Geology Along the Northwest Border Zone of the Idaho Batholith, Northern Idaho

U.S. GEOLOGICAL SURVEY BULLETIN 1608

Geology Along the Northwest Border Zone of the Idaho Batholith, Northern Idaho

By ANNA HIETANEN

Stratigraphy, correlation, and some petrologic aspects of the metamorphic rocks northwest of the Idaho batholith

U.S. GEOLOGICAL SURVEY BULLETIN 1608

DEPARTMENT OF THE INTERIOR
WILLIAM P. CLARK, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE : 1984

For sale by the
Distribution Branch, Text Products Section
U.S. Geological Survey
604 South Pickett St.
Alexandria, VA 22304

Library of Congress Cataloging in Publication Data

Hietanen, Anna Martta, 1909–
Geology along the northwest border zone of the Idaho
batholith, northern Idaho.

(U.S. Geological Survey Bulletin 1608)
Bibliography: p. 16-17
Supt. of Docs. no.: I 19.3:1608
1. Rocks, metamorphic. 2. Batholiths—Idaho. I. Title. II. Series:
United States. Geological Survey. Bulletin 1608.
QE75.B9 no. 1608 557.3s 84-600041
[QE475.A2] [552'.4]

CONTENTS

FIGURES

TABLES

GEOLOGY ALONG THE NORTHWEST BORDER ZONE OF THE IDAHO BATHOLITH, NORTHERN IDAHO

By Anna Hietanen

Abstract

The metasedimentary rocks bordering the Idaho batholith on the northwest are correlative with the five lowest formations of the Belt Supergroup in the Coeur d'Alene area, to the north. These rocks are underlain by the Boehls Butte Formation, exposed in an uplifted block between the North Fork and Little North Fork of the Clearwater River. The metamorphic grade of the rocks of the Belt Supergroup in the study area ranges from greenschist facies near the St. Joe River in the north to sillimanite grade of amphibolite facies near the Idaho batholith in the south. In the schist of the Boehls Butte Formation, all three aluminum silicates—kyanite, andalusite, and sillimanite—occur together with staurolite, cordierite, garnet, muscovite, and biotite. Lenses of two-plagioclase anorthosite occur in this schist.

The study area is along the west margin of the Precambrian continent and within the area where two arcuate segments of Cordilleran trends meet. Owing to the complexity of this position and several episodes of deformation, the structures are intricate. In the southern part of the study area, fold axes and lineations parallel the northeastward trends that are prevalent in Permian to Jurassic rocks to the south and southwest. In the northern part of the study area, northwestward trends are predominant, and northeast-trending fold axes and lineations occur locally. These northwestward trends are present as a second lineation in the southern part of the area. These structures could have been formed in response to the collision and accretion of Permian and early Mesozoic units to the continent. Locally, east-plunging fold axes and lineations occur in addition to either northwestward or northeastward trends. In the uplifted Boehls Butte block, this N. 70°–90° W.-trending lineament is a distinct structural feature. In some places it is older, but in other places younger, than the northwest- and northeast-trending fold axes and lineations. Folds on north-south-trending axes occur near some faults.

INTRODUCTION

This report is based on petrologic and structural studies during 1950–64, 1966, and 1968 in western Clearwater County and in southern Shoshone County south of the St. Joe River, Idaho. Its purpose is to record the new data and reconsider the correlation, stratigraphy, and some petrologic aspects of the metamorphic rocks. Revision of correlation of the oldest metamorphic rocks is supported by fieldwork done in 1966 and 1982 and by new information on their constituent minerals. The study area encompasses about 6,000 km^2 between long 115°20′ and 116°20′ W., and lat 46°15′ and 47°15′ N. (fig. 1).

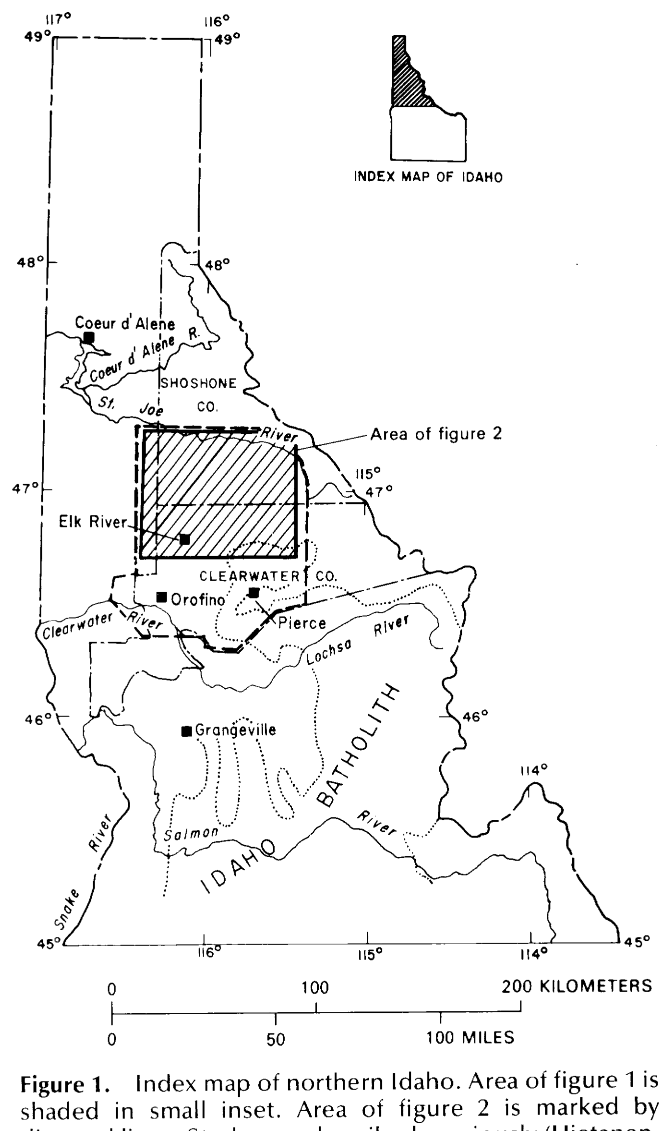


Figure 1. Index map of northern Idaho. Area of figure 1 is shaded in small inset. Area of figure 2 is marked by diagonal lines. Study area described previously (Hietanen, 1962, 1963a, b, c, 1967, 1968) is encircled with broken line. Outline of northern part of the Idaho batholith is shown by dotted line.

The tectonic position of the study area, along the west margin of the Precambrian continent and within an area where two arcuate segments of late Paleozoic and early Mesozoic trends meet (Hietanen, 1981), has resulted in a complex structural pattern. These arcuate segments probably were controlled by the shape of the west margin of the North American Continent during the time of accretion of Permian and Triassic units. During Proterozoic time, a deep embayment that extended into northern Idaho and western Montana provided a basin into which the shelf sediments of the Belt Supergroup were deposited. Harrison (1972) bracketed the deposition from 1,450 to 850 m.y. ago. The Proterozoic folding, trending N. 70°–90° W., probably reflects the shape of the depositional basin and, later, the late Paleozoic and early Mesozoic structural trends developed parallel to the arcuate margin of the continent. Structures in the southern arc trend from western Idaho through Oregon and the Klamath Mountains to the Sierra Nevada in California (Hietanen, 1981). The northern arc trends through Washington to British Columbia. Units of Paleozoic and Mesozoic rocks, many of them exotic in origin, collided during plate-tectonic movements against the arcuate continental margin. Parts of these Paleozoic and Mesozoic units were accreted to the continent in both the northern and southern arcs, but other parts probably were subducted with the oceanic plate that carried them, thus giving rise to the extensive Mesozoic plutonism along the continental margin.

EARLIER WORK

Brief reconnaissance work in Clearwater County was done by Anderson (1930), who distinguished two units of metasedimentary rocks: The gneissic rocks near the Idaho batholith and the Belt Supergroup north of lat 46°40′. Ross and Forrester (1947) followed this subdivision on their geologic map of the State of Idaho. In southern Shoshone County, Calkins and Jones (1911) mapped the five lowest formations of the Belt Supergroup: the Prichard, Burke, Revett, St. Regis, and Wallace Formations. Umpleby and Jones (1923) divided the Wallace Formation into three map units and combined the quartzites of the Revett and Burke Formations into a single unit that they showed to overlie the Prichard Formation. Wagner (1949) mapped and described the Burke, Revett, St. Regis, Wallace, and Striped Peak Formations on the south slope of the St. Joe Mountains north of the St. Joe River. Tullis (1944) suggested that the quartzite and schist in Latah County could be correlated with the lower formations of the Belt Supergroup. Johnson (1947) described the igneous metamorphism near Orofino.

STRATIGRAPHY, LITHOLOGY, AND CORRELATION

Belt Supergroup

The Belt Supergroup formations of Calkins and Jones (1911) and Umpleby and Jones (1923) in southern Shoshone County continue southward into Clearwater County, where high-grade metamorphism has obliterated the characteristic colors and relict sedimentary features—such as ripple marks, mud cracks, raindrops, crossbedding, and channels—that in the Coeur d'Alene area serve as distinguishing features for the formations. The change from low-grade muscovite-chlorite schist and quartzite with relict sedimentary structures into coarse-grained high-grade schist, quartzite, and gneiss takes place through progressive zones of regional metamorphism. The isograds indicating the metamorphic grade cut across the stratigraphic layers (Hietanen, 1967, 1968, 1969b). Each of the formations consists of interbedded schist and quartzite in varying proportions, and preserves its characteristic lithology and stratigraphy through the metamorphic zones. Because of the absence of relict sedimentary structures, the contacts between the formations of the metamorphosed Belt Supergroup as shown on my geologic maps (Hietanen, 1962, 1963a, b, c, 1968) may differ from the contacts used in subdivision of unmetamorphosed Belt rocks. Therefore, a short account of essential lithologic features in each formation of the metamorphosed Belt follows. The five oldest formations—the Prichard, Burke, Revett, St. Regis, and Wallace—were mapped in the eastern part of the area (Hietanen, 1968, pls. 1, 2). The Prichard Formation consists of a lower schist unit, a middle quartzite unit of one or two layers of light-gray foliated quartzite, and an upper schist unit (table 1).

The schist of the Prichard Formation is a coarse- to medium-grained muscovite-biotite-garnet schist, with fine- to medium-grained interlayers rich in quartz and plagioclase. Biotite and muscovite laminae separate individual thin (1–4 cm thick) beds in the interlayers. Kyanite occurs in places in the northern part of the study area, and sillimanite in the southern part. The middle quartzite unit consists of two layers of foliated white to light-gray medium-grained muscovite quartzite with minor biotite and occasional garnet-bearing beds, and an intervening layer of muscovite-biotite-garnet schist ranging from almost zero to 100 m in thickness.

Coarse-grained light-gray distinctly bedded and foliated quartzite that overlies the upper schist unit of the Prichard Formation was mapped as the Burke Formation. In the quartz-rich layers, individual beds of coarse-grained quartzite, 3 to 20 cm thick, are sepa-

Table 1. Generalized stratigraphic sequence of the Belt Supergroup northwest of the Idaho batholith

	Unit	Estimated thickness (m)		Rock type
Wallace Formation	Upper schist	200	800-2,600	In southern part of study area, garnet-mica schist containing aluminum silicates, with some thin interbeds of biotite-plagioclase gneiss; not exposed in northernmost part of study area.
	Upper quartzite	200		In western part of study area near the Elk River, abundant thin-bedded biotite gneiss, biotite quartzite, and schist, interbedded with scapolite-bearing diopside gneiss; in southern part of study area, mainly diopside-plagioclase gneiss containing some biotite and hornblende gneiss; not exposed in northernmost part of study area.
	Lower schist	200-300		In northern part of study area, fine-grained muscovite-biotite schist; grain size coarsens southward; garnet, staurolite, kyanite, and sillimanite appear, in that order, with increasing temperature and pressure.
	Lower quartzite	200-1,900		White granular quartzite, overlain in northern part of study area by thin-bedded gray biotite quartzite, biotite-granofels, and phlogopite-bearing carbonate granofels gneiss (locally containing scapolite and actinolite), and in southern part of study area by interbedded diopside gneiss and biotite gneiss; the diopside gneiss, biotite granofels, and carbonate granofels contain scapolite.
Ravalli Group	St. Regis Formation	100-300	500-2,100	Garnet-mica schist with some layers of biotite gneiss or biotite quartzite.
	Revett Formation	200-500		Thick-bedded coarse-grained pure quartzite; muscovite laminae separate individual beds.
	Burke Formation	200-1,300		Upper 200 m is medium-grained biotite schist; lower part is micaceous quartzite, with some thick beds of pure quartzite.
Prichard Formation	Upper schist	600-900	1,470-2,300	Garnet-mica schist, with layers of medium- to dark-gray thin-bedded fine-grained biotite quartzite in upper part.
	Middle quartzite	70-200		White to light-gray beds of medium-grained granular to foliated muscovite-bearing quartzite with intervening layer of schist; uppermost part consists of thin-bedded biotite-rich quartzite.
	Lower schist	800-1,200		Garnet-mica schist containing some biotite quartzite; locally rich in kyanite.

rated by thin micaceous layers. The upper part of this formation consists of garnet-mica schist with interbedded quartzite.

The schist of the Burke Formation is overlain by thick-bedded white to very light gray, medium- to coarse-grained quartzite of the Revett Formation. Thick beds of pure quartzite are separated from one another by paper-thin micaceous laminae that in places contain some plagioclase (An_{10}). The St. Regis Formation, stratigraphically above the Revett Formation, consists of medium- to coarse-grained garnet-mica schist with interbedded fine- to medium-grained micaceous quartzite.

The Wallace Formation overlies the schist of the St. Regis Formation. The lowest part of the Wallace consists of medium-grained white granular quartzite with some thin light-gray quartzite layers. Thin-bedded gray quartzite with interbedded thin micaceous layers is the major rock type above the white granular quartzite. Toward the top of the unit, scapolite and carbonate-bearing layers are common (Hietanen, 1967). Prisms of actinolite, hornblende, and diopside crystallized in carbonate-bearing layers in the kyanite zone and higher grade zones to the south. The schist unit that overlies the quartzite is mineralogically different throughout the study area. Another quartzite-gneiss unit and schist unit overlie the lower schist unit in the southern part of the study area.

The schist unit overlying the quartzite of the Wallace Formation in the northeastern part of the study area southeast of Avery is a fine-grained dark muscovite-biotite schist in which metamorphism increases to the south through successive zones, as shown by the isograds in figure 2. Along the St. Joe River west of Avery and to the south, the Ravalli Group (the Burke, Revett, and St. Regis Formations) is exposed under the lower quartzite unit of the Wallace Formation. The schist of the Prichard Formation, with its interbedded layers of quartzite, underlies the Ravalli Group (Hietanen, 1967). The continuity with correlative formations to the southeast is interrupted by the Roundtop pluton and by an uplifted block of pre-Beltian rocks, the Boehls Butte Formation (fig. 2). The lithology and thickness of the formations in the two parts of the study area are similar, but the degree of metamorphism is lower in the northern part.

A series of faults belonging to the White Rock fault zone (fig. 2) separates high-grade rocks of the Prichard Formation from low-grade rocks of the Wallace Formation to the west in the northwestern part of the study area (fig. 2). The Wallace Formation there consists mainly of a gray thin-bedded fine-grained micaceous quartzite in which ripple marks, mud cracks, crossbedding, and channel features are preserved. Interbedded are layers rich in carbonate minerals and scapolite (Hietanen, 1967) and some units consisting of white to very light gray or beige granular quartzite and others rich in muscovite and biotite. A very fine grained dark-gray to black scapolite-bearing muscovite-biotite schist overlies the quartzite unit of the Wallace Formation conformably on the east. Near Huckleberry Mountain, this low-grade schist unit is separated from high-grade schist of the Prichard Formation by the northern part of the White Rock fault.

With increasing metamorphism to the south, all the rocks in all formations became coarser grained, and such minerals as actinolite, hornblende, and diopside crystallized in the carbonate-bearing quartzitic layers, whereas garnet, staurolite, and kyanite appeared in the aluminum-rich schist layers. First appearances of these index minerals are shown by isograds (fig. 2; Hietanen, 1967, pl. 1) that transect the south-southeast-trending structures which wrap around the northwest corner of the Idaho batholith. South of the East Fork of Potlatch Creek, the schist units are recrystallized to coarse-grained garnet-sillimanite schist, with interbedded layers of laminated biotite-plagioclase schist and gneiss (Hietanen, 1963b). The quartzitic units contain layers rich in diopside and plagioclase, or in biotite and plagioclase. Recrystallized white granular quartzite can be recognized in several localities in the canyon of the North Fork of the Clearwater River, which cuts through folded and faulted sillimanite-grade rocks of the Wallace Formation for more than 50 km. Farther southeast, in the Headquarters quadrangle, sillimanite-garnet schist, quartzite, and gneiss are the major rock types in the Wallace Formation (Hietanen, 1962).

Massive coarse-grained quartzite that I mapped as the Revett Formation is folded and faulted with the Wallace Formation east of the mouth of the Little North Fork of the Clearwater River, in the vicinity where the north-northwestward trends turn to the east, wrapping around the southwest corner of the uplifted Boehls Butte block (fig. 2). As mapped, this quartzite sequence probably includes beds that may belong to the Burke Formation, a formation which was not identified in the southern part of the area (Hietanen, 1963a, b, c; 1967, pl. 1). The schist above the Revett was mapped as the St. Regis Formation.

The metasedimentary rocks included in the rocks of the Idaho batholith east of Pierce (Hietanen, 1963c) consist mainly of diopside and biotite gneiss, with interbedded garnet-mica schist that locally contains sillimanite. These rocks are similar to the Wallace Formation in the Headquarters quadrangle and near Elk River. They are underlain by rather thin units of schist and coarse-grained quartzite, mapped as the Revett Formation (Hietanen, 1963c, pl. 2).

Anderson (1930) named the metamorphic rocks near Orofino (fig. 1) the "Orofino Series" and suggested that they may be the lowest part of the Prichard Formation not exposed elsewhere or, alternatively, that they may be much younger than the Belt Supergroup.

Hietanen (1962, pl. 3, 4) mapped as the Revett Formation the coarse-grained quartzite exposed near Dent (northeast of Orofino, fig. 1), on Huckleberry Butte, and along Orofino Creek at Lime Mountain (east of Orofino). The thin-bedded biotite-hornblende and biotite-diopside gneiss with scapolite-bearing layers overlies the Revett Formation at Lime Mountain and near Dent. The stratigraphic position and lithology of this thin-bedded gneiss-quartzite sequence suggest that it is equivalent to the lower quartzite unit of the Wallace Formation. A similar thin-bedded schist-and-gneiss sequence is exposed 4 to 5 km east of Orofino; its possible equivalence to the lower quartzite-gneiss unit of the Wallace Formation was suggested by Hietanen (1962, p. 46–48). This correlation was adopted on later maps (Hietanen, 1967, pl. 1) on which the metamorphic rocks near Orofino are shown as the Wallace Formation and the gneissic plutonic rocks as gabbro, quartz diorite, and tonalite. Metamorphosed peridotite and gabbro exposed in the canyon of the Clearwater River west of Orofino probably mark the west margin of the Proterozoic formations. Layers of metatuff, some containing euhedral plagioclase crystals, near Peck, 13 km east of Orofino, are similar to the Permian rocks to the south.

Boehls Butte Formation

The rocks in an uplifted block south of the Roundtop pluton (fig. 2) differ mineralogically and chemically from the Belt Supergroup and were named the Boehls Butte Formation (Hietanen, 1969b). The major rock types are coarse-grained aluminum silicate-rich schist, layered and massive anorthosite, and quartzite that locally contains calcium silicates (table 2).

The Boehls Butte Formation is separated from the lower part of the Belt Supergroup by faults and igneous masses. The Orphan Point fault, the large north-south-trending fault near the center of the study area (fig. 2), separates the Boehls Butte Formation from schist of the Prichard Formation on the west. A wide migmatized zone along the south border marks the North Fork fault (fig. 2) between schist of the Boehls Butte Formation and the Wallace Formation to the south. Roundtop pluton and associated gabbro bodies are along the north margin of the Boehls Butte Formation.

On the east side, no definite contact was located during early geologic mapping of the Boehls Butte area (Hietanen, 1963a) because of an absence of exposures and the similarity of the schist and quartzite on either side of the faults. Additional fieldwork (fig. 3), however, shows that the Boehls Butte Formation is, indeed, bounded by a fault on the east. Southwest of Miller Peak (fig. 3), a long narrow body of pyroxene gabbro, and plagioclase porphyry north of the gabbro, occur along a fault that separates white coarse-grained muscovite-bearing quartzite and strongly deformed muscovite-biotite schist of the Boehls Butte Formation on the west from light-gray medium-grained thin-bedded quartzite and interbedded garnet-mica schist of the Prichard Formation on the east. To the south, deeply weathered gneissic plagioclase-rich hornblende-biotite tonalite occurs along this fault zone, which farther south passes just west of Indian Dip, follows Delate Creek to the southeast, and crosses the Little North Fork of the Clearwater River at the mouth of Minnesaka Creek. This fault zone is continuous with the Canyon fault, mapped earlier along this creek (Hietanen, 1968, pl. 1). The Canyon fault continues more than 30 km farther to the east-southeast (Childs, 1982) and crosses the North Fork of the Clearwater River at the mouth of Kelly Creek, 10 km east of the map area (fig. 2). Near Canyon Ranger Station, this major fault separates the Prichard Formation on the north from the Wallace Formation on the south (fig. 2; Hietanen, 1968, pl. 1). To the northwest, along Dog Creek, the Prichard Formation continues on the northeast side of the Canyon fault, but on the southwest side of the fault lies the Boehls Butte Formation—not the Wallace—separated from the Wallace Formation by the Beaver Creek pluton (fig. 2; Hietanen, 1968, pl. 1). Porphyritic dike rocks, pyroxene gabbro, and amphibolite are common along this fault.

Table 2. Generalized section of the Boehls Butte Formation

Unit	Rock type	Thickness (m)
Upper schist-----	Garnet-biotite-muscovite schist, in part laminated with thin biotite-plagioclase-quartz layers; locally rich in kyanite.	800
Quartzite--------	Thin-bedded fine-grained biotite quartzite and coarse-grained white to very light gray foliated quartzite; interbedded locally are lime silicate rocks, phlogopite- or biotite-plagioclase rocks, and kyanite-andalusite-sillimanite schist containing plagioclase.	300-800
Feldspathized schist.	Coarse-grained kyanite-andalusite-sillimanite-garnet-mica schist containing plagioclase (An_{25-45}) and cordierite or staurolite.	0-200
Anorthosite------	Layered and foliated or massive bimodal or trimodal plagioclase rock. In the layered rocks, white to light-gray layers consisting of large oval grains of andesine (An_{40-45}) with inclusions and groundmass of bytownite and anorthite (An_{80-95}) are interbedded with thin layers rich in aluminum silicates, biotite, and muscovite, or in hornblende. Massive parts are composed of coarse-grained bimodal andesine-bytownite rocks or trimodal labradorite rocks, with anorthite-andesine inclusions. Layers of bytownite-anorthite rocks containing garnet and quartz or containing hornblende occur along contacts.	800-2,500
Lower schist-----	Andalusite-kyanite-sillimanite-biotite-muscovite schist, locally containing cordierite and staurolite. Contains plagioclase and small lenses of anorthosite.	400-600

In the north, the Canyon fault is cut off by the Roundtop pluton but seems to continue on the pluton's northwest side as north- and northwest-trending faults that cut the Ravalli Group and Wallace Formation (fig. 2; Hietanen, 1967, pl. 1).

The schist of the Boehls Butte Formation is coarse-grained muscovite-biotite-garnet schist; near the anorthosite masses it contains plagioclase (An_{25-45}), all three aluminum silicates (andalusite, kyanite, and sillimanite), and locally as much as 40 percent cordierite (Hietanen, 1956, 1963a, 1969b). Staurolite occurs with the aluminum silicates in the northern part. The proportion of plagioclase and its anorthite content increase toward the anorthosite masses (Hietanen, 1969b, p. 378). The upper part of

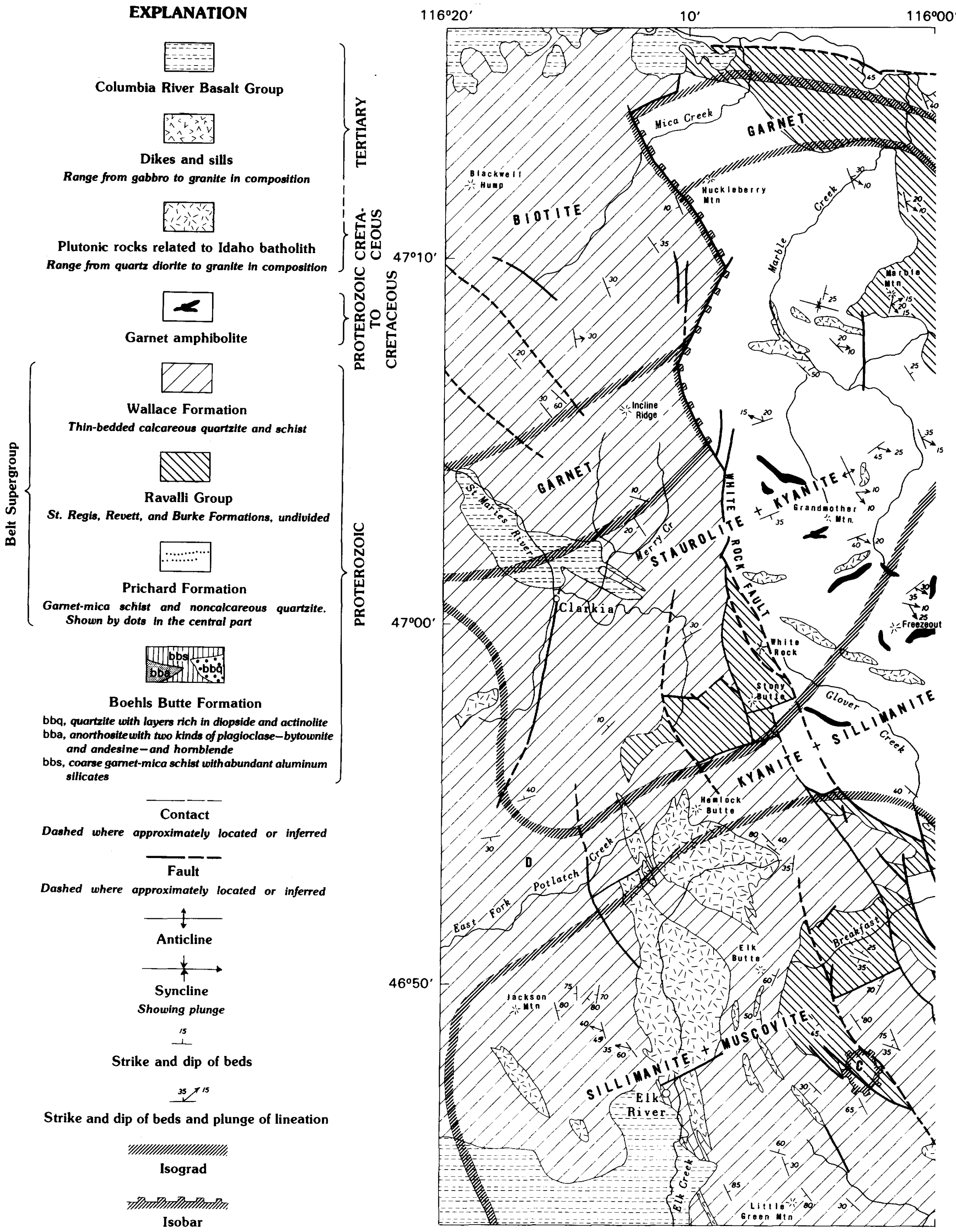


Figure 2. Geologic map of St. Joe-Clearwater region, showing the uplifted Boehls Butte Formation and metamorphic zones. A, kyanite-andalusite zone; B, zone where kyanite, andalusite, and sillimanite occur together; C, sillimanite-staurolite zone; D, kyanite with staurolite or with sillimanite; E, kyanite-almandite zone. Modified from Hietanen (1969b).

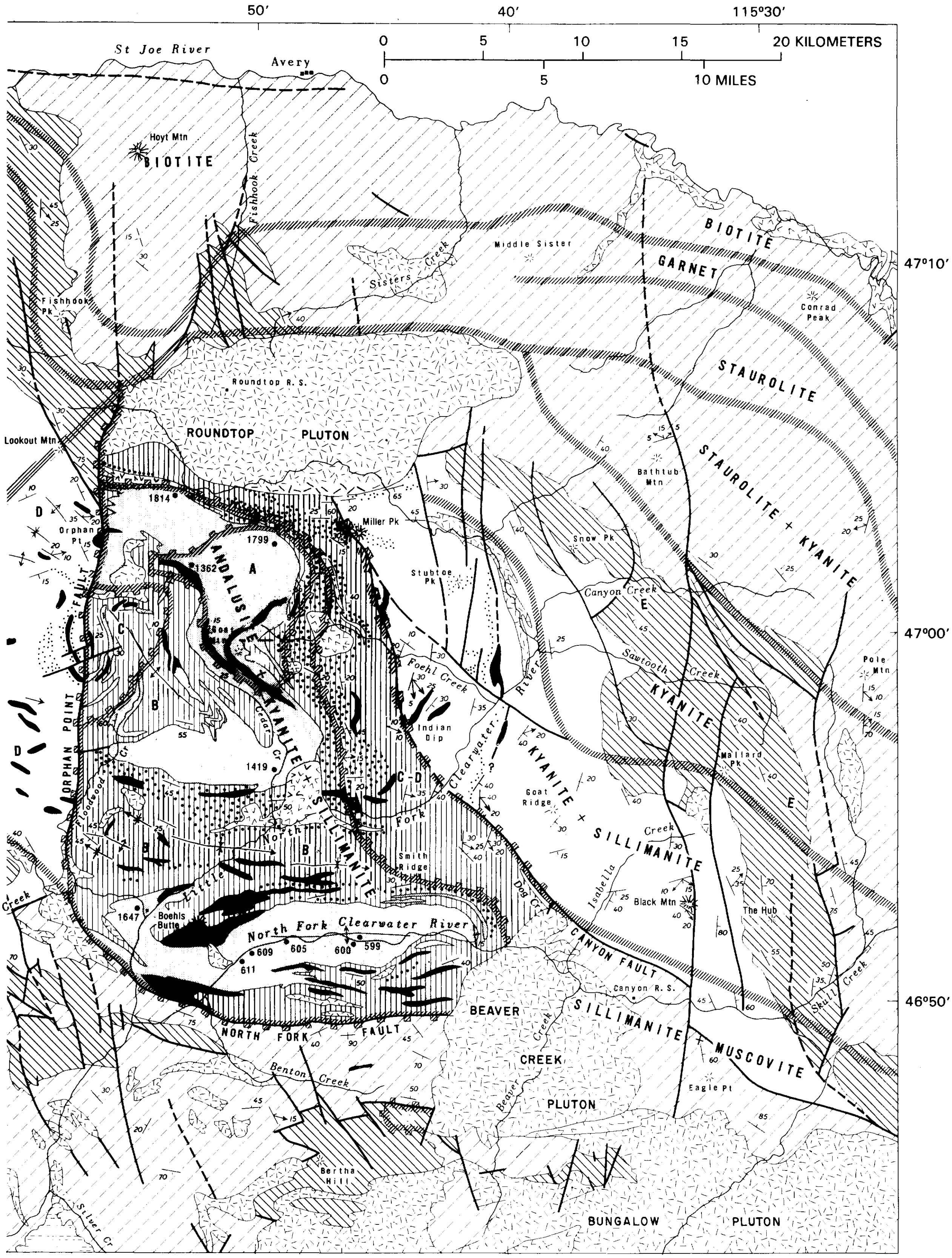


Figure 2. Continued.

the schist in a syncline between two southern anorthosite masses is a distinctly laminated coarse-grained garnet-mica schist. Thin (1–3 mm thick) layers that consist of plagioclase (An_{25-38}) and quartz are separated by biotite-muscovite laminae. Thick beds of this laminated schist are well exposed on the south slope of Smith Ridge. Abundant kyanite in elongate grains with irregular outlines and ranging from 0.5 to 3 mm in length occurs in strongly foliated biotite-muscovite schist at the mouth of Minnesaka Creek (fig. 3). Muscovite schist on the west side of the Canyon fault south of the Roundtop pluton (figs. 2, 3) shows a strong post-crystallization deformation and rolling. Thin sections show an intensive wrinkling and strongly bent large muscovite flakes among strained quartz grains.

The quartzite of the Boehls Butte Formation includes coarse-grained pearly-white to very light gray muscovite-bearing layers and fine-grained gray biotite-rich layers. Large clear grains of quartz are scattered in grayish-white muscovite-bearing quartzite west of Miller Peak and east of Monumental Buttes (fig. 3). Locally, calc-silicate-bearing quartzite and gneiss occur in the coarse-grained white layers; the largest occurrence is at Cedar Creek (fig. 2).

Three large and several small lens-shaped masses of anorthosite are interlayered with the aluminum-silicate-rich schist (Hietanen, 1963a). Exposures along new logging roads show that the western part of the middle body is continuous with the southward extension of the northernmost mass (Nord, 1973). Most rocks of the middle and southern masses are distinctly layered and consist of white to light-gray layers, 5 to 50 cm thick, of andesine-bytownite rock and thin dark layers that are rich in biotite and muscovite or in hornblende (Hietanen, 1963a). In the light-colored layers, calcic plagioclase, commonly An_{85-95} (Nord, 1973), forms a fine-grained groundmass between large oval andesine (An_{40-45}) grains and occurs as irregularly shaped and lamellalike inclusions in andesine. Both types of plagioclase occur also in the thin dark layers, which locally contain all three aluminum silicates, with muscovite and biotite and such rare assemblages as kyanite-hornblende and kyanite-anthophyllite-cordierite.

Anorthosite in the northernmost large body is coarse grained and massive, and consists of andesine or labradorite with inclusions and interstitial grains of bytownite and (or) anorthite. Many of the inclusions have kyanite centers. Generally, fewer interstitial small grains of bytownite or anorthite occur between the large labradorite crystals than between the andesine grains.

Nord (1973) made a detailed electron-microprobe study of the plagioclase in the two northern masses and found three distinct compositions in lath-shaped labradorite crystals: the host grains consist of An_{55-65}, inclusions of An_{90-95}, and rims of An_{40-45} around the inclusions. These crystals are trimodal and contain numerous rimmed inclusions of calcic plagioclase, several of which include kyanite or andalusite. In some localities, the lath-shaped and subhedral labradorite crystals are twinned according to the Carlsbad, albite, and complex twin laws, as is typical of plagioclase crystallized from a magma. It may be that an anatectic labradorite magma was formed locally by melting of the metasedimentary parent rocks and that calcium from andesine rims combined with aluminum and silicon to form anorthite shells around the remnants of Al-silicate.

Electron-microprobe analyses of other constituent minerals in several specimens I collected (Hietanen, 1963a) from massive anorthosite and its foliated and layered border zone were kindly provided by Leonid Perchuk. Calculation of these (table 3) shows that the composition of garnet varies widely. In the massive anorthosite on Rocky Run Creek (loc. 1696), grossularite containing 7.7 percent almandite and 0.7 percent pyrope occurs with garnet that is a mixture of almandite, pyrope, grossularite, and spessartite (sample 1696, table 3). Pink grossularite in layered andesine-bytownite and anorthite rocks along the border zone 3 to 4 km east of Orphan Point contains 14 percent almandite and less than 1 percent each of pyrope and spessartite (sample 1352, table 3). The associated minerals are hornblende, diopside, and zoisite (see Hietanen, 1963a, fig. 40). Garnet in micaceous layers that contain staurolite and aluminum silicates at this locality (see Hietanen, 1963a, figs. 39, 41) is almandite containing some pyrope and grossularite (sample 1353, table 3). Large garnets in border-zone rocks rich in biotite, chlorite, and kyanite near Monumental Buttes (sample 1319) are composed of about 60 percent almandite, 28.5 percent pyrope, and 11.4 percent grossularite. Large garnets at Goat Mountain contain 10 percent spessartite (sample 971).

The FeO/MgO ratios in biotite, chlorite, and cordierite vary considerably (table 3). In sample 1353, biotite and chlorite are relatively rich in iron, whereas in sample 971 both of these minerals and the associated garnets are rich in magnesium. Cordierite in the massive anorthosite is an iron-rich variety, whereas most cordierite in the border-zone rocks is rich in magnesium.

Staurolite containing about 1 weight percent MgO occurs in the schist under the northernmost anorthosite mass and in its border zone. Garnet in this schist (spec. 1368) is almandite containing 9 percent pyrope, 15 percent grossularite, and 1 percent spessartite. Associated biotite and chlorite are rich in iron, and their respective FeO/MgO ratios are 5.42 and 5.97.

Table 3. Composition of garnet and FeO/MgO ratios in biotite, chlorite, and cordierite in massive anorthosite and its foliated border zone

[Calculated from electron-microprobe analyses by L. Perchuk]

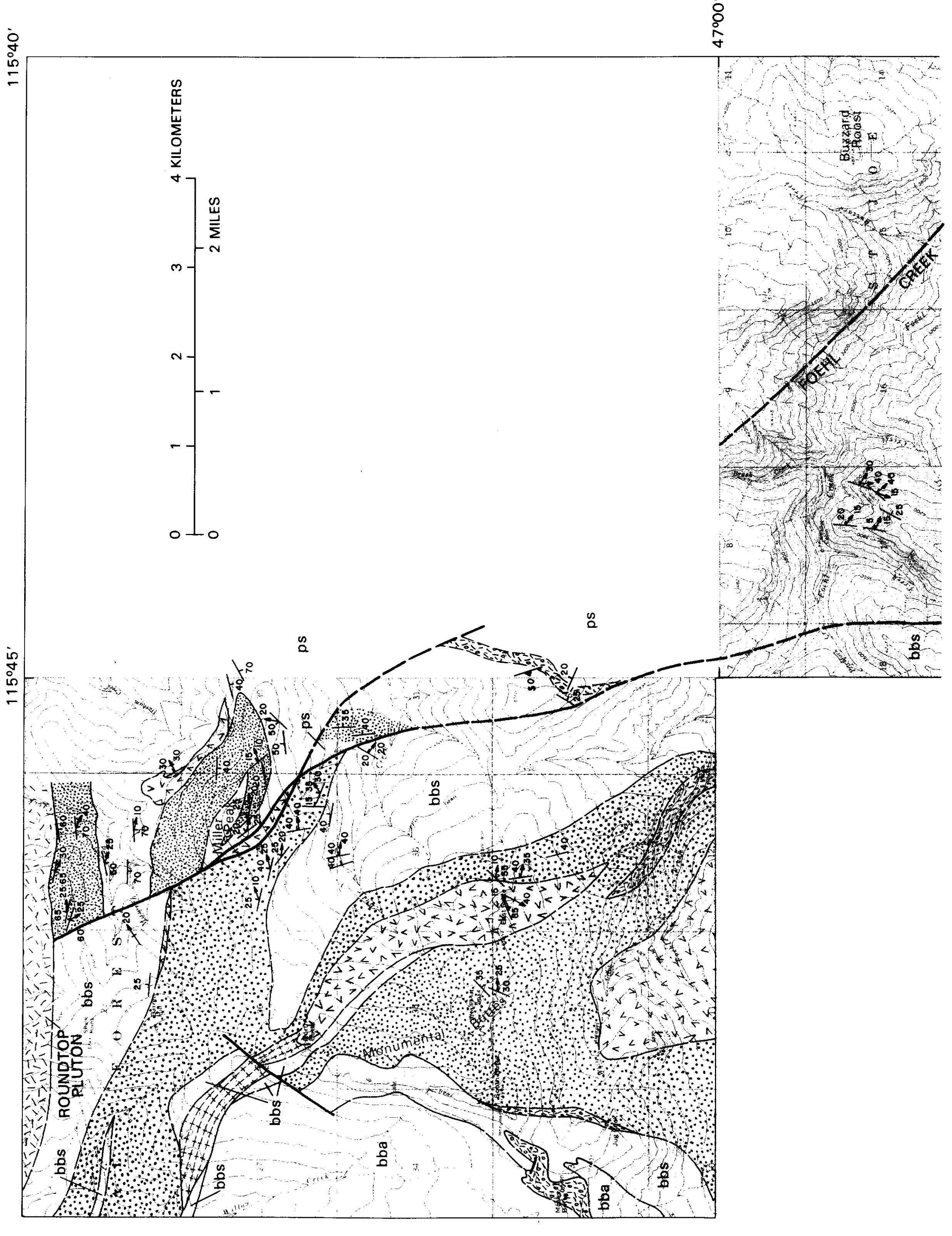
Rock type----	Massive anorthosite		Layered border zone of anorthosite		Border zone rich in biotite and Al-silicates	Plagioclase-biotite-kyanite-garnet	
Location------	Rocky Run Creek		3 km east of Orphan Point		Monumental Buttes	Goat Mountain	
Sample--------	1696		1353	1352	1319	971	
Mineral-------	Garnet	Grossularite	Garnet	Grossularite	Garnet	Garnet	
Almandite-----	64.67-52.05	7.70	79.70-62.90	14.24	61.12-59.43	50.00	49.16
Pyrope--------	17.73-20.90	.66	6.86-18.89	.78	29.08-27.69	24.13	25.96
Grossularite--	13.55-25.09	91.51	10.91-25.03	84.11	10.07-12.69	15.98	14.84
Spessartite---	4.05-1.96	.13	2.53-0.0	.87	.0	9.89	10.04
			Average FeO/MgO ratios				
Biotite-------	---	---	1.93	---	---	.84	---
Chlorite------	1.58	---	3.69, 2.24	---	1.16	.54	---
Cordierite----	1.71	---	---	---	.59	---	---

Layers and lenses of bytownite anorthosite, containing either garnet, biotite, and quartz or hornblende and biotite, are interbedded with the aluminum-silicate-rich garnet-mica schist beneath the large anorthosite masses and along their border zones. Some of these grade to two-plagioclase anorthosite by replacement of part of the bytownite by andesine. A medium-grained light-bluish-gray bytownite anorthosite with layers of foliated hornblende-bytownite gneiss is exposed along a tributary to the West Fork of Cedar Creek. The possibility of an igneous origin of the bytownite anorthosite was discussed earlier (Hietanen, 1963a, p. 69).

The long thin bodies of garnet amphibolite and hornblende-plagioclase gneiss in the southern part of the northernmost large anorthosite mass could represent cogenetic gabbroic rocks. However, only one kind of plagioclase—labradorite—occurs with the hornblende, garnet, and quartz in the garnet amphibolite, which locally cuts the anorthosite and thus is younger. The relict sedimentary structures, such as paper-thin micaceous laminae and the large amount of aluminum silicates in the anorthosite, also speak against an igneous origin.

Juras (1974) chose shear differentiation and exsolution of igneous labradorite into anorthite and andesine to explain the unique textures of the two-plagioclase anorthosite. The possibility of exsolution and arguments against it were discussed earlier by Hietanen (1963a, p. 65). One of the main arguments against an igneous origin and later exsolution is the large variation in andesine/calcic-plagioclase ratio, resulting in notable inhomogeneity of bulk composition in various parts of the masses. Moreover, if exsolution of labradorite to andesine and anorthite were possible under certain physicochemical conditions, then one would expect to find it in some other anorthosite occurrences and in some gabbroic and noritic rocks. Because this is not the case, we should view with scepticism any mode of origin that involves exsolution until such a possibility is proven in the laboratory or found elsewhere in nature.

The distinct layering, the abundance of aluminum silicates, the presence of two or three types of plagioclase with unique textures, the occurrence of lenses of bytownite anorthosite containing quartz, garnet, and hornblende along the contacts of large masses, the varying composition of garnet, and the abundance of secondary andesine in the aluminum-silicate-rich garnet-mica schist of the contact aureoles are features different from those of any other known anorthosite. A metasedimentary origin with later addition of sodium to form andesine is therefore preferred for these layered anorthosite masses (Hietanen, 1963a, 1969b; Nord, 1973; G. L. Nord, Jr., written commun., 1976). The potassium-poor igneous rocks related to an early phase of the Idaho batholith could have been the source of the added sodium. The layered garnet- and hornblende-bearing bytownite anorthosite, which occurs along the border zones of the two northern


115°40'
115°45'
47°00'
0
1
2
3
4 KILOMETERS
0
1
2 MILES
ROUNDTOP PLUTON
FOEHL CREEK
Buzzard Roost
Miller Peak
Monumental
ps
bbs
bba

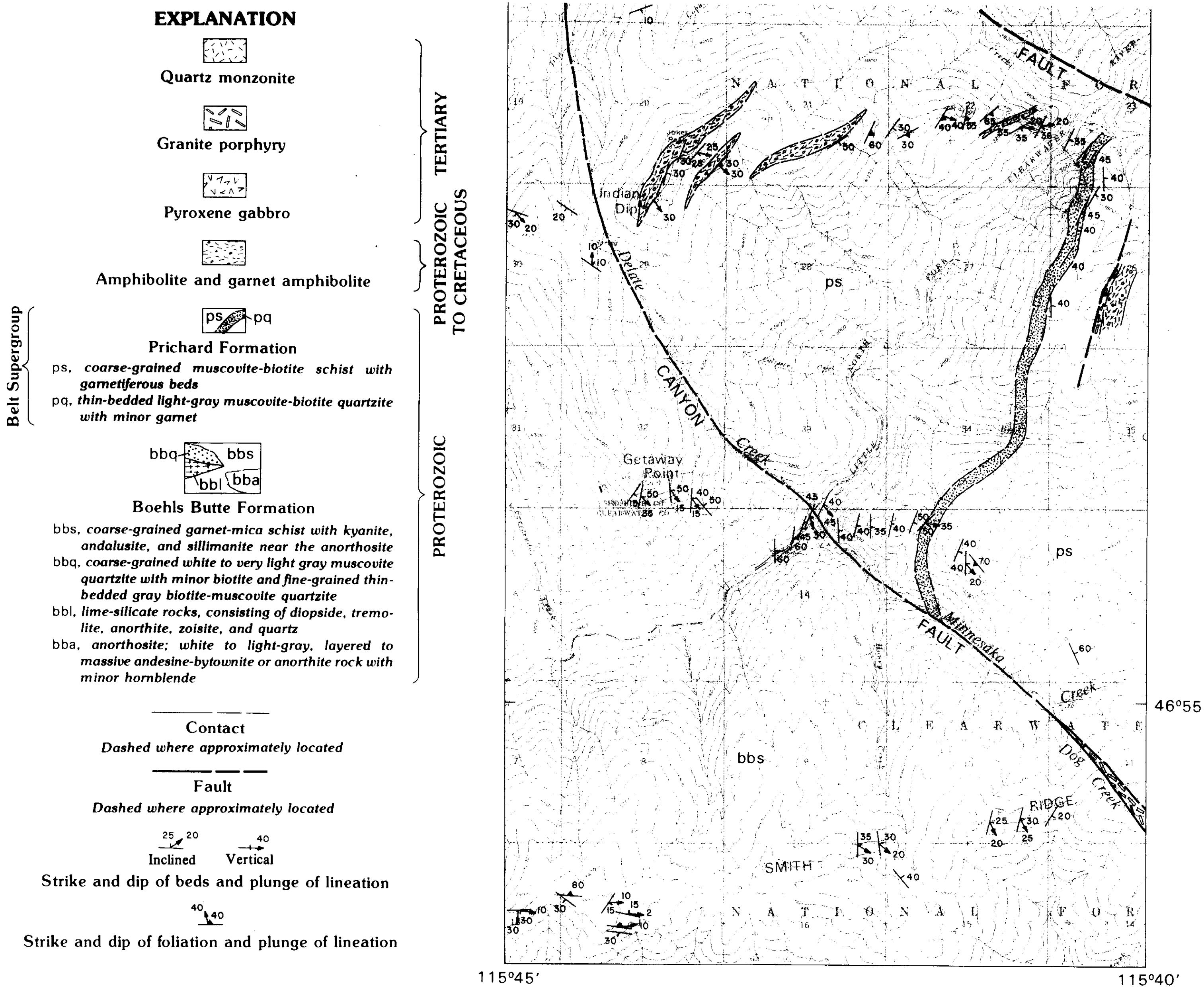


Figure 3. Fault contact (Canyon fault) between the Boehls Butte and Prichard Formations in the vicinity of Miller Peak and Indian Dip.

masses and in many small bodies and thin layers in the underlying schist, could have formed from interbedded calcareous and aluminum-rich shale. Migration of aluminum from pelitic layers over a short distance to calcareous shale would produce calcic plagioclase, part of which was later replaced by andesine. Excess calcium would have entered the hornblende that is common in all layers. None of the ilmenitic iron ores that are commonly associated with igneous anorthosites occur in this area. Partial melting and mobilization could account for the massive appearance of parts of the northern masses.

The strontium-isotopic ratios (table 4) in the massive anorthosite are similar to those in the layered anorthosite; both average 0.7046. In the bytownite-rich border-zone rocks, however, this ratio is higher, averaging 0.7061 and supporting the contention of a mixed origin for these anorthosite masses.

Table 4. Strontium-isotopic ratios in anorthosite

[Analyst, Stanley A. Heath]

	Sample	$^{87}Sr/^{86}Sr$	Average
Massive anorthosite			
Northern body--------	1799	0.7049	0.7046
	1814	.7039	
Middle body----------	1419	.7039	
Layered anorthosite			
Southern body--------	605	.7040	.7046
	600	.7049	
	609	.7049	
Border zone---------------	1362	.7064	.7061
	1647	.7058	

STRUCTURES

Multiple sets of structures are apparent in the study area; two or three sets of folds and lineations can be observed in many outcrops. Lineations are parallel to and interchangeable with the fold axes, and so the fold axes in a given outcrop are represented by lineations in nearby outcrops. Four major trends of fold axes and parallel lineations are common: westerly (N. 70°– 90° W.), northwesterly, northeasterly, and north-south. The age relations between these four major sets of folds are complex. In the central part of the study area and in the Boehls Butte block, large gentle folds with easterly plunges are modified by southeast-plunging northwest-trending folds, which are therefore younger. In many outcrops in the northern part of the study area, overturned and recumbent folds of outcrop size on northwesterly axes are refolded by west-northwest- or northeast-trending folds, whereas in many other outcrops, axial planes of small overturned west-northwest- and northeast-trending folds are refolded by northwest-trending folds. I concluded earlier (Hietanen, 1961c, 1963b, 1968) that these three sets of folds were formed simultaneously over a long period. Folding on north-south axes may be related to faulting and is in places older than the northwest-trending folds, but some late folding and doming on north-south axes also occurs.

One of the oldest (Proterozoic?) sets of fold axes trends N. 70°–90° W. and thus parallels the long axis of the basin into which the sediment of the Ravalli Group was deposited (Harrison, 1972; Armstrong, 1975). Armstrong's (1975) suggestion that the south limit of this depositional basin was a short distance to the south of the south border of Clearwater County agrees with the thinning of the Ravalli Group toward the south in the study area (Hietanen, 1963c, pl. 2). Late folds on N. 70°–90° W. axes also are common and may represent rejuvenation of the earlier structures.

In the uplifted Boehls Butte block, the distribution of sheetlike masses of anorthosite (Hietanen, 1963a) shows a gentle folding on east-plunging axes. The two large northern masses are exposed in the nose of a double-crested anticline, and the southernmost mass that is exposed along the canyon of the North Fork of the Clearwater River has an anticlinal structure (fig. 2). The laminated biotite-muscovite-garnet schist on Smith Ridge—stratigraphically above the anorthosite and quartzite overlying it—forms a syncline between the two anticlines (fig. 2). In the central part of the Boehls Butte block, these structures have been modified by northwest folding, and in the northwestern and southern parts by gentle doming.

The schist that is exposed to the west of the two large northern anorthosite masses underlies them. Reid and others (1973) reported a pre-Beltian $^{206}Pb/^{207}Pb$ age of 1,625 m.y. for the anorthosite at Goat Mountain and a somewhat older age of 1,665 m.y. for the underlying schist at O'Donnell Creek. Quartzite overlying the anorthosite to the east is folded on an east-plunging axis and locally has an earlier wrinkling parallel to south-plunging axes. The schist farther east, west of Indian Dip and near Getaway Point (fig. 3), and that east of Smith Ridge are folded on southeast-plunging axes. On Smith Ridge, the laminated coarse-grained garnet-biotite-muscovite schist is folded and wrinkled on axes that plunge 5°–15° E., and these folds are overturned to the south. An older wrinkling on the north-south axis occurs locally.

Juras (1974) made a detailed field study of folds in the anorthosite area and suggested nine episodes of folding, from oldest to youngest: (1) North-south-trending recumbent folds, (2) east-west to northwest-trending recumbent isoclinal folds, (3) northwest-trending tight flexural flow folds, (4) northeast-trending tight to recumbent subisoclinal folds, (5) north-south-trending tight to recumbent folds, (6) north-south-trending large closed to tight flexural folds, (7) northeast-trending gentle to closed parasitic folds, (8) west-northwest-trending large concentric flexural-slip folds, and (9) northwest-trending chevron-like folds.

The schist of the Prichard Formation on the east side of the Canyon fault, north of Indian Dip, contains a set of early folds strongly overturned to the west—with amplitudes of about 1 m—on south-plunging axes, and a later set of larger folds on southeast-plunging axes (fig. 3). East of Indian Dip, the major fold axes plunge 20°–40° SE.

Two sets of folds can be observed in many outcrops in the northeastern part of the study area, as described previously (Hietanen, 1961b, c, 1968). Large overturned and recumbent folds on southeast-plunging axes have axial-plane cleavages that are refolded on south-southwest- or northeast-plunging axes. In some places, mica flakes have recrystallized parallel to the axial planes of these later small folds, which have wave lengths of 20 to 30 cm. On Goat Ridge and south of Black Mountain, large folds strongly overturned to the north have east-plunging axes, and their later small folds have northeast-plunging (on Goat Ridge) or south-plunging axes. Two sets of small folds whose axes plunge east-southeast and northwest have twisted the flanks of the large north-south-trending folds east of The Nub (Hietanen, 1968, fig. 13). North- or south-plunging lineation and a few folds on axes parallel to it occur with two other sets of folds. Gentle open folds on north-plunging axes occur locally along the North Fork of the Clearwater River. Many large blocks bordered by faults seem to form structural units in which the trends and roles of major and secondary fold axes differ from those in neighboring blocks (Hietanen, 1968, p. 26). The style of folding changes with the grade of metamorphism and with the type of material folded (Hietanen, 1961a, c). In places, round flexural-slip folds are common in quartzite layers interbedded with thick layers of schist that, instead of folding, show intense wrinkling (Hietanen, 1968, p. 25).

In the western part of the study area, the axes of major folds parallel the northwesterly regional trends, and their plunges are either northwestward or southeastward, indicating later doming. The flanks of large folds are straight, and the hinges are tight; many 25°–30°-slope hillsides represent dip slopes. Lineation parallels the axes of small earlier folds, many of which are overturned to the northwest and plunge southwest or northeast. In some places, three sets of folds can be observed: (1) Small overturned folds with wavelengths of 10 to 100 cm on northeast axes that plunge 10° SW., (2) later large mappable folds on east-west axes, and (3) still later large open folds on northwest axes that plunge 10° SE.

In the southern part of the study area, two sets of folds commonly have northeast- and east-plunging axes. A strong northeasterly lineation also occurs in the igneous rocks near Orofino (Hietanen, 1962, pl. 4). The northeasterly lineation in these rocks parallels the Permian structural trends at the north end of a major Paleozoic and early Mesozoic structural zone that can be traced from California through Oregon to Idaho (Hietanen, 1981).

Several active periods of plate convergence, each with associated deformation, are known in the northern as well as the southern arcs of the Cordillera during Paleozoic and Mesozoic time. It is probably all these tectonic events along the continental margin that make the structures exceptionally complex in this area, which lies within the convergence of the two arcs.

METAMORPHISM

The Belt Supergroup rocks to the north of the study area were metamorphosed to greenschist facies during Middle Proterozoic time, about 1,200 m.y. ago (Hobbs and others, 1965). Several episodes of recrystallization resulted from later periods of deformation and associated igneous activity. In the study area, the degree of metamorphism increases toward the Idaho batholith (Hietanen, 1961a,b, 1963b, 1968), and the K-Ar ages of biotite and muscovite (76 and 57 m.y., respectively) in the kyanite-sillimanite zone north of the batholith are within the age range of the intrusion. The lower units recrystallized at higher pressure and temperature, as shown by the displacement of isograds by younger faults (fig. 2; Hietanen, 1967). A good example of this displacement is in the northwestern part of the study area, where fine-grained biotite-grade rocks of the Wallace Formation on the west side of the White Rock fault are juxtaposed against coarse-grained staurolite-kyanite schist of the Prichard Formation on the east (Hietanen, 1963b, 1967). This feature could have been accentuated by a gentle dip of isograd surfaces due to a possible extension of the batholith and its forerunners to the north, under the present exposed surface.

In the northern part of the study area, two episodes of metamorphism—a synkinematic and a postkinematic—can be recognized in thin sections and, in places, mapped in the field (Hietanen, 1968). Higher temperatures during the second episode moved the isograds farther north. Pseudomorphs of kyanite after staurolite and zonal textures in garnets resulted from the increase in temperature during the second episode. Biotite, garnet, and some plagioclase are characteristic additional constituents in this kyanite-staurolite zone and in the higher grade zones to the south. Muscovite is common in the sillimanite zone next to the Idaho batholith; this association indicates temperatures below 640°C. Occurrence of potassium feldspar with sillimanite in a few places indicates that only locally did temperatures exceed 640°C during recrystallization. In this highest grade zone, wollastonite crystallized with grossularite and diopside in some calcareous layers of the Wallace Formation near Dent (Hietanen, 1967, p. 24).

The pre-Beltian Boehls Butte Formation contains andalusite in addition to kyanite and sillimanite. In many places andalusite crystallized from kyanite, but in other places all three aluminum silicates seem to occur together in equilibrium, indicating pressures and temperatures close to the triple point, here estimated to occur at a pressure of 0.5 GPa (5 kbar) and a temperature of 580°C (Hietanen, 1956, 1968, 1969a). A pressure of 0.5 GPa would indicate that about 18 km of overlying rocks was removed by erosion after the recrystallization of these pre-Beltian rocks.

The absence of andalusite in the Belt Supergroup rocks in the study area indicates that the rocks of the kyanite-sillimanite zone recrystallized at pressures higher than the pressure at the triple point but lower than that of the staurolite-kyanite-sillimanite association. The stability field of staurolite overlaps that of sillimanite near the triple point of kyanite, andalusite, and sillimanite; and the rare staurolite-kyanite-sillimanite association was found near Orofino (Hietanen, 1959). A few small crystals of staurolite and bundles of sillimanite needles occur with kyanite and gedrite (aluminous anthophyllite containing 18 weight percent Al_2O_3) in rocks exposed 6 km east of Orofino. This mineral assemblage indicates temperatures at the boundary of the stability fields of kyanite and sillimanite and within the stability field of staurolite. The pressures during recrystallization were higher than the pressure at the triple point. Cordierite, which is stable at the pressure and temperature of the triple point in the Boehls Butte area, was not found near Orofino. Aluminous anthophyllite containing 12 weight percent Al_2O_3 occurs with kyanite and garnet in gneissic rocks on the Little North Fork of the Clearwater River (Hietanen, 1963a, p. 12). Seams of cordierite separate anthophyllite and kyanite on Monumental Buttes. Nord (1973) calculated the slopes of cordierite-producing reactions there and estimated the temperature and pressure of crystallization at 580°C and 0.5 GPa, close to the temperature and pressure of the triple point. Garnet in garnet-amphibole rocks is almandine containing 18 to 42 percent pyrope and 3 to 17 percent grossularite (Hietanen, 1959, 1962, table 13; 1963a, table 4). All these relations indicate maximum temperatures of about 650°C and pressures less than 0.6 GPa in the highest grade zone next to the batholith.

The calcium mica margarite occurs in schist of the Wallace Formation at the south border of the Boehls Butte quadrangle. It forms white bundles with muscovite and probably replaces sillimanite, which occurs in similar bundles in nearby outcrops. Skeletal crystals of hematite and prisms of rutile replace biotite in the margarite-muscovite schist (Hietanen, 1963a, p. 24–26).

The west contact of the batholith dips about 45° E. At the time of its emplacement, therefore, the metamorphic rocks west of the border were structurally under the igneous rocks of the batholith, which in the study area consist of coarse-grained hornblende-biotite-quartz diorite (Hietanen, 1962, pl. 2). The Belt Supergroup rocks along this western contact zone show metasomatic changes due to the introduction of mainly water, iron, magnesium, calcium, and sodium and the removal of silicon. This exchange of material has resulted in local crystallization of secondary hornblende, biotite, and plagioclase in quartzite and biotite schist (Hietanen, 1962). Addition of water into diopside-plagioclase quartzite and gneiss changed diopside to hornblende in many places in the Headquarters quadrangle.

Most metasomatic changes west of the batholith are postkinematic, and the secondary minerals commonly occur along structural surfaces that facilitated migration of the material introduced. Thus, postkinematic elevated temperatures resulted in an isochemical second episode of recrystallization in the outer part of the contact aureole of the batholith, and in crystallization of metasomatic minerals in the inner part of the aureole in places where new material was introduced from magmatic sources. It is not known whether the replacement of bytownite by andesine in the anorthosite in the Boehls Butte area took place during this or an earlier metasomatic phase. The source of the added sodium here could have been a northward extension of an early igneous activity below the present ground surface. The occurrence of many small igneous masses of tonalite, many of them gneissic, and plagioclase pegmatite bodies to the northwest of the batholith supports this suggestion.

AGE OF PLUTONISM AND METAMORPHISM

Igneous activity in the study area may have started during Proterozoic time in the form of small gabbroic sills and dikes. In Clearwater County and the southernmost part of Shoshone County, these sills and dikes have been recrystallized to amphibolite and garnet amphibolite. Most of these intrusions parallel the bedding in the schist and quartzite, but some parallel faults. These sills and dikes are common in the Boehls Butte and Prichard Formations but occur only sparsely elsewhere. The major minerals in the amphibolite are hornblende, plagioclase, quartz, and, in most sills, garnet. Sphene and magnetite are common accessory minerals. The texture of the rock is granoblastic or lepidoblastic. The foliation parallels the foliation of the enclosing host rock, and the hornblende prisms parallel the local lineation. The dikelike bodies of amphibolite along fault zones rarely contain garnet and contain very little quartz and biotite. In contrast, the sill-like amphibolite bodies in the garnet-mica schist contain abundant quartz, garnet, and biotite; contacts with the host are gradational. In the anorthosite masses, amphibolite occurs as long layerlike bodies that grade to hornblende gneiss.

The northwestern part of the Idaho batholith is exposed in the southeastern part of the study area (Hietanen, 1962, 1963c). Three large and several small satellitic bodies intrude the Belt Supergroup and the Boehls Butte Formation. Two distinct differentiation series are distinguished among the rocks of the batholith and its satellitic bodies: (1) An older quartz diorite-tonalite-plagioclase pegmatite series and (2) a younger quartz monzonite-granite-granite pegmatite series. The rocks of the quartz diorite series contain less than 15 percent normative potassium feldspar and are cut by rocks of the quartz monzonite series that contain as much as 26 percent normative potassium feldspar. For the northern part of the Idaho batholith (the Bitterroot lobe), Armstrong (1975) reported K-Ar ages ranging from 38 to 61 m.y. and lead-alpha ages ranging from 60 to 100 m.y. but probably not much older than 80 m.y. The K-Ar age of biotite in a sample of granite 1.6 km east of Bungalow was determined to be 43 m.y. (Hietanen, 1969a). The K-Ar age of biotite in quartz monzonite from the Roundtop pluton was given by Reid and Greenwood (1968) as 41 m.y. Structural relations show that the rocks of the quartz diorite-tonalite suite are older than these (Hietanen, 1963c). Armstrong and others (1977, fig. 2A) reported K-Ar ages of 71 m.y. for biotite, and 82 m.y. for hornblende, from a hornblende-biotite-quartz diorite near Orofino. In the tonalite along the Clearwater River south of Greer (5.6 km north of Kamiah), the K-Ar age for biotite is 115 m.y., and for hornblende 124 m.y (McDowell and Kulp, 1969; McDowell, 1971). It is not known whether this tonalite and associated quartz diorite near Greer (Hietanen, 1962, pl. 4) is a satellitic intrusion or part of the quartz dioritic border zone of the batholith that is exposed 10 km to the east (Hietanen, 1963c). Farther south, near McCall and south of Cascade, McDowell and Kulp (1969) reported biotite ages of 73 and 77 m.y. for the granodioritic and tonalitic western border zone of the batholith, respectively.

A $^{206}Pb/^{207}Pb$ age on zircons from quartz diorite near Orofino was given as 283 m.y. by Reid and others (1973). The difference between the biotite and zircon ages supports the concept that older sedimentary material was incorporated into the igneous rocks near Orofino, as suggested by Hietanen (1962). Reid and others' (1973) report of zircon ages of 1,473 m.y. for quartz diorite in the Headquarters quadrangle ("type locality"; loc. 292 of Hietanen, 1962) suggests that older, zircon-bearing rocks (Belt Supergroup) were also incorporated into this quartz diorite.

In the Belt Supergroup, the metamorphic grade increases over a distance of 40 km from the biotite zone near St. Joe River, through the garnet, staurolite, kyanite, and sillimanite-muscovite zones, to the sillimanite-potassium feldspar zone south of the North Fork of the Clearwater River near the batholith (Hietanen, 1967). The K-Ar age of biotite in a kyanite-garnet schist is 76 m.y., and of muscovite in the same rock 57 m.y. (Hietanen, 1969a). These dates are within the age range of the intrusive rocks of the Idaho batholith. K-Ar ages for biotites in the Boehls Butte Formation are within the same range: 61 m.y. for biotite in cordierite-kyanite-andalusite-sillimanite gneiss 1 km east of Boehls Butte (loc. 912) and 46 m.y. for biotite in kyanite-garnet-plagioclase gneiss next to the anorthosite at Goat Mountain (loc. 971) (Hietanen, 1969a). This similarity indicates that the micaceous minerals recrystallized during the intrusion of rocks related to the Idaho batholith in this pre-Beltian basement.

The approximate age of pyroxene gabbro in the study area can be deduced from the ages given above. The occurrence of many dikes and sills of pyroxene gabbro along fault zones indicates that these bodies are contemporaneous with, or postdate, the faulting. The White Rock fault displaces isograds and thus is younger than the recrystallization which occurred during the interval 76–46 m.y. ago. All the faults are cut by the 41- to 43-m.y.-old plutons and thus predate these plutons. These relations delimit the time of faulting and of intrusion of the pyroxene gabbro to between 76 and 41 m.y. ago.

The possible continuation of the Idaho batholith and its forerunners farther northward below the presently exposed ground surface gives rise to a wide contact aureole in which the uplifted lower stratigraphic units show considerably higher metamorphic grade than the upper ones. Gentle dips of some isograd surfaces and local introduction of elements from magmatic sources support this contention. As a rule, the metasomatic transformations, such as the introduction of sodium to produce andesine from bytownite in the anorthosite of the Boehls Butte area, took place during intrusion and at lower pressures than those that prevailed during the synkinematic regional metamorphism. Alteration of some kyanite to andalusite probably resulted from the release of pressure and may have occurred during the feldspathization of the schist. Kyanite alone occurs in the garnet-mica schist in the eastern part of the Boehls Butte block, where no sodium was introduced.

REFERENCES CITED

Anderson, A. L., 1930, The geology and mineral resources of the region about Orofino, Idaho: Idaho Bureau of Mines and Geology Pamphlet 34, 63 p.

Armstrong, R. L., 1975, Precambrian (1500 m.y. old) rocks of central Idaho—the Salmon River arch and its role in Cordilleran sedimentation and tectonics: American Journal of Science, v. 275-A, p. 437–467.

Armstrong, R. L., Taubeneck, W. H., and Hales, P. O., 1977, Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, no. 3, p. 397–411.

Calkins, F. C., and Jones, E. L., Jr., 1911, Geology of the St. Joe-Clearwater region, Idaho, *in* Contributions to economic geology (short papers and preliminary reports), 1911: U.S. Geological Survey Bulletin 530, p. 75–86.

Childs, John, 1982, Geology of the Precambrian Belt Supergroup and the northern margin of the Idaho batholith, Clearwater County, Idaho: Santa Cruz, University of California, Ph.D. thesis.

Harrison, J. E., 1972, Precambrian Belt basin of northwestern United States: Its geometry, sedimentation, and copper occurrences: Geological Society of America Bulletin, v. 83, no. 5, p. 1215–1240.

Hietanen, Anna, 1956, Kyanite, andalusite, and sillimanite in the schist in Boehls Butte quadrangle, Idaho: American Mineralogist, v. 41, no. 1–2, p. 1–27.

———1959, Kyanite-garnet gedritite near Orofino, Idaho: American Mineralogist, v. 44, no. 5–6, p. 539–564.

———1961a, Metamorphic facies and style of folding in the Belt Series northwest of the Idaho batholith: Commission Geologique de Finlande Bulletin 196, p. 73–104.

———1961b, Relation between deformation, metamorphism, metasomatism, and intrusion along the northwest border zone of the Idaho batholith, Idaho, *in* Geological Survey research 1961: U.S. Geological Survey Professional Paper 424-D, p. D161–D164.

———1961c, Superposed deformations northwest of the Idaho batholith: International Geological Congress, 21st, Copenhagen, 1960, Report, pt. 26, p. 87–102.

———1962, Metasomatic metamorphism in western Clearwater County, Idaho: U.S. Geological Survey Professional Paper 344–A, p. A1–A116.

———1963a, Anorthosite and associated rocks in the Boehls Butte quadrangle and vicinity, Idaho: U.S. Geological Survey Professional Paper 344–B, p. B1–B78.

———1963b, Metamorphism of the Belt Series in the Elk River-Clarkia area, Idaho: U.S. Geological Survey Professional Paper 344–C, p. C1–C49.

———1963c, Idaho batholith near Pierce and Bungalow, Clearwater County, Idaho: U.S. Geological Survey Professional Paper 344–D, p. D1–D42.

———1967, Scapolite in the Belt Series in the St. Joe-Clearwater region, Idaho: Geological Society of America Special Paper 86, 56 p.

———1968, Belt Series in the region around Snow Peak and Mallard Peak, Idaho: U.S. Geological Survey Professional Paper 344–E, p. E1–E34.

———1969a, Distribution of Fe and Mg between garnet, staurolite, and biotite in aluminum-rich schist in various metamorphic zones north of the Idaho batholith: American Journal of Science, v. 267, no. 3, p. 422–456.

———1969b, Metamorphic environment of anorthosite in the Boehls Butte area, Idaho, *in* Isachsen, Y. W., ed., The origin of anorthosite and related rocks: New York State Museum and Science Service Memoir 18, p. 371–386.

———1981, Extension of Sierra Nevada-Klamath suture system into eastern Oregon and western Idaho, *in* Petrologic and structural studies in the northwestern Sierra Nevada, California: U.S. Geological Survey Professional Paper 1226–C, 11 p.

Hobbs, S. W., Griggs, A. B., Wallace, R. E., and Campbell, A. B., 1965, Geology of the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geological Survey Professional Paper 478, 136 p.

Johnson, C. H., 1947, Igneous metamorphism in the Orofino region, Idaho: Journal of Geology, v. 55, no.6, p. 490–507.

Juras, D. S., 1974, The petrofabric analysis and plagioclase petrography of the Boehls Butte anorthosite: Moscow, University of Idaho, Ph.D. thesis, 132 p.

McDowell, F. W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1–16.

McDowell, F. W., and Kulp, J. L., 1969, Potassium-argon dating of the Idaho batholith: Geological Society of America Bulletin, v. 80, no. 11, p. 2379–2382.

Nord, G. L., Jr., 1973, The origin of the Boehl's Butte anorthosite and related rocks, Shoshone county, Idaho: Berkeley, University of California, Ph.D. thesis, 159 p.

Reid, R. R., and Greenwood, W. R., 1968, Multiple deformation and associated progressive polymetamorphism in the Beltian Rocks north of the Idaho batholith, Idaho, U.S.A.: International Geological Congress, 23d, Prague, 1968, Report. v. 4, p. 75–87.

Reid, R. R., Morrison, D. A., and Greenwood, W. R., 1973, The Clearwater orogenic zone: A relict of Proterozoic orogeny in central and northern Idaho, *in* Belt Symposium, 1973: Moscow, University of Idaho, Department of Geology, and Idaho Bureau of Mines and Geology, v. 1, p. 10–56.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the State of Idaho: U.S. Geological Survey, scale 1:500,000.

Tullis, E. L., 1944, Contribution to the geology of the Latah County, Idaho: Geological Society of America Bulletin, v. 55, no. 2, p. 131–164.

Umpleby, J. B., and Jones, E. L., 1923, Geology and ore deposits of Shoshone County, Idaho: U.S. Geological Survey Bulletin 732, 156 p.

Wagner, W. R., 1949, The geology of part of the South Slope of the St. Joe Mountains, Shoshone County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 82, 48 p.

GPO 787-042/120