biotite monzonite porphyry that trends northeast from the vicinity of the abandoned town of Quartzburg, which is about 4 km northwest of Placerville. Had Anderson used the current international classification of granitic rocks (Streckeisen, 1973), he no doubt would have classified the rock as quartz monzodiorite. Other discontinuous exposures of quartz monzodiorite extend from the western edge of the Hailey 1°×2° quadrangle northeast along the broad ridge that separates Grimes Creek from Mores Creek to and beyond the northern edge of the quadrangle. The largest and most continuous exposures extend northeast through Mt. Heinen to beyond Thorn Creek Butte (Worl and others, 1991). In this expanse, the rock composition undergoes gradational west-to-east change from quartz monzodiorite to hornblende-biotite granodiorite. The persistent northeast trend of the exposures in the western part of the quadrangle suggests that emplacement of the quality monzodiorite was guided by pre-intrusive northeast-trending faults that are either components of, or more or less parallel to, the Trans-Challis fault system (Kiilsgaard and Lewis, 1985). Other large exposures of the quartz monzodiorite are in the vicinity of Trinity Mountain, and peripheral to the northern and eastern parts of Soldier Mountains (Worl and others, 1991).

The quartz monzodiorite typically contains 10-30 percent hornblende and biotite. Hornblende is euhedral, acicular, and commonly glomerocrystic. Pseudohexagonal books of vitreous biotite are a distinctive feature. Clinopyroxene is present in some of the quartz monzodiorite both as small phenocrysts and as cores of hornblende grains. Euhedral to subhedral plagioclase is strongly and complexly zoned and is dominantly andesine. Quartz and potassium feldspar (chiefly intermediate microcline) are subordinate interstitial minerals. Principal accessory minerals are magnetite, apatite, and sphene; minor amounts of allanite, zircon and monazite are also present. Ellipsoidal inclusions of fine-grained, hornblende-rich rock are common at some localities.

Biotite Granite

Discontinuous exposures of biotite granite (also called pink granite) extend across the Hailey 1°×2° quadrangle (fig. 2, unit Tg) (Worl and others, 1991). The largest exposure extends northeast, more or less along the Middle Fork of the Boise River, from an area about 2 km east of Cottonwood Creek to beyond Steel Mountain. The rock in the area was called the Twin Springs pluton by Swanberg and Blackwell (1973); however, that name is inappropriate because the plutonic rock that crops out at Twin Springs, supposedly the type locality, is a small stock of hornblende-biotite granodiorite not biotite granite. Instead of the name Twin Springs pluton, Lewis and Kiilsgaard (1991) proposed that the large, continuously exposed pluton, which covers about 470 km^2, be named the Sheep Creek batholith. The entire drainage area of Sheep Creek, a major tributary of the Middle Fork of the Boise River, is within boundaries of the batholith. Other large exposures of biotite granite include the Smoky Dome stock, north of Fairfield, and the southern part of the Sawtooth batholith, which extends north from the vicinity of Atlanta (fig. 2). Similar to exposures of the dioritic suite, exposures of the biotite granite show a preferred northeast trend. This northeast trend is illustrated by the Sheep Creek batholith and smaller stocks of biotite granite to the southwest and by the alignment of several stocks that begin southwest of Fairfield and extend discontinuously to beyond the northeastern border of the quadrangle (Worl and others, 1991).

Coarse euhedral crystals of potassium feldspar account for the characteristic pink color of the biotite granite. Finer grained varieties of potassium feldspar and some medium-grained varieties are light gray, not pink. These varieties commonly are present in small stocks or chilled margins near the contacts of larger bodies. Biotite granite typically is equigranular. Modes average 30 percent quartz, 35 percent potassium feldspar, and 35 percent plagioclase (fig. 3*E*). Subordinate porphyritic variants contain phenocrysts of potassium feldspar. The quartz commonly is dark. The potassium feldspar, which is intermediate microcline, is highly perthitic and turbid in thin section. Granophyric intergrowths of quartz and potassium feldspar are common. The plagioclase is euhedral to anhedral oligoclase and commonly has albitic rims. Biotite content averages less than 4 percent, and the biotite commonly is partly altered to chlorite. Crystals of hornblende may be present, but no primary muscovite is present except as rare relict(?) crystals enclosed in quartz. Accessory minerals include allanite, apatite, zircon, and pyrite. A distinctive characteristic of the biotite granite is the presence of small miarolitic cavities, commonly 1-3 mm in long dimension, that indicate emplacement at shallow levels. These are not present in all exposures but are prominent on high points of the Sheep Creek batholith and on peaks of Sawtooth batholith northeast of Atlanta.

Petrographic Differences Between Cretaceous and Eocene Plutonic Rocks

Petrographic features of Cretaceous and Eocene plutonic rocks are described in foregoing paragraphs, but there are diagnostic differences that aid in differentiating the two groups of rocks. Large quartz grains, actually clusters of quartz grains that have the appearance of a single large grain, are characteristic of Cretaceous plutonic rocks but are not prominent in Eocene intrusive rocks. Cretaceous rocks also typically have abundant myrmekitic texture and albite-pericline twinning in the potassium feldspar, both of which are rare in Eocene granodiorite. The distinct pink color of the Eocene biotite granite is a useful field criteria with which to distinguish the rock from most Cretaceous rocks. Granophyric textures and miarolitic cavities are also common in Eocene biotite granite, and its highly perthitic potassium feldspar is diagnostic. Plagioclase is much more strongly zoned in Eocene plutonic rocks. Hornblende is common in Eocene dioritic rocks and in the more mafic Cretaceous granodiorite and tonalite but is uncommon in Cretaceous biotite granodiorite and two-mica granite, which make up most of the Idaho batholith (Lewis and Kiilsgaard, 1991, table 1).

Geochemistry of Eocene Plutonic Rocks

Averages of analytical determinations from 54 samples of Eocene plutonic rocks are shown in table 3. As expected, the SiO_2 content of the rocks decreases from a mean value of 73.8 percent in biotite granite through progressively lower values in the quartz monzodiorite, diorite, and gabbro. The K_2O content also diminishes progressively from granite to gabbro, whereas the FeO, MgO, and CaO content increase. Average TiO_2 and P_2O_5 contents are highest in diorite. Granite is peraluminous (table 3, A/CNK ratios), whereas rocks of the dioritic suite are metaluminous.

A distinctive characteristic of the biotite granite is its radioactive nature (Swanberg and Blackwell, 1973; Bennett, 1980a, b; Bennett and Knowles, 1985). Many sediment samples from streams that drain the Sawtooth batholith contain anomalous quantities of uranium, as do samples on the unaltered biotite granite (Kiilsgaard and others, 1970). Uranium also is present in sediment samples collected from streams that drain a stock of biotite granite that crops out near the headwaters of Bear River, along the northern border of the Hailey 1°×2° quadrangle (Kiilsgaard, 1982). Unpublished National Uranium Resource Evaluation (NURE) airborne gamma-ray spectrometry surveys of uranium and thorium clearly outline exposures of the Sheep Creek batholith, the Smokey Dome stock, and smaller stocks in the Boulder Mountains in the northeastern corner of the quadrangle.

The biotite granite is also enriched in fluorine, tin, beryllium, molybdenum, and rare-earth elements. Disseminated fluorite is present in biotite granite of the Sawtooth batholith and in crosscutting pegmatites and along fractures (Reid, 1963; Pattee and others, 1968). Panned-concentrate samples from streams draining the Sawtooth batholith are enriched in the above mentioned elements (Kiilsgaard and others, 1970). Rarely did that extensive stream-sediment and panned-concentrate sampling program find concentrations of the above-mentioned elements in samples collected any distance away from the biotite granite. Fluorine, beryllium, and molybdenum also are present in sediment samples from streams draining the biotite granite exposure at Bear River, in the northern part of the Hailey 1°×2° quadrangle (Kiilsgaard, 1982). Microprobe analyses of biotite from Tertiary granite show that it contains more fluorine than does biotite from Cretaceous plutonic rocks (Bennett and Knowles, 1985). Tertiary granite in the vicinity of Twin Springs contains anomalous amounts of uranium and molybdenum (Bennett, 1980b). Smith (1995) called attention to unusual concentrations of Sn, Be, Bi, La, Nb, Th, Y, Mo, Pb, and W in panned-sample concentrates from Devils Creek and Sheep Creek and its tributaries, an area in the heart of the Sheep Creek batholith. Some of the panned samples have metal concentrations measured in thousands of parts per million. Two hundred and five chip samples of biotite granite collected on the ridge between Devils Creek and Sheep Creek average 829 ppm F, 24 ppm Sn, and 17 ppm Mo, and 105 soil samples from the same locality average 405 ppm F (Patrick DeWilliams, written commun., 1991). Prospects near the junction of Devils Creek and Sheep Creek have been explored for beryllium by the Beryllium Corp. of America. Molybdenum prospects in the Sheep Creek batholith crop out in upper reaches of Roaring River and are reported to contain associated fluorite (Schrader, 1924). Beryl, disseminated in biotite granite and as fillings of miarolitic cavities, is present at several locations north of North Star Lake and on the ridge between the headwaters of Sheep Creek and Smith Creek (Pattee and others, 1968). The Dismal Swamp placer deposit, near the eastern end of the Sheep Creek batholith, contains an assemblage of fluorine-bearing and radioactive minerals including, topaz, cyrtolite, xenotime, cassiterite, columbite, monazite, and samarskite (Armstrong, 1957).

The biotite granite has many characteristics similar to those of anorogenic granite (Loiselle and Wones, 1979), and these characteristics make it different from Tertiary dioritic rocks and from granitic rocks of the Cretaceous Idaho batholith (Bennett and Knowles, 1985; Lewis and Kiilsgaard, 1991). Anorogenic granite magmas have a high fugacity ratio of fluorine to water, and the resultant rocks contain associated fluorite (Collins and others, 1982; Hannah and Stein, 1990). Manning and Hill (1990) noted that, experimentally, residual F-OH-bearing minerals become increasingly enriched in fluorine as melting proceeds. Such enrichment could have resulted in development of a dryer magma that crystallized to form biotite granite.

The magmatic origin of the Eocene biotite granite and the dioritic suite, however, is debatable. The two categories of rock may have crystallized from two separate magmas and not from fractional crystallization of a single magma (Lewis, 1984; Stewart, 1987; Lewis and Kiilsgaard (1991). Although the close spatial relationship of the two categories at several different outcrop localities suggests a single magmatic source, the spatial relationship could be a structural relationship in which more than one magma was intruded along northeast-trending faults. Accepting the postulation that F-OH-bearing minerals become increasingly enriched in fluorine as melting proceeds (Manning and Hill, 1990), the dioritic suite could be the product of a first melting event, and a second melting event, or a continuation of melting of the residual magma, might have resulted in a fluorine-enriched and dryer magma that crystallized to form the biotite granite. Alternatively, basaltic magma emplaced in the lower crust during crustal extension may have been contaminated by enclosing rocks as the magma was intruded toward the surface, resulting in the formation of the dioritic suite.

Hypabyssal Rocks

Hypabyssal rocks, chiefly dikes and small stocks, are abundant in the Hailey 1°×2° quadrangle. Although little radiometric dating has been done on these rocks, their close spatial and chemical association with dated Eocene plutons suggests that most are of Eocene age. A few mafic dikes may be of Cretaceous age, and basaltic dikes of Miocene age are present locally.

Hypabyssal Rocks of Probable Eocene Age

Countless dikes, swarms of dikes, and small stocks crosscut both Cretaceous and Eocene plutonic rocks in the Hailey and Challis 1°×2° quadrangles. The dikes range from andesite to rhyolite in composition, are porphyritic, and range in width from less than 1 m to more than 100 m and in strike length from a few meters to more than 1,000 m.

Dikes of different composition are present throughout the region. For purposes of geologic mapping, most of the dikes were classed in two suites: a rhyolitic suite of light to reddish-tinted felsic dikes and a dacitic suite of dark-green to grayish intermediate to mafic dikes. This field classification was adopted because the aphanitic texture and composition of the rocks made accurate field identification difficult. Identification was further hindered by mineralogical and textural variations within single dikes. Dikes of the rhyolitic suite abound near or as crosscutting features in Eocene biotite granite, which suggests a genetic relationship. Dikes of the dacitic suite, on the other hand, are more numerous near or as crosscutting features in Eocene plutonic rocks of the dioritic suite, which suggests a genetic relationship with those more mafic plutonic rocks.

A significant percentage of the dikes have diverse attitudes, but the overwhelming majority strike northeast (Worl and others, 1991). Emplacement of the dikes probably was guided by the northeast-trending pattern of regional faults and associated shears that is widespread throughout central Idaho. Fault gouge commonly is present along dike walls, particularly in underground mine workings where the rocks are well exposed. Parallel-trending dikes of different compositions commonly are in sharp contact with each other, as though a fissure was opened to admit one type of dike, only to be reopened to admit another type. Locally, dikes are so numerous and so closely spaced to each other that they constitute a swarm extending for many kilometers in strike length. At such sites, the dikes may aggregate more volume than does the plutonic rock they intrude. Anderson (1947) mapped a northeast-trending dike swarm in the northwestern corner of the Hailey 1°×2° quadrangle, a swarm since referred to as the Boise Basin dike swarm. Other northeast-trending dike swarms extend along the northwest ridge that bounds the southwest-flowing Middle Fork of the Boise River. The swarms are particularly conspicuous in the interval between Swanholm Creek and Queens River. Still others cross the area north of the junction of South Fork of the Boise River and Big Smoky Creek and in the area northwest of Camas Prairie (Worl and others, 1991).

The northeast-trending regional faults, Tertiary dikes, and Eocene stocks and batholiths are principally contained within northeast-trending zones of crustal extension that cross the Hailey and Challis 1°×2° quadrangles (Kiilsgaard and others, 1989). In aggregate, the Tertiary dikes, stocks, and batholiths constitute an enormous volume of igneous rock that has been intruded into the Cretaceous plutonic rocks and other older rocks.

Potassium-argon age determinations of the dikes were not attempted. The only exception is a dacite dike sample collected northwest of Dollarhide Mountain, which yielded a K/Ar age on hornblende of 47.2$\pm$0.9 Ma (table 1). The dikes may have been intruded over a considerable time span, but dikes that cut Eocene plutonic rocks cannot be older than late Eocene. In the vicinity of Quartzburg, about 2 km northwest of Placerville, dacitic dikes are crosscut by dikes of quartz monzodiorite and by rhyolitic dikes. Coarser textured, more porphyritic rhyolite dikes are crosscut by finer textured rhyolite dikes.

Dacitic Suite

The dacitic suite consists of chiefly dark colored porphyritic dacite and lesser amounts of highly porphyritic quartz monzodiorite and weakly porphyritic andesite.

Dacite

Dacite dikes (unit Tda of Worl and others, 1991) are dark greenish to gray and porphyritic. Phenocrysts range from 2 to 10 mm in long dimension and make up as much as half of the rock mass. Commonly, the rock is bimodal; feldspar phenocrysts of about the same size are set in an aphanitic groundmass composed chiefly of feldspar and quartz. Most of the phenocrysts are plagioclase (chiefly zoned andesine), although some are quartz that commonly is resorbed and rounded. Small phenocrysts of hornblende and biotite also are common. Magnetite is a common accessory mineral. The plagioclase is moderately to intensely altered to sericite and the biotite altered to chlorite. In the eastern part of the Hailey 1°×2° quadrangle are small stocks of dacite porphyry that, except for size, are similar to the dacite dikes described above (Worl and others, 1991).

Quartz Monzodiorite

Quartz monzodiorite dikes (unit Tqm of Worl and others, 1991) have a mineral composition similar to the quartz monzodiorite plutonic rocks but have an aphanitic rather than a granitic texture. They differ from the dacite dikes in that they are highly porphyritic and contain less than 20 percent quartz. The rock is greenish gray; phenocrysts commonly range from 2 to 6 mm in size and consist chiefly of zoned andesine and hornblende. The groundmass is aphanitic, and the pinkish-gray color results from finely crystalline potassium feldspar. Magnetite is a common accessory mineral.

Andesite

Andesite dikes (unit Ta of Worl and others, 1991) are dark gray to almost black, fine grained, and weakly porphyritic. Many such dikes have been mapped previously as lamprophyre (Lindgren, 1900; Anderson, 1939; Anderson and others, 1950). Field identification of these dark, fine-grained dikes is so debatable that many dikes designated as andesite may indeed be more properly identified as lamprophyre. The dikes weather readily and are not seen on soil- or grus-covered surfaces. The phenocrysts are plagioclase (andesine) and commonly are 2-4 mm in size. Biotite, various amphibole and pyroxene minerals, and calcic plagioclase are the principal constituents. Laths of andesine compose the groundmass in which is interspersed clinopyroxene, hornblende, and magnetite. The silica content is low; an average SiO_2 value for two samples is 51.8 percent (table 3). Distinction between andesite and basalt is difficult, and it is likely that some dikes mapped as andesite may be basalt, or vice versa.

Some andesite dikes, present locally in Cretaceous plutonic rocks, are small, generally only a few centimeters wide but in places 2 m or more. They range from a few meters to 100 m or so in strike length and have diverse strike attitudes. The dikes tend to be of a wispy nature, with one pinching at one locality and another one of similar composition starting in an en echelon location a short distance away. Some of these mafic dikes may be of Cretaceous age, but we have no proof of this age assignment. The assumption is based on location, on the limited number and extent, and on lithologic and structural differences as compared to dikes known to be of Tertiary age.

Rhyolitic Suite

Light-reddish to light-gray to tan rhyolite, rhyodacite, and quartz trachyte dikes are the principal members of the rhyolitic suite.

Rhyolite

Rhyolite (unit Tr of Worl and others, 1991) is a common Tertiary dike rock in the Hailey 1°×2° quadrangle. It is light gray on fresh surfaces but commonly is stained reddish to pinkish by iron oxides on weathered surfaces. It may be weakly to intensely porphyritic; phenocrysts of potassium feldspar, plagioclase, and quartz range from 2 to 15 mm in size and are set in an aphanitic groundmass of quartz and feldspar. Rounded and resorbed phenocrysts of quartz are common, and some have chalcedonic rims. Spherulitic intergrowths of quartz and potassium feldspar are common in the aphanitic groundmass. The plagioclase in phenocrysts and groundmass is oligoclase. Some rhyolite dikes contain minor amounts of hornblende. The rhyolite also contains sparse amounts of biotite, which usually is altered to chlorite. The feldspar is moderately to intensely altered to sericite. Pyrite is a common accessory and, at the outcrop, is typically altered to iron oxides.

Chemically, the rhyolite contains more than 70 percent SiO_2 (table 3) and is comparable to the biotite granite, with which it is probably genetically related. The rhyolite also is much more radioactive as measured by a gamma-ray spectrometer than are the other Tertiary dikes, which is another indication of its relation to the more radioactive biotite granite.

Rhyodacite

Rhyodacite (unit Trd of Worl and others, 1991) includes dike rock that is pinkish and porphyritic and contains more than 20 percent quartz and more plagioclase than potassium feldspar. The phenocrysts are 2-5 mm in size and are chiefly plagioclase, potassium feldspar, and hornblende, with lesser amounts of biotite and quartz. The quartz phenocrysts are rounded and resorbed. The plagioclase is andesine and is moderately altered to sericite. The pinkish groundmass is chiefly fine grained potassium feldspar and is characterized by intergrown chalcedonic spherulites.

Quartz Trachyte

Large dikes of quartz trachyte (unit Ttr of Worl and others, 1991) crop out near the head of Blacks Creek, near the southwestern border of the Hailey 1°×2° quadrangle. The dikes form spines on the ridges, commonly standing as much as 3 m above the ground level. Many of the quartz trachyte dikes trend north, as opposed to the more common northeast trend of dikes in the quadrangle.

Quartz trachyte is light gray to brownish gray and porphyritic and has an aphanitic groundmass. Phenocrysts are dominantly plagioclase (oligoclase-andesine) that has reaction rims of albite. They range from 2 to 10 mm in size and are intensely altered. The finely crystalline groundmass is dominantly potassium feldspar, which makes up more than 60 percent of the rock. Quartz also forms part of the groundmass, but the content is low, less than 20 percent. Considerable hornblende and some biotite also are present but are intensely altered to chlorite. Although the trachytic composition is unusual, the dikes are tentatively assigned an Eocene age. The presence of hydrous mafic phases is characteristic of most Eocene igneous rocks, unlike the pyroxene-bearing rhyolite of the Miocene Idavada Volcanics.

The quartz trachyte dikes differ from rhyolite dikes in that they contain less SiO_2 and Rb and more Al_2O_3, iron oxides, MgO, CaO, Ba, and Sr (table 3).

Basaltic Dikes of Miocene and Younger(?) Age

The youngest dikes are of diabasic or basaltic composition and crosscut all others (unit Tb of Worl and others, 1991). They commonly trend north-northwest, across the trend of most other Tertiary dikes in the area. Some of the basaltic dikes have been dated as Miocene (Armstrong, 1975) and are probably related to the Columbia River Basalt Group. Others may be related to the Snake River Group basalts and Pleistocene age, in age or even younger. The dikes are dark colored and dense, have ophitic to subophitic textures, and consist chiefly of microlites of labradorite enclosed by clinopyroxene. Magnetite is common, as are sparse amounts of olivine. Quartz content is less than 5 percent. The coarser-grained dikes are diabasic, whereas other dikes may be andesitic because the plagioclase is andesine rather than labradorite.

Summary

Plutonic and hypabyssal rocks underlie much of the Hailey 1°×2° quadrangle of south-central Idaho. The plutonic rocks are of two general ages: Cretaceous rocks of the Atlanta lobe of the Idaho batholith and Eocene plutonic and batholithic rocks related to the Challis magmatic episode.

The oldest of the Cretaceous plutons consist of pyroxene-biotite quartz diorite, hornblende-biotite tonalite, and potassium-rich hornblende-biotite granodiorite. These rocks are intruded by a voluminous mass of biotite granodiorite. Biotite granodiorite in the western part of the quadrangle has higher contents of SiO_2, Na_2O, and Ba and lower contents of iron oxides, MgO, CaO, TiO_2, P_2O_5, Y, and Zr relative to petrographically similar biotite granodiorite in the eastern part of the quadrangle. The chemical differences probably reflect a differing magma source from west to east. In the western half of the quadrangle the biotite granodiorite locally grades into two-mica

Table 3. Mean values of major oxides and trace elements, Tertiary plutonic and hypabyssal rocks, Hailey 1°×2° quadrangle, Idaho.

[Analytical determinations by X-ray fluorescence and optical spectroscopy. Analysts: J. Taggart, A. Bartel, T. McCollom, C. Papp, P. Briggs, E. Brandt, C. Stone, S. Roof, L. Jackson, J. Christie, K. Stewart, K. Slaughter, N. Elsheimer, D. Siems, J. Evans, M. Malcolm, and S. Pribble, U.S. Geological Survey. Rock units: Tg, biotite granite; Tqm, quartz monzodiorite; Td, diorite; Tgb, gabbro; Tr, rhyolite; Ttr, quartz trachite; and Ta, andesite. NA, not analyzed. A/CNK, $Al_2O_3/(CaO+Na_2O+K_2O)$ molecular ratio]

Rock unit	Tg	Tqm/Tgd	Td	Tgb	Tr	Ttr	Ta
No. of samples------------	16	29	5	4	8	3	2
In percent							
SiO_2	73.8	66.8	54.4	49.2	73.9	64.8	51.8
Al_2O_3	13.7	15.5	14.3	11.6	13.5	15.6	13.6
Fe_2O_3	0.72	1.18	4.23	2.24	0.68	2.48	3.61
FeO	0.72	2.03	5.04	7.57	0.86	1.10	5.79
MgO	0.40	1.58	6.51	13.80	0.35	1.06	3.85
CaO	1.25	3.32	8.02	9.65	0.95	1.97	7.36
Na_2O	3.68	3.85	3.30	1.83	3.74	3.94	2.75
K_2O	4.41	3.35	1.77	0.88	4.30	4.86	1.87
TiO_2	0.21	0.49	0.98	0.90	0.19	0.71	1.41
P_2O_5	0.07	0.19	0.45	0.17	0.03	0.07	0.14
A/CNK	1.04	0.97	0.65	0.54	0.08	1.02	0.68
In parts per million							
Ba	820	1370	NA	510	510	1750	1250
Sr	240	610	NA	660	180	620	660
Y	16	13	NA	15	26	21	14
Zr	110	160	NA	90	110	140	170
Rb	160	100	NA	30	170	10	60

granite, that contains small books of muscovite. Dikes, sills, and small stocks of leucocratic granite cut sharply across the other Cretaceous units. Pegmatite and aplite dikes are present throughout the batholith but are concentrated in a roof zone at the southern edge of the Atlanta lobe in the vicinity of Anderson Ranch reservoir. Most of the age determinations of Cretaceous samples are believed to be too young, because of slow cooling and local argon loss. Nevertheless, a review of available data indicates that Cretaceous intrusive activity began about 95 Ma and continued until about 70-65 Ma.

Eocene plutonic rocks in the Hailey 1°×2° quadrangle can be subdivided into two categories: a dioritic suite and biotite granite. Rocks of the dioritic suite range in composition from pyroxene gabbro to hornblende-biotite granite, and the average composition and most common rock type is quartz monzodiorite. The biotite granite is relatively homogeneous and typically pink in color. It is enriched in uranium, fluorine, and various lithophile elements relative to other plutonic rock types in the quadrangle. The two categories of rock may have originated from two separate magmas or from a single magma source. The Eocene plutons are probably about 50-40 Ma.

Crosscutting all of the plutonic rocks is a myriad of hypabyssal dikes, dike swarms, and small stocks. Most of these are probably Eocene in age, but few have been dated. Rhyolite and dacite are common, but the rocks range from rhyolite to basalt in composition. Most, if not all, of the basalts are probably Miocene or younger in age.

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