Anorthosite and Associated Rocks in the Boehls Butte Quadrangle and Vicinity Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 344-B

Anorthosite and Associated Rocks in the Boehls Butte Quadrangle and Vicinity Idaho

By ANNA HIETANEN

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

GEOLOGICAL SURVEY PROFESSIONAL PAPER 344-B

Petrologic study of anorthosite and its country rocks northwest of the Idaho batholith

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

ANORTHOSITE AND ASSOCIATED ROCKS IN THE BOEHLS BUTTE QUADRANGLE AND VICINITY, IDAHO

By Anna Hietanen

ABSTRACT

Three large and several small bodies of anorthosite occur in the schist of the Prichard formation of the Precambrian Belt series in the Boehls Butte quadrangle and vicinity in the southern part of the Idaho panhandle. The Prichard formation, the oldest formation of the Belt series, consists mainly of garnet-mica schist with one or two quartzitic units in the middle of the formation. The lower quartzite unit of the Prichard formation grades laterally from white and gray quartzite to lime-silicate rock near the Little North Fork of the Clearwater River. The anorthosite occurs in the schist just under the lower quartzite unit. The composition, structure, and texture of the anorthosite are in no way affected by the change in the lithology of the overlying quartzite beds. As a rule, a thin layer of aluminum-rich schist occurs between the anorthosite and the overlying quartzite or lime-silicate rocks, and numerous thin, sheetlike inclusions of schist and aluminum-silicate minerals (kyanite, andalusite, and sillimanite) occur in the anorthosite. The schist under the anorthosite is coarse-grained mica schist with abundant kyanite, andalusite, sillimanite, garnet, and occasional staurolite. All schist next to the anorthosite bodies contains numerous large round grains of calcic plagioclase (An_{25-45}), and an amount of quartz far less than that in the schist farther from the anorthosite.

Locally the anorthosite contains thin, dark layers rich either in biotite and aluminum-silicates or in hornblende, or in places in all these minerals. These dark layers are parallel to the bedding of the country rocks; they are extremely common in the southernmost large body and occur locally in the other bodies. The central parts of the two northern large bodies consist of massive coarse-grained hornblende-bearing anorthosite in which sheetlike micaceous portions are found only in a few localities. Almost all of the anorthosite contains two types of plagioclase, large round grains of andesine (An_{45-48}) and small grains of bytownite (An_{85}), the latter occurring either between the andesine grains or as platelike inclusions in the andesine. Neither plagioclase is zoned. A few small bodies consisting almost exlusively of bytownite are interbedded with hornblende and biotite gneisses near the contacts of anorthosite. Several small bodies of garnet amphibolite occur in the schist near the anorthosite masses and some are included in the anorthosite.

The change from garnet-mica schist through aluminous schist rich in oligoclase and andesine to anorthosite could be due to a gradual change in the chemical composition of the sediment from which these various layers crystallized. However, where the contact zone was studied in detail, it was found that the change from garnet-mica schist to aluminous schist rich in plagioclase takes place paralled to as well as across the bedding and that the distribution of plagioclase is highly irregular. Moreover, the mineralogy, structure, and texture of the isochemically metamorphosed sedimentary layers rich in andesine differ considerably from those of the plagioclase-bearing schist that occurs next to the anorthosite. Yet, the inclusions, structure, texture, and mineralogy of the anorthosite indicate that much, if not all, of the anorthosite was formed by metamorphic and metasomatic processes rather than by intrusion.

The occurrence of two types of plagioclase, andesine and bytownite, in separate grains proves that the anorthosite in the Boehls Butte quadrangle is not a product of simple fractional crystallization of a magma. The layers of bytownite anorthosite interbedded with gneisses are most likely of sedimentary origin, perhaps metamorphosed shaly limestone. In the anorthosite that contains two types of plagioclase, andesine crystallized later as a result of sodium metasomatism. Thus all anorthosite could have been shaly limestone in which bytownite crystallized during the regional metamorphism and andesine formed later as a result of reaction between the early bytownite and introduced sodium. A small portion of coarse-grained anorthosite consists of labradorite with some tiny platelike inclusions of bytownite. Probably in this rock the reaction between the bytownite and the sodium-rich solutions proceeded further and produced an almost homogeneous labradorite anorthosite, thus nearly the variety which is common in the large Adirondack-type anorthosite masses.

The conclusions are supported by 7 new chemical analyses of minerals and by 20 quantitative chemical and spectrographic analyses of anorthosite, its country rocks, and associated metamorphic rocks.

INTRODUCTION

THE ANORTHOSITE PROBLEM

The very earliest investigators classed anorthosite and other monomineralic rocks with the sedimentary formations, but since the turn of the century it has been generally agreed that anorthosite is of igneous origin. This change in the development of thought is clearly indicated in Adams' report (1896) on the anorthosite near Montreal, Quebec. Of his fieldwork in 1891, he writes (in Selwyn, 1892, p. 40): "These [anorthosites], together with some of the associated gneisses and limestones, were formerly supposed to constitute a separate overlying series, to which the name Upper Laurentian was given. Their boundaries have, however, now been traced out, and their stratigraphical relations determined, and they have been found to be without doubt igneous rocks." Most anorthosites described since the time of Adams occur in plutonic surroundings and are undoubtedly of igneous origin. The associated rocks are usually either gabbro, granite, and syenite or rocks of the charnockite series. The crystallization differentiation of anorthosite from a normal basaltic magma has been proved in many sill-like stratiform intrusions in which anorthosite was formed near the roof of the sill above the gabbroic rock. Examples of such occurrences of anorthosite in North America are at Stillwater, Mont.; Bay of Islands, Newfoundland; Duluth (Winchell, 1899) and Pigeon Point (Grout, 1928), Minn.; and Preston, Conn. Similar stratiform sheets occur in Bushveld complex (Wagner, 1924) and in Sierra Leone in Africa.

The study of these sheetlike occurrences proved that gravitative crystallization differentiation in place, as suggested by Bowen (1917), gave rise to a separation and accumulation of labradorite crystals on the upper parts of a floored magma chamber. The field relations, for example, in the diabase sill in Pigeon Point, Minn. (Grout, 1928), leave no doubt that the anorthosite there was derived from a basaltic magma by crystallization differentiation. The anorthosite in Vancouver Island also occurs with intrusive gabbro (Clapp, 1917; Cooke, 1919). In many other areas, however, the large amount of anorthosite as compared with the known gabbroic rocks makes it difficult to adopt a similar explanation. Such large bodies are, for example, the Adirondack, New York (Buddington, 1939; Balk, 1930, 1931); St. Urbain, Quebec (Mawdsley, 1927); Morin district, Quebec (Adams, 1896, Osborne, 1949); Lower Romaine River area, Quebec (Retty, 1944); Saguenay district, Quebec (Dresser and Denis, 1944); St. Paul, Labrador; Nain, Labrador (Wheeler, 1942); and many others on the Labrador peninsula; Honeybrook quadrangle, Pennsylvania (Smith, 1922); Laramie Mountains, Wyoming (Fowler, 1930); San Gabriel Mountains, California (Miller, 1931); Bergen district, Norway (Kolderup, 1903, 1936); Egersund, Norway (Kolderup, 1914, Michot, 1939); Sogn district, Norway (Goldschmidt, 1916; Vogt, 1924); Volhynia, U.S.S.R. (Polkanov, 1937); and Angola, Africa (Mouta and O'Donnell, 1933). Many of these large bodies of anorthosite, with only a subordinate amount of gabbroic rocks in their surroundings, were earlier thought to represent crystallization products of a liquid anorthosite magma (Miller, 1914). It was pointed out by Bowen (1917), however, that the geologic evidence was against the hypothesis of a liquid anorthosite magma, because the surrounding rocks do not show signs of such high temperature as would be required by a molten plagioclase. Bowen suggested that the anorthosite was separated from a gabbroic magma by the separation of the femic constituents while the plagioclase crystals remained suspended. Later, when the liquid is lighter (composition of diorite-syenite) the plagioclase (now labradorite) would accumulate by sinking and give masses of anorthosite. The residual liquid would be syenitic in composition. The movements of such masses of anorthosite would give rise to protoclastic structures, which are common in many large anorthosite bodies. If anorthosite has this mode of origin, no truly intrusive anorthosite dikes should occur.

Bowen's suggestion was criticized by Cushing (1917) and Miller (1918), who pointed out that syenite in the Adirondack region is not a differentiation product from the same magma as the anorthosite, but is a distinctly younger intrusion. An opposing view was suggested also by Goldschmidt (1922), who, in his investigation of a Norwegian anorthosite, came to the conclusion that plagioclase crystals separated from the parent magma by rising. According to Goldschmidt, the anorthosite in Norway is a differentiate of the so-called mangerite magma that differs from the normal basaltic magma essentially because of its dryness. The scarcity of water would make the mangerite magma heavier than the normal basaltic magma and the labradorite crystals would accumulate by rising. Vogt (1924, p. 91) compared the specific gravities of the assumed magmas and the plagioclase in the anorthosite in Norway and concluded that the plagioclase crystals must have been sinking also in the dry magma. Suter (1922) suggested that anorthosite is universally a member of the mangerite magma. The scarcity of water (or OH) in this magma gives rise to a series of rocks in which minerals poor in OH are predominant. Hypersthene and potassium feldspar substitute for biotite in the granites and give rise to a rock series known as charnockites. In the more mafic rocks of this series hypersthene is a predominant dark mineral, but augite and biotite also may occur.

The possibility of a liquid anorthosite magma was raised again by Mawdsley (1927, p. 33) in his study of the St. Urbain area, Quebec. He found andesine anorthosite cutting the older labradorite anorthosite; this seemed "* * * to imply that the andesine anorthosite as a whole did exist in a liquid state * * *." He found no reason for supposing that labradorite anorthosite also came to its place in a liquid condition.

Balk (1930, 1931) made a detailed structural study of the Adirondack anorthosite and suggested that it was differentiated by filter-pressing from a magma that resembled diorite. This magma was squeezed upward as a crystal mush and formed a tilted large body and several small outliers. In the crystal mush the solid part was assumed to have been plagioclase crystal and the lubricating liquid to have been syenitic in composition. Because of the subordinate amount of gabbroic rocks exposed in the Adirondack region, Buddington (1939) assumed that the parent magma was gabbroic anorthosite. He expanded his hypothesis by suggesting that calcic labradorite may have differentiated from the basaltic magma in the lower part of the crust and formed an anorthosite shell above the peridotite shell (Buddington, 1936). Partial melting of such an anorthosite stratum would yield gabbroic anorthosite magma of Adirondack type. Earlier, Kolderup (1936, p. 292) had suggested that the anorthosite near Bergen, Norway, is a differentiation product of a magma, the composition of which must have been that of anorthosite-gabbro in the same area. Osborne (1949) defended the possibility of liquid anorthosite magma in his study of the western part of the Morin massive and claimed that the white andesine anorthosite there forms a dike, 5 miles thick, that served as a feeder along which anorthosite magma was brought to a higher level to form the stratiform Morin mass.

Barth (1952, p. 228) claimed that the anorthosite in the Egersund-Sogndal district in southern Norway shows no evidence of squeezing but instead shows features that cannot be explained by assuming a magmatic origin alone. He points out that "* * * these rocks have gone through complicated processes of metasomatic nature," and compares the problem of origin of anorthosite to that of the granite.

A small wedge-shaped occurrence of gneissic anorthosite in Rodil District, South Harris, Outer Hebrides, shows, according to Davidson (1943), features that are similar to those of the anorthosites in Norway. This anorthosite is metamorphosed and contains schlieren of metamorphosed gabbroic rocks, now amphibolites, garnet amphibolites, and eclogites.

Thus, the investigators seem to agree that the anorthosite in the stratiform sheets of Bushveld and Stillwater type and that in smaller sills (for example, Pigeon Point) is a product of crystallization differentiation of basaltic or gabbroic magma. The origin of the anorthosite bodies of the Adirondack type is more problematic and a matter of controversy. The earlier discussions are centered around the composition of the parent magma, mechanism of the differentiation, type of intrusion, and time relation between the differentiation and intrusion. Recently Michot has advanced a different approach; in several papers he has suggested that such great masses of anorthosite could have been formed in the catazone through magmatic and metasomatic processes (Michot, 1955, 1957). Synkinematic basic magmatism and assimilation of pelitic sediments could produce magmatic anorthosites; the anatectic and metasomatic processes, essentially the removal of ferromagnesian minerals from noritic and leuconoritic rocks, could give rise to residual anorthosite and enrichment of ferromagnesian minerals and ilmenitic iron ores.

A common principal feature of all these anorthosites described in the literature is their association with plutonic rocks. The closest approach to an effusive equivalent is a porphyritic dike rock, kenningite, named and described by Eckermann (1938) from the Nordingrå-Rödö region, Sweden. Eckermann assumed that the anorthosite is a product of the differentiation of a doleritic magma at constant silicon value and that a partial redissolving of plagioclase crystals took place in the Rödö region. No true effusive equivalents of anorthosite are found.

The anorthosite in Boehls Butte quadrangle, Idaho, differs strikingly in many respects from the anorthosites described in the literature. The mode of occurrence resembles in some respects that of the Adirondack type of anorthosite, but the masses in Idaho are much smaller. The floors of most bodies are exposed but contain little if any mafic rocks, and the border zones of the anorthosite are not more mafic than their centers. The most striking differences, however, were found in the mineral content, structure, and texture.

AREA STUDIED

The area studied comprises the Boehls Butte quadrangle and an area of about 120 square miles adjoining this quadrangle on the east and on the north. The Boehls Butte quadrangle lies in the southern part of the Idaho panhandle (fig. 1) and is bounded by 115°45′ and 116°00′ west longitudes and by 46°45′ and 47°00′ north latitudes. The northern part of the quadrangle lies along the western part of the Bitterroot Mountains, which in this area rise 5,000 and 6,000 feet above sea level. The North Fork of the Clearwater River and its tributaries have eroded steep canyons between the mountains.

Most of the area is heavily wooded with white pine, yellow pine, cedar, white fir, spruce, and hemlock. In the northernmost part, however, forest fires have destroyed the timber, and the highest mountains are vegetated mainly by grass, low brush, and scattered groups of young trees. In this part of the area the exposures are good and geology can be mapped with greater certainty than in the southern wooded part.

The area can be reached through Elk River or through Clarkia, both about 30 miles to the west. From Elk River a narrow dirt road leads to Boehls where it joins a dirt road leading from the North Fork of the Clearwater River to Goat Mountain. The road from Clarkia traverses a scenic mountain area and joins a road going from Goat Mountain to Avery, a town about 30 miles to

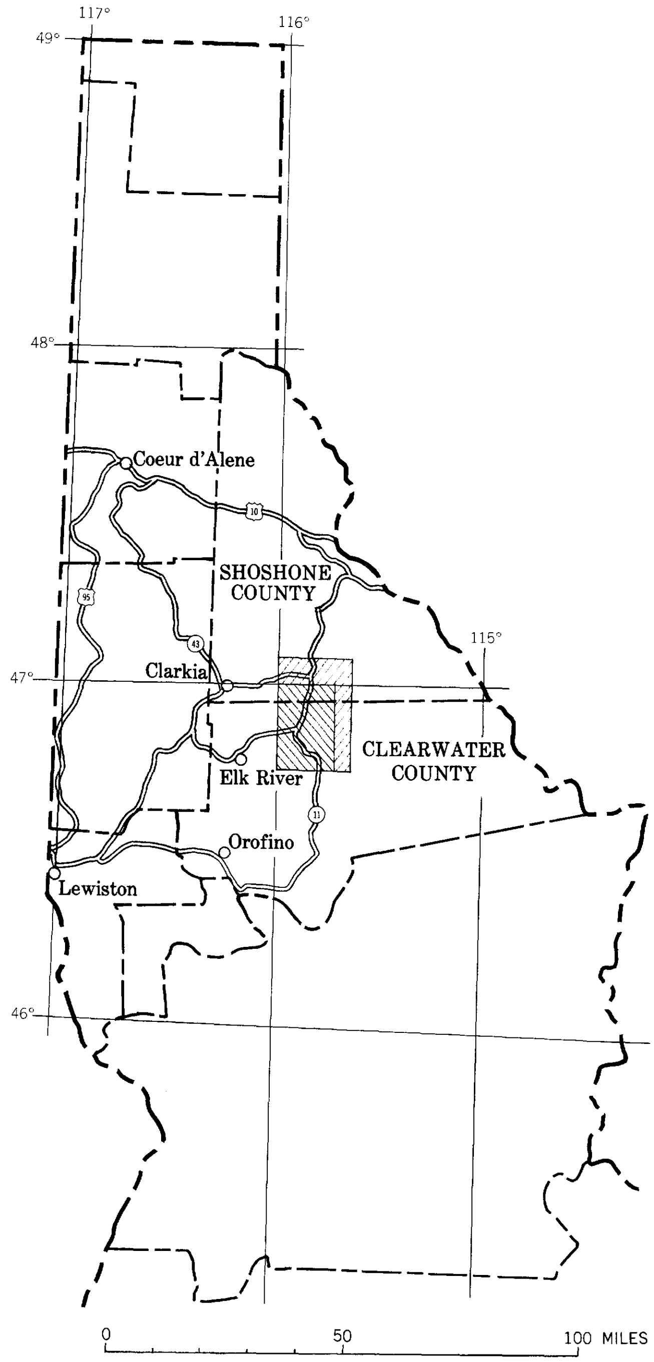

FIGURE 1.—Map of northern Idaho showing location of the Boehls Butte quadrangle and vicinity.

the north. During recent years, logging has been extended to the southern part of the map area. A new logging road that was constructed along the lower part of the Little North Fork of the Clearwater River and along Cedar Creek exposed parts of two large anorthosite bodies which, until then, were accessible only with difficulty.

PREVIOUS WORK

An occurrence of anorthosite in the vicinity of Goat Mountain was indicated on the map and mentioned in the text of Umpleby and Jones (1923, p. 10). On the "Geologic Map of the State of Idaho," compiled by Ross and Forrester (1947), the same occurrence is indicated as a Precambrian intrusive body.

FIELDWORK

Fieldwork for this report was done in the summers of 1951-55. The canyon of the North Fork of the Clearwater River was mapped the first summer. A rubber raft, used as a means of access to the area, was launched 4 miles upstream from the eastern border of the map area (pl. 1), at a point where a road leading to the Canyon Ranger Station crosses the river. Anorthosite is well exposed for 9 miles along the North Fork of the Clearwater River. In the summer of 1952 a trip from Boehls to Goat Mountain revealed a fairly large body of anorthosite near Stocking Meadows. A section through this body was exposed when a logging road along Cedar Creek was opened in the summer of 1953. Most of the mapping of the anorthosite bodies was done during the summers of 1953 and 1955. During the summer of 1953 the author was assisted in the field by Katherine Wagner and Patty Newbold and during 1955 by Alice Vrbsky and Frances Gilbert.

SPECIMEN AND LOCALITY NUMBERS

Localities from which specimens mentioned in the text were taken are shown with specimen numbers on the geologic map (pl. 1). Specimen numbers are also used to identify the chemical analyses of rocks. If two or more analyses are made from the same hand specimen and one or more minerals analyzed in addition to the rock, a letter (a, b, c) is added to the number to identify the mineral.

The following list gives township, range, and section for each locality:

Locality Number	*Township (North)*	*Range (East)*	*Sec.*	*Locality Number*	*Township (North)*	*Range (East)*	*Sec.*
599	41	5	25	956	42	5	19
600	41	5	25	963	42	5	17
607	41	5	33	967	42	5	16
608	41	5	33	968	42	5	16
611	41	5	33	971	42	5	16
613	41	5	32	1014	42	5	9
630	41	4	26	1015	42	5	4
632	41	4	26	1016	42	5	3
633	41	4	26	1018	42	5	3
669	40	6	19	1021	43	5	31
684	40	6	31	1023	43	4	28
694	40	6	32	1154	42	5	1
947	42	5	30	1197	41	4	25
949	42	5	30	1210	41	4	1
954	42	5	19	1225	41	5	9

Locality Number	Township (North)	Range (East)	Sec.	Locality Number	Township (North)	Range (East)	Sec.
1227	41	5	9	1484	39	4	1
1234	41	5	10	1495	41	5	1
1299	41	4	26	1681	42	4	2
1306	41	5	23	1683	42	4	2
1308	41	5	23	1690	42	4	12
1321	42	5	3	1692	42	5	18
1353	43	4	25	1744	42	4	2
1363	43	5	31	1747	43	4	36
1381	41	6	27	1749	43	4	36
1386	42	4	4	1751	42	4	1
1393	42	4	26	1753	42	5	33
1418	42	5	34	1759	42	5	20
1474	40	4	25				

CLASSIFICATION OF THE ROCKS

The oldest rocks in the area are metamorphic rocks belonging to the Precambrian Belt series (pl. 1). In the northwestern and northeastern parts of the area, schist and quartzite are continuous with the Prichard formation, the lowest formation of the Belt series of Shoshone County. In the southern part of this county, Umpleby and Jones (1923) show some younger formations in addition to the Prichard formation. These were the Burke and Revett formations combined, and the Wallace formation, listed in order of deposition. St. Regis formation, which in the northern part of Shoshone County occurs between the Revett quartzite and the Wallace formation, was not shown in the southern part. All these formations are exposed in the northeastern corner of the map area (pl. 1), and their equivalents probably occur in the southern part of the Boehls Butte quadrangle where higher grade metamorphism has obliterated most of the sedimentary structures on which the formational subdivisions are based. The shaly layers were metamorphosed to schists that have approximately the same mineral assemblages regardless of the formation in which they occur. Therefore, the petrologically different rock units, rather than the formations, were mapped; specifically, the schist that overlies the thick beds of pure Revett quartzite and is probably equivalent to the St. Regis formation was mapped with the lowest schist unit of the Wallace formation, and the layers that may be equivalent to the Burke formation are included either in the upper part of the Prichard formation or in the lower part of the Revett quartzite.

Among the plutonic rocks two distinctly different groups can be distinguished: older plutonic rocks and young discordant intrusive bodies. The older plutonic rocks are gneissic and occur as small elongate conformable masses in the schist, whereas the younger intrusive bodies are massive or the structures in them are not conformable with the structure of the country rock. The older plutonic rocks range from serpentine and gabbro through quartz diorite to tonalite in composition. The younger intrusive bodies consist of gabbro or quartz monzonite or granite.

The anorthosite could not be included in any of the groups mentioned and is therefore discussed in a separate section. The anorthosite is older than the younger intrusive rocks, but its age relative to the older plutonic rocks remains uncertain. Amphibolite and garnet amphibolite occur as layers and lenslike bodies in the shist and quartzite and are most common in the Prichard formation.

BELT SERIES

CORRELATION

Correlation is mainly based on the work by Pardee (1911) and Umpleby and Jones (1923) in the southern part of the Shoshone County. The northernmost part of plate 1 overlaps their geologic maps, and the formations were first identified there and then traced south. Specifically, the quartzite and schist exposed along the northern boundary in the northwestern part of the area (on Lookout Mountain and to the southwest) were mapped as the Prichard formation by Pardee (1911). The descriptions by Wagner (1949), Ransome and Calkins (1908) were helpful especially in identifying various compositional units in the Wallace formation.

A normal depositional sequence—the Prichard, Burke, Revett, St. Regis, and Wallace formations listed in the order of deposition—is exposed in the northeastern corner of the area on the northeast side of the Little North Fork of the Clearwater River (table 1).

TABLE 1.—*Generalized section through the Belt series northeast of the Little North Fork of the Clearwater River along Spotted Louis Creek*

Formation and rock type	Estimated thickness (meters)	Estimated thickness (feet)
Revett, coarse-grained pure quartzite	470	1, 550
Burke, schist and fine-grained biotite quartzite	200	660
Prichard:		
Schist	420	1, 390
Quartzite	360	1, 180
Schist	130	430
Amphibolite	70	230
Garnet-mica schist	80	260
Granodiorite and granite	200	660
Total	1, 930	6, 360

A coarse-grained thick-bedded fairly pure quartzite in this section is a part of the layers shown as the Revett and Burke formations by Umpleby and Jones (1923). This quartzite is easy to identify in the field (see petrographic description) and was used as a key during the mapping and correlating of the highly metamorphic schists, quartzites, and gneisses of the area studied with the Belt series exposed farther north. On plate 1, it is shown as the Revett quartzite but it may include beds equivalent to parts of the Burke formation. The formations beneath it are considered to be equivalents to the Burke and Prichard formations; those overlying it are equivalents to the St. Regis and Wallace formations.

In the northeastern corner of the map area, the Revett quartzite is underlain by a thin-bedded biotite quartzite and a coarse-grained mica schist in which one or two layers of fairly pure, medium- to coarse-grained granular quartzite are interbedded about in the middle of the section. The stratigraphic position of the thin-bedded biotite quartzite just beneath the massive beds of the pure coarse-grained Revett quartzite corresponds to that of the Burke formation in the Coeur d'Alene district, and the composition and stratigraphic position of the mica schist with one or two quartzitic units are those assigned to the Prichard formation. However, no contact could be placed between the beds of the Burke formation and the underlying beds of the Prichard formation because identical beds occur in each. The Prichard formation consists mainly of schist with less biotite quartzite, whereas the beds just under the Revett quartzite are mainly biotite quartzite with less schist.

The problem of distinguishing the petrologically similar beds of various formations is more complicated in the southern part of the Boehls Butte quadrangle where numerous faults interrupt the normal sequence and bring the Revett quartzite into contact with layers of schist and gneisses which may belong to any of the other four formations—Prichard, Burke, St. Regis, or Wallace.

In many conformable sections, the beds underlying the thick-bedded quartzite consist of coarse-grained garnet-biotite-muscovite schist with some thin beds of biotite quartzite. The contact between the massive quartzite and the schist is sharp, and the lower contact of the Revett quartzite was placed on the bottom of the massive pure quartzite beds. A layer of schist, about 20 m thick, is interbedded with the Revett quartzite in the lower part of this formation. The equivalent of the Burke formation could not be identified with certainty. It is possible that the schist just mentioned and the quartzite beneath it are equivalent to the Burke formation or that an upper part of this formation, which is transitional between the Revett quartzite and the shale of the Prichard formation in the Coeur d'Alene district, is in the Boehls Butte quadrangle included in the massive white quartzite and the lower beds in the schist underneath (schist of the Burke and Prichard formations on pl. 1). It is also possible that the equivalent of the Burke formation was not deposited in the southern part of the area or that it is not exposed because of faulting. Fault contacts are extremely common next to the Revett quartzite and it is impossible to tell how much of the section is missing. A definite correlation cannot be done until after mapping the belt, about 10 miles wide, that separates the low-grade metamorphic Belt series of the Coeur d'Alene district from their high-grade metamorphic equivalents near the Clearwater River.

A similar reasoning is used in mapping the schist of the St. Regis formation with the lower schist unit of the Wallace formation. The faulting is common also along the upper contact of the Revett quartzite, and in such places it is impossible to tell which schist overlies the quartzite.

Umpleby and Jones (1923, p. 8) state that in the southern part of Shoshone County in general the St. Regis formation could not be traced with certainty because of a perfect gradation between the lower beds of this formation and the underlying massive Revett quartzite and also because of a gradation between the upper beds of the St. Regis formation and the lowest shaly beds of the Wallace formation. These shaly beds (the lower part of them probably belongs to the St. Regis, and the upper part to the Wallace formation, as assigned by Umpleby and Jones) would correspond to the schist (Wss) that in the area of plate 1 normally overlies the thick-bedded coarse-grained quartzite that has been mapped as the Revett quartzite.

A heterogeneous sequence of white granular quartzite, thin-bedded biotite and diopside quartzite, diopside-plagioclase gneiss, and sillimanite-garnet schist with thin layers of biotite-plagioclase gneiss is considered to be equivalent to the Wallace formation. The dolomitic sand layers which are typical of this formation in areas farther north, were recrystallized as light-green diopside-plagioclase gneiss. Together with the interbedded biotite gneiss and biotite quartzite, the diopside-plagioclase gneiss forms a major portion of the quartzite-gneiss units (pl. 1) of the Wallace formation. Interbedded with the quartzite-gneiss units are at least two schist units, each several hundred meters thick. The stratigraphic sections correlate fairly well with those given by Wagner (1949) on the south slope of the St. Joe River, about 10 miles north of the northern boundary of plate 1.

The host rocks of the anorthosite bodies are separated by faults from rocks identified as equivalents of the Belt series. Petrologically the schist and the quartzite that form the host rock are similar to the schist and quartzite of the Prichard formation except that calcareous layers are interbedded with the quartzite in the central part. Because a petrologically similar quartzite with some calcareous layers is exposed near Pinchot Butte about 1,500 m below the upper quartzite unit on Widow Mountain, it is thought that the host rocks of the anorthosite belong to a lower part of the Prichard formation not exposed elsewhere in Shoshone County.

PRICHARD FORMATION

Most of the area is covered by the Prichard formation, a portion of which is a direct continuation of this formation from areas farther north. This portion is exposed in the northwestern and northeastern parts of the area, whereas the north-central part is covered by rocks that probably belong to lower units in the Prichard formation. The main rock type in the Prichard formation is a coarse-grained mica schist that contains layers rich either in quartz or in minerals such as biotite, muscovite, garnet, kyanite, andalusite, and sillimanite. One or two thick layers of pure quartzite are interbedded with the schist in the northwestern and northeastern parts of the area, and a quartzite layer with abundant calcareous material in the central part. These quartzitic parts of the formation are referred to as upper and lower quartzite units for distinction from the other quartzitic layers in the same formation. The Prichard formation includes numerous lenticular bodies and layers of amphibolite, a part of which is garnetiferous. The anorthosite bodies occur in the schist just beneath the lower quartzite unit.

STRATIGRAPHIC SEQUENCE

The lithology of the Prichard formation varies from place to place because it includes many lenticular petrologically different rock units. Most of these individual rock units show a similar lack of homogeneity on a small scale; for instance, the main rock type, a coarse-grained mica schist, includes chemically and mineralogically different layers and lens-shaped bodies. The minority rock types that are included in the schist—amphibolite, garnet amphibolite, lime-silicate rocks, phlogopite-plagioclase rocks, and quartzite—are more abundant in the lower part than in the upper part of the formation.

The lowest part of the Prichard formation is exposed along Floodwood Creek where thick layers of coarse-grained mica schist rich in aluminum silicates underlie the anorthosite and the lower quartzite unit. This schist dips gently under the large bodies of anorthosite, and small bodies are included in it. In the northern part of the area, the contacts of anorthosite follow the bedding toward the Orphan Point, where a fault separates the anorthosite and the aluminum-rich schist from the quartzite and garnet-mica schist of the upper part of the Prichard formation in the west. The schist west of this fault contains only locally some aluminum silicates, and it has much less plagioclase than the schist on the east side of the fault. The thickness of the lowest schist unit south of the mouth of Timber Creek is about 600 meters. Conformably on this schist rests anorthosite (500 to 2,000 m thick) and the lower quartzite unit with lime silicate layers (20 to 600 m thick). A thin layer of schist separates the anorthosite from the overlying quartzite unit. On Monumental Buttes and near Goat Mountain, this schist contains an exceptionally large amount of kyanite, andalusite, and sillimanite.

A great thickness of garnet-mica schist with only little if any aluminum silicates and plagioclase overlies the lower quartzite unit. This schist, which petrologically is similar to the schist in the westernmost part of the area, is well exposed in the 2,000 feet deep gorges of Foehl Creek and the Little North Fork of the Clearwater River near Brush Hill, Indian Dip, and Getaway Point. The bedding in the schist is gently dipping and the fold axes plunge to the east. The younger beds occur thus toward the east where north-trending steeply dipping faults separate this schist unit from the normal sequence of the Prichard, Burke, Revett, and Wallace formations.

The quartzite layers interbedded with the schist of the Prichard formation in the northeastern part of the area, such as those exposed between the various northward-trending faults on Stubtoe Peak, near Buzzard Roost, and on the northeast side of the Little North Fork, are petrologically similar to the quartzite on the west side of the anorthosite and its country rocks (on Lookout Mountain). This petrologic similarity supports the structural interpretation and correlation according to which these quartzite layers belong to the same (upper) unit.

The stratigraphic position of the quartzite layers exposed on the northeast side of the steep canyon of the Little North Fork of the Clearwater River leaves no doubt that this part of the formation is equivalent to the uppermost part of the Prichard formation, and that the quartzite there is the upper unit. In this section (table 1), gneissic granodiorite and granite are exposed on the bottom of the canyon along the river; on the top of this plutonic unit is a coarse-grained garnet-mica schist with one or two quartzite layers, together about 360 meters thick. These two layers are mapped together in this vicinity because the layer of schist that separates them is only 1 to 20 meters thick, but attains a thickness of about 60 meters east of the mapped area. The quartzite layers are medium grained, foliated, and contain some micas. The major part of the schist above the quartzite layers is similar to the schist under the quartzite, both being rich in micas. Toward the top of the formation, more fine-grained layers are interbedded with the coarse-grained schist. The stratigraphic position of the last 200 meters just under the coarse-grained Revett quartzite corresponds to that of the Burke formation (table 1), provided that no large fault occurs just under the Revett quartzite.

The schist on either side of the fault zone that borders the anorthosite block in the east is petrologically sim-

TABLE 2.—*Four generalized sections through various parts of the Prichard formation*

1. Section through upper quartzite unit

Rock types on a ridge south of Little Lost Lake	Estimated thickness (meters)	Estimated thickness (feet)
Gabbro	200	660
Coarse-grained gray quartzite	30	100
Anorthosite	30	100
Garnet-muscovite-biotite schist	30	100
Fault.		
Thin-bedded fine-grained quartzite	20	65
Coarse-grained gray quartzite	20	65
Coarse-grained white quartzite	30	100
Fault.		
Gray quartzite with garnets	20	65
Fault.		
Garnet-muscovite-biotite schist	20	65
Coarse-grained gray quartzite with drawn-out garnets	40	130
Coarse-grained white quartzite	30	100
Fault.		
Coarse-grained gray quartzite with drawn-out garnets	40	130
Coarse-grained white quartzite	50	165
Biotite schist	120	400
Amphibolite	5	17
Biotite schist	--------	-------
Total	685	2,262

2. Section through lower quartzite unit

Rock types near Monumental Buttes, lower quartzite unit	Estimated thickness (meters)	Estimated thickness (feet)
Coarse-grained garnet-muscovite-biotite schist.		
Thin-bedded fine-grained gray biotite quartzite	130	430
Coarse-grained white quartzite	30	100
Amphibolite	60	200
Fault.		
Thin-bedded fine-grained gray biotite quartzite	100	330
Coarse-grained white quartzite	35	115
Fault.		
Thin-bedded fine-grained gray quartzite	140	460
Coarse-grained white quartzite	40	130
Amphibolite	20	65
Kyanite-andalusite-garnet schist	60	200
Anorthosite.		
Total	615	2,030

3. Section through lower quartzite unit

Rock types at the mouth of Cedar Creek, lower quartzite unit	Estimated thickness (meters)	Estimated thickness (feet)
Garnet biotite gneiss.		
Actinolite- and graphite-bearing biotite quartzite	50	165
Lime-silicate rock	280	920
Amphibolite	60	200
Lime-silicate rock	160	530
Actinolite-bearing biotite quartzite	10	30
Lime-silicate rock	20	65
Kyanite-andalusite-sillimanite-biotite-muscovite-plagioclase rock	200	660
Anorthosite	50	165
Andesine-bearing mica schist	100	330
Anorthosite	--------	-------
Total	930	3,065

4. Section above anorthosite

Rock types on south slope of Smith Ridge, one mile east of section A–A′, average dip 30° N.	Estimated thickness (meters)	Estimated thickness (feet)
Crest of the syncline, elev. 4,900 ft.		
Garnet-biotite schist	220	730
Garnet amphibolite	130	430
Garnet-biotite schist	280	930
Garnet amphibolite	160	530
Coarse-grained quartzite with some biotite and muscovite	40	130
Garnet-biotite schist	15	50
Amphibolite	2	7
Garnet-biotite schist	20	65
Amphibolite	5	17
Fine-grained dark biotite-muscovite quartzite	55	180
Amphibolite	25	80
Biotite schist	15	50
Amphibolite	50	165
Biotite-muscovite-garnet schist	100	330
Kyanite-andalusite-sillimanite schist	100	330
Tremolite-quartz-plagioclase rock (no. 1306)	60	200
Granular white quartzite	30	100
Tremolite-quartz-plagioclase rock	30	100
Kyanite-andalusite-sillimanite schist	50	170
Actinolite-plagioclase rock	10	33
Diopside-plagioclase rock, pyrrhotite in the lower part	5	17
Kyanite-andalusite-sillimanite schist rich in biotite	10	30
Anorthosite	1,380	4,550
North Fork of the Clearwater River, elevation 1,500 feet	--------	-------
Total	2,792	9,224

ilar and only a minor displacement may have occurred along the faults east of Indian Dip and Getaway Point.

In the northwestern part of the area, the upper quartzite unit is composed of thick layers of white to light-gray medium- to coarse-grained quartzite overlain by fine-grained thin-bedded gray biotite-bearing quartzite. The best section is along the ridge south of Little Lost Lake (table 2, column 1). This section is interrupted by several faults, and the repetition of similar sequences in it is apparently due to the faulting. Allowing for this repetition, the section shows that coarse-grained white quartzite, 30 to 50 m thick, occurs in the lower part of the quartzite unit and is overlain by garnetiferous gray beds that show a strong lineation. The upper part consists of fine-grained thin-bedded gray biotite quartzite and is overlain by a coarse-grained muscovite-biotite-garnet schist similar to that which occurs under the upper quartzite unit.

The thickness of the schist exposed southwest of Widow Mountain under the upper quartzite unit is estimated to be 1,500 meters. Another layer of micaceous light-gray quartzite is exposed under this schist in the deep stream valleys north and west of Pinchot Butte. This quartzite is petrologically similar to the upper layers of the quartzite unit that in the north-central part overlies the anorthosite and may belong at the same stratigraphic horizon.

Near Little Lost Lake, a northward-trending vertical fault cuts off the upper quartzite unit. On the east side of this fault a fine-grained garnet-bearing mica schist forms an interfingering contact with the anorthosite and only a thin layer of quartzite, belonging to the lower unit is exposed between the anorthosite and the gabbro at Long Hike Rock. This quartzite layer becomes thicker toward the east and extends about 25 miles from Long Hike Rock in the northwest to Crescendo Peak in the southeast. The southward extension of this lower quartzite unit is exposed along the ridge south of Crescendo Peak and along the steep canyon of the Little North Fork of the Clearwater River where it trends again westward. An intrusive gabbro interrupts the stratigraphic sequence east of the mouth of Cedar Creek. Provided there is no great fault concealed by the gabbro and amphibolites east of it, the fine-grained biotite quartzite and the thick layers of lime-silicate rocks exposed at the mouth of Cedar Creek belong at the same stratigraphic horizon as the lower quartzite unit. If they do, the lithologic character of the lower quartzite unit of the Prichard formation changes considerably from the northwestern part of the map area toward the southeast.

Near Monumental Buttes a good section of white to gray quartzite is exposed along the road leading to Buzzard Roost. In this section (table 2, column 2) the white quartzite beds are overlain by fine-grained thin-bedded biotite quartzite layers. Two small masses of lime-silicate rock occur between the schist and quartzite on Monumental Buttes. One of them is exposed just on the northwest side of the North Butte, and boulders of the other were found on the trail between North Butte and South Butte. The one at North Butte is about 10 meters thick and is cut by intrusive fine-grained amphibolite. The thickness of the white quartzite near Monumental Buttes is about 35 m but it thins toward the northwest and southeast.

The section through the lower part of the Prichard formation east of Goat Mountain is much the same as that near Monumental Buttes. The lower quartzite unit continues farther to the southeast toward Crescendo Peak. The gray thin-bedded fine-grained layers of the section there are exposed along the road leading from Goat Mountain to Crescendo Peak and the white coarse-grained layers are exposed on the ridge that extends southward from Crescendo Peak. Diopside and actinolite were found in a few thin layers interbedded with thick beds of pure white to cream-colored quartzite between Goat Mountain and Crescendo Peak. Their occurrence indicates that some calcareous material was deposited with quartz sand in this part of the section. At the south end of the ridge that extends southward from Crescendo Peak, white coarse-grained quartzite is overlain by fine-grained gray biotite quartzite which contains several layers of fine-grained plagiolase-phlogopite rock and some coarser layers rich in plagioclase, scapolite, diopside, hornblende, and other lime-silicates. Toward the Little North Fork of the Clearwater River, the layers rich in calcic plagioclase and lime-silicates become more abundant.

A fairly abrupt change in composition occurs between the top of this ridge and the bottom of the canyon of the Little North Fork of the Clearwater River to the south. The section near the river dips 50° south, parallel to the slope of the steep canyon, and therefore only a few layers are exposed; but these layers are definitely richer in calcium than any of the layers exposed between Little Lost Lake and Crescendo Peak. At the bottom of the canyon, 2 miles east of the mouth of Cedar Creek, the main rock type is a fine-grained biotite quartzite. Several layers rich in lime-silicates and a few layers of coarse-grained marble, 1 to 5 cm thick, are interbedded with this quartzite.

Toward the west, at the mouth of Cedar Creek, dark-gray thin-bedded graphite-bearing biotite quartzite is exposed on the south side of the river and lime-silicate rocks on the north side, along the lower drainage of Cedar Creek, overlying there the kyanite-andalusite-

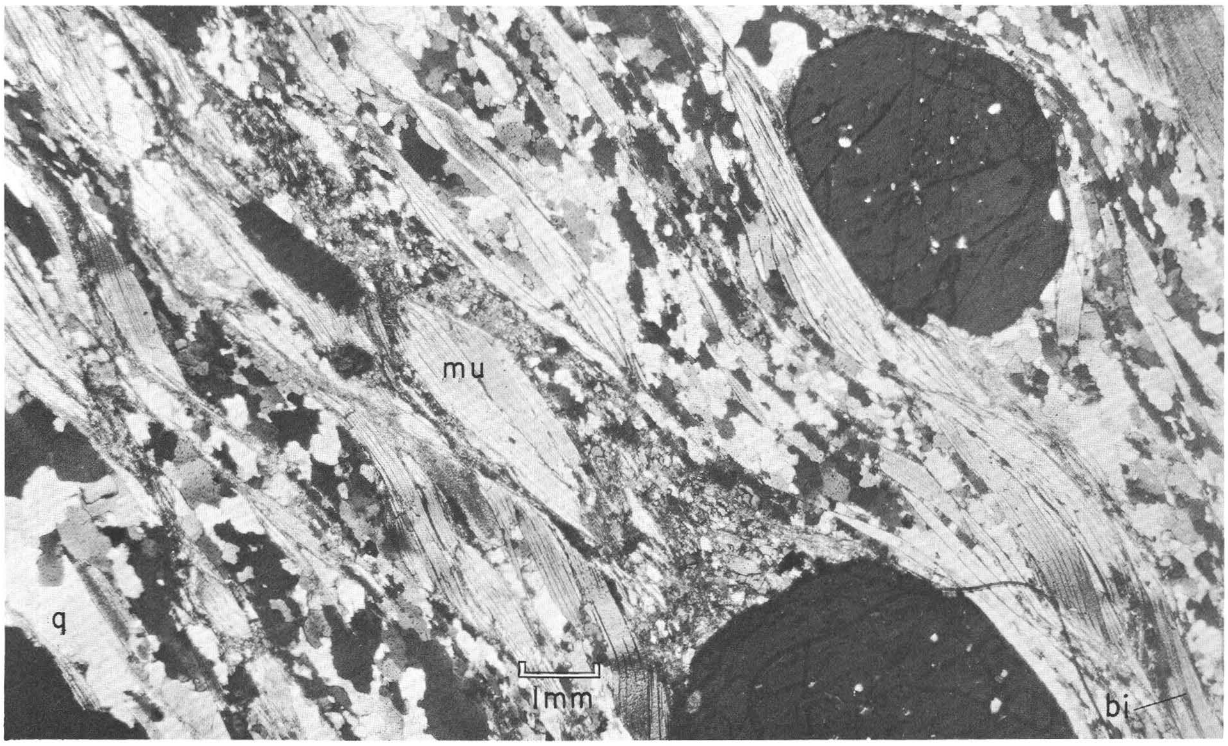

FIGURE 2.—Photomicrograph of a common type of schist in the Prichard formation. Contains numerous round garnet crystals embedded in laminated mica schist. The micaceous laminae contain large flakes of muscovite (mu) and small flakes of muscovite and small flakes of biotite (bi). Tiny quartz grains (q) occur in small lenticles and in thin layers. Loc. 1023, 1 mile west of Orphan Point. Crossed nicols.

sillimanite schist and anorthosite (table 2, column 3). The fine-grained gray beds of biotite quartzite on the south side are stratigraphically above the coarse-grained lime-silicate rocks. Thus, these calcareous layers apparently substitute for the coarse-grained white quartzite, which elsewhere is beneath the fine-grained gray beds of this quartzite unit (compare columns 2 and 3 in table 2). Farther to the west, between Cedar Creek and Stocking Meadow Lookout, the lime-silicate rocks are interbedded with layers of coarse-grained fairly pure quartzite and fine-grained biotite-rich quartzite which are similar to the corresponding quartzite layers between Big Talk Lake and Crescendo Peak and probably belong at the same stratigraphic horizon. Near Stocking Meadow Lookout diopside-plagioclase-phlogopite rock, tremolite quartzite, and a thick layer of pure quartzite are exposed along the road leading from Boehls to Goat Mountain and along the road leading to the lookout.

The fine-grained dark graphite-bearing quartzite extends from the mouth of Cedar Creek westward and forms steep outcrops along the Little North Fork of the Clearwater River. Three miles east of Boehls a layer of biotite gneiss with abundant large anthophyllite prisms and huge garnet crystals, a kyanite-andalusite-sillimanite-cordierite gneiss, and anorthosite are exposed under this quartzite.

Synclinal structure on Smith Ridge suggests that this rock series is the same as is exposed along the south slope of Smith Ridge (table 2, column 4). However, only two rather thin layers of quartzite, the upper one rich in biotite, are exposed above the kyanite-andalusite-sillimanite schist on the south slope of Smith Ridge. The uppermost part of the section there consists of coarse-grained garnetiferous biotite-muscovite schist interbedded with amphibolite and dark fine-grained biotite quartzite or biotite schist. The lowest 180 meters of the section consist of kyanite-andalusite-sillimanite schist interbedded with quartzitic layers rich in tremolite, actinolite, or diopside and containing a considerable amount of calcic plagioclase. This sequence overlies an anorthosite which locally shows a distinct layering. A similar aluminous schist with tremolite- or actinolite-bearing layers is exposed north and south of the anorthosite at Stocking Meadows where also it overlies a layered anorthosite.

PETROGRAPHY

The schist between the lower and upper quartzite units and that above the upper unit are much alike, consisting of a common garnet-mica schist, whereas the schist under the lower quartzite unit is exceptionally rich in aluminum silicates.

GARNET MICA SCHIST

The most common variety of schist in the middle and upper parts of the Prichard formation is coarse grained and contains abundant flakes of muscovite and biotite

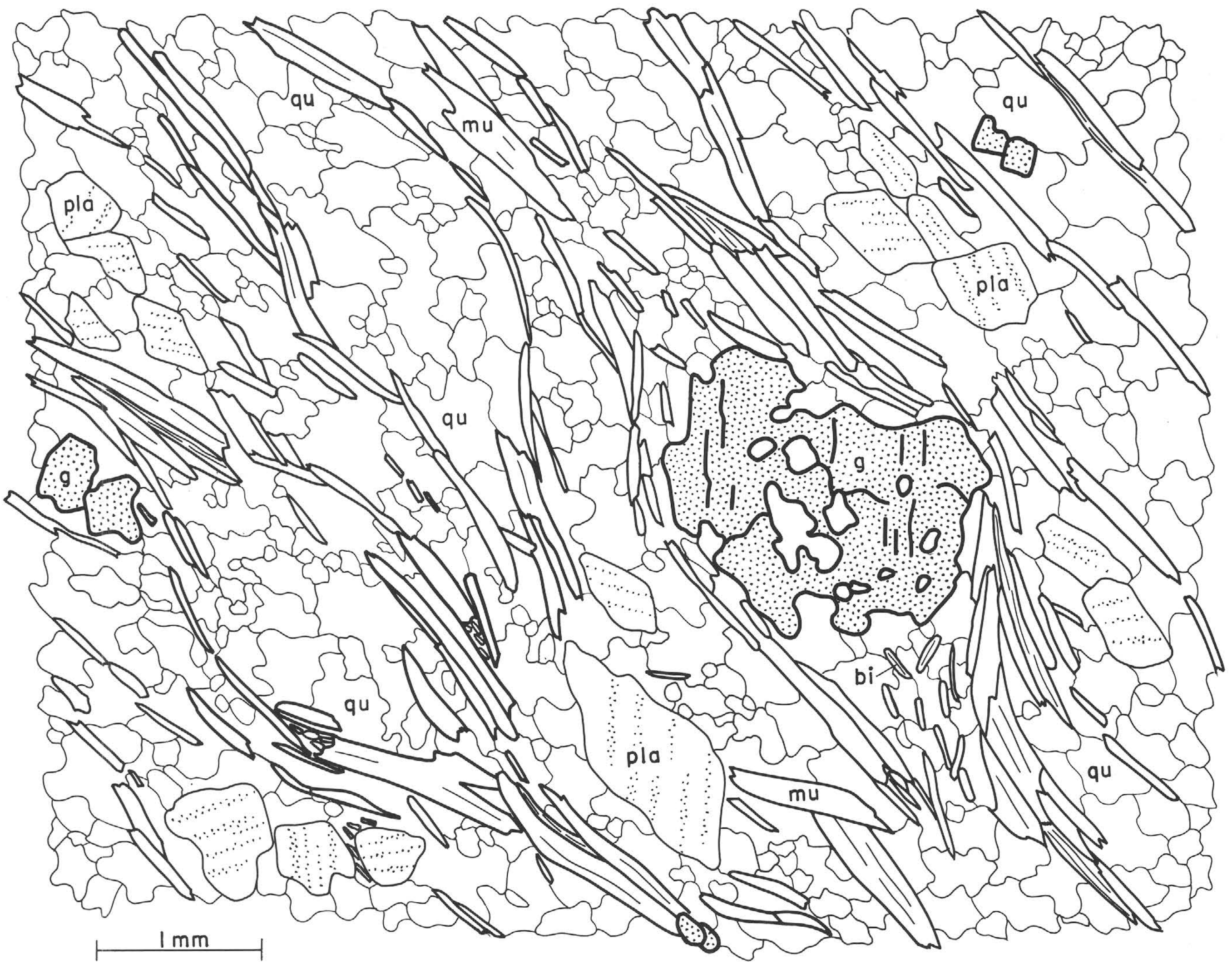

FIGURE 3.—A camera lucida drawing from a common type of garnet-mica schist in the Prichard formation shows subhedral to anhedral garnet (g), muscovite (mu), biotite (bi), quartz (qu), and plagioclase (pla). Anhedral quartz grains with irregular borders occur in small lens-shaped aggregates and in thin layers. Laminae of mica flakes separate these layers and curve around the aggregates of quartz and grains of garnet. Plagioclase (pla) occurs sparingly with quartz. One mile west of Orphan Point (loc. 1023)

2 to 3 mm in diameter, which lend a glittering bronze luster to the cleavage planes of weathered rock. The fresh rock is medium gray and hard. Most of the schist contains garnet crystals in varying sizes and amounts. In the upper part of the formation garnet crystals abound but are rather small, ranging from 2 to 5 mm in diameter. In the middle part of the formation, most garnet crystals are about 5 mm in diameter, but locally they measure as much as 15 cm in diameter; for example, near Twin Springs Creek, east of Freezeout Lookout, and along the Little North Fork of the Clearwater River about a mile southwest of the mouth of Cedar Creek.

Microscopic study shows that in the middle schist unit exposed in the extreme northwestern corner of the area, the muscovite is far more abundant than the biotite, whereas toward the south, near the southern border of Shoshone County, the amount of biotite usually exceeds that of muscovite. In the northwestern part of the area, the common mica schist is strongly sheared (fig. 2). Small lens-shaped mosaic aggregates and discontinuous layers that are 0.1 to 1 mm thick and that consist of small strained grains of quartz and larger grains of plagioclase are enveloped by large sheared flakes of muscovite that converge at either end of the aggregate. The muscovite flakes are bent, showing slight strain shadows under crossed nicols. Biotite occurs as flakes of medium size either interleaved with muscovite or as small flakes oriented at random along the shear zones and on small areas at either end of the large muscovite flakes. Muscovite flakes also envelope the garnet crystals which are slightly elongated parallel to the schistosity, and include small round grains of quartz and magnetite (fig. 3). Many garnet crystals show well-developed dodecahedral faces. Small flakes of biotite and grains of quartz fill the wedge-shaped areas at either end of elongated garnet crystals. These flakes of biotite butt against the garnet but muscovite flakes bend around the garnet and are thus earlier. The ends of some elongated garnet crystals are altered to chlorite. The chlorite flakes are subparallel to the grain boundary of the garnet, and thus about at right angles to the small flakes of biotite. Locally, abudant magnetite occurs as thin films along the cleavage in the muscovite and also as irregularly shaped grains between the other minerals. Ilmenite scales abound in some layers and tourmaline in others. Zircon occurs in subhedral grains that have rounded corners and that measure 0.1 to 0.4 mm in diameter.

As a rule, the layers poorer in mica are finer grained. In these layers the mica flakes of medium size are more evenly distributed throughout the rock and the quartz shows less tendency to occur in lens-shaped segregations. Locally, thin quartzitic layers are interbedded with the schist. A considerable amount of biotite occurs in these layers and there is every gradation from the quartzite to the schist. The chemical composition of a common type of mica schist calculated from a modal analysis is shown in table 5, locality 1023. This analysis shows it to be a metamorphosed equivalent of a common argillite.

The schist of the middle part of the Prichard formation that is exposed above the anorthosite in the central part of the area, on Smith Ridge, and along the Little North Fork of the Clearwater River, is much coarser grained and contains less muscovite than its equivalent in the northwestern part of the area. This change in texture and mineral content indicates an increase in the degree of metamorphism toward the south. In the schist on Smith Ridge thin layers of fine-grained biotite-plagioclase schist are interbedded with coarse-grained biotite-muscovite-plagioclase schist. Abundant ilmenite and zircon occur as accessory minerals in all layers. Plagioclase (An_{38}) forms about 30 percent of the rock and occurs as large- to medium-sized grains embedded in granulated quartz and micaceous minerals. In the mica-rich beds, micas occur in thin laminae between layers, 1 to 3 mm thick, that consist of plagioclase (An_{38}) and quartz. A similar thin lamination was found in some beds of the Prichard formation along Sawtooth Creek under the upper quartzite unit just east of the northeast corner of the mapped area. There the lamination seems to be a primary feature due to deposition, whereas on Smith Ridge its more irregular magnitude and distribution suggest that the depositional feature was accentuated during the metamorphism by segregation of micaceous minerals and quartzo-feldspathic material into separate thin layers. This suggestion is strengthened by the fact that at a lower altitude, along the Little North Fork of the Clearwater River, a similar segregation took a coarser form leading in places to formation of veined gneisses, in which the quartzo-feldspathic veins range from 2 mm to 10 cm in thickness.

In the gneiss exposed in a roadcut 1 mile west of the mouth of Cedar Creek, huge garnet crystals and long anthophyllite prisms were found in some intensely recrystallized layers. In one layer, the garnets are as much as 15 cm in diameter and most are enveloped by biotite and anthophyllite. At the same locality, in the lowest part of the roadcut, garnet-biotite-anthophyllite (gedrite) rock is exposed (fig. 4). In this rock the garnet crystals range from 0.2 to 3 cm in diameter and the anthophyllite prisms are 0.5 to 1 cm long. Some plagioclase and quartz are between the dark constituents (fig. 5); and rutile, magnetite, and apatite are the common accessories. The garnet and the amphibole were separated from the coarse-grained gneissic layer and studied in detail.

The amphibole prisms are 2 to 5 cm long and dark green in hand specimen. Under the microscope they show a parallel extinction and a weak pleochroism γ=light bluish green, β=light yellowish green, α=colorless. The indices of refraction measured in immersion liquids are $\alpha=1.652\pm0.001$, $\beta=1.659\pm0.001$, $\gamma=1.671\pm0.001$, $\gamma-\alpha=0.019$ (when the right liquid was found,

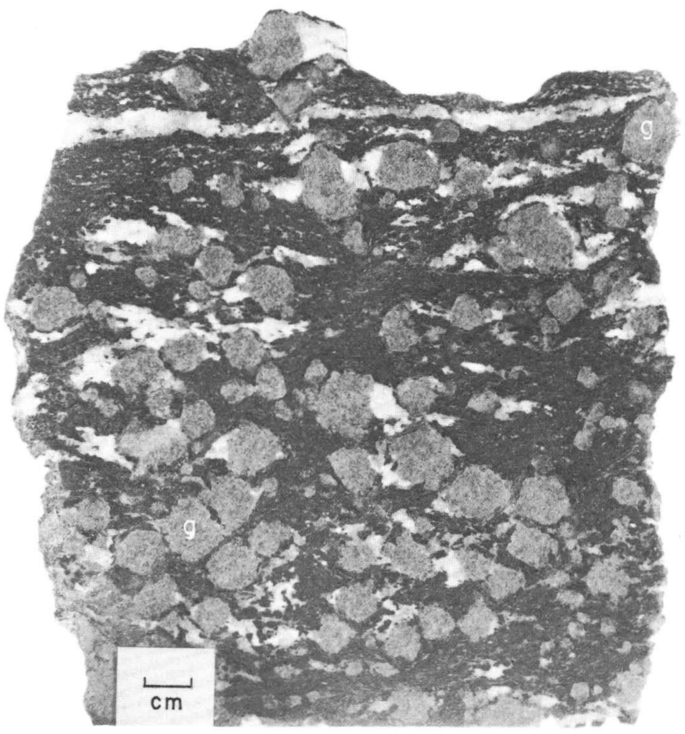

FIGURE 4.—A specimen of a coarse-grained garnet-gedrite-biotite rock with numerous round garnet crystals (g). The black parts are rich in gedrite and biotite; white is plagioclase and quartz. One mile west of the mouth of Cedar Creek (loc. 1227).

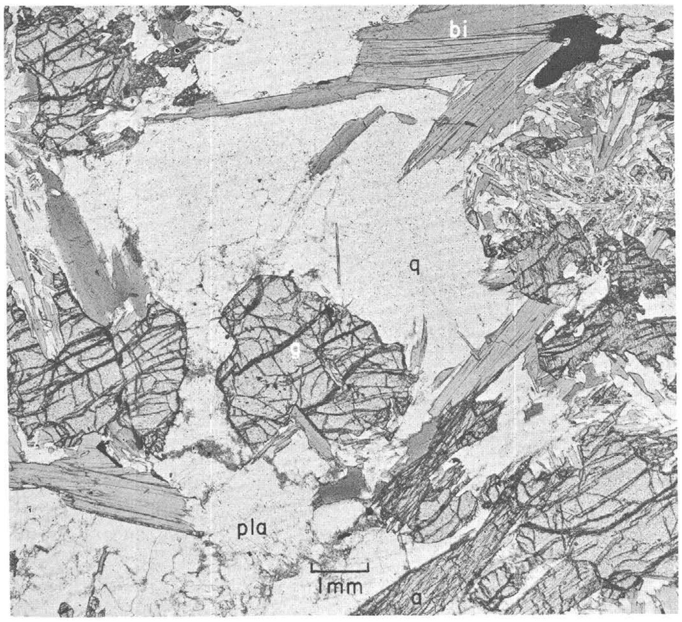

FIGURE 5.—Photomicrograph of a thin section made of the specimen shown in fig. 4. The constituent minerals are large garnets (g), euhedral to subhedral aluminous anthophyllite (a), quartz (q), plagioclase (pla), and biotite (bi). Plane-polarized light. (Loc. 1227.)

it was immediately measured by Abbé refractometer in order to avoid the influence of change of temperature). This mineral was separated by Richard P. Marquiss, U.S. Geological Survey, and a fraction with the specific gravity of 3.17±0.02 was analyzed chemically (table 3). The analyzed material contained a few tiny grains of quartz and rutile.

TABLE 3.—*Chemical analysis of an aluminous anthophyllite (gedrite) from garnet-biotite gneiss of the Prichard formation, 1 mile west of the mouth of Cedar Creek on Little North Fork of Clearwater River (loc. 1227)*

[Analyst, L. N. Tarrant, U.S. Geol. Survey]

Constituents	Weight percent	Molecular equivalent	Number of atoms		
SiO_2	46. 87	7804	Si	6. 74	8. 00
Al_2O_3	12. 11	1188	Al	1. 26	
Fe_2O_3	1. 04	65	Al	. 79	. 90
FeO	18. 20	2533	Fe^{+3}	. 11	
MnO	. 18	25	Fe^{+2}	2. 19	5. 91
MgO	17. 14	4251	Mn	. 02	
CaO	. 50	89	Mg	3. 67	
Na_2O	1. 08	174	P	. 00	
K_2O	. 10	11	Ti	. 03	
TiO_2	. 30	38	Ca	. 08	. 40
P_2O_5	. 01	1	Na	. 30	
F	. 10	53	K	. 02	
H_2O+	2. 19	1216	F	. 05	2. 15
H_2O-	. 12	--------	H	2. 10	
	99. 94	--------	O	24. 00	
Less O for F	. 04	--------			
Total	99. 90	--------			
Sp gr=3.17±0.02					

Calculation of the formula from the chemical analysis (table 3) gave the following result:

$$(H_{2.10}F_{0.05})_{\Sigma=2.15}(K_{0.02}Na_{0.30}Ca_{0.08})_{\Sigma=0.4}(Mg_{3.67}Fe^{+2}_{2.19}Mn^{+2}_{0.02}Ti^{+4}_{0.03})_{\Sigma=5.91}(Al_{0.79}Fe^{+3}_{0.11})_{\Sigma=0.9}(Al_{1.26}Si_{6.74})_{\Sigma=8.0}O_{24}.$$

A considerable amount of aluminum is present and substitutes for silicon in the tetrahedral groups and for magnesium in the octahedral positions. The optical properties and the chemical composition are those typical of the aluminous anthophyllite (gedrite) with magnesium: iron=5:3 (Winchell and Winchell, 1951, p. 427).

The large garnet crystals are subhedral and contain numerous inclusions of quartz, magnetite, and biotite. The index of refraction of the garnet is n=1.784±0.003 and specific gravity is 3.80±0.02. The X-ray study made by F. Hildebrand of the U.S. Geological Survey shows that two phases of garnet are present, one having a cell dimension a_0=11.576±0.006A and the other a_0=11.557±0.006A, resembling in this respect the garnet in garnet amphibolite along Orofino Creek, about 20 miles south of Boehls (cf. Hietanen, 1962, table 13). The garnet was analyzed chemically (table 4, no. 1225) and the ratios of various compounds were calculated in molecular percents. The analyzed material contains about 1 percent impurities, mainly

TABLE 4.—*Chemical analyses and optical properties of garnets*

[Chemical analyses by Lucile N. Tarrant, U.S. Geol. Survey. Mineral separation by Richard P. Marquiss, U.S. Geol. Survey]

Locality No.	1225		1353.	
Location	Little North Fork of Clearwater River.		Two miles east of Orphan Point.	
Rock type	Garnet-anthophyllite rock.		Anorthosite.	
Constituent	Weight percent	Molecular equivalent	Weight percent	Molecular equivalent
SiO_2	38. 30	6377	38. 34	6384
Al_2O_3	21. 33	2092	21. 40	2099
Fe_2O_3	. 32	20	. 17	11
FeO	27. 79	3868	28. 33	3943
MnO	. 84	118	. 48	68
MgO	4. 59	1138	3. 37	836
CaO	6. 36	1134	7. 65	1364
Na_2O	. 04	7	. 03	5
K_2O	. 02	2	. 03	3
TiO_2	. 21	26	. 11	14
P_2O_5	. 28	20	. 01	1
H_2O+	. 05	28	. 10	55
H_2O-	. 00	-----------	. 00	-----------
Total	100. 13	-----------	100. 02	-----------
	Composition		Composition	
Pyrope	18. 15		13. 45	
Almandite	61. 73		63. 36	
Spessartite	1. 87		1. 11	
Grossularite	17. 29		21. 55	
Andradite	. 96		. 53	
a_0	11. 576±0. 006 A			
a_0'	11. 557±0. 006 A		11. 611±0. 006 A	
n	1. 784±0. 003		1. 784±0. 003	
Sp gr	3. 80 ±0. 02		3. 93 ±0. 02	

quartz, anthophyllite, rutile, and magnetite. Comparison with the analyses of garnets published earlier shows that this garnet is similar to garnet found in eclogites (Eskola, 1921) and in anorthosite (Kemp, 1921).

Some layers in the schist contain a considerable amount of plagioclase (An_{15-30}) which occurs in small grains with quartz, its compounds being in all probability sedimentary in origin. The schist west of Orphan Point contains in places abundant plagioclase which, however, differs in its mode of occurrence from the plagioclase crystallized from sedimentary material. The plagioclase-bearing layers west of Orphan Point also contain some hornblende and are in places transformed to quartz dioritic or tonalitic gneiss. The composition and mode of occurrence of this gneiss resemble those of the gneissic quartz diorite and tonalite that occur south of the area under investigation and that were found to be metasomatic in origin (Hietanen, 1962).

SCHIST RICH IN ALUMINUM SILICATES

Most of the schist under the lower quartzite unit contains aluminum silicates and plagioclase (An_{25-40}) in variable amounts. A chemical analysis (table 5, No. 1690) shows that this schist is considerably richer in aluminum, calcium, and sodium and poorer in silicon and potassium than the normal garnet mica schist (no. 1023) in the upper part of the formation. Sillimanite is the most common aluminum silicate near Floodwood Creek and around the mouth of Timber Creek (fig. 6), but abundant kyanite and andalusite occur with the sillimanite near the anorthosite bodies (pl. 1). In many places schist in a zone 200 to 500 m wide next to the anorthosite bodies contains 20 to 40 percent kyanite and andalusite, and 1 to 5 percent sillimanite. Schist that is exceptionally rich in aluminum silicates is generally very coarse grained, the kyanite and andalusite crystals averaging 2 to 5 cm in length and the mica flakes 3 to 8 mm in diameter. In some occurrences, however, the grain size is somewhat smaller; for example, in the staurolite-bearing schist near Timber Creek and locally in the kyanite-andalusite-sillimanite schist on the north side of the North Fork of the Clearwater River east of Larson Cabin, the crystals of aluminum silicates are only 5 to 10 mm long and the individual mica flakes 1 to 4 mm in diameter. The largest kyanite crystals are on the southeast slope of Goat Mountain, where they range from 2 or 3 cm to 30 cm in length. The mineralogy of the kyanite-andalusite-sillimanite schist has been discussed in an earlier paper (Hietanen, 1956).

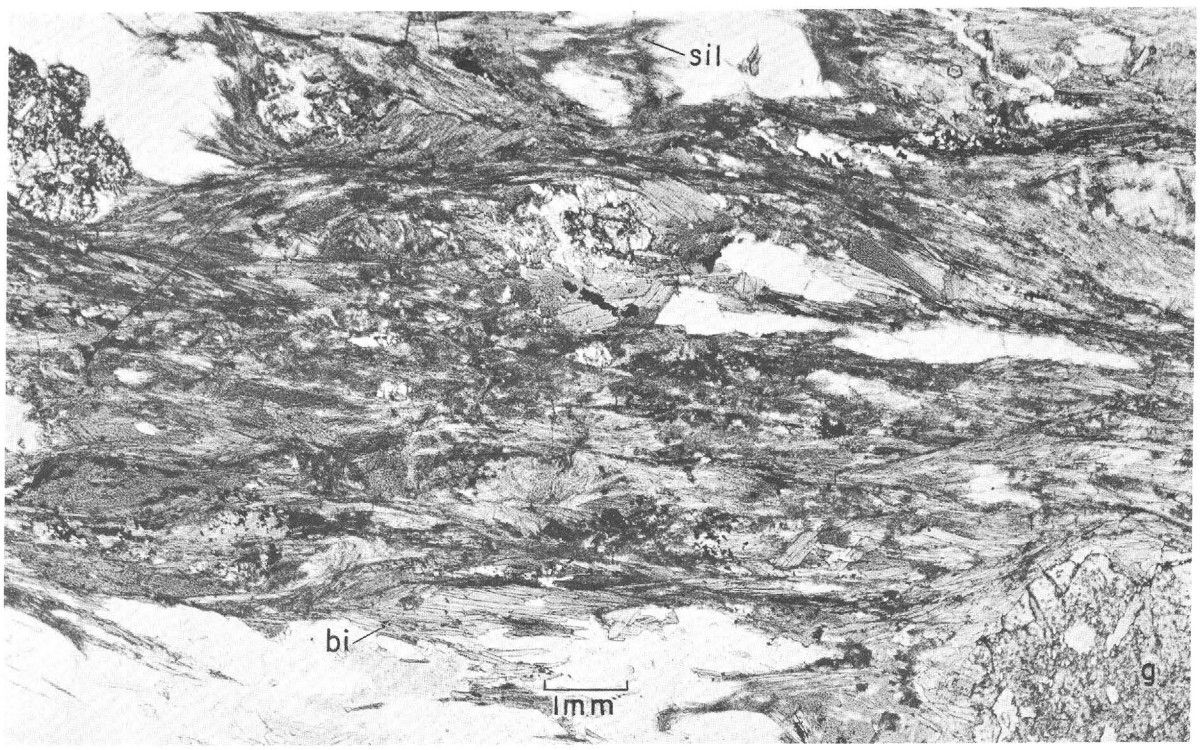

FIGURE 6.—Photomicrograph of a sillimanite-garnet-biotite schist southeast of Orphan Point (Loc. 1751 on pl. 1). A part of the biotite (bi) has been replaced by sillimanite (sil). Light-colored constituents are quartz and plagioclase. g, garnet. Plane-polarized light.

Staurolite is found only in the northwestern part of the area; toward the south its place is taken by aluminum silicates and garnet. The lowest part of the Prichard formation exposed around Floodwood Creek, Pinchot Creek, and Timber Creek generally contains some staurolite in addition to abundant sillimanite. The staurolite crystals are small, ranging mostly from 1 to 5 mm in length. Many small grains are included in biotite or in garnet, apparently forming armored relicts.

TABLE 5.—*Chemical analyses in weight and ionic percentage, molecular norms, and modes of rocks of the Prichard formation*

Locality and specimen No.	1023 [1]	1690 [2]	1234 [3]	1306 [3]	1308 [3]	1495 [3].
Rock type	Garnet-mica schist.	Sillimanite-garnet schist.	Lime-silicate rock.	Tremolite-plagioclase rock.	Diopside-plagioclase rock.	Plagioclase-phlogopite rock.
Location	One mile west of Orphan Point.	Mouth of Timber Creek.	Mouth of Cedar Creek.	South slope of Smith Ridge.	South slope of Smith Ridge.	Little North Fork Clearwater River.
Weight percent						
SiO_2	71.24	60.77	50.94	64.12	49.81	53.80
Al_2O_3	14.23	21.83	8.32	9.81	13.56	24.66
Fe_2O_3	.39	.89	.35	.24	.31	.45
FeO	6.13	6.39	2.76	2.36	4.06	.72
MnO	.14	.10	.07	.07	.12	.02
MgO	1.88	1.25	8.34	10.67	8.10	3.89
CaO	.51	1.88	21.22	9.78	21.88	6.61
Na_2O	.54	1.06	.76	.77	.59	4.69
K_2O	3.07	2.99	.57	.19	.06	2.75
TiO_2	.10	.78	.29	.35	.58	.24
P_2O_5		.06	.08	.09	.26	.05
CO_2		.01	3.65	.02	.07	.01
F						.11
S			.90			
C			1.67			.80
H_2O+	1.66	1.43	.35	1.22	.68	.98
H_2O-	.11	.16	.05	.12	.07	.17
Subtotal			100.32			99.95
Less O			.45			.05
Total	100.00	99.60	99.87	99.81	100.15	99.90
Cation percent						
SiO_2	69.87	59.02	48.06	60.33	46.56	49.12
$AlO_{3/2}$	16.45	24.98	9.25	10.88	14.93	26.53
$FeO_{3/2}$	.29	.65	.25	.17	.21	.31
FeO	5.02	5.19	2.18	1.77	3.17	.55
MnO	.12	.08	.06	.06	.10	.02
MgO	2.76	1.81	11.72	14.95	11.28	5.29
CaO	.53	1.95	21.45	9.86	21.90	6.47
$NaO_{1/2}$	1.03	1.99	1.39	1.40	1.07	8.30
$KO_{1/2}$	3.85	3.70	.68	.23	.07	3.20
TiO_2	.08	.57	.20	.25	.41	.16
$PO_{5/2}$		.05	.06	.07	.21	.04
CO_2		.01	4.70	.03	.09	.01
C			(7.88)			(3.65)
H_2O	(5.76)	(4.63)	(1.10)	(3.83)	(2.12)	(2.98)
	100.00	100.00	100.00	100.00	100.00	100.00
O	170.12	165.01	155.67	161.59	152.25	154.05
OH	11.52	9.26	2.20	7.66	4.24	5.96
F						.32
S			1.59			
Total anions	181.64	174.27	159.46	169.25	156.49	160.33
Molecular norm						
Q	46.49	32.04	8.78	24.65	0.74	
Or	19.25	18.50	3.40	1.15	.35	16.00
Ab	5.15	9.95	6.95	7.00	5.35	39.15
An	2.65	9.30	17.95	23.12	34.47	31.95
Ne						1.41
C	10.51	15.57				2.25
Wo			26.12	10.18	29.14	
En	5.52	3.62	23.44	29.90	22.56	
Fs	9.84	8.76	2.22	3.00	5.52	
Fo						7.94
Fa						.39
Ap		.13	.16	.19	.56	.11
Il	.16	1.14	.40	.50	.82	.32
Mt	.43	.97	.38	.25	.31	.46
Pr			2.39			
Cc		.02	9.40	.06	.18	.02
Total	100.00	100.00	101.59	100.00	100.00	100.00

See footnotes at end of table.

TABLE 5.—*Chemical analyses in weight and ionic percentage, molecular norms, and modes of rocks of the Prichard formation*—Continued

Locality and specimen No.	1023 [1]	1690 [2]	1234 [3]	1306 [3]	1308 [3]	1495 [3].
Rock type	Garnet-mica schist.	Sillimanite-garnet schist.	Lime-silicate rock.	Tremolite-plagioclase rock.	Diopside-plagioclase rock.	Plagioclase-phlogopite rock.
Location	One mile west of Orphan Point.	Mouth of Timber Creek.	Mouth of Cedar Creek.	South slope of Smith Ridge.	South slope of Smith Ridge.	Little North Fork Clearwater River.
Molecular mode calculated from cation percent [4] (measured)						
Quartz	(51.0)	29.56	8.78	23.90	0.39	
Plagioclase		An_{46} 18.50	An_{72} 24.90	An_{79} 21.20	An_{86} 40.17	An_{44} 73.5
Orthoclase		10.80	3.40	.45		7.7
Muscovite	(26.0)					
Biotite	(9.4)	14.89				22.6
Chlorite	(1.2)					
Garnet	(12.1)	8.56				
Diopside			51.78		57.56	
Tremolite				57.26		
Sillimanite		19.07				
Apatite		.13	.16	.19	.56	
Sphene				.54	.72	
Ilmenite		1.00	.40		.11	.3
Magnetite	(0.3)	.45	.38	.57	.31	.6
Pyrite			2.39			
Calcite			9.40	.06	.18	
Graphite			7.88			
Total	100.0	102.96	109.47	104.17	100.00	104.7

[1] Weight percent calculated from measured mode.
[2] Analyst, Faye H. Neuerburg, U.S. Geol. Survey.
[3] Analysts, M. Balazs and Lucile N. Tarrant, U.S. Geol. Survey.
[4] Molecular mode is received directly from cation percentage by simple regrouping of the cations and anions to form minerals found in the thin sections. The optical properties and chemical analyses of the minerals are used as a guide to their formula. The excess over 100 in totals shows the number of anions (OH, F, S, C) used in calculation.

Sillimanite is the most common aluminum silicate in this lowest part of the Prichard formation. It occurs as fine needles and as brownish nodules which show irregular parting and contain small brown patches of biotite. The nodules are commonly embedded in biotite, and abundant fine needles of sillimanite transect the biotite flakes. It is apparent that sillimanite crystallized from the biotite. The first sign of this replacement is a much lighter color of the biotite that contains sillimanite needles. Thin sections show every gradation from the biotite schist without sillimanite to sillimanite schist with remnants of biotite. Apparently the recrystallized sillimanite used the aluminum and silicon contained in biotite, but the other elements of biotite—potassium, magnesium and most of the iron—migrated to the country rocks to form more biotite there. Muscovite occurs with biotite, but its amount is less than in garnet-mica schist of the upper part of the formation. In some layers of sillimanite schist along Floodwood Creek it is scarce or absent.

Cordierite abounds in a few layers on Smith Ridge and along the Little North Fork of the Clearwater River, but is scarce in the northern part of the area. In the southern part some layers may contain more than 37 percent cordierite (Hietanen, 1956, table 3), raising the percentage of magnesium abnormally high for an aluminous sedimentary rock.

On the south slope of Smith Ridge the layer of kyanite-andalusite-sillimanite schist that is exposed just above the anorthosite is considerably richer in biotite than the other schist layers. Since biotite is the only ferromagnesian mineral present and it is a magnesium-rich variety, this layer is rich in magnesium. Biotite rather than cordierite crystallized in it because sufficient potassium was present. An exceptionally large amount of biotite in the schist near its contact with the anorthosite also occurs in several localities near Goat Mountain and along the Little North Fork of the Clearwater River. Locally the biotite was segregated into discontinuous layers and lens-shaped bodies that range from 5 to 50 cm in thickness. Biotite in such segregations occurs in flakes that range from 5 to 15 mm in diameter. Small flakes of greenish soft muscovite and some white grains of andesine usually are embedded between the biotite flakes.

Garnet in round to subhedral crystals, which are 2 to 10 mm in diameter, is common in the schist rich in aluminum silicates. In most layers the amount of this mineral ranges from 2 percent to about 20 percent. Some outcrops near the anorthosite bodies contain many large garnet crystals; for example, anhedral crystals that include abundant kyanite and quartz and measure as much as 12 cm in diameter constitute about 15 percent of the schist and plagioclase-rich contact rock south of Monumental Buttes. On the south slope of Goat Mountain sporadic crystals that range from 3 to 5 cm in diameter are sparsely distributed throughout a coarse-grained plagioclase-biotite-kyanite rock. These large garnet crystals are 24 to 30 cm apart and the matrix next to them is free from biotite, indicating that iron and magnesium from the surrounding matrix joined the garnet.

QUARTZITE UNITS

The lower part of the upper quartzite unit of the Prichard formation consists of thick beds of white to light-gray coarse- to medium-grained quartzite. Many of the white beds ranging from 10 to 30 cm in thickness are almost pure quartz and have only a few muscovite and graphite flakes along their bedding planes. The texture seems crudely granular through a hand lens, but an examination under the microscope shows that quartz grains are recrystallized and have sutured borders, and that small interstitial grains occur between the larger ones. In most beds the grains are elongate parallel to the lineation. Layers that contain more mica and some garnet are interbedded with these beds of pure quartz. In many localities, for example, on Widow Mountain, large red garnet crystals or groups of crystals abound and appear spectacular against the light-gray quartzite, because on the bedding planes they are drawn out to long spindles parallel to the lineation. Numerous large garnet crystals were also found in coarse-grained white to gray muscovite-bearing quartzite southwest of Buzzard Roost. The garnet crystals there are strongly flattened but appear almost equidimensional along the bedding planes. The quartz grains show a similar deformation. Most of the muscovite is concentrated into thin laminae, but some scattered grains that transect the grain boundaries occur in the beds of pure quartz.

The white quartzite on Stubtoe Peak is similar to that near Buzzard Roost except that no garnet was found in the beds exposed and that the quartz grains and muscovite flakes show a strong elongation parallel to the lineation. The quartzite on the northeast side of the Little North Fork is fairly coarse grained, has a granular texture as most of the quartzite in the Prichard formation, and contains a considerable amount of muscovite.

The dark-gray fine-grained biotite quartzite that overlies the white and light-gray quartzite on Widow Mountain is thin-bedded and contains biotite-rich laminae and layers of garnet-mica schist.

Many layers of the lower quartzite unit resemble the rock types of the upper unit. There are, however, enough differences in the appearance, sequence, and thickness of the individual layers to make distinction between the two units possible. In the northern part of the area, coarse-grained white granular quartzite of the lower unit is overlain by a much thicker layer of thin-bedded gray micaceous quartzite than that found in the upper unit, and the coarse-grained garnetiferous gray beds are missing. Toward the south, lime-silicate rocks substitute for the coarse-grained white quartzite of the lower unit in increasing quantitites.

Most beds of the white quartzite that forms the bottom of the lower quartzite unit in the vicinity of Monumental Buttes and Goat Mountain have a light-brownish hue and contain less muscovite than the white quartzite of the upper unit. Some biotite occurs in this quartzite near Monumental Buttes and its amount increases toward Goat Mountain and Crescendo Peak. The individual beds of fairly pure quartz range from 10 to 50 cm in thickness and are separated by micaceous layers 2 to 10 mm thick. The grains are 0.1 to 10 mm in diameter, have sutured borders, and strong strain shadows are seen under the microscope.

The thin-bedded dark-gray quartzite that overlies the white and coarse-grained light-gray quartzite layers of the lower unit is fine grained and contains a considerable amount of biotite. The thickness of the individual beds ranges from a few millimeters to several centimeters. Microscopic study shows that quartz in this fine-grained gray quartzite occurs in small round or polygonal grains, with biotite filling the interstices. Sphene, small grains of magnetite, graphite, and zircon are common accessories. Some beds south of Big Talk Lake contain scapolite, actinolite, and diopside. Scapolite occurs in small round grains with quartz, whereas actinolite and diopside form large holoblasts that include numerous round quartz grains. Under the microscope the actinolite is yellowish, shows no pleochroism, and has $\alpha=1.615\pm0.001$ and $\gamma=1.638\pm0.001$. Also the orthoclase forms large grains which contain many small round quartz inclusions.

The lime-silicate-bearing layers that were found about half a mile west and south of Crescendo Peak are rather thin (1–5 cm thick) and are interbedded with coarse-grained pure quartzite. A thin layer containing tremolite and diopside was also found in the lower quartzite unit 1½ miles south of Orphan Point. A layer of light-gray fine-grained quartzite with tremolite, zoisite, muscovite, and graphite was found interbedded in biotite-plagioclase schist on Buzzard Roost. The colorless tremolite prisms of this layer are oriented at random. Abundant graphite in small flakes and some plagioclase occur as additional constituents. The scarcity of lime-silicate minerals and scapolite in the northern part of the area suggests that very little calcareous material was deposited there with the quartz-rich sediment.

The quartzite at Stocking Meadow Lookout is fine to medium grained, light bluish gray, and contains some small biotite flakes. A thick layer of quartzite exposed along Twin Springs Creek west of Pinchot Butte and a layer south of Orphan Point are coarse to medium grained, light gray, well foliated, and contain some muscovite and biotite. Quartzite beds at higher altitudes on Pinchot Butte are dark-gray, fine-grained, thin-bedded, and rich in biotite. They are petrographically similar to the fine-grained gray beds above

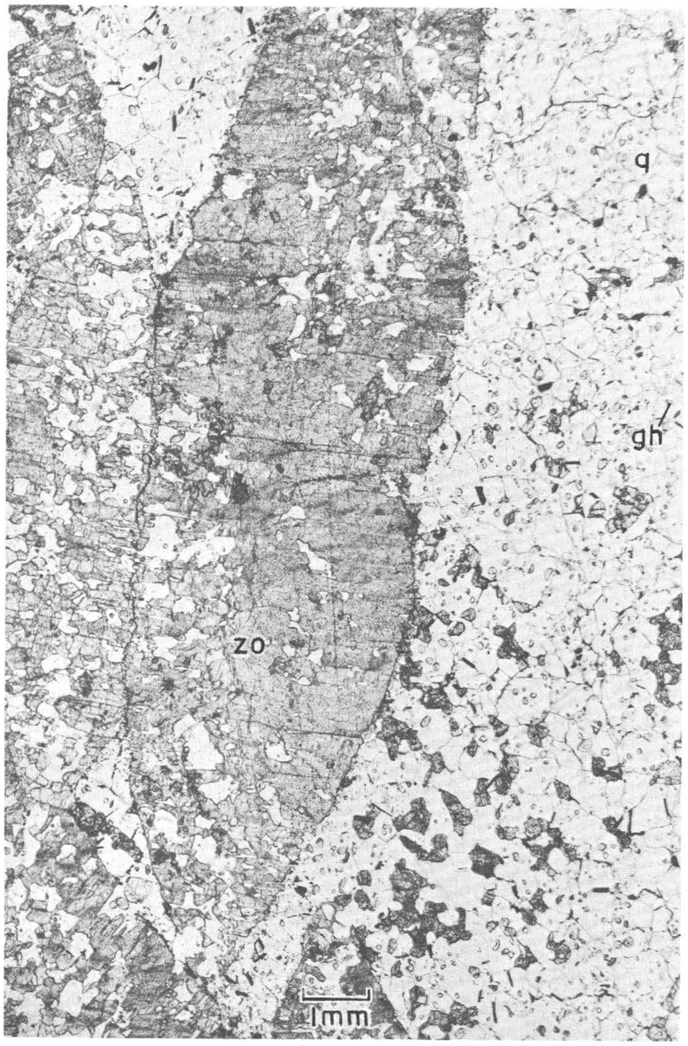

FIGURE 7.—Photomicrograph of large zoisite (zo) prisms in fine-grained graphite-bearing quartzite. Includes numerous small grains of quartz. gh, graphite; q, quartz. Location 1386, about 1¾ miles north-northwest of Pinchot Butte. Plane polarized light.

the white and gray quartzite near Monumental Buttes.

A layer exposed on the southwest side of Twin Springs Creek about 1½ miles southwest of Pinchot Butte consists of fine-grained gray quartzite overlain by a layer of coarse-grained white quartzite, 6 m thick. Both layers are schistose and contain biotite and muscovite. In the upper layer biotite flakes, 1 to 3 mm long, are evenly distributed throughout the rock. A layer of garnetiferous mica schist separates the two quartzite layers, and a thin layer of amphibolite is included in the lower quartzite layer. Quartzite exposed on Stony Creek is white to very light gray and contains some muscovite and scattered flakes of biotite.

Layers of biotite-bearing quartzite, only a few meters in thickness, were found at several localities. Some thin beds in these layers contain abundant diopside or actinolite; for example, a layer of quartzite exposed on the northern border of Clearwater County along the road leading from Boehls to Freezeout Lookout, another layer along Floodwood Creek, and still another exposed on the the ridge north of Pinchot Butte (pl. 1). A thin layer of quartzite occurs between anorthosite and amphibolite about a mile east of Orphan Point. This quartzite is fine to medium grained and well foliated and contains diopside and scapolite as additional constituents. Magnetite, apatite, and sphene occur as accessory minerals.

A zoisite-bearing quartzite with an exceptional texture was found on the ridge north of Pinchot Butte and another layer near Getaway Point. Both layers occur in the schist overlying the lower quartzite unit. Zoisite forms long, light-gray prisms, which are oriented at random in a fine-grained dark graphite-bearing quartzite (fig. 7). Study under the microscope shows that the zoisite prisms contain numerous round quartz inclusions, and that some diopside, hornblende, and garnet, occur as additional constituents in the layer north of Pinchot Butte and garnet in that near Getaway Point.

Small blocks of another rare type of rock were found east of the mouth of Salmon Creek on the north side of North Fork of the Clearwater River (loc. 1381). This rock is greenish blue-gray, fine grained, and weathers readily to a sandy material. About 75 percent of this rock is tourmaline ($\epsilon=1.620\pm0.005$ and $\omega=1.640\pm0.005$) and about 25 percent quartz. A few tiny muscovite flakes are the only additional constituents.

LIME-SILICATE ROCKS

The rocks rich in lime-silicates are bluish green or green and coarse to medium grained. Minerals in most layers are oriented at random, but in some they show a subparallel orientation that lends a gneissic appearance to the rock. A thickness of about 470 m of lime-silicate rocks is well exposed along the lower drainage of Cedar Creek. Coarse-grained layers there are distinctly bedded, the dark-bluish or greenish beds alternating with the light-colored ones. The thickness of the individual beds ranges from 2 to 50 cm.

Microscopic study shows that the darker layers are rich in diopside or in actinolite, whereas the light-colored layers contain more plagioclase. Layers with a bluish tint are generally rich in diopside and those with a greenish tint rich in actinolite. Some layers consist of about 70 percent diopside with plagioclase, quartz, scapolite, and calcite in varying amounts. Some other layers are rich in quartz and contain plagioclase, diopside, and tremolite in lesser quantities. Tremolite in some of these quartzose layers forms large holoblasts that include numerous round small quartz and plagioclase grains. In some other layers quartz occurs as medium-sized rounded grains with the other minerals—

calcic plagioclase (An_{85}), diopside, and actinolite—filling the interstices. However, this texture is rare. Most layers are fully granoblastic, the dark minerals show a tendency to form larger crystals, and the plagioclase is more sodic.

Diopside in this common type of lime-silicate rock has the indices of refraction $\alpha=1.670\pm0.001$, $\beta=1.676\pm0.001$, $\gamma=1.697\pm0.001$ being thus rich in magnesium. Many sections parallel to the long dimension of the prisms show polysynthetic twinning. The actinolite has $\alpha'=1.634\pm0.001$ and $\gamma'=1.653\pm0.001$ which suggest that it contains about 24 percent iron end-member. The indices of refraction of scapolite, $\epsilon=1.551\pm0.001$, $\omega=1.581\pm0.001$, indicate it to be $Ma_{40}Me_{60}$ (Winchell and Winchell, 1951, p. 353). Several scapolite grains include rods of quartz, their texture resembling that of myrmekite. Plagioclase is oligoclase An_{25-30}. A few grains of uniaxial positive åkermannite with low interference colors were found in some sections.

A chemical analysis of a typical layer in the lime-silicate rock is shown in table 5, no. 1234. This layer is rich in calcium, contains a considerable amount of aluminum and magnesium, and thus has a composition of a shaly limestone. The aluminum is contained mainly in plagioclase which constitutes about 25 percent of the rock.

A lenticular mass rich in calcite was found interbedded with the lime-silicate rocks about a mile north of the mouth of Cedar Creek. Farther north several very hard light-gray layers are interbedded with actinolite rocks. These layers are rich in plagioclase (An_{80-94}) and quartz and contain diopside, grossularite, prehnite, clinozoisite, tremolite, graphite, pyrrhotite, magnetite, sphene, rutile, and hematite. Diopside has $\alpha=1.676\pm0.001$, $\beta=1.680\pm0.001$, $\gamma=1.702\pm0.001$, which indicate that it contains about 15 percent hedenbergite. Yellowish prehnite with $\alpha=1.611\pm0.001$, $\beta=1.621\pm0.001$, $\gamma=1.638\pm0.001$, $+2V\sim75°$ was found as cavity filling in several specimens. Many tabular crystals of prehnite are covered by fine needles of tremolite with $\gamma=1.633\pm0.001$ and $Z\wedge c=12°$. The index of refraction of grossularite varies around $n=1.74$. Scapolite and phlogopite are common in calcite-bearing layers. Wollastonite was found only in one thin-section studied.

Toward the east the sequence that is exposed along Cedar Creek is interrupted by an intrusive gabbro, but the lime-silicate rocks exposed east of the gabbro have the same stratigraphic position. However, these rocks are finer grained and are interbedded with dark-gray fine-grained biotite quartzite. A few layers, 3 to 5 cm thick, consisting of pure coarse-grained calcite are also interbedded. Many samples collected along the Little North Fork of the Clearwater River, 2 miles east of the mouth of Cedar Creek, contain abundant diopside in round or oval holoblasts which are 5 to 12 mm in diameter. The indices of refraction of the diopside $\alpha=1.667\pm0.001$, $\beta=1.674\pm0.001$ and $\gamma=1.696\pm0.001$ indicate that it is an almost pure magnesium member. The main part of the rock is fine-grained biotite-tremolite-quartz rock. Microscopic study shows that the biotite is very light brown and has $2V=0$ and the indices of refraction $\beta=1.590\pm0.001$ and $\gamma=1.591\pm0.001$, being thus a member of the phlogopite-eastonite series.

One of the samples collected from a plagioclase-phlogopite layer along the Little North Fork of the Clearwater River 2 miles east of the mouth of Cedar Creek contains oval aggregates of plagioclase surrounded by thin shells of orthoclase (fig. 8). On the polished surface many of these aggregates show an asymmetric concentric structure resembling that of brachiopods. Microscopic study shows that the rock is completely recrystallized to form a fine-grained granoblastic graphite-bearing plagioclase-phlogopite

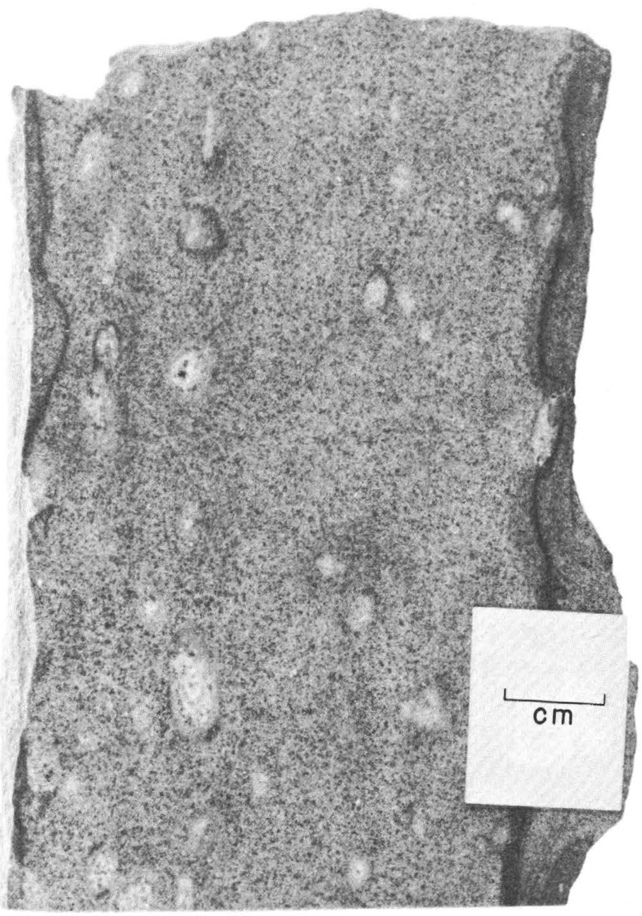

FIGURE 8.—A specimen of a fine-grained phlogopite-andesine rock with light-colored oval areas shelled by orthoclase. Loc. 1495 along the Little North Fork of the Clearwater River about 2 miles east of the mouth of Cedar Creek.

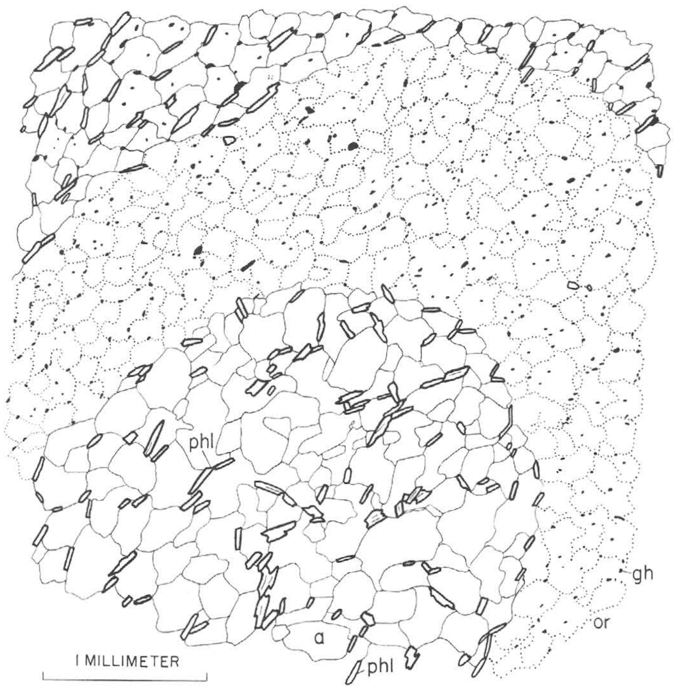

FIGURE 9.—A camera lucida drawing of an end of a nodule shelled by orthoclase from the phlogopite-andesine rock along the Little North Fork of the Clearwater River 2 miles east of the mouth of Cedar Creek (loc. 1495). The center of the nodule (lower center of the figure) is free of graphite that abounds elsewhere in the rock (small black spots). The orthoclase shell (or) is about 1 mm thick along the long sides of the oval nodules and about 1½ mm at the ends. a, andesine; phl, phlogopite; gh, graphite.

rock (fig. 9). The aggregates consist of the same minerals as the main part of the rock except that there is no graphite in them. The shells consist of small grains of orthoclase with $\alpha=1.519\pm0.001$, $\beta=1.523\pm0.001$, $\gamma=1.525\pm0.001$, and tiny flakes of graphite. There is no microstructure that would prove whether these shelled aggregates are remnants of fossils or products of some mechanism such as rolling during the sedimentation. The fact that the main part of the rock contains only a little orthoclase makes the orthoclase shells seem more problematic. Chemical analysis (table 5, no. 1495) shows that this layer is rich in aluminum and contains considerably more calcium and sodium and less silicon than the normal quartzite; magnesium dominates greatly over the iron.

Plagioclase (An_{48}) in this layer crystallized from sedimentary material. It occurs in small granoblastic grains and there are no signs of metasomatic action in any of the fine-grained quartzite layers with which this layer is interbedded. The fine-grained dark biotite quartzite layers are similar to the gray biotite-rich layers in the upper part of the lower quartzite unit of the Prichard formation elsewhere and they are continuous with the quartzite layers on Crescendo Peak. The thin amphibole-bearing layers and the marble layers that are interbedded with the biotite quartzite in this locality prove that some calcareous material was deposited with the shaly sand.

Layers rich in amphibole (hornblende, or tremolite, or actinolite) are interbedded with schist and quartzite on south slope of Smith Ridge and along the Little North Fork of the Clearwater River. From the Little North Fork this sequence extends westward to the area north of Boehls and to the vicinity of Stocking Meadow Lookout. On the south slope of Smith Ridge the tremolite- and actinolite-bearing rocks are interbedded with kyanite-andalusite-sillimanite schist and include only a few rather thin biotite quartzite layers. The hornblende-bearing layers are interbedded with biotite quartzite and schist; they contain about 50 percent hornblende and 50 percent quartz with only very little plagioclase. In fresh hand specimen the hornblende schist appears much like the normal amphibolite, which is rich in plagioclase, but on the weathered surface the plagioclase of the amphibolite is easily distinguished from the quartz of the hornblende schist because of its white weathering. The gradational and fine-grained rocks, however, can be identified only under the microscope. The hornblende-quartz schist probably represents metamorphosed dolomitic and shaly sand layers. No tuffaceous layers have been found in the less metamorphosed equivalents of the Belt series farther north.

Mineral content of the tremolite- and actinolite-bearing layers varies from place to place. Most are rich in actinolite and calcic plagioclase (An_{90}) and contain quartz in varying amounts. Pyrrhotite and graphite are common minor constituents. The iron-to-magnesium ratio in the amphibole varies considerably. Some layers contain light-green tremolite, whereas the others are rich in dark-green actinolite. The light-green tremolite was separated from specimen 1306; a pure fraction with specific gravity of 3.033–3.060 was analyzed chemically. The result (table 6) shows that it contains only about 8 percent iron end member. Calculation to the base of O=24 gives the following formula:

$$(H_{1.66}F_{0.30})_{\Sigma=1.96}\,(Ca_{1.94}\,Na_{0.13}\,K_{0.04})_{\Sigma=2.11}\,(Mg_{4.22}\,Fe^{+2}_{0.36}\,Mn^{+2}_{0.01}\,Ti^{+4}_{0.02}\,Fe^{+3}_{0.03}\,Al_{0.37})_{\Sigma=5.01}\,(Si_{7.51}\,Al_{0.49})_{\Sigma=8.0}\,O_{24}.$$

The optical properties of this tremolite are as follows: $\alpha=0.617\pm0.001$, $\beta=1.625\pm0.001$, $\gamma=1.637\pm0.001$, $\gamma-\alpha=0.020\pm0.001$, and $\gamma\wedge c=20°$. The chemical analysis of the host rock (table 5, no. 1306) shows a larger iron-to-magnesium ratio because of the presence of magnetite.

In addition to the amphibole-bearing layers there are a few lens-shaped bodies and discontinuous layers of light-green rocks in which diopside is a main constituent.

TABLE 6.—*Chemical analysis of tremolite from tremolite-plagioclase rock no. 1306, south slope of Smith Ridge*

[Analyst, M. Balazs, U.S. Geol. Survey]

Constituents	Weight percent	Molecular equivalent	Number of atoms			Number of atoms after correction of $H_2O=1.8$ percent	
SiO_2	54.15	9019	Si	7.63	8.00	7.51	8.00
Al_2O_3	5.27	518	Al	.37		.49	
Fe_2O_3	.32	20	Al	.51	.54	.37	.40
FeO	3.13	436	Fe^{+3}	.03		.03	
MnO	.09	13	Fe^{+2}	.37	4.69	.36	4.61
MgO	20.42	5065	Mn	.01		.01	
CaO	13.10	2336	Mg	4.29		4.22	
Na_2O	.50	81	Ti	.02		.02	
K_2O	.22	23	Ca	1.98	2.16	1.94	2.11
TiO_2	.22	28	Na	.14		.13	
F	.68	358	K	.04		.04	
H_2O+	.94	522	F	.32	1.20	.30	1.96
H_2O-	.03	--------	H	.88		1.66	
			O	24.00			
Subtotal	99.07	--------					
Less O for F	.29	--------					
Total	98.78	--------					

In some lacalities these layers are interbedded with the tremolite-bearing layers, as on the south slope of Smith Ridge; in other localities they are found in the schist next to the lower quartzite unit, as on Monumental Buttes. A chemical analysis of a diopside-rich layer on the south slope of Smith Ridge (table 5, no. 1308) shows that this layer contains considerably more calcium and aluminum than the tremolite-bearing layer (no. 1306). The difference in aluminum content is due to a larger amount of plagioclase (An_{80}) in the diopside-bearing layer and is not essential. Another difference appears in the iron-to-magnesium ratio. The only dark constituent in the diopside-bearing layer is diopside, the composition of which can be calculated from the rock analysis (table 5, no. 1308). The result $CaMg_{0.78}Fe_{0.22}Si_2O_6$ suggests that the iron-to-magnesium ratio is about 1:4, whereas in the tremolite of the neighboring layer it is 1:12. The optical properties of the diopside—$\alpha=1.675\pm0.001$, $\beta=1.681\pm0.001$, $\gamma=1.703\pm0.001$, $Z\wedge c=38°$—are in good accordance with the calculated chemical analysis. The small lenticles of lime-silicate rock on Monumental Buttes consist mainly of similar diopside. Very little plagioclase, sphene, magnetite, and locally some quartz occur as additional constituents.

RAVALLI GROUP

LITHOLOGY AND STRATIGRAPHIC SEQUENCE

For convenience of discussion, the rocks that are equivalent to the Burke, Revett, and St. Regis formations, are described here under the heading Ravalli group, the name applied to this part of the Belt series in areas where subdivisions are difficult (Ransome and Calkins, 1908, p. 26–28). A fairly complete conformable section through all three formations of the Ravalli group is exposed northeast of the Little North Fork of the Clearwater River (table 1). Thick beds of coarse-grained fairly-pure quartzite form the major part of this section, which is interrupted by several faults. The beds beneath the quartzite, which are those stratigraphically equivalent to the Burke formation, consist of medium-grained schist and thin-bedded fine-grained biotite quartzite. Similar beds occur in the Prichard formation, and without the stratigraphic guide, the massive Revett quartzite, it would be impossible to tell to which formation these beds belong. The beds that overlie the Revett quartzite conformably, which are those equivalent to the St. Regis formation, consist of garnetiferous muscovite-biotite schist and fine-grained biotite gneiss. A white granular quartzite, which forms the lowest beds of the Wallace formation, marks the upper contact of the St. Regis formation in the conformable sections of the northeastern part of the area.

Parts of all three formations of the Ravalli group—Burke, Revett, and St. Regis—are probably exposed in the southern part of the area, but only the Revett quartzite can be identified with certainty. The schist overlying the Revett quartzite is thought to be equivalent to the St. Regis formation, and the schist and impure quartzite between the coarse-grained garnet-mica schist of the Prichard formation and the first thick beds of the massive Revett quartzite equivalent to the Burke formation. However, the Burke and St. Regis formations can be identified only where found with the Revett quartzite. Without this stratigraphic guide their separation from the schist of the Prichard formation or from the schist of the Wallace formation is highly uncertain, if not impossible. The numerous faults have interrupted the stratigraphic sequence wherever the massive Revett quartzite occurs, and no good section of this part of the Belt series exists. The best section in the southern part of the Boehls Butte quadrangle is along the Little North Fork near its mouth and continues along the North Fork of the Clearwater River south of the mouth of the Little North Fork (table 7).

In this section (table 7) layers of fairly homogeneous schist and thin-bedded hornblende-bearing diopside-plagioclase gneiss underlie the Revett quartzite and probably represent the Burke and Wallace formations, the latter in a fault contact. The layers overlying the Revett quartzite consists of medium-grained homogeneous biotite schist with some thin-bedded biotite quartzite layers. Along Robinson Creek intensive faulting has obscured the sequence. However, a conformable contact between the underlying Burke formation and the Revett quartzite is exposed in some localities; for example, along a tributary of the North Fork of Robinson Creek northwest of logging Camp X. The beds that are stratigraphically equivalent to the Burke formation here consists of a heterogeneous schist with some hornblende gneiss layers.

TABLE 7.—*A generalized section along the North Fork and the Little North Fork of the Clearwater River south of the southernmost anorthosite mass*

Formation	*Rock type*	*Estimated thickness (meters)*	*Estimated thickness (feet)*
	Anorthosite.		
	Fault.		
Wallace	Banded hornblende-biotite gneiss with diopside in some layers.	300	980
St. Regis	Biotite-plagioclase schist, homogeneous.	560	1, 840
	Biotite-plagioclase gneiss	150	490
	Fault.		
Revett	Thick-bedded coarse-grained quartzite.	100	330
	Fault.		
St. Regis(?)	Garnet-mica schist, kyanite-bearing.	560	1, 840
	Fault.		
	Thin-bedded gray quartzite	150	490
Revett	Thick-bedded coarse-grained pure quartzite with some sillimanite in the middle part.	140	460
	Sillimanite-mica schist	20	70
	Thick-bedded coarse grained pure quartzite.	140	460
Burke(?)	Garnet-sillimanite schist	50	160
Total		2, 170	7, 120

Elsewhere in the southern part of the Boehls Butte quadrangle, the beds that overlie the Revett quartzite and underlie the thin-bedded quartzite or schist that are equivalent to the Wallace formation have a varied lithologic character. In most localities the beds resting on the Revett quartzite consist of fairly homogeneous biotite schist and probably are equivalent to the St. Regis formation. It is not clear whether all diopside-plagioclase quartzite and gneiss which are interbedded with this schist belong to the St. Regis or to the lower part of the Wallace formation. North of the mouth of Robinson Creek a layer of thin-bedded biotite-plagioclase quartzite with diopside-bearing layers occurs just above the Revett quartzite and this thin-bedded quartzite is overlain by mica schist. In other localities along Robinson Creek the equivalent of St. Regis formation consists of mica schist with some sillimanite and garnet.

A white granular quartzite with some diopside is exposed in the southwest corner of the area on the ridge between the North Fork of the Clearwater River and Boathouse Creek and also along the ridge on the east side of the river opposite the mouth of Gold Creek. This quartzite is similar to the quartzite of the lowest part of the Wallace formation on Surveyors Ridge, and the schist underlying it may therefore be equivalent to the St. Regis formation and the schist overlying it equivalent to the Wallace formation.

Another locality where the Revett quartzite and probably rocks equivalent to the St. Regis formation are exposed is around Bertha Hill along the south central edge of the map. The Revett quartzite there is bordered by hornblende-diopside-plagioclase gneiss interbedded with coarse-grained mica schist, many layers of which contain sillimanite and garnet. Diopside-plagioclase gneiss is exposed just north of the Revett quartzite near Thunder Creek, but toward the east a biotite-muscovite schist overlies the quartzite. This schist is similar to the schist north of the mouth of Robinson Creek, but because the Wallace formation also contains layers of similar schist, it is impossible to tell whether the schist north of Bertha Hill is equivalent to the St. Regis or to the Wallace formation. The formation overlying the Revett quartzite east of Bertha Hill is composed of mica schist and of thin-bedded biotite- or diopside-bearing quartzite.

PETROGRAPHY

BURKE FORMATION

Layers that lie conformably just under the Revett quartzite and that are considered equivalent to the Burke formation are exposed in several localities. A layer of biotite schist which separates the Revett quartzite from the underlying hornblende-bearing diopside-plagioclase gneiss south of the mouth of Robinson Creek is coarse grained and contains impure quartzite layers. A similar schist is exposed under the Revett quartzite in many other localities near Robinson Creek. The major constituents in this schist are quartz and biotite; the muscovite and plagioclase occur in small quantities. Garnet- and sillimanite-bearing layers are not as common as in the schist overlying the Revett quartzite. The schist just under the Revett quartzite shown in the northeast corner of plate 1 is similar to the schist described above except that it contains more muscovite. Thin beds of fine-grained biotite-rich quartzite are interbedded with this muscovite-biotite schist lower in the section. The thin-bedded layers grade to a coarse-grained muscovite-biotite-garnet schist (most likely the top of the Prichard formation) which contains beds of fine- to medium-grained muscovite-biotite schist and quartzite.

REVETT QUARTZITE

Most of the coarse-grained massive quartzite whose stratigraphic position is equivalent to that of the Revett quartzite in the Coeur d'Alene district is white or bluish, but it also contains some reddish beds. The individual beds of massive pure quartzite range from 3 to 100 cm in thickness and are separated by paper-thin laminae of biotite and muscovite. In blocks of the massive Revett quartzite, glittering, fairly smooth fracture surfaces of individual large grains make this formation easy to identify. A few grains of plagioclase, rutile, and magnetite occur as minor constituents. Abundant sillimanite was found in reddish beds exposed just north of the mouth of Robinson Creek and on Bertha Hill. Some beds of biotite-sillimanite schist and medium-grained biotite-plagioclase quartzite are interbedded with the coarse-grained quartzite.

ST. REGIS FORMATION

The rocks that overlie conformably the Revett quartzite and are considered to be equivalent to the St. Regis formation consist mainly of schist and thin-bedded quartzite. In the thin-bedded quartzite north of the mouth of Robinson Creek, gray biotite quartzite layers alternate with light-colored plagioclase-bearing layers. Some light-greenish layers containing diopside also are interbedded. The thickness of the individual beds ranges mostly from 2 mm to 3 cm. Paper-thin laminae of biotite are common between the individual layers. This quartzite grades over to a coarse-grained muscovite-biotite-garnet-sillimanite schist, which is very similar to the schist of the Wallace formation.

Biotite is the main micaceous mineral in the schist farther north, but a considerable amount of muscovite occurs in some layers. Plagioclase and quartz are the light-colored constituents; garnet, magnetite, and zircon appear in small quantities. The thick layer of homogeneous schist that overlies the Revett quartzite just north of the mouth of the Little North Fork of the Clearwater River is medium-grained and contains more plagioclase than the other layers. Biotite is the main micaceous mineral and muscovite occurs in small quantities. A few garnet crystals and magnetite grains are commonly present.

In the canyon of Breakfast Creek the schist above the Revett quartzite is rich in quartz and contains in addition to biotite a considerable amount of muscovite. The muscovite occurs as large flakes, many of which are bent. Elongated quartz grains are strained and have sutured borders or tiny grains occur between the larger ones. Biotite, intermingled with muscovite, forms thin laminae between layers (0.5 to 2 mm thick) that consist of quartz with some oligoclase.

WALLACE FORMATION

DISTRIBUTION AND LITHOLOGY

Sillimanite-garnet schist and interbedded diopside-plagioclase gneiss exposed in the southern part of the area are considered to be equivalent to the Wallace formation. The contact between the St. Regis formation and the overlying Wallace formation was not mapped because it could not be placed accurately, and some of the schist and the gneiss considered to be St. Regis may be equivalent to the Wallace formation. The lowest part of the Wallace formation contains thick beds of medium-grained biotite quartzite, thin-bedded biotite-plagioclase quartzite, white granular quartzite with some diopside, diopside-plagioclase gneiss with local development of hornblende, and garnet-biotite schist, all interbedded. This part of the formation is exposed in the southwestern part of the area along Elkberry Creek west of the logging Camp T, along the load leading from Bertha Hill to the river about a mile east of the junction to Armstrong Lookout, along the ridge between Grandad Creek and the head of Little Meadow Creek, along the ridge between the river and Boathouse Creek, and on the ridge between Little Silver Creek and Elkberry Creek. A layer of mica schist overlies the lowest unit and is in turn overlain by a thick unit of light-green diopside-plagioclase gneiss which locally contains abundant hornblende. Thus, the lower part of the Wallace formation is heterogeneous and contains layers that are petrographically very similar to the layers in the St. Regis formation and in the upper part of the Wallace formation. Near Benton Creek and in the area south of Township Butte two fairly thick layers of diopside-plagioclase gneiss are interbedded with the schist (pl. 1).

At the mouth of Benton Creek and along the Little North Fork of the Clearwater River a rather homogeneous biotite-plagioclase schist is underlain by a layer of banded hornblende-biotite-plagioclase gneiss. This gneiss is hetergeneous, consisting of white layers of quartz-plagioclase rock interbedded with dark layers rich in hornblende, or in hornblende and biotite, or in biotite. Small crystals of garnet occur in some layers. The thickness of individual layers ranges from ½ to 5 cm.

A similar gneissic layer continues toward the east along the North Fork of Benton Creek, and forms a sheared zone half a mile wide between the Prichard formation to the north and the Wallace formation to the south. On the basis of the interrupted stratigraphic sequence, it is evident that this gneiss zone represents one of the major faults in the area.

PETROGRAPHIC DESCRIPTION

QUARTZITE

Three types of quartzite occur in the lowest unit of the Wallace formation: medium-grained light-colored biotite quartzite, white granular quartzite, and thin-bedded biotite quartzite with or without plagioclase. Only a few discontinuous beds of medium-grained biotite quartzite are interbedded either with the schist or with the diopside-plagioclase gneiss. These layers weather readily to coarse quartz sand. The beds are thicker than those in the other types of quartzite, ranging from 1 to 5 m in thickness. Biotite flakes of medium size are evenly distributed throughout the rock.

Beds of white granular quartzite, ranging from 5 to 20 cm in thickness, are interbedded with thinner layers of biotite and biotite-plagioclase quartzite along the road leading from Bertha Hill to the river. Similar beds are interbedded with diopside-bearing quartzite and diopside-plagioclase gneiss in the southeastern part of the quadrangle. These beds are medium grained and consist of almost pure quartz with only a few biotite flakes or diopside grains. The thin-bedded layers are fine grained and contain biotite and plagioclase in varying amounts. They are interbedded either with the other quartzite layers or with the schist. Muscovite is a common additional constituent, and apatite and magnetite occur as accessories.

The thin-bedded biotite-plagioclase quartzite and diopside-plagioclase gneiss interbedded with the schist east of Bertha Hill are probably equivalent to the St. Regis or to the lower part of the Wallace formation. In the quartzite, alternating layers, 2 to 5 cm thick and rich in either quartz or plagioclase are separated by paper-thin laminae rich in biotite (fig. 10). A few green layers, 1 to 5 m thick, of diopside-plagioclase gneiss with some honblende (fig. 11) are interbedded with this quartzite.

A very thin bedded biotite quartzite is exposed under the diopside-hornblende gneiss along Gyppo Creek, 1½ miles north of the mouth of Elkberry Creek. Some of the thin-bedded layers, which consist mainly of quartz,

FIGURE 11.—A hand specimen of diopside-plagioclase gneiss with some hornblende (dark bands). The white bands consist mainly of plagioclase. Diopside is gray in the photograph. About half a mile east of Bertha Hill, loc. 694.

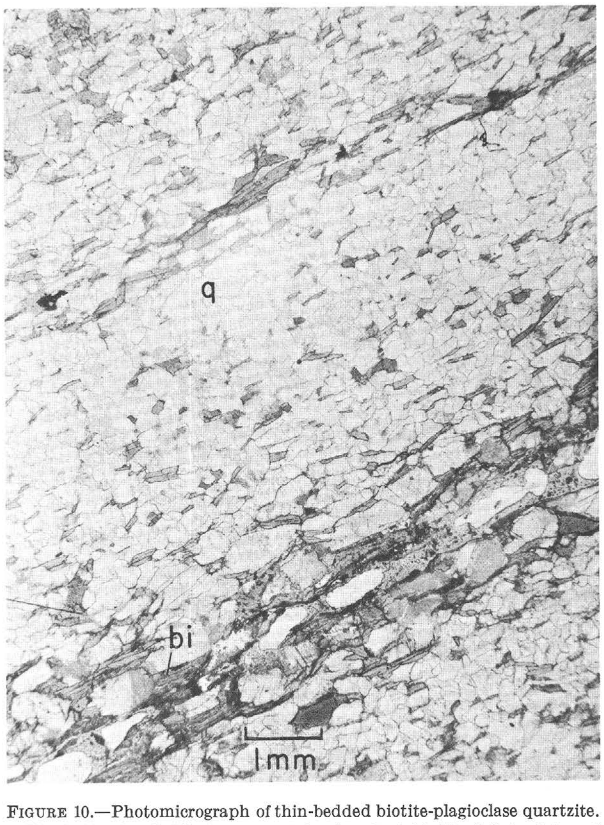

FIGURE 10.—Photomicrograph of thin-bedded biotite-plagioclase quartzite. The dark-colored thin layers contain abundant biotite (bi) in flakes of medium size. In the light-colored layers quartz (q) and plagioclase are the major constituents, with the biotite occurring only sparingly. Loc. 684 east of Bertha Hill. Plane-polarized light.

plagioclase, and biotite, are very similar to the thin-bedded biotite quartzite interbedded with diopside quartzite in the Wallace formation along Couger Creek in Headquarters quadrangle (Hietanen, 1962). However, a major part of the formation near Gyppo Creek contains paper-thin laminae rich in sillimanite.

SCHIST AND THE OCCURRENCE OF MARGARITE IN IT

The schist interbedded with the quartzite in the lowest part of the Wallace formation is medium to coarse grained and contains abundant biotite and garnet, and muscovite in varying amounts. Sillimanite is not as common as it is in the upper part of the Wallace formation. In most outcrops the muscovite occurs as larger flakes than the biotite and forms thin laminae between the biotite-bearing layers. Garnet crystals are small and their number is far less than that in the upper part of the formation.

The schist units interbedded with the diopside-plagioclase gneiss in the upper part of the Wallace formation are similar to the corresponding layers in the Wallace formation in the Headquarters quadrangle (Hietanen, 1962), except that abundant light bluish-gray to white micaceous mineral occurs instead of sillimanite in the schist southwest of Township Butte. Large blocks of this micaceous material were found on the southern border of the quadrangle along a fire road

TABLE 8.—*Chemical analyses of margarite and margarite-sericite rock. Locality 1484, 1 mile southwest of Township Butte*
[Analyst: M. Balazs, U.S. Geol. Survey]

	Margarite							Margarite-sericite rock					
	Weight percent	Molecular equivalent	Number of atoms			Number of atoms after correction to H_2O=4.4 percent		Weight percent		Cation percent		Molecular norm	
SiO_2	32.59	5426	Si	4.43	8.00	4.28	8.00	SiO_2	37.38	SiO_2	35.14	Or	25.35
Al_2O_3	49.95	4900	Al	3.57		3.72		Al_2O_3	44.80	$AlO_{3/2}$	49.62	Ab	9.90
Fe_2O_3	.20	13	Al	4.43	4.45	4.00	4.02	Fe_2O_3	.18	$FeO_{3/2}$	.13	Ne	2.52
FeO	.35	49	Fe^{+3}	.02		.02		FeO	.33	FeO	.26	An	32.20
MnO	.00	00	Fe^{+2}	.04		.04		MnO	.00	MnO	.00	C	28.85
MgO	.25	62	Mn	.00	.10	.00	.10	MgO	.28	MgO	.39	Fo	.59
CaO	10.09	1799	Mg	.05		.05		CaO	6.43	CaO	6.48	Fa	.21
Na_2O	1.97	318	Ti	.01		.01		Na_2O	1.55	$NaO_{1/2}$	2.82	Ap	.05
K_2O	.69	73	Ca	1.47		1.42		K_2O	4.23	$KO_{1/2}$	5.07	Il	.12
TiO_2	.08	10	Na	.52	2.11	.50	2.04	TiO_2	.09	TiO_2	.06	Mt	.19
F	.39	205	K	.12		.12		P_2O_5	.03	$PO_{5/2}$	.02	Cc	.02
H_2O+	2.51	1393	F	.17	2.44	.16	4.01	CO_2	.01	CO_2	.01		
H_2O-	.05	----------	H	2.27		3.85		H_2O+	4.43	H_2O+	(13.88)		
			O	24.00		24.00		H_2O-	.07	H_2O-	(.22)		
Subtotal	99.12	----------						Total	99.81	Total	100.00	Total	100.00
								Molecular percent					
Less O for F	.16	----------						Margarite	64.6				
Total	98.96	----------						Muscovite	35.4				

leading from Township Butte southward to Lightning Point in the Headquarters quadrangle (loc. 1484, pl. 1). These blocks consist of light bluish-gray dense minerals that appear fibrous to a naked eye and resemble sillimanite in their mode of occurrence. Microscopic study shows that there are two major constituents, a white sericitic mica with an index of refraction $\gamma=1.593$ to 1.594 ± 0.001 and another micaceous mineral with indices of refraction $\alpha=1.629\pm0.001$ and $\gamma=1.639\pm0.001$. The latter mica was separated from the rock by means of heavy liquids. The fraction, which had specific gravities between 3.063 and 3.066 and contained some tiny inclusions of sericite, was analyzed chemically (table 8). This micaceous mineral is margarite. Its formula calculated from the chemical analysis is

$$(H_{3.85}F_{0.16})_{\Sigma=4.01}(Ca_{1.42}Na_{0.50}K_{0.12})_{\Sigma=2.04}(Fe^{+2}_{0.04}Mg_{0.05}Ti_{0.01})_{\Sigma=0.01}(Al_{4.00}Fe^{+3}_{0.02})_{\Sigma=4.02}(Si_{4.28}Al_{3.72})_{\Sigma=8.00}O_{24}.$$

Comparison with the theoretical formula $CaAl^2(OH)^2 Al_2(OH)_2O_{10}$ suggests that Na substitutes for a part of Ca and Al for a part of Si. The mode of occurrence suggests that it is an alteration product after sillimanite.

Chemical analysis of the margarite-sericite rock (table 8) from which margarite was separated shows considerably more potassium; this suggests that the other mica is mainly muscovite. Indeed, if all calcium is assumed to go to form margarite and the amount of margarite is calculated (64.6 molecular percent) and deducted from the rock analysis, the remainder gives a composition of muscovite with the following formula:

$$H_4(Na_{0.21}K_{1.79})_{\Sigma=2.00}(Mg_{0.06}Fe^{+2}_{0.03})_{\Sigma=0.09}(Al_{3.85}Fe^{+2}_{0.02})_{\Sigma=3.87}(Si_{6.17}Al_{1.83})_{\Sigma=8.0}O_{24}.$$

In the schist south of locality 1484, margarite forms conspicuous white clusters that look fibrous in a hand specimen (fig. 12). They are, in all probability, an alteration product after sillimanite, which commonly occurs in similar clusters in other parts of the same formation. The schist rich in margarite is strongly sheared and finer grained than the common sillimanite-bearing schist. Quartz occurs in thin laminae which are separated by thin micaceous layers. Study under the

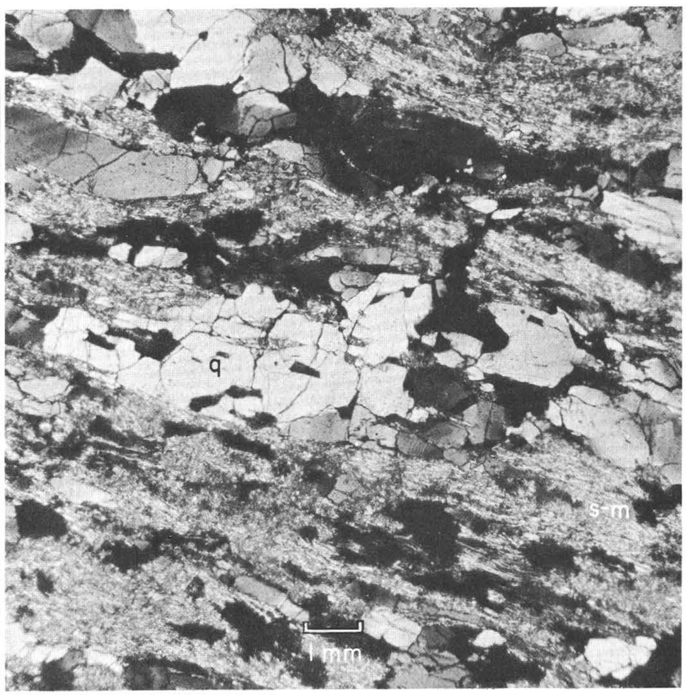

FIGURE 12.—Photomicrograph of sericite-margarite schist a mile southwest of Township Butte. Quartz (q) occurs in thin discontinuous layers that are separated by micaceous layers consisting of a fine-grained mixture of sericite and margarite (s-m). Crossed nicols.

microscope shows that sericite in these micaceous layers is intermingled with margarite and that hematite, including tiny prisms of rutile, occurs instead of biotite as flakes of medium size. The occurrence of margarite, sericite, and hematite instead of sillimanite and biotite indicates that considerably more calcium and less magnesium are present in this schist than in a normal schist of the Wallace formation. The alteration of margarite to sillimanite suggests that calcium was introduced locally into the schist. This introduction probably took place during a shearing because the micas are well oriented parallel to the shear planes. The magnesium of the biotite was removed when calcium was introduced, leaving only skeletons of biotite consisting of hematite. The potassium of the biotite probably reacted with sillimanite to form sericite.

The blocks of the margarite-sericite rock (no. 1484) were found next to a pegmatite dike. The introduction of calcium may have proceeded from the dikes to the country rock. These relations suggest that the margarite crystallized in the temperatures corresponding to those of the pegmatitic stage.

DIOPSIDE-PLAGIOCLASE GNEISS

Most layers of the diopside-plagioclase gneiss interbedded with the garnet-sillimanite schist in the Boehls Butte quadrangle contain more diopside and in places also more hornblende than the corresponding layers in the Headquarters quadrangle south of the present area. The name "gneiss" is used, even if a small portion of these layers consists of quartzite.

The diopside-plagioclase gneiss south of the mouth of Robinson Creek is thin bedded and contains a considerable amount of hornblende. The major constituents—quartz, diopside, and plagioclase—occur in equal amounts. The distribution of hornblende is highly irregular; it is concentrated to thin layers parallel to the bedding, or it is scattered as individual large grains throughout the rock, or it occurs on both sides of thin pegmatitic dikelets that cut the rock across the bedding. In its mode of occurrence it is thus similar to the metasomatic hornblende described earlier from the Headquarters quadrangle (Hietanen, 1962). The original sediment was a dolomite-bearing clayey sand that recrystallized to a fine-grained diopside-plagioclase gneiss during a regional metamorphism. Hornblende is later than the main constituents—quartz, plagioclase, and diopside. Adjacent to many small pegmatitic veins and dikes it crystallized as large grains replacing the diopside and including small grains of quartz and plagioclase. A somewhat higher content of iron in the hornblende-bearing parts of the rock suggests that some iron was added to the rock during the crystallization of hornblende.

Tremolite and epidote group minerals, especially clinozoisite, occur locally in the gneiss instead of diopside (for example, locality 1474). In specimen 669 clinozoisite with $\alpha=1.715\pm0.001$, $\beta=1.719\pm0.001$, $\gamma=1.724\pm0.001$ has replaced zoisite along the cracks and borders. The indices of refraction of the zoisite are lower than those of the clinozoisite: $\alpha=1.701\pm0.001$ and $\gamma=1.7085\pm0.001$. Also some epidote and diopside, the latter with $\gamma=1.715\pm0.001$, occur in the same rock.

METAMORPHIC FACIES OF THE BELT SERIES

The critical assemblages in the rocks of the Belt series in the southernmost part of the area are almandine-sillimanite-biotite with only a little muscovite in the pelitic layers, and diopside-hornblende in the calcareous layers. These mineral assemblages suggest recrystallization to the sillimanite-muscovite subfacies of the amphibolite facies. In the northern part more muscovite occurs, and the assemblage kyanite-andalusite-sillimanite is typical. The mutual relations among these three aluminum silicates (Hietanen, 1956) indicate that the temperature and pressure during the recrystallization fluctuated around the triple point at which all three are stable. Some staurolite occurs with the three aluminum silicates, and it seems that the upper limit of the stability field of staurolite is close to the temperature of the triple point. Because this temperature is also the lower limit of the stability field of sillimanite, it forms a natural boundary between the amphibolite and epidote-amphibolite facies as has also been suggested by Francis (1956). In the calcareous layers, tremolite and actinolite are as abundant as the diopside. This also suggests recrystallization in a somewhat lower temperature field than prevailed in the southernmost part of the area where tremolite is found only in layers that are exceptionally rich in magnesium and that did not contain enough calcium for the formation of diopside.

STRUCTURE OF THE BELT SERIES

The regional structures of the rocks of the Belt series have been discussed in another paper (Hietanen, 1961); therefore attention here is given only to some specific local features.

FAULTS

The anorthosite and its country rocks are separated by north- and east-southeast-trending faults from the upper schist and quartzite units of the Prichard formation. In the northwestern part of the area, two north-trending faults with a vertical displacement of east side up are exposed on the ridge southeast of Little Lost Lake. Near Orphan Point a north-trending fault between the anorthosite and schist was mapped on the basis of boulders, and a narrow gulley marks the extension of the same fault south of Orphan Point.

Near Pinchot Butte a fault occurs on either side of the mountain and is transected by east-northeast-trending transverse faults. Farther to the south the fault follows the gorge of Floodwood Creek and ends in an intrusive body of granite which conceals its junction with the east-southeast-trending fault zone that borders the anorthosite and its country rocks in the south.

In the northeastern part of the area several north-trending faults separate the normal sequence of the Belt series in the east from the anorthosite and its country rocks in the west. A southeast-trending fault was traced along Foehl Creek south of Buzzard Roost and another along Minnisaka Creek. These faults, together with north-trending faults, form the eastern border of the anorthosite block.

The uplift of the anorthosite block along this eastern border was probably much less than along the western border. The schist above the lower quartzite unit is petrologically similar to the schist under the upper quartzite unit on the east side of the fault zone. Both schists probably belong to the same unit, the thickness of which near Orphan Point is about 1,500 m.

In the western part of the area, the rocks of the anorthosite block are in the fault contact with the schist that occurs between the two quartzite units of the Prichard formation. If the anorthosite occurring at the 4,500-foot elevation on the southeast slope of Pinchot Butte has stratigraphically the same position as the large anorthosite bodies, and if the quartzite along Twin Springs Creek is equivalent to the lower quartzite unit that in the central part overlies the large anorthosite bodies, the amount of uplift in this vicinity is more than 400 m.

In the southern part of the area, the rocks of the Wallace formation are faulted against the anorthosite and its country rocks. Thus the vertical displacement there is much larger than along the north-trending faults, probably more than 1,000 m.

BEDDING

Bedding is distinct in quartzitic units and in some of the diopside-plagioclase gneiss; however, in most outcrops of the diopside-plagioclase gneiss, recrystallization has obliterated all structures ascribed to the equivalent formations in the Coeur d'Alene district. In the schist, bedding is visible where fine-grained quartzitic layers or biotite-plagioclase gneiss layers are interbedded. In small outcrops of coarse-grained homogeneous schist only one planar structure, the foliation, is visible, and bedding may or may not be parallel to it.

FOLDING

A large double-crested anticline in the Prichard formation in the vicinity of Monumental Buttes and Cedar Creek forms a major structure in the area. The axis of this fold plunges gently to the southeast. Another large anticline occurs along the North Fork of the Clearwater River, west of the mouth of Salmon Creek. The river valley there is an anticlinal valley, and the high ridges to the north and to the south (Smith Ridge and vicinity of Benton Butte) have synclinal structures. (See section on pl. 1.) Several other somewhat smaller folds are seen on the geologic map (pl. 1).

In most parts of the area, the fold axes plunge gently to the east or to the east-southeast, but at places horizontal or westward-plunging axes were observed. In the northern part of the area, the schist and quartzite are gently or moderately folded and the same formation covers large areas, whereas in the southern part the folding is more intense, the flanks of the folds in many localities are either steep or overturned, and a strong crenulation appears along the flanks.

The trend of the measurable fold axes varies greatly and in several localities two sets of folds are apparent. The major fold axis trends about S. 70° E. and the second axis makes an angle from 50° to 90° with it. The trend of the second fold axes is in either northeasterly or northwesterly direction coinciding with the regional trends of the Nevadan folding (Hietanen, 1961). Generally the second set of folds appears as a local crenulation and minor folding of the flanks of the major folds. In some localities, however, larger folds were formed around the northwestward-trending axes. Small overturned folds exposed along a logging road between Elkberry Creek and Gyppo Creek belong to this second set; their axes plunge 10° NW. and the axial planes dip 10° NE.

FOLIATION

Foliation parallels the bedding in the areas of gentle folding (for example, on Smith Ridge, near Indian Dip, and in many localities near Floodwood Creek) and along the flanks of steep folds. On the crests of the folds, transecting cleavage parallel to the axial plane of the folds is common (fig. 13). Thin sections show that on the crests of the folds in many thin-bedded quartzite layers some of the micaceous minerals are subparallel to the bedding plane and some subparallel to the axial plane. Thus, both of these structural planes served as glide planes during the various phases of deformation which was accompanied by recrystallization.

LINEATION

Lineation is a fine wrinkling of bedding planes, or elongation of mineral grains, or parallel orientation of pencil-shaped minerals, such as hornblende. It is clearly visible in most micaceous layers, but cannot be detected in many pure quartzite layers. However, many exceptions to this rule were found; some coarse-grained

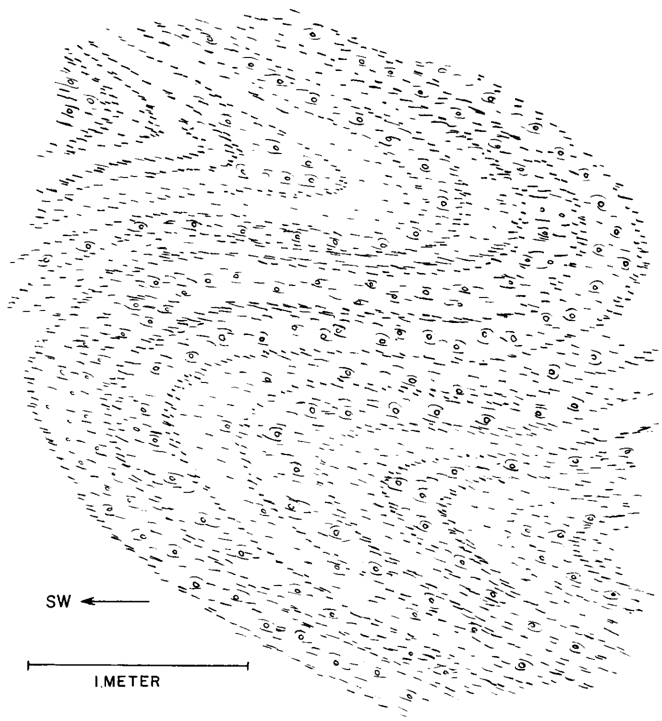

FIGURE 13.—A small fold overturned to south in garnet-mica schist of the Prichard formation about 1 mile west of Orphan Point (loc. 1023). The mica flakes are parallel to the axial plane of the folds and render to the rock a good foliation that transects the bedding on the crests of the folds. Vertical road cut facing southeast.

schist layers show only irregular crumbling and some pure quartzite layers in the Prichard formation may show a distinct lineation. The lineation in the quartzite is noticeable because of stretching of grains or because of a strong shearing. The stretching of grains is conspicuous in garnetiferous gray coarse- to medium-grained quartzite in which garnet crystals are drawn out parallel to the lineation. Near Lost Lake this lineation is parallel to the fold axis (*b* lineation). The axis of the wrinkling in the micaceous layers is either parallel to the major fold axis (*b* lineation) or parallel to the second fold axis (*b'* lineation).

IGNEOUS ROCKS

Several structurally and petrologically different groups of igneous rocks occur in the area. Coarse-grained gneissic hornblendite, gabbro, and quartz dioritic and tonalitic rocks form an older group and occur mostly as conformable bodies in the Belt series. This group is called the quartz dioritic suite, and the rocks that belong to it are, in their mode of occurrence, structure, and petrology, similar to the corresponding rocks in the Headquarters quadrangle and vicinity (Hietanen, 1962). The rocks of the quartz dioritic suite are therefore discussed in this paper only briefly.

In contrast to the quartz dioritic suite, medium-grained gabbro with fine-grained contacts and medium-grained reddish-gray granite cut the rocks of the Belt series and the anorthosite discordantly and are younger than the rocks of the quartz dioritic suite. The large body of quartz monzonite around Beaver Butte, just east of the Boehls Butte quadrangle, and that in the northernmost part of the area probably are of the same age as or somewhat older than the reddish-gray granite. The quartz monzonite and granite belong genetically to the same suite, which is here referred to as the quartz monzonitic suite. Porphyritic dikes, mainly of granitic and dioritic composition, are common both in the rocks of the Belt series and in the older intrusive series.

QUARTZ DIORITIC SUITE

SERPENTINE

A small body of serpentine occurs in the schist along the county road leading from Boehls to Elk River about 1 mile northwest of logging Camp X (western margin of pl. 1). Most of this body consists of fine-grained, dark greenish-gray serpentine with rust-colored specks, but a small portion contains radiating crystals of anthophyllite interleaved with chlorite.

Study under the microscope shows that the mesh of serpentine minerals is transected by numerous rows of tiny magnetite grains that originally crystallized along the crack of olivine. Some small specks of carbonate, talc, and a few flakes of chlorite occur as additional constituents. More chlorite and talc are in that portion of serpentine, in which anthophyllite prisms occur. Olivine with only narrow serpentinized cracks fills the interstices between the anthophyllite prisms in the fresh part of the anthophyllite-bearing outcrop. The cracks in the anthophyllite are filled by talc. Small grains of magnetite are along the cracks in the olivine and a few larger grains occur next to the anthophyllite.

The mineralogy and texture of the serpentine suggest that originally most of it was dunite and that only a small part contained anthophyllite in addition to olivine.

HORNBLENDITE

Small bodies of coarse-grained black hornblendite occur in the rocks of the Belt series and in the rocks of the quartz dioritic suite. These bodies consist of 80 to 90 percent hornblende and some biotite, plagioclase, and very little quartz. Hornblendite included in gabbro near Benton Butte probably represents accumulation of hornblende in the gabbro, but the small irregular bodies in the rocks of the Belt series were formed at least in part by replacement, their mode of occurrence being similar to the hornblendite and garnet-amphibolite in the Headquarters quadrangle and in the vicinity of Dent (Hietanen, 1962). Several small bodies, ranging from 2 to 10 m in diameter, were found in the Revett quartzite along Robinson Creek. These bodies are irregular in shape, and hornblende fills cracks and joints in the quartzite near the contact.

GABBRO

Several small bodies of gneissic medium-grained gabbro occur within quartz diorite and tonalite or in their vicinity. Thin sections show that the gabbro consists of about 55 percent hornblende, 40 percent plagioclase (An_{35}), and 5 percent quartz in small round grains, and that accessories are sphene, epidote, apatite, and magnetite. Hornblende and plagioclase occur in groups of small polygonal grains, giving an impression of granulation and recrystallization.

QUARTZ DIORITE

The quartz diorite exposed in the southeast corner of the mapped area (pl. 1) is a part of a large body in the northern part of the Idaho batholith. Its petrography and structure have been discussed in the earlier paper (Hietanen, 1962). Two large and several small bodies of quartz diorite are exposed in the southern part of the Boehls Butte quadrangle. Most of these bodies consist of heterogeneous hornblende-plagioclase rocks with a considerable amount of quartz. Gabbroic and hornblenditic portions are included in the quartz diorite on Benton Butte. Smaller inclusions consisting of hornblende-rich rock are common elsewhere. The petrography and structure of these bodies are similar to those of the satellitic bodies of the same composition in the Headquarters quadrangle.

TONALITE

The occurrence of tonalite is restricted to the southern part of the Boehls Butte quadrangle in the same area where quartz diorite occurs. The bodies are small, have a gneissic structure, and show gradational contacts toward the country rocks. Most are petrographically similar to the gneissic tonalite in the Headquarters quadrangle. Many are distinctly banded and grade over to a banded gneiss in which veins consist of plagioclase and quartz. Biotite is usually the only dark constituent in these tonalites; magnetite and zircon occur as accessories.

PLAGIOCLASE PEGMATITE

Heterogeneous medium-grained pegmatitic veins consisting mainly of quartz and plagioclase are common in the rocks of the Belt series in the map area. These pegmatites are similar to those in the Headquarters quadrangle.

A very coarse grained sheared plagioclase-biotite pegmatite, about 5 m thick, is exposed on the road cut about half a mile east of the mouth of the Little North Fork of the Clearwater River. This dike extends eastward and is exposed again along the road leading from the river to Bertha Hill. The pegmatite is strongly sheared, with biotite covering the irregular shear zones. The quartz has sutured borders and is strongly deformed. Large undeformed albite grains are embedded in the deformed quartz. Magnetite and zircon occur as accessories. The pegmatitic veins in the biotite-plagioclase schist north of the mouth of the Little North Fork of the Clearwater River consist of quartz and plagioclase. Plagioclase-biotite pegmatites were found also 0.3 mile south of the mouth of the Little North Fork of the Clearwater River and along the logging roads curving around the tributaries of Benton Creek about 3 miles northeast of Bertha Hill along the same structural zone as the two other occurrences.

QUARTZ MONZONITIC SUITE

Two large bodies of rocks of the quartz monzonitic suite are exposed in the area studied, one in the southeastern and the other in the northern part of the area. In addition to these two plutons, granitic stocks and dikes belonging to this suite occur at the mouth of Floodwood Creek, opposite Larsons Cabin, south of Stocking Meadow Lookout, and southeast of Orphan Point.

QUARTZ MONZONITE

Quartz monzonite around Beaver Butte is a medium-grained light-gray rock in which minerals are oriented at random. The dark constituents are hornblende and biotite or biotite alone. Most biotite flakes are small and occur in clusters. Plagioclase (An_{20-43}) forms euhedral to subhedral zoned crystals, many of which are included in large orthoclase grains (fig. 14). Quartz is abundant and occurs as irregularly shaped grains among the other minerals. Sphene, magnetite, apatite, and zircon are the common accessories.

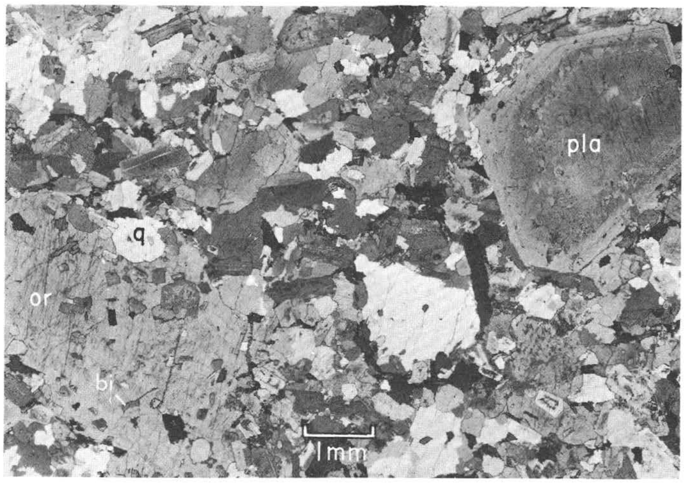

FIGURE 14.—Photomicrograph of quartz monzonite along the North Fork of the Clearwater River 2½ miles east of the mouth of Thompson Creek. Euhedral plagioclase (pla) occurs as phenocrysts in the medium-grained rock. The orthoclase grains (or) are anhedral; larger grains include small euhedral plagioclase, some quartz (q), and biotite (bi). Crossed nicols.

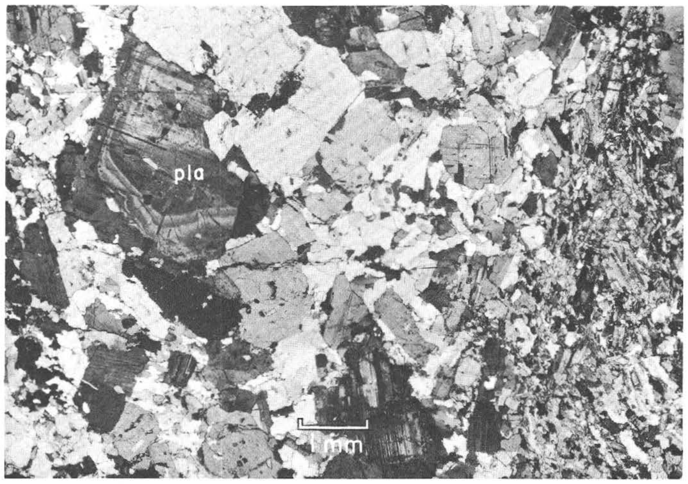

FIGURE 15.—Photomicrograph of quartz monzonite along the North Fork of the Clearwater River 1 mile east of the mouth of Thompson Creek. Fine-grained portion on the right is dioritic in composition. This fine-grained gneissoid rock contains veinlets of similar medium-grained quartz monzonite (on the left) as shown in figure 14. pla, plagioclase. Crossed nicols.

A small mass of fine-grained dark gneissoid rock of dioritic composition is included in the quartz monzonite body near its western border along the North Fork of the Clearwater River. Quartz monzonite forms narrow veinlets and small pods in this fine-grained rock. Thin sections made from the quartz monzonitic portions show abundant strained quartz between euhedral zoned plagioclase grains (fig. 15). Straining of quartz indicates a slight postcrystallization deformation.

Quartz monzonite in the northern part of the area is very similar to that near Beaver Butte. In the center of the pluton the minerals are oriented at random; the border zone, however, is gneissic. The border zone contains more biotite and less orthoclase than the main part of the pluton.

The quartz monzonite dikes on the east side of Breakfast Creek at Boehls have a gneissic structure parallel to the walls. Biotite clusters are drawn out into long shreds, and plagioclase tablets are oriented parallel to the planar structure. Under the microscope the borders of the mineral grains appear more irregular than those in the large intrusive bodies.

GRANITE

The granite of the stocks is gray and fine to medium grained. Gneissic structures occur near many contacts, but the centers of the stocks are massive. A stock south of Stocking Meadow Lookout and a part of two large bodies, one at the mouth of Floodwood Creek and the other southeast of Orphan Point, consist of coarser grained granite than the rest of the occurrences. The contact zones and locally also the centers of these three bodies show a well-developed planar structure parallel to the bedding of the country rocks. The minerals in the granite are quartz, plagioclase (An_{23-30}), orthoclase, biotite, and some muscovite. Magnetite, sphene, apatite, and zircon are the common accessories.

The granite exposed under the middle schist unit of the Prichard formation in the canyon of the Little North Fork of the Clearwater River in the northeast corner of the area is coarse to medium grained, gray, and heterogeneous. This granite includes abundant schlieren of schist and in many places grades over to schist. Pegmatitic veins parallel to the planar structure are common. These features suggest that much of the granite is a product of granitization of the schist, the amount of intrusive material being minor if not negligible.

The granite dikes are either equigranular or porphyritic. Phenocrysts in the porphyritic dikes are plagioclase and hornblende or biotite. The groundmass is medium grained and granoblastic, and consists of quartz, plagioclase, orthoclase, and some biotite. Many dikes are strongly sheared; in these the biotite occurs in long shreds parallel to the planar structure which is parallel to the walls of the dikes. Granite cuts anorthosite discordantly on the north side of the North Fork of the Clearwater River opposite Larson Cabin. This granite is fine grained, and tiny biotite flakes are evenly distributed throughout it. An exceptionally light-colored fairly coarse-grained granite occurs in a dike at the head of Benton Creek. In this granite, euhedral small albitic plagioclase crystals and large orthoclase crystals are included in quartz. Biotite is altered to chlorite and some calcite is present, both of which suggests a low temperature during the latest phase of crystallization of this dike.

ORTHOCLASE DIKE

A dike, about 2 m thick, and consisting of white medium-grained equigranular homogeneous rock, was found along the Little North Fork of the Clearwater River south of the junction of the road leading from Boehls to Elk River. This dike occurred near the contact of the anorthosite and its country rock, biotite-plagioclase gneiss, and cut the country rock discordantly. The dike was quarried out during the following spring when the road was widened. Megascopically this dike rock resembles the white anorthosite nearby except that no kaolin coating occurs on the weathered surface of the dike rock and there is a very slight pinkish hue to it. Study under the microscope showed that this dike consists of almost pure orthoclase with very little plagioclase, sericite, magnetite, tourmaline, rutile, and a few small myrmekitelike blebs of quartz. Some coarse perthitic plagioclase occurs in places. A chemical analysis (table 9) shows about 80 molecular percent orthoclase, 16 percent albite, and a little more than 1 percent anorthite. The analysis shows a considerable amount of barium—apparently contained in orthoclase.

TABLE 9.—*Chemical composition of orthoclase dike south of Boehls (loc. 633)*

[Analyst: Lois D. Trumbull, U.S. Geol. Survey]

Weight percent		*Cation percent*		*Molecular norm*	
SiO_2	64.86	SiO_2	59.89	Q	1.63
Al_2O_3	18.80	$AlO_{3/2}$	20.45	Or	80.60
Fe_2O_3	.01	$FeO_{3/2}$	.01	Ab	15.80
FeO	.07	FeO	.05	An	1.40
MnO	.00	MnO	----	C	.44
MgO	.00	MgO	----	Fs	.06
CaO	.30	CaO	.30	Ap	.03
BaO	.47	BaO	.17	Il	.02
Na_2O	1.77	$NaO_{1/2}$	3.16	Mt	.02
K_2O	13.55	$KO_{1/2}$	15.95		
TiO_2	.01	TiO_2	.01		
P_2O_5	.01	$PO_{5/2}$	.01		
CO_2	.00	CO_2	----		
H_2O+	.08	H_2O	[.24]		
H_2O-	.01				
			100.00		
Total	99.94	O	160.35		100.00
		OH	.48		
		Total	160.83		

Mode calculated from molecular norm

Quartz	1.61
Orthoclase ($Or_{88}Ab_{12}$)	91.44
Plagioclase ($Ab_{78}An_{22}$)	6.36
Muscovite	.05
Tourmaline	.11
Apatite	.03
Ilmenite	.02
Magnetite	.04
Total	99.66

YOUNGER GABBRO SILLS

Four large sills of pyroxene gabbro intrude the rocks of the Belt series. Three of them occur near the northernmost anorthosite body and one just east of the anorthosite body along Cedar Creek. The centers of these sills consist of medium-grained, massive rock in which dark augite crystals and light-colored plagioclase (An_{74}) are clearly visible. Thin sections show that augite grains are rimmed by light-green hornblende and that spots of hornblende occur in the grains. Toward the borders and locally also in the centers of the sills all augite is altered to hornblende. Plagioclase occurs in clusters of small lath-shaped crystals between the large rounded augite crystals. A few reddish-brown biotite flakes, some magnetite, and apatite are the additional constituents. Locally abundant zoisite occurs in those parts of the sills where augite is altered to hornblende, as on the south side of Big Talk Lake. There is every gradation from this massive gabbro that occurs in the center to foliated amphibolite and to a fine-grained dark hornblende gabbro near the contacts of the sills.

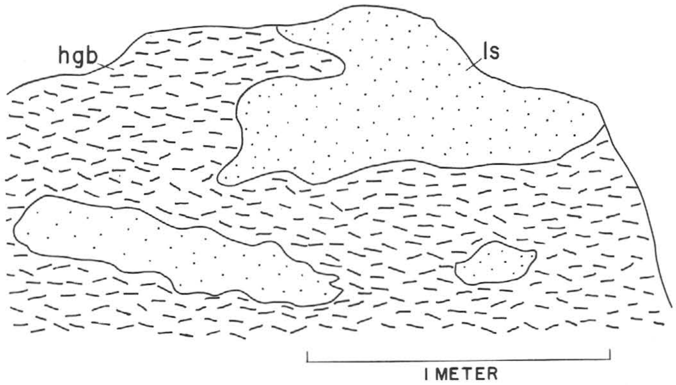

FIGURE 16.—Inclusions of lime-silicate rock (ls) in gneissic hornblende gabbro (hgb) on North Butte. Vertical wall facing north.

Most of the center of the sill at the mouth of Cedar Creek consists of similar massive gabbro, but the border zones and a part of the center are fine-grained amphibolite. Amphibolite exposed next to quartzite and to lime-silicate rock contains some garnet. This garnet amphibolite is similar to that which occurs as conformable small bodies in the schist, and its relation to the gabbro is not clear because no contact between the two is exposed.

In most localities the border zones of the gabbro sills consist of dark fine-grained rock which is either massive or is slightly schistose and in which hornblende is the only dark constituent. These border zones apparently represent chilled borders and indicate that the gabbro sills were emplaced at shallower depths than the other intrusive bodies in this area, and thus after the area had been uplifted and erosion had removed much of the cover. A sill-like body of fine-grained gabbro-amphibolite on Monumental Buttes is more deformed than the gabbro bodies described above. The main dark constituent is hornblende, and in most outcrops this mineral is well oriented parallel to the lineation. Only a minor part of the rock on North Butte appears massive. A discordant contact between this foliated gabbro-amphibolite and lime-silicate rock is exposed just northwest of North Butte. Rectangular fragments of lime-silicate rock in the gabbro-amphibolite in the contact zone (fig. 16) prove that the gabbro-amphibolite was emplaced by mechanical intrusion.

DIKES NOT DIRECTLY ASSOCIATED WITH THE PLUTONIC ROCKS

Most of the fault zones, many joints, and other structurally weak planes are locations for porphyritic dikes that range from dioritic to granitic in composition. These dikes transect all other rocks except the younger gabbro sills. As a rule the porphyritic dikes have fine-grained borders and coarse- to medium-grained centers.

659097 O—63——4

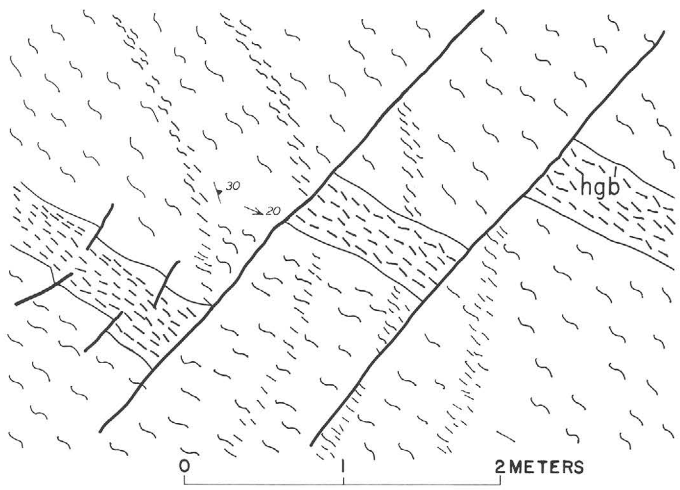

FIGURE 17.—A dike of gneissic hornblende gabbro (hgb) in plagioclase-rich biotite-hornblende gneiss. The dike is subparallel to the lineation that plunges 20° E. and transects the planar structure that strikes N. 20° W. and dips 30° NE. The faults (heavy lines) that have displaced the dike are vertical and strike N. 45° E. Horizontal surface about a mile north of Orphan Point.

The mineralogy and petrography of these dikes are similar to those of the porphyritic dikes in the Headquarters quadrangle and vicinity that have been described in an earlier paper (Hietanen, 1962).

In addition to granitic and dioritic dikes there are a few dikes of gabbroic composition. Some of these dikes have a mineralogy similar to that of the younger gabbro sills, but some consist of foliated hornblende gabbro in which the major constituents are plagioclase and hornblende with some quartz, sphene, epidote, and zircon. Foliation is parallel to the walls of the dikes that cut the planar structure of the country rock discordantly but is subparallel to the lineation of the country rock. North of Orphan Point a dike of this type is transected by small faults that indicate that the east side moved several meters toward the north-northeast along the vertical fault planes that strike N. 25° E. (fig. 17). This dike is thus older than the faults that trend in a north-northeasterly direction.

Dikes of basaltic composition occur along the southern contact of the anorthosite on the west side of the Little North Fork of the Clearwater River south of Boehls. These dikes consist of dark fine-grained rock that weathers to small round boulders. Study under the microscope shows that the major constituents are lath-shaped plagioclase (about 35 percent) and augite (about 55 percent). Brownish-green fine-grained material, in which some chlorite and ilmenite can be identified, fills the interstices.

A few small blocks of coarse-grained rock were found along the road traversing the middle anorthosite body (pl. 1), about 1 mile north of the junction to Stocking Meadows. These blocks consist of light-green prehnite and pink zoisite, thulite, with $\alpha = 1.689 \pm 0.001$, $\beta = 1.694 \pm 0.001$, $\gamma = 1.703 \pm 0.001$, and $2V \approx 45°$. Some tiny muscovite flakes occur as an additional constituent. Thulite has been found in several other localities in the United States (Schaller and Glass, 1942).

METASOMATIC ROCKS

AMPHIBOLITE

The amphibolite could not be conveniently included in any of the preceding groups of rocks and is therefore discussed separately. A part of amphibolite is probably of igneous origin, and some of the layers may be sedimentary, but many sill-like bodies show mineralogy and contact relations that suggest metasomatic replacement. Most of the amphibolite bodies contain abundant garnet and quartz and some biotite in addition to the regular constituents, plagioclase and hornblende. Some contain actinolite or anthophyllite instead of common hornblende. Most of the amphibolite sills occur in the surroundings of the anorthosite bodies and may be genetically connected. A few bodies appear to be discordant dikes.

MAFIC AMPHIBOLITE

Two of the occurrences of amphibolite consist of only ferromagnesian minerals. One of them is exposed along the road to Stocking Meadow Lookout about half a mile east of the lookout tower. This rock is dark greenish-gray and well foliated. It consists of actinolite, chlorite, and olivine in about equal amounts (fig. 18). The accessories are magnetite and green spinel.

FIGURE 18.—Photomicrograph of olivine- and chlorite-bearing amphibolite, half a mile east of the Stocking Meadow Lookout (loc. 1210). ol, olivine; ho, hornblende; chl, chlorite. Plane-polarized light.

The olivine is chrysolite ($Fo_{77}Fa_{23}$) with $\alpha=1.684 \pm 0.001$, $\beta=1.696\pm0.001$, $\gamma=1.717\pm0.003$, and $-2V$ =large. The optical properties of the actinolite are α (colorless)$=1.623\pm0.001$, γ(colorless)$=1.645\pm0.001$ and $Z\wedge c=16°$; these indicate that the actinolite contains about 16 molecular percent iron member.

This amphibolite may represent an ultramafic sill metamorphosed to the amphibolite facies. Olvine may be a relict mineral and chlorite crystallized because of lack of potassium.

The other occurrence of mafic amphibolite is in the anorthosite on the west slope of Goat Mountain about a mile west of the road. This amphibolite consists of hornblende and chlorite with some magnetite. The hornblende is dark green in hand specimen but shows only a very light coloring under the microscope. It is slightly pleochroic with X=colorless, Y=pale green, Z= pale bluish-green, and $Z\wedge c=17°$.

These amphibolite bodies are apparently metamorphosed ultramafic sills. Their mineralogy resembles that of the schistose hornblende-bearing gabbro-amphibolite found on and east of Monumental Buttes (specimen 1154) except that there is no plagioclase in the mafic amphibolite.

AMPHIBOLITE OF GABBROIC COMPOSITION

Some of the amphibolite bodies have a normal gabbroic composition and are probably metamorphosed intrusive sills petrologically similar to the gabbro-amphibolite on Monumental Buttes, but emplaced considerably earlier. These amphibolite bodies are dark and well foliated. The major constituents are hornblende and plagioclase, but in some bodies quartz and biotite occur in varying amounts. Every gradation from a biotite-muscovite schist to normal amphibolite can be found. In the normal amphibolite, the parallel orientation of hornblende needles makes the lineation conspicuous, whereas in the biotite-bearing occurrences, the foliation is more pronounced. The amount of quartz is highly variable. As a rule the biotite-bearing amphibolite contains more quartz than the normal amphibolite. Many of these biotite-bearing amphibolite bodies grade into biotite schist and may be metasomatic in origin. The mode of occurrence of hornblende and plagioclase in them resembles that of these minerals in the metasomatic quartz diorite and tonalite in the Headquarters quadrangle, only more hornblende occurs in the amphibolite.

GARNET AMPHIBOLITE

Garnet amphibolite occurs as sill-like bodies in the schist and in the anorthosite. Several bodies were found along the contacts of the anorthosite (pl. 1). The garnet amphibolite in the schist generally contains more biotite than that in the anorthosite. In most garnet amphibolite red garnet crystals are embedded in a dark fine- to medium-grained rock. A coarse-grained gneissic variety with abundant plagioclase was found locally in a sill next to the anorthosite along the upper drainage of Timber Creek 2 miles east of Orphan Point.

The mineralogy of the garnet amphibolite is fairly uniform. The major constituents are hornblende, garnet, plagioclase, and quartz; and common accessories are sphene and magnetite. Hornblende and plagioclase occur usually in equal amounts, but the amount of quartz and of garnet ranges from negligible to about 30 percent. Biotite is more abundant along the border zones than in the centers of the garnet amphibolite bodies.

Hornblende is of a common green variety with pleochroism X=light green, Y=green, Z=bluish green, and $Z\wedge c=20°$. Abundant round red garnet crystals are scattered throughout most amphibolite layers (fig. 19). Their diameter ranges from a few millimeters to about 10 cm, those with a diameter of ½ to 1 cm being most common. Euhedral garnet crystals showing dodecahedral faces and ranging from 3 to 4 cm in diameter were found in a few localities in the northwestern part of the area. Just west of the mapped area near Freezeout Lookout, these large crystals occur in a contact zone between garnet amphibolite and mica schist, together

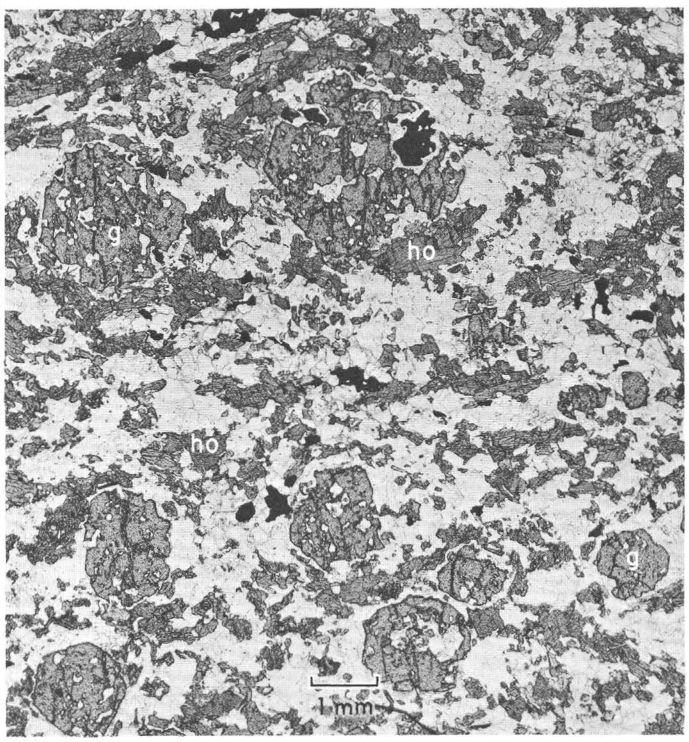

FIGURE 19.—Photomicrograph of garnet amphibolite on south slope of Goat Mountain (loc. 963). Garnet (g) crystals are round and contain inclusions of quartz. Hornblende (ho) prisms are oriented parallel to the foliation. Light-colored constituents are plagioclase and quartz; black is magnetite. Plane-polarized light.

with amphibole prisms, which are larger than those commonly found in the amphibole-bearing rocks of this region. All garnet crystals contain numerous inclusions of quartz, biotite, hornblende, and plagioclase. The index of refraction is $n=1.794 \pm 0.001$ to $n=1.797 \pm 0.001$, which, with a specific gravity of about 4.0, suggests that the garnet is almandite with about 20 percent pyrope.

Plagioclase is labradorite and occurs in anhedral grains that show polysynthetic twinning. In some occurrences, for example, in the garnet amphibolite 2 miles east of Orphan Point and in that 2 miles south of Stocking Meadow Lookout, spongelike grains of plagioclase include numerous small round quartz grains. Samples collected from these two localities contain more quartz than is normally present in the garnet amphibolite. Ilmenite grains, which are a common accessory

TABLE 10.—*Chemical analyses of garnet amphibolite in weight and cation percentage, their molecular norms and measured modes*

[Analyst, Faye H. Neuerburg, U.S. Geol. Survey]

Locality and specimen No.		1321		963	
Location		Southwest of Monumental Buttes.		Three-fourths mile southwest of Goat Mountain	
Constituent					
Conventional symbol	*Symbol rearranged for cation percent*	*Weight percent*	*Cation percent*	*Weight percent*	*Cation percent*
SiO_2		59.02	57.48	57.96	57.04
Al_2O_3	$AlO_{3/2}$	13.24	15.20	13.80	16.01
Fe_2O_3	$FeO_{3/2}$	1.23	.90	1.21	.89
FeO		11.90	9.69	10.82	8.90
MnO		.34	.28	.49	.41
MgO		5.03	7.30	3.83	5.62
CaO		4.25	4.43	5.69	6.00
Na_2O	$NaO_{1/2}$	1.57	2.96	2.68	3.20
K_2O	$KO_{1/2}$	.19	.23	.28	.35
TiO_2		1.85	1.36	1.93	1.43
P_2O_5	$PO_{5/2}$	.18	.15	.19	.15
CO_2		.01	.01	.00	
H_2O+		1.03	(3.34)	.73	(2.39)
H_2O-		.09		.09	
Total		99.93	99.99	99.70	100.00
	O		162.18		162.98
	OH		6.69		4.79
	Total anions		168.87		167.77
Molecular norm					
	Q		24.11		21.83
	Or		1.15		1.75
	Ab		14.80		16.00
	An		20.85		28.75
	C		3.67		.96
	En		14.60		11.24
	Fs		16.32		14.88
	Ap		.40		.40
	Il		2.72		2.86
	Mt		1.35		1.33
	Cc		.02		
	Total		99.99		100.00
Measured mode in volume percentage					
	Quartz		24		22
	Plagioclase		25		32
	Hornblende		28		32
	Garnet		20		12
	Biotite		1		
	Magnetite		1		2
	Total		100		100

in garnet amphibolite, are surrounded by sphene in these samples. Epidote in small grains occurs in some localities; for example, in locality 1018.

The texture of the garnet amphibolite is granoblastic or lepidoblastic, most of the hornblende prisms being parallel to the lineation. The grains of quartz are, as a rule, smaller than those of the plagioclase. A slight banding caused by accumulation of hornblende into thin discontinuous layers is common in the garnet amphibolite between Orphan Point and Goat Mountain.

Table 10 shows chemical analyses of a fine-grained quartz-bearing garnet amphibolite (no. 963) and of a coarse-grained garnet amphibolite (no. 1321). The higher content of silicon, iron, and magnesium, and a lesser quantity of calcium in no. 1321 is mineralogically seen in a larger amount of quartz and garnet and less plagioclase in this coarse-grained variety. The fine-grained variety is rich in hornblende and contains considerably more plagioclase than quartz (fig. 19).

ANORTHOSITE

OCCURRENCE AND DISTRIBUTION

Three large and several small bodies of anorthosite occur in the lower part of the Prichard formation in the Boehls Butte quadrangle and vicinity. The exposed parts of all the bodies are oblong, the large bodies ranging from 6 to 12 miles in length and 1½ to 3 miles in width. Fifteen of the small bodies—all concordant layerlike or sill-like bodies—are shown on the map (pl. 1), but in addition there are numerous small aggregates and lens-shaped bodies ranging from 1 to 5 m or more in length. These small bodies are in the schist surrounding the three largest bodies. No anorthosite was found outside the area shown on plate 1. However, a feldspathized kyanite-garnet-bearing layer, similar to the country rock of the anorthosite in the Boehls Butte quadrangle, was found in the schist of the Prichard formation just west of this quadrangle 3 miles northwest of Pinchot Butte.

The southernmost anorthosite body is well exposed for a distance of more than 9 miles along the North Fork of the Clearwater River. The Little North Fork traverses the western end of this body. The anorthosite along Cedar Creek is well exposed along the logging roads that follow Cedar Creek and its tributaries, but poorly exposed elsewhere. Most of the center of the northernmost anorthosite body between Goat Mountain and Widow Mountain is also poorly exposed. However, the outcrops are sufficient for determination of the major structure, and the white powdery soil and numerous blocks of anorthosite are a good indication of the underlying anorthosite. The anorthosite weathers more readily than the schist and quartzite and forms level areas in this mountainous country where relief is more than 3,000 feet.

STRUCTURE

STRUCTURAL LOCATION AND THICKNESS OF THE ANORTHOSITE BODIES

The three largest bodies of anorthosite are situated along crests of various anticlines (section, pl. 1). For a length of about 8 miles west of the mouth of Salmon Creek, the North Fork of the Clearwater River forms an anticlinal valley. The anorthosite occupies the bottom and lower part of the slopes of this valley. On the north slope of the valley the layers of schist and quartzite overlying the anorthosite dip 30° to 40° N.; on the south slope the dip in the overlying schist is 20° to 50° S. The schist layers turn around the nose of this anticline at the mouth of Salmon Creek where the axis plunges 15° to 40° E. On the west end of the body, near Boehls, the axis plunges gently to the west or northwest, suggesting the structure to be a gentle dome along a major anticline. The thickness of this body could not be determined. The contact of the anorthosite and schist along the north side of the river follows the 2,750-foot contour line, but on the south side of the river the anorthosite is exposed up to an altitude of 3,500 feet; the bottom of the river is 1,500 feet above sea level and consists of anorthosite. If the contact is considered to have a dip of about 30° N., a thickness of about 1,380 meters is exposed. The two other bodies have a sheetlike structure on the nose of a double-crested anticline; this permits the estimation of thickness. Between Monumental Buttes and Goat Mountain and along Rocky Run Creek, the average dip of anorthosite at 30° E. suggests that the thickness of this body is about one-half of its width as shown on the map; thus more than 2 km. This thickness is about one-eighth of the length of this body. The body along Cedar Creek ranges from about ½ to 1 km in thickness in its eastern end. The folded structure makes estimation of the thickness elsewhere impossible. For the small lens-shaped bodies of anorthosite that occur parallel to the bedding in the schist, the relation of the thickness to the length is about the same as, or less than, that of the large bodies.

CONTACTS

The most common country rock around the anorthosite bodies is a coarse-grained mica schist. In many places, where quartzite is mapped next to the anorthosite, a layer of schist, 2 to 5 m thick, separates these two rock types. Most contacts of the anorthosite with the schist are gradational. The contact line on the map was drawn between the first layer of the anorthosite, which consists of about 85 percent calcic plagioclase, and the feldspathized schist, which in places contains as much as 60 percent andesine or oligoclase. The contact line between the anorthosite and the schist seems concordant when studied in the outcrops; however, the map (pl. 1) suggests that the northernmost body cuts its country rocks slightly discordantly. Near Monumental Buttes, the anorthosite is overlain by a thin layer of schist and a thick layer of quartzite, whereas about 4 miles to the west, near Lund Creek, only a thin layer of quartzite is exposed above the anorthosite and the place where the major part of the quartzite should occur seems to be occupied by the anorthosite. Furthermore, the schist 1½ miles east of Orphan Point overlies the anorthosite, whereas the same schist layers seem to dip under the anorthosite farther toward the southeast. At its western end, this anorthosite body interfingers on a large scale with a fine- to medium-grained mica schist. The outcrops in this vicinity are few and small, but a study of the soil and numerous small blocks permits the tracing of the contact fairly accurately.

Anorthosite and a feldspar-rich schist inter finger on a small scale along a logging road following the West Fork of Cedar Creek (fig. 20). At a distance of about 5 m from the contact the schist contains about 20 percent biotite as a dark constituent. The light minerals are plagioclase and some quartz. Toward the anorthosite, the amount of biotite becomes less and muscovite appears between the plagioclase grains. In a zone that extends from 1 to 5 m outside the contact the percentages of biotite and muscovite are about 5 and 10, whereas next to the contact they are 2 and 10 respectively. The anorthosite is a very pure white plagioclase rock with very little chlorite as an additional constituent.

Fault contacts between massive coarse-grained anorthosite and the rocks of the Prichard formation occur south of Orphan Point and about 2 miles sonth

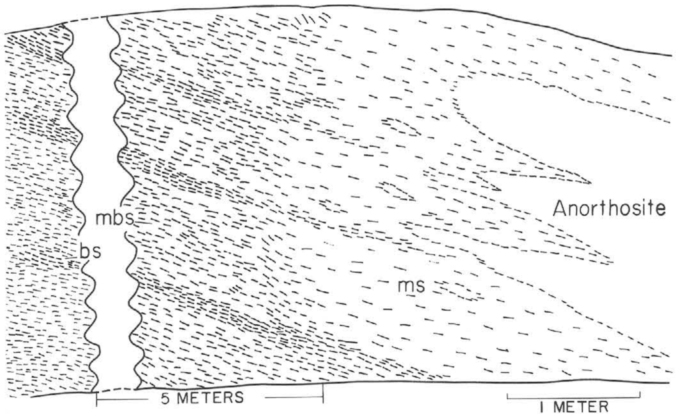

FIGURE 20.—Interfingering of the anorthosite and the schist along the West Fork of Cedar Creek. The rock (ms) next to the anorthosite consists of 88 percent plagioclase and 12 percent micas, mainly muscovite. In the next zone (mbs), 5 m wide, the amount of biotite is about 5 percent and that of muscovite 10 percent. Only biotite is found in the schist (bs) farther from the anorthosite and its amount is about 20 percent. Vertical roadcut facing south.

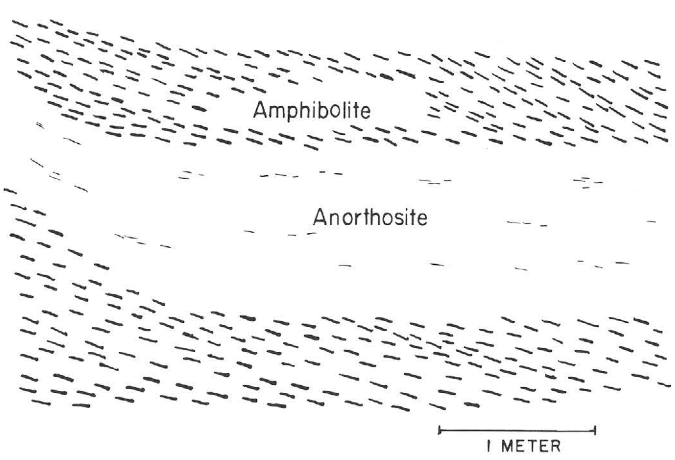

FIGURE 21.—A slightly discordant contact between the amphibolite and a small dikelike body of anorthosite west of the mouth of Cedar Creek. Vertical roadcut facing southwest.

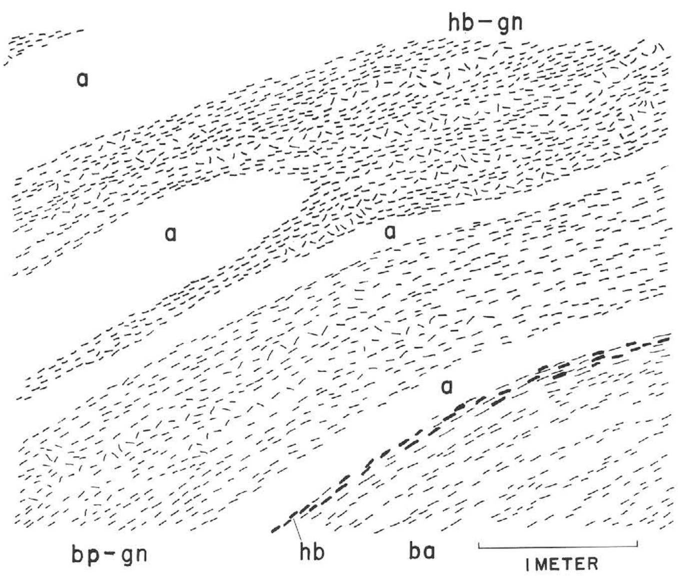

FIGURE 22.—Lens-shaped and layerlike bodies of anorthosite (a) in fine-grained biotite-hornblende gneiss (hb-gn) and in biotite-plagioclase gneiss (bp-gn). Vertical roadcut facing west about half a mile south of Boehls (loc. 1197). a, anorthosite; hb, coarse-grained hornblende-biotite rock; ba, biotite-rich anorthosite.

of Boehls. A strongly sheared plagioclase-rich rock suggesting a fault between schist and anorthosite was also found at the mouth of Lund Creek where a thin layer of schist is exposed between the anorthosite and the quartzite.

Most of the contacts between the amphibolite and anorthosite are concordant and fairly sharp. A slightly discordant contact between the anorthosite and the amphibolite was observed only near the mouth of Cedar Creek (fig. 21). Lens-shaped and layerlike bodies of anorthosite in a fine-grained biotite-hornblende gneiss are exposed along the logging road south of Boehls (fig. 22). The contact at the end of lenses is comparable with that at the end of the fingers in figure 20 except that no muscovite appears in this locality.

PLANAR STRUCTURES

About 50 percent of all anorthosite exposed is massive, but the other 50 percent locally shows a planar structure caused by an arrangement of dark constituents, biotite or hornblende, along discontinuous planes. The center and most of the western part of the northernmost body and a part of the body at Cedar Creek consist of massive coarse-grained anorthosite in which constituent minerals are distributed and oriented at random. In the southernmost large body, in which only about 30 percent of the exposures consist of massive anorthosite, planar structure is common along the borders and locally occurs in the center also. In all bodies exposed, planar structure generally is more prevalent along the borders than in the centers, but exceptions to this generalization are not rare; for example, the anorthosite between Goat Mountain and Widow Mountain locally preserves its massive texture up to the contact, and an excellent planar structure occurs in several outcrops in the centers of the two large southern bodies.

Differential weathering brings out another planar structure that is common in all small bodies and along borders of the large bodies. This structure is a thin lamination; the more deeply weathered bytownite laminae, 1 to 5 mm thick, alternate with the less weathered layers that consist mainly of andesine with some bytownite and are 2 to 10 mm thick. Also this structure is more common along the borders than in the centers of the bodies.

Most of the outcrops of anorthosite along the North Fork of the Clearwater River, along the Little North Fork, and along Cedar Creek show a beddinglike structure (fig. 23). This structure is caused by accumulation of constituent minerals like muscovite, biotite, kyanite, and hornblende into thin parallel or subparallel layers. In some localities along Cedar Creek, the biotite-bearing layers are paper thin and occur at regular intervals, giving a laminated structure to the anorthosite. The anorthosite between the biotite laminae is a white coarse-grained variety that consists of pure plagioclase. Along the North Fork of Clearwater River and along the Little North Fork, the layering is more irregular, and sheetlike inclusions of coarse-grained muscovite-biotite schist with the aluminum silicates—kyanite, andalusite, and sillimanite—are common. Small lenticles and scattered grains of plagioclase occur in the included schist. In some dark layers on both sides of the river west of Larson Cabin and along the road between Goat Mountain and Monumental Buttes hornblende is found with aluminum silicates. The

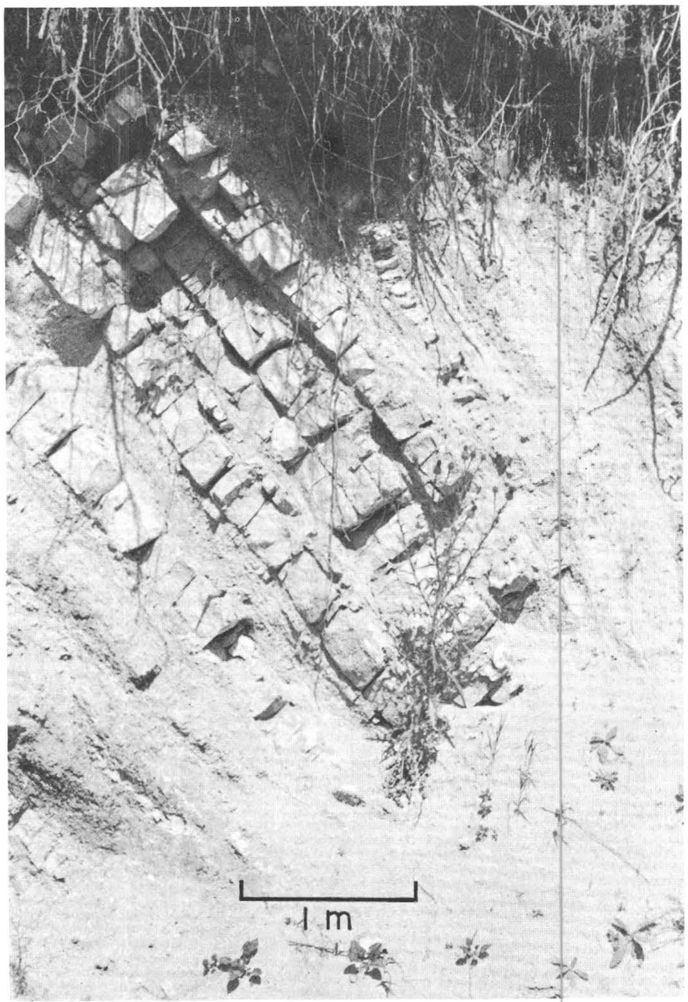

FIGURE 23.—Layering in anorthosite in a roadcut facing southeast on the north side of the North Fork of the Clearwater River just west of Larson Cabin. Thick layers that consist of almost pure plagioclase are less weathered than the thin hornblende bearing more schistose layers.

layering in these localities is very regular, the dark layers range from 2 to 5 cm in thickness and the plagioclase layers from 5 to 20 cm in thickness; the outcrops resemble bedded marble when seen from a distance (fig. 23).

In the northernmost anorthosite body biotite- and muscovite-bearing layers are found locally, but a layering caused by accumulation of hornblende into thin sheets is more common, especially in the thinner parts of the body south of Goat Mountain. The thickness of the hornblende-bearing layers ranges from 2 mm to 5 cm and that of the interbanded plagioclase layers from 1 to 10 cm. Some of the hornblende-bearing layers are thicker and resemble amphibolite. Coarse-grained massive anorthosite consisting of almost pure plagioclase occurs as layers 2 to 10 m thick with all layered varieties.

The planar structure is always parallel to the bedding of the surrounding rocks. This orientation is especially noticeable in the small bodies that consist mainly of fine- to medium-grained banded anorthosite.

FOLDING OF PLANAR STRUCTURE

Many outcrops of anorthosite along the North Fork of Clearwater River show round folds (fig. 24). Folding on a larger scale becomes evident when the orientation of planar structure is measured with a compass. It was possible to do such measuring only along the North Fork of Clearwater River, along the Little North Fork, and along Cedar Creek. The anorthosite between Goat Mountain and Widow Mountain is too poorly exposed to allow a detailed determination of structure. The numerous boulders, many of which measure 3 m and more in diameter, consist of massive anorthosite. The fold axis could be measured in several places in the two southern bodies and was found to be parallel to the fold axis in the surrounding schist and quartzite.

An intense minor wrinkling of a thin layering is common in some anorthosite blocks near the contact 1½ miles south of Orphan Point. No outcrops occur at this locality (no. 1744), and therefore the orientation of the axis of the wrinkling could not be determined. The neighboring schist shows a wrinkling around the fold axis, which plunges 15° E. Many good outcrops between this locality and Orphan Point consist of massive anorthosite.

LINEAR STRUCTURE

Linear structure is rare in the anorthosite. Only some of the contact zones of small bodies of banded anorthosite and some of the hornblende-bearing layers in the thin southern part of the northernmost large body

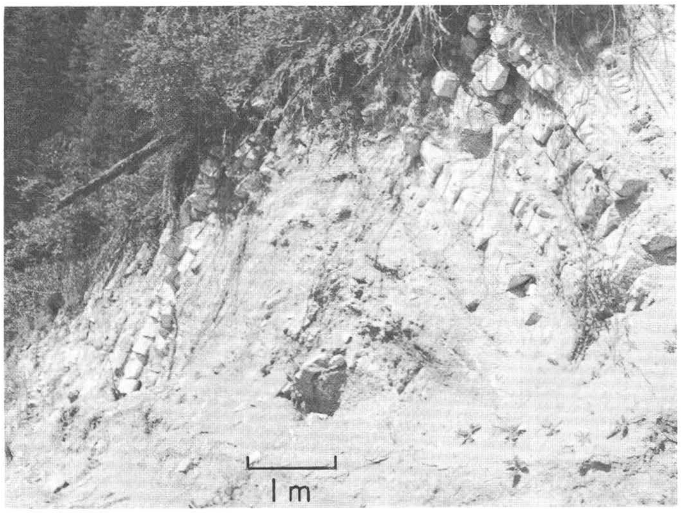

FIGURE 24.—A fold in the same layered anorthosite as shown in figure 23. The axis of folding is plunging gently toward the observer.

show a crude lineation. This structure is caused by a parallel orientation of the hornblende prisms and elongated flakes or groups of small flakes of biotite. The lineation is parallel to the corresponding structure in the surrounding country rock.

INCLUSIONS

Inclusions of schist are extremely common in the anorthosite that shows a beddinglike structure, but rare in the massive variety. Inclusions of amphibolite were found at only a few localities. Quartzite and lime-silicate rock are included in anorthosite between the forks of Cedar Creek.

The schist inclusions are oriented with their longest dimension parallel to the planar or linear structure of the anorthosite. Their size is highly variable; the sheetlike inclusions range from a few centimeters to 100 m or more in length. The smallest inclusions are only 1 to 2 mm thick, but the larger ones are 1 to 10 m thick. Generally all these inclusions are rich in aluminum silicates, and plagioclase is their main light constituent. Thus, their mineral content is very similar to that of the schist that occurs next to the anorthosite bodies.

A few large bodies of amphibolite are included in the three largest bodies of anorthosite as shown on the map (pl. 1). Small inclusions of amphibolite were found in an anorthosite boulder along the road at Goat Mountain.

PETROGRAPHIC DESCRIPTION

There is a considerable variation in the mineral content, texture, and chemical composition of the anorthosite in individual bodies. The three largest bodies are therefore described separately. The anorthosite in the small bodies differs from that in the large bodies in several respects.

ANORTHOSITE ALONG THE NORTH FORK OF THE CLEARWATER RIVER

The southernmost of the three large bodies of anorthosite lies along the North Fork and along the Little North Fork of the Clearwater River. Most outcrops consist of coarse-grained anorthosite that shows a beddinglike structure. A massive variety occurs only in some localities south of Boehls and along the river in the middle of the body, where it constitutes about one third of the entire body. The anorthosite with discontinuous layers rich in micaceous minerals has a coarsely granular texture owing to the roundness of the plagioclase grains. Small flakes of biotite and muscovite are common between the large plagioclase grains. The anorthosite weathers to chalky white powder, and the outcrops are white because they are beginning to weather. The fresh anorthosite is light bluish or bluish gray, rarely light brownish.

LIGHT-COLORED LAYERS

The white to light-grayish layers consist of about 97 percent plagioclase with very little quartz, muscovite, biotite, chlorite, sphene, magnetite, ilmenite, rutile, epidote, and occasional kyanite, andalusite, sillimanite, garnet, cordierite, hornblende, and orthoclase. The amount of these additional constituents rarely exceeds 3 percent except in the coarsely granular layers where the amount of micas is larger, ranging from 5 to 10 percent. Small masses of laumontite were found near Boehls; a zeolite, probably also laumontite, was found in one thin section studied (no. 611).

As a rule, two varieties of plagioclase, bytownite and andesine, are present in the anorthosite. The composition of twinned plagioclase was determined by universal stage and use of Nikitin's curves. The results were verified and the untwinned grains measured by immersion method. Bytownite—usually An_{85}—occurs in small grains between the large round andesine grains and also as numerous tiny platelike inclusions in the andesine. The composition of the andesine is An_{43} to An_{45}, but An_{32}, An_{36}, and An_{47} were each measured by universal stage in one specimen. Both types of plagioclase are twinned but not zoned (fig. 25). The only exception is found in a weak reversed zoning in the

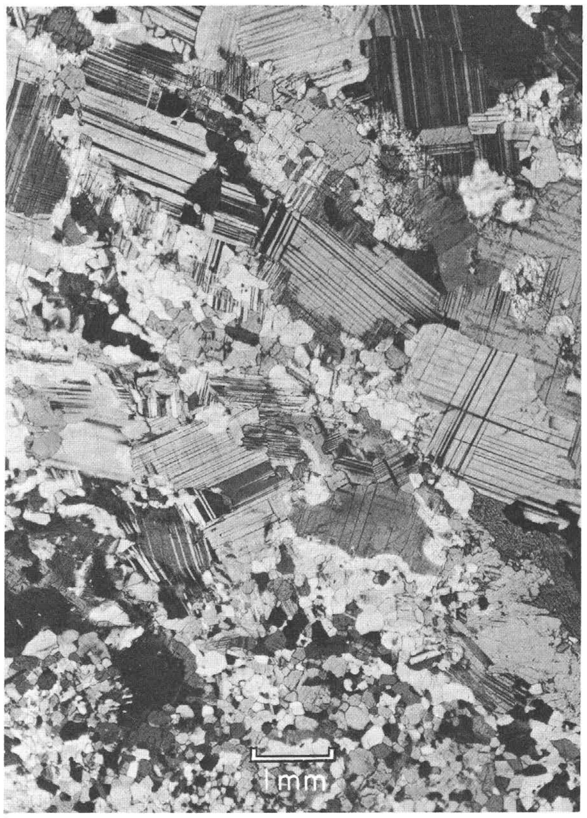

FIGURE 25. Photomicrograph of a light-colored layer in anorthosite similar to the one shown in figures 23 and 24. The large grains are andesine and the small ones bytownite. (Loc. 611)

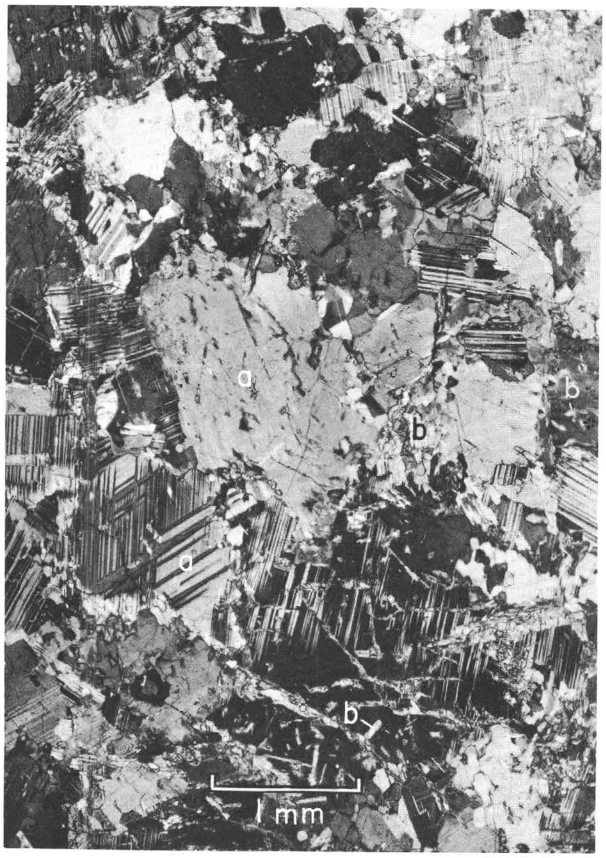

FIGURE 26. Photomicrograph of anorthosite 1½ miles east of Larson Cabin on the north side of the North Fork of the Clearwater River. (Loc. 603.) Large twinned grains (a) are andesine. Inclusions and small grains (b) are bytownite. Crossed nicols.

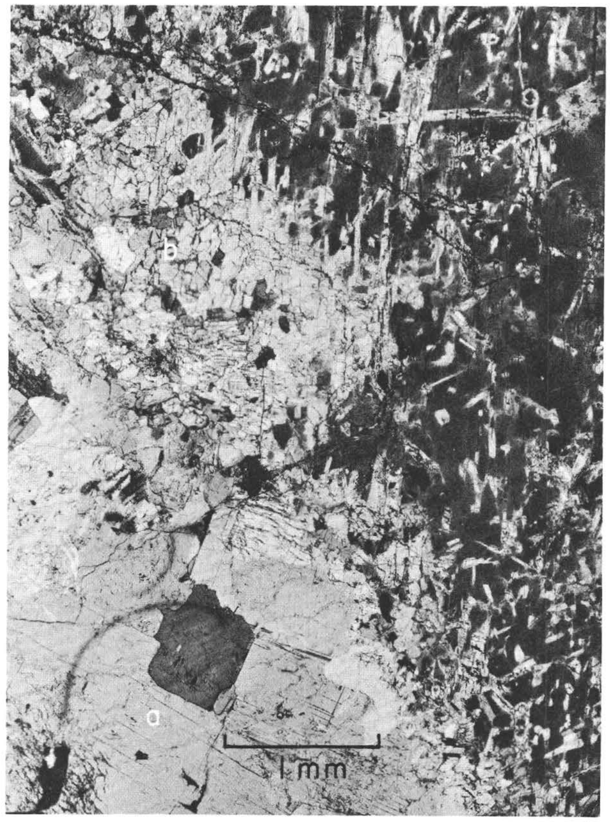

FIGURE 27. Photomicrograph of anorthosite 1¼ miles east of Larson Cabin on the south side of the North Fork of the Clearwater River. The large grains on the upper right and the lower left corner are andesine (a). Small grains between these two large grains and the inclusions in the upper right corner are bytownite (b). (Loc. 605)

andesine in specimen no. 600. The relation between the types of plagioclase is illustrated in the photomicrographs in Figures 26 and 27. In Fig. 26 the large grains (a) that show complex twinnings consist of An_{43}, and the platelike inclusions and small grains (b) consist of An_{85}. Larger bytownite grains show uneven extinction resembling the extinction in the spots occupied by groups of small grains. The long dimension of most bytownite inclusions in andesine is parallel to some crystallographic face of the host but some inclusions have a random shape orientation. Each group of inclusions in one individual andesine grain has a contemporaneous extinction and a common cleavage (010), which together indicate that the inclusions have the same crystallographic orientation in spite of a random shape orientation. The small bytownite grains between the andesine grains are oriented at random.

Figure 27 shows the contact between a large round andesine grain (a) and a group of small bytownite grains (b). The light-colored lamellae in the dark andesine are bytownite. Platelike extensions from the bytownite grains extend into the andesine along its border. The bytownite grains adjacent to the andesine grain are larger than those that commonly occur between the andesine grains, and they have an extinction that is parallel to the extinction of the bytownite lamellae in the andesine. A ghostlike mosaic texture, similar to the one found in many larger bytownite grains, is common in this bytownite adjacent to the andesine and suggests that several small grains recrystallized to form a larger grain.

In some thin sections made of layers that contain aluminum silicates small remnants of andalusite found in the centers of several bytownite inclusions suggest that at least a part of the bytownite crystallized replacing the andalusite. In these layers chlorite is the most common dark constituent and is probably an alteration product after biotite. The minor constituents occur as small grains between the plagioclase grains or are included in the andesine. The micaceous minerals are usually oriented parallel to the planar structure, but the small flakes included in the andesine are either oriented at random or parallel the cleavage of the andesine. Small light-colored grains of rutile are included parallel to the cleavage in the chlorite. Brown rutile occurs as larger grains with ilmenite or is included in ilmenite; (for example, specimen nos. 599 and 600). In some other specimens, as in no. 613, ilmenite is surrounded by sphene.

In some layers of anorthosite along the North Fork of the Clearwater River small scattered grains or groups of grains of kyanite, andalusite, and sillimanite occur as major additional constituents. Numerous bluish kyanite prisms ranging from 1 to 2 cm in length and showing $\alpha=1.1712\pm0.001$, $\beta=1.720\pm0.001$, and $\gamma=1.728\pm0.001$ were found southwest of Larson Cabin (loc. 607). In this locality chlorite, with some rutile and hornblende, occurs with kyanite (fig. 28). Chlorite is uniaxial and positive, and shows $\gamma=1.585\pm0.001$, suggesting it to be clinochlore. Hornblende grains are few and small and show pleochroism Z=blue green, Y=green, X=light yellowish green.

Near Boehls, anorthosite layers, light gray to white, and 10 to 100 cm thick, are interbedded with thin layers that contain biotite, cordierite, and garnet and with some others that contain hornblende as the dark constituent. Accumulations of tourmaline as blue radiating crystals and masses of tiny dark-green prisms were found on the east side of Breakfast Creek near the bridge at Boehls. The green prisms have $\epsilon=1.620$ to 1.623

FIGURE 28.—Photomicrograph of kyanite (ky) and chlorite (chl) in layered anorthosite half a mile southwest of Larson Cabin (loc. 607). pla =plagioclase. Plane-polarized light.

±0.001, $\omega=1.649$ to $1.652+0.001$, and $\omega-\epsilon$ $0.029=\pm0.001$; these data suggest that this tourmaline consists of 30 percent iron compound, schorlite, and 70 percent magnesium compound, dravite. In the same locality euhedral to subhedral prisms of laumontite with $\alpha=1.504\pm0.001$, $\gamma=1.516\pm0.001$, and $Z\wedge c=44°$ form small accumulations and line the walls of vugs and cracks in the anorthosite.

On the east side of the Little North Fork of the Clearwater River south of Boehls, layers of fine-grained biotite-hornblende gneiss with pegmatitic veinlets and lenticles alternate with layers and lens-shaped bodies of anorthosite (fig. 22). The anorthosite contains light greenish-gray fine-grained granular layers and bluish-gray gneissic hornblende-bearing layers. The fine-grained layers are granoblastic and consist of polygonal grains of plagioclase with some epidote and chlorite. The gneissic layers show a fine banding in weathered surface; pinkish laminae about 1 mm thick alternate with white laminae that are from 2 to 5 mm thick. Thin sections show that the pinkish laminae consist of small grains of bytownite that have been altered to kaolin along their cracks. Most of the cracks are subparallel to the layering. The white to grayish laminae consist of large grains of a more sodic plagioclase, which looks fresh and has no cracks. Hornblende prisms are oriented parallel to the layering. Some sericite, chlorite, epidote, sphene, and ilmenite-magnetite occur as additional constituents.

The sill-like body of coarse-grained anorthosite that occurs in amphibolite just west of the mouth of Cedar Creek (fig. 21) is almost pure plagioclase, mottled white and gray, and has only a few streaks of biotite, in part altered to chlorite.

Chemical analysis of a coarse-grained white layer on the south side of the North Fork of the Clearwater River south of Larson Cabin (table 11, no. 611) shows that these layers contain less than 1 percent combined iron and magnesium. The amounts of aluminum and calcium are high, and there is more sodium than potassium, as would be expected in normal anorthosite.

DARK LAYERS

The dark layers constitute 10 to 20 percent of the total amount of the layered anorthosite exposed. The minerals constituting the dark layers are the same as those of the light-colored layers, but their quantities vary greatly. Some of the dark layers are rich in biotite, some in biotite and muscovite, and still others in hornblende. Aluminum silicates, especially kyanite, are far more abundant in dark layers than in light-colored layers. Generally, the micaceous layers are more irregular in their shape and distribution than the

TABLE 11.—*Chemical analyses of anorthosite in weight and cation percentage, molecular norms, and modes*

Locality and Specimen no.	1747 [1]	949 [2]	1016 [2]	1015 [2]	611 [3]	608 [4]
Rock type	Gabbroic anorthosite.	Anorthosite	Anorthosite	Anorthosite	Anorthosite	Hornblende-kyanite-bearing layer in anorthosite.
Location	2 miles southeast of Orphan Point.	1.9 miles north of junction to Stocking Meadow Lookout.	South of Monumental Buttes.	South of Monumental Buttes.	North Fork of Clearwater River one-fourth mile southwest of Larson Cabin.	North Fork of Clearwater River one-fourth mile southwest of Larson Cabin.
Weight percent						
SiO_2	39.88	47.06	52.70	50.54	53.47	46.68
Al_2O_3	29.03	32.61	28.84	26.82	29.08	27.49
Fe_2O_3	2.14	.18	.03	.26	.22	1.04
FeO	2.34	.65	.50	2.60	.37	4.50
MnO	.05	.01	.01	.04	.01	.07
MgO	2.33	.28	.59	2.58	.13	5.70
CaO	20.59	16.03	11.73	11.67	11.63	7.98
Na_2O	.54	1.97	4.41	3.51	4.65	2.73
K_2O	.21	.29	.28	.40	.06	.53
TiO_2	.10	.05	.08	.09	.08	.12
P_2O_5	.01	.03	.01	.01	.04	.04
CO_2	.01	.00	.00	.01	.00	.00
H_2O+	2.05	1.00	.66	1.58	.46	2.66
H_2O-	.27	.07	.06	.06	.03	.41
Total	99.55	100.23	99.90	100.17	100.23	99.95
Cation percent						
SiO_2	37.26	43.57	48.11	46.67	48.59	43.71
$AlO_{3/2}$	31.97	35.58	31.02	29.19	31.14	30.33
$FeO_{3/2}$	1.50	.13	.02	.18	.15	.73
FeO	1.83	.50	.38	2.01	.28	3.52
MnO	.04	.01	.01	.03	.01	.06
MgO	3.24	.38	.80	3.55	.18	7.95
CaO	22.84	15.89	11.46	11.54	11.31	8.00
$NaO_{1/2}$	.98	3.54	7.80	6.28	8.19	4.96
$KO_{1/2}$	.25	.35	.33	.47	.07	.63
TiO_2	.07	.03	.06	.06	.05	.08
$PO_{5/2}$	.01	.02	.01	.01	.03	.03
CO_2	.01	.00	--	.01	.00	--
H_2O	(3.19)	(3.09)	(2.01)	(4.86)	(0.25)	(8.30)
	100.00	100.00	100.00	100.00	100.00	100.00
O	150.30	156.45	157.64	153.21	159.96	148.27
OH	6.39	6.18	4.02	9.72	.50	16.60
Total anions	156.69	162.63	161.66	162.93	160.46	164.87
Molecular norm						
Q	--	--	--	--	0.95	--
Or	--	1.75	1.65	2.35	.35	3.15
Ab	--	17.25	39.00	31.40	40.95	24.80
An	74.95	79.23	57.20	56.10	56.30	39.75
Ne	2.94	.27	--	--	--	--
Kp	.75	--	--	--	--	--
C	.76	--	.01	--	.36	8.84
Wo	--	.02	--	.58	--	--
Cs	11.73	--	--	--	--	--
En	--	--	.80	2.56	.36	15.76
Fs	--	--	.32	1.36	.32	6.22
Fo	4.86	.57	.60	3.40	--	.11
Fa	1.57	.60	.24	1.81	--	.04
Ap	.03	.05	.03	.03	.08	.08
Il	.14	.06	.12	.12	.10	.16
Mt	2.25	.20	.03	.27	.23	1.09
Cc	.02	--	--	.02	--	--
Total	100.00	100.00	100.00	100.00	100.00	100.00
Molecular mode calculated from cation percent						
Quartz		--	--	--	1.17	0.42
Plagioclase		An_{82} 95.33	An_{60} 96.20	An_{63} 80.00	An_{58} 96.50	An_{47} 35.50
Orthoclase		1.75	1.65	2.35	.35	2.35
Chlorite		1.81	2.93	5.29	--	2.17
Hornblende		--	--	14.33	1.23	48.17
Kyanite		--	--	--	.44	17.85
Epidote		1.31	--	--	--	--
Apatite		.05	.03	.03	.08	--
Ilmenite		.06	--	.12	.10	--
Magnetite		.20	.03	.27	.28	.13
Calcite		--	--	.02	--	--
Total		100.51	100.84	102.41	100.15	106.59

[1] Faye H. Neuerburg, analyst, U.S. Geol. Survey.
[2] Lois D. Trumbull, analyst, U.S. Geol. Survey.
[3] Ruth H. Stokes, analyst, U.S. Geol. Survey.
[4] Robert N. Eccher, analyst, U.S. Geol. Survey.

hornblende-bearing layers, and their mineral content varies more. In many outcrops of micaceous anorthosite, biotite-bearing layers, 1 to 3 cm thick, and muscovite-rich layers of the same thickness alternate with layers that consist of plagioclase, some biotite, and occasional chlorite. The plagioclase-rich layers are 5 to 20 cm thick and have an appearance similar to that of the feldspathized schist along the border zones of the anorthosite bodies. Only one kind of plagioclase (An_{45}) is found in some layers, but the others contain also bytownite. The andesine in all layers occurs as large rounded grains. Biotite, chlorite, kyanite, and andalusite are interstitial. Some tourmaline and apatite occur as accessories. The mica-rich layers contain abundant large flakes or segregations of large flakes of either biotite or muscovite, or of both. Along the Little North Fork of the Clearwater River opposite Boehls, a layer of biotite about 30 cm or more in thickness is exposed near the contact of anorthosite with feldspathized schist. This layer consists of about 90 percent biotite with only a few white grains and small clusters of plagioclase embedded between the dark large flakes. The biotite is greenish, and the index of refraction, $\gamma = 1.623 \pm 0.001$, indicates that this biotite is richer in iron than the greenish biotite in the cordierite gneiss nearby (Hietanen, 1956, table 2).

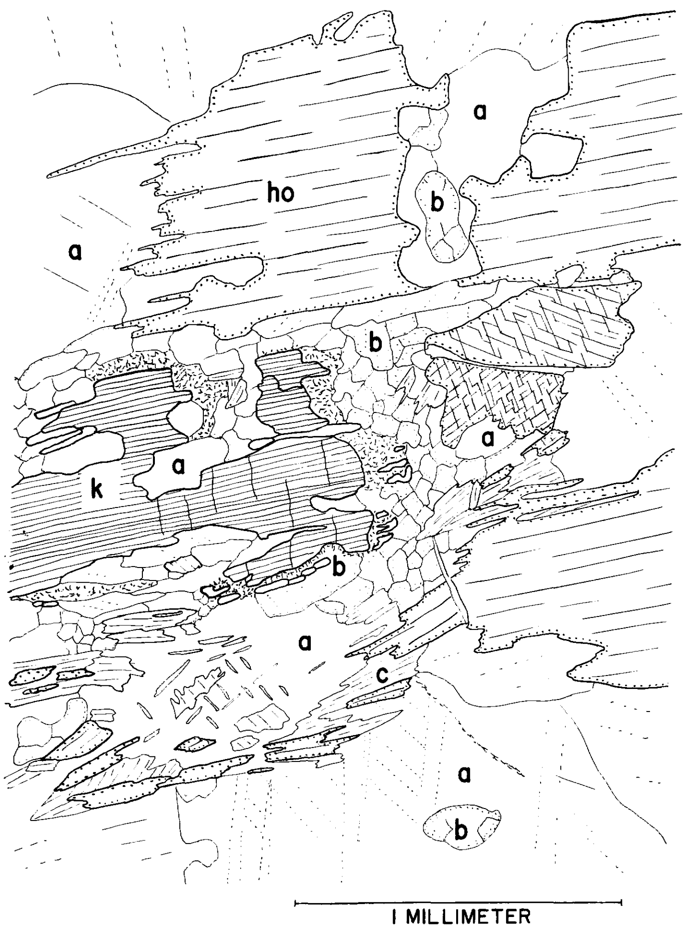

FIGURE 29.—A camera lucida drawing of a kyanite- and hornblende-bearing layer in anorthosite. Small grains of bytownite (b) occur between the kyanite (k) and the hornblende (ho). a, andesine; c, chlorite. Location 608, half a mile southwest of Larson Cabin.

Along the North Fork of the Clearwater River west of Larson Cabin, the dark hornblende-bearing layers, ranging from 2 to 10 cm in thickness, alternate with thicker layers that consist of coarse-grained white anorthosite. Differential weathering is typical of these outcrops, the hornblende-bearing layers being less resistant. The structure is more gneissic than that in the coarse-grained pure anorthosite, owing to the orientation of hornblende crystals subparallel to the planar structure.

An extraordinary petrologic feature of these dark layers is the occurrence together of kyanite and hornblende (fig. 29). The kyanite occurs in small bluish prisms, 1 to 2 cm, long showing $\alpha = 1.713 \pm 0.001$, $\beta = 1.722 \pm 0.001$, $\gamma = 1.728 \pm 0.001$, the indices commonly found for kyanite. The hornblende is dark green in hand specimen but very light greenish in thin section. It shows a weak pleochroism X=yellowish, Y=light green, Z=light bluish green. The indices of refraction are $\alpha = 1.640 \pm 0.001$, $\beta = 1.655 \pm 0.001$, $\gamma = 1.669 \pm 0.001$, $2V = 90°$, and $Z \wedge c = 15°$. The hornblende was separated by means of heavy liquids from specimen no. 608. A fraction having the specific gravity of 3.16 ± 0.02 and containing only a few tiny grains of magnetite and quartz was analyzed chemically (table 12). The result shows that this hornblende is of a common variety in which the percentages of iron, magnesium, and calcium are practically equal. The formula can be expressed as follows:

$$H_{2.17}(Ca_{1.70}Na_{0.43}K_{0.06})_{\Sigma=2.19}(Mg_{2.55}Fe_{1.28}Mn_{0.02}Ti_{0.03}P_{0.01})_{\Sigma=3.89}(Al_{1.04}Fe_{0.22})_{\Sigma=1.26}(Si_{6.3}Al_{1.7})_{\Sigma=8.0}O_{24}.$$

The percentage of Al_2O_3 is fairly high, as would be expected in a rock rich in aluminum.

Kyanite and hornblende are usually considered to be incompatible. Garnet or cordierite or both should appear instead of hornblende. In the dark layers under discussion the relations between the hornblende and kyanite fail to give definite evidence as to whether or not these two minerals crystallized in a stable equilibrium. Most of the hornblende is fairly fresh, although some alteration to chlorite was observed; and some of the kyanite crystals are in part rimmed by sericite. Both of these alterations however are common in the anorthosite and are due to a late hydrothermal activity. Two types of plagioclase, andesine (An_{43}) and bytownite

TABLE 12.—*Chemical analysis of hornblende (no. 608a) in anorthosite along the North Fork of Clearwater River one-fourth mile southwest of Larson Cabin* (loc. 608)

[Analyst, Robert N. Eccher, U.S. Geol. Survey]

Constituents	Weight percent	Molecular equivalent	Number of atoms		
SiO_2	43.70	7,276	Si	6.30	8.00 (Si, Al)
Al_2O_3	16.11	1,580	Al	1.70	
Fe_2O_3	2.02	126	Al	1.04	1.26 (Al, Fe^{+3})
FeO	10.60	1,475	Fe^{+3}	.22	
MnO	.15	21	Mg	2.55	3.89 (Mg, Fe^{+2}, Mn, Ti, P)
MgO	11.86	2,941	Fe^{+2}	1.28	
CaO	11.02	1,965	Mn	.02	
Na_2O	1.53	247	Ti	.03	
K_2O	.35	37	P	.01	
TiO_2	.27	34	Ca	1.70	2.19 (Ca, Na, K)
P_2O_5	.07	5	Na	.43	
H_2O+	2.26	1,254	K	.06	
H_2O-	.10	--------	H	2.17	
			O	24.0	
	100.04	--------			

Sp gr 3.16 ± 0.02

(An_{85}), also occur in these dark layers. The andesine grains are large and fresh, but the bytownite grains are small and have some cracks that are filled by chlorite and sericite. Commonly the bytownite occurs next to the kyanite. A few small grains of andalusite, biotite, rutile, and ilmenite occur as additional constituents.

A chemical analysis (table 11, no. 608) shows that these dark layers are considerably richer in iron and magnesium than the light-colored layers, but the amounts of aluminum, calcium, and sodium are smaller.

MASSIVE ANORTHOSITE

Coarse-grained massive anorthosite occurs locally east of Larson Cabin and south of Boehls. It resembles the light-colored layers in the layered variety and may be thicker layers of this light type. Along the North Fork of Clearwater River and south of Boehls the anorthosite is white or bluish gray. On the south side of the Little North Fork of Clearwater River just east of Boehls, a light brownish variety with exceptionally large plagioclase grains is exposed. The individual grains of plagioclase in this rock are as much as 3 cm in diameter; elsewhere they range only from 1 to 5 mm in diameter.

Thin sections show that two types of plagioclase occur also in the massive anorthosite; the amount of bytownite, however, is less than it is in the layered part of the rock. The outcrop of brownish very coarse grained massive anorthosite east of Boehls consists of labradorite with bluish-gray hornblende and some chlorite, biotite, and epidote. The labradorite grains are rounded, have interlocking borders, and contain numerous tiny platelike inclusions of more calcic plagioclase. As in the other varieties, all bytownite inclusions in each individual labradorite grain show a parallel extinction whose direction differs from that of the host mineral. The hornblende occurs in clusters of small elongated grains which in places have their longest dimensions perpendicular to the boundaries of the labradorite grains. Tiny biotite flakes are as scattered inclusions in labradorite. Chlorite is usually adjacent to the hornblende. The amount of dark constituents, hornblende and biotite ranges from 1 to 5 percent.

Along the North Fork of the Clearwater River, the most common dark constituent is biotite, which occurs in small lenticular clusters of small grains and constitutes 2 to 5 percent of the rock. These clusters are scattered throughout the rock and their longest dimension is parallel to the planar structure in the layered rock nearby. Near Boehls the most common dark constituent is hornblende, which shows a tendency to cluster into irregularly shaped dark spots. The additional constituents are the same as those that occur in the light-colored layers. A few grains of pyrrhotite surrounded by magnetite were found in some thin sections studied.

FINE-GRAINED GRANOBLASTIC VARIETY

The outcrops along the Little North Fork of the Clearwater River, from half a mile to a mile south of Boehls, consist of heterogeneous fine-grained granular white to light-gray to greenish rock, which locally grades into layered hornblende-bearing or micaceous gneiss and in which there is only one kind of plagioclase (An_{55} or An_{85}). The white portions of this rock are homogeneous, but the light-gray and greenish parts contain schlieren and spots of gray or greenish material. Thin-section study shows that the white portions consist of pure plagioclase and that the darker portions contain biotite or epidote, or, more rarely, hornblende. The texture is granoblastic, with plagioclase (An_{54-55}) occurring in polygonal grains, some of which show a weak reversed zoning. In the greenish parts of the rock the epidote is found in small grains between the plagioclase grains. On the west side of the Little North Fork south of Boehls, many fine-grained patches consist of a myrmekite-like intergrowth of bytownite (An_{85}) and epidote (as at loc. 632). Tiny grains of epidote and small hornblende prisms are scattered throughout this anorthosite, the outcrop of which contains shadowy remnants of diopside-plagioclase gneiss. In the light-gray anorthosite south of this locality, biotite occurs in varying quantities and forms small dark-gray spots and schlieren in a white to light-gray plagioclase (An_{55}) rock (fig. 30). The schlieren are only from 10 to 50 cm long and from 1 to 5 mm thick, and there is every transition from the biotite-plagioclase quartz rock in the center of the schlieren to about 99 percent plagioclase in the white portions of the outcrop.

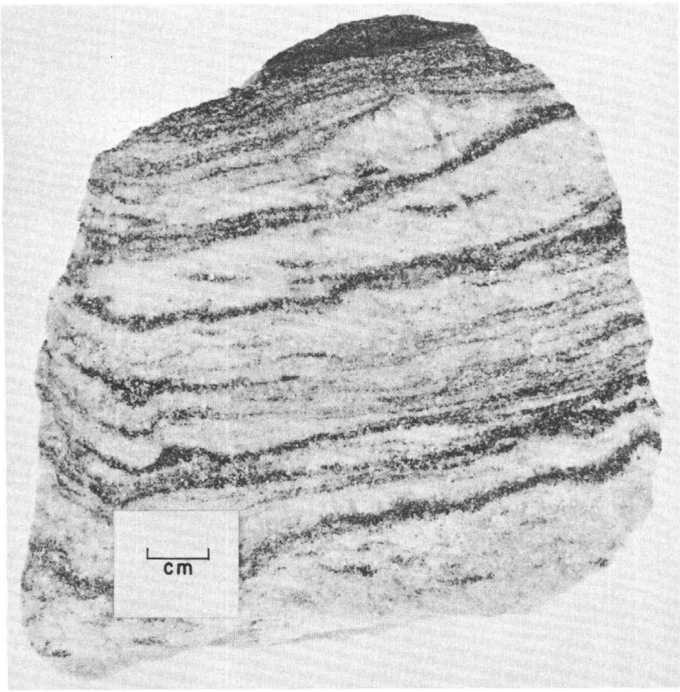

FIGURE 30.—Photomicrograph of dark biotite-rich schlieren in white granular anorthositic rock about a mile south of Boehls (loc. 1299). The dark layers consist of plagioclase, biotite, and quartz in about equal amounts. The white layers consist of 98 percent plagioclase (An_{45}) with some biotite and some small round grains of quartz included in plagioclase.

FIGURE 31.—Photomicrograph of phlogopite-andesine rock from the border zone of the anorthosite south of Boehls (loc. 630). phl, phlogopite; a, andesine. Crossed nicols.

A thick layer of white pure labradorite (An_{55})anorthosite with a sugary granular texture occurs just north of the granular anorthosite with ghostlike remnants of diopside-plagioclase gneiss. Only a few small quartz grains were found in this white portion of the rock. Farther to the north a plagioclase-rich gneiss, in which muscovite, phlogopite, and hornblende-bearing layers alternate, is included in anorthosite (fig. 31). Megascopically these layers resemble the gneissic and micaceous layers in the Belt series but contain far more plagioclase and less quartz. Moreover, no distinct bedding but only schlieren and ghostlike remnants of schistose and gneissic rocks occur in the anorthositic rock. All thin sections made of these layers of granoblastic plagioclase rock contain only one kind of plagioclase, mostly An_{55} but some An_{85}. These rocks are comparable with the bytownite rocks described in the following section.

ANORTHOSITE ALONG CEDAR CREEK

About 70 percent of the anorthosite in the middlemost large body that is exposed along Cedar Creek shows a layering or a banding, but the outcrops near the forks of Cedar Creek and locally in the north-central part of the body are massive and coarse grained. A very fine grained variety consisting of almost pure bytownite is exposed along the tributaries of the West Fork of Cedar Creek. Blocks of similar bytownite rock were found west of Cedar Creek along the road leading from Boehls to Goat Mountain.

LAYERED ANORTHOSITE

In the northern part of the body exposed along the tributaries of Cedar Creek, most of the anorthosite is fine to medium grained, white or light bluish gray, and contains dark streaks or thin layers rich in hornblende or rich in hornblende, chlorite, and biotite. These hornblende-bearing layers are 1 to 2 mm thick and discontinuous. Study under the microscope shows that they consist of andesine, bytownite, hornblende, and chlorite. In some specimens many long grains, or groups of grains of epidote, are included in chlorite parallel to its cleavage. Small grains of sphene, apatite, and magnetite occur as accessories.

The light-colored layers consist of andesine and bytownite. The andesine occurs as larger grains, most of which are elongated parallel to the layering; the bytownite occurs as small grains between the thin andesine layers and also forms platelike inclusions in andesine. On the weathered surface this thin layering is visible as fine striations because of the differential weathering of andesine and bytownite. This striation is similar to that found in the hornblende-bearing layers near Boehls. The layers consisting of bytownite

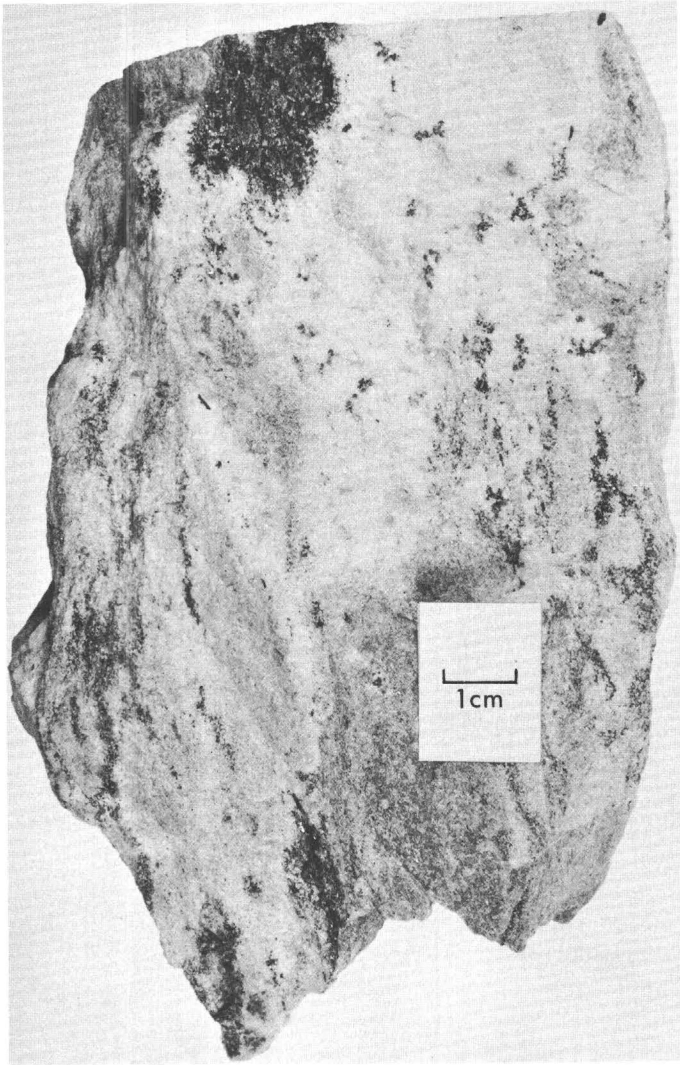

FIGURE 32.—Dark-colored remnants of biotite schist in granoblastic fine-grained border zone of anorthosite along the West Branch of Cedar Creek (loc. 1759).

are usually fractured and weather more readily than those consisting of andesine. In thin sections, andesine appears much fresher and shows no alteration, whereas many of the bytownite grains have sericite and clay minerals along their fractures.

The border zone of the tonguelike extension of anorthosite along the West Branch of Cedar Creek consists of granular andesine rock with irregular biotite-rich patches and schlieren (fig. 32). The country rock in this locality is a biotite schist with fine-grained biotite quartzite layers.

The anorthosite along Cedar Creek, about 1 mile northwest of the forks of the East Branch and West Branch, consists of a medium- to coarse-grained layered anorthosite in which the constituent minerals are the same as those in the northern part, but in which there is more biotite and less hornblende. In many outcrops the major part of the biotite occurs in thin laminae that separate the thicker layers consisting of light bluish-gray plagioclases. The thickness of the plagioclase layers ranges from 2 to 4 cm, and that of the biotite layers from ½ to 5 mm.

MASSIVE VARIETY

About half a mile northwest of the forks of the West and East Branches of Cedar Creek the layered anorthosite grades to a coarse-grained variety that is rich in hornblende and contains small dark clusters of biotite elongated parallel to the planar structure. Toward the south this variety grades over to a massive hornblende- and biotite-free light-greenish or grayish coarse-grained anorthosite in which epidote and some chlorite, ilmenite, and sphene are the only additional constituents. A similar coarse-grained massive anorthosite is exposed north of the layered anorthosite. Two types of plagioclase, andesine and bytownite, are the major constituents of this massive variety and the texture is similar to that in many other occurrences of coarse-grained anorthosite, with andesine occurring in large rounded grains and bytownite as small grains between the andesine grains and as platelike inclusions in andesine. In one of the thin sections studied, a few small andesine grains showed a weak reversed zoning. A few tiny orthoclase grains were found in another thin section.

South of the light-colored anorthosite, the amount of hornblende increases again, and the massive, very coarse grained anorthosite at the forks of Cedar Creek contains dark patches rich in hornblende (fig. 33). Andesine (An_{43}) grains in this rock are as much as 10 cm in diameter and include small grains of hornblende. A thin-banded anorthosite is found south of the coarse-grained variety, and farther south layers of this thin-banded anorthosite, 5 to 10 cm thick, alternate with andesine-rich schist. Some orthoclase is included in andesine in the banded anorthosite.

BYTOWNITE ANORTHOSITE

Blocks of very fine grained anorthosite along the road near the northern border of the anorthosite body along Cedar Creek consist of almost pure bytownite (An_{83}). Bytownite occurs in small twinned grains that are elongated parallel to a beddinglike structure. Some small grains of epidote, sphene, hornblende, and chlorite are as additional constituents. Chemical analysis (table 11, no. 949) shows that this fine-grained bytownite rock is richer in calcium and aluminum than the normal anorthosite. About half a mile east of this locality (loc. 949, pl. 1) a similar fine-grained bluish bytownite rock is exposed along a logging road between a white layered anorthosite and a coarse-grained massive variety. Toward the north, the massive

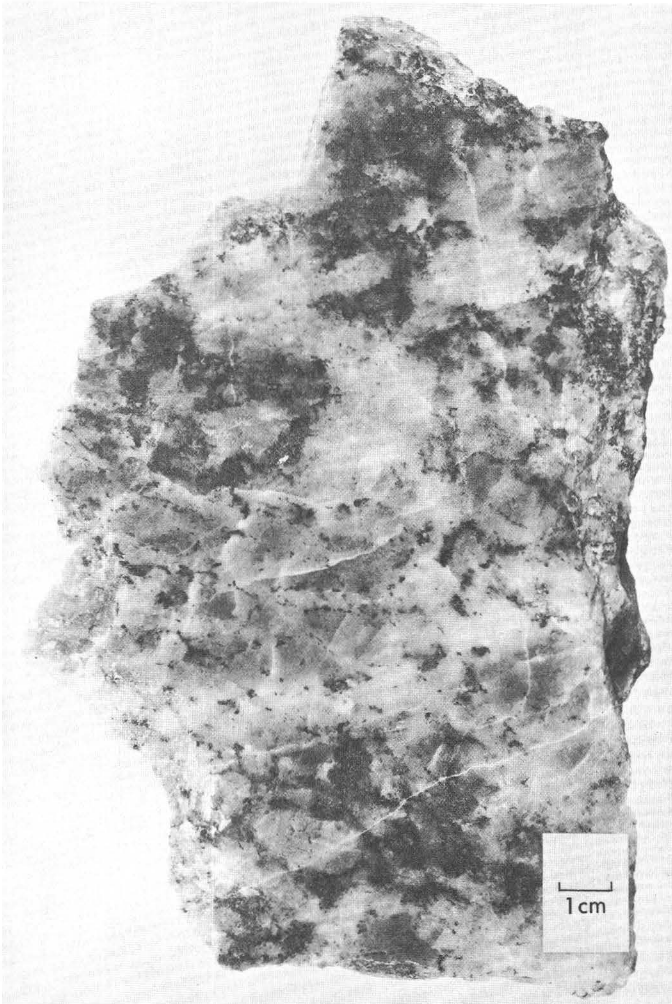

FIGURE 33.—Massive coarse-grained anorthosite at the forks of West Branch and East Branch of Cedar Creek. The dark constituent is mainly hornblende (loc. 1418).

variety contains patches of biotite and grades over to a biotite-plagioclase gneiss. Another layer of fine-grained bluish bytownite rock is found in this plagioclase-rich gneiss, which toward the north grades over to a thin-banded hornblende-bearing anorthosite. White anorthosite with thin discontinuous layers of biotite and muscovite occurs north of the hornblende-bearing variety and still farther north a feldspathized schist is found.

The measured mode of the bytownite rock exposed on the logging road shows 96 percent bytownite, 2 percent orthoclase, and 2 percent combined diopside and hornblende. A few small grains of quartz, chlorite, and magnetite also occur.

Blocks of hornblende-rich bytownite anorthosite were found along the road leading from Stocking Meadows to Goat Mountain (loc. 947) just north of a small occurrence of amphibolite. The hornblende in this anorthosite occurs as anhedral to subhedral blocky prisms that are evenly scattered throuhgout the rock and oriented parallel to a linear structure in the plane of foliation. Plagioclase (An_{80}) grains have sutured borders and contain numerous small round to irregularly shaped inclusions of quartz. Large quartz grains occur among the plagioclase grains. A considerable amount (about 1 percent) of sphene occurs in round clusters of small grains. Some ilmenite is included in a few of these clusters. Epidote and apatite are the additional constituents. The mineralogy of this gabbroic anorthosite is between that of amphibolite and the bytownite rock. Small blocks of a similar hornblende-rich rock were found 2½ miles east of this locality between the forks of Cedar Creek near locality 1753.

ANORTHOSITE AT GOAT MOUNTAIN AND VICINITY

The third large body of anorthosite, which occurs near Goat Mountain, mainly repeats the varieties found in the body exposed along Cedar Creek. However, the amount of the coarse-grained massive variety is much larger (about 60 percent), and a garnetiferous fine- or medium-grained variety was found along the southwestern contact. The center and the northwestern part of the body consist mainly of light-grayish massive coarse-grained hornblende-bearing andesine-bytownite rock, whereas the border zones have a gneissic structure or show a fine layering similar to the layering found locally in the northern part of the body along Cedar Creek. However, the banded and layered structure occurs in some localities in the center of the body.

Differential weathering, which is pronounced in many outcrops and boulders, shows the distribution of bytownite either into thin laminae or into interstitial areas between the large less weathered andesine or labradorite grains.

MASSIVE VARIETY

The coarse-grained anorthosite near Goat Mountain, west of Monumental Buttes, and near tributaries of Lund Creek, is light bluish gray in fresh outcrops and white on weathered surface. Most of this rock consists almost entirely of plagioclase, the amount of dark constituents being less than 3 percent (fig. 34).

Near Lund Creek the anorthosite is coarse to medium grained and consists of about 98 percent labradorite (An_{57}) with only minute inclusions of bytownite. Tiny grains of epidote and chlorite with or without hornblende and sparse small grains of plagioclase occur between the labradorite grains which range from ½ to 3 cm in diameter. A few small grains of ilmenite surrounded by sphene are the accessories. Two small grains of myrmekitelike intergrowth were found in one of the thin sections studied and some small grains of orthoclase in another.

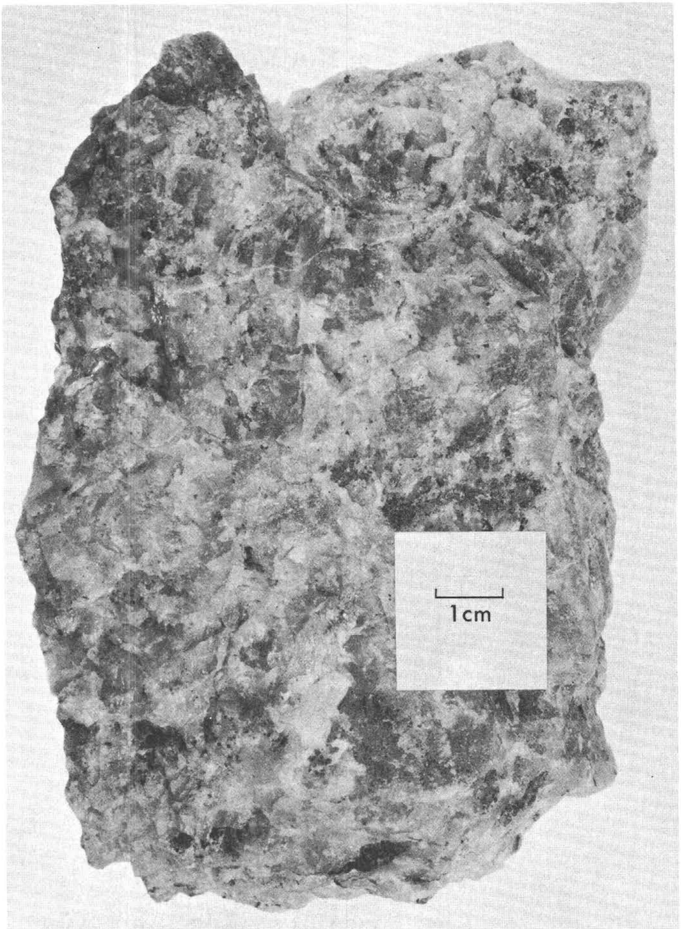

FIGURE 34.—A specimen of massive anorthosite near Lund Creek. About 98 percent of this rock is labradorite (An $_{57}$).

Near Monumental Buttes hornblende and chlorite are the common dark constituents, but in the majority of the outcrops the total amount of the dark constituents is less than 3 molecular percent (table 11, no. 1016). The amount of bytownite (An_{80-85}) is much larger than that near Lund Creek. The host plagioclase is more sodic, consisting of An_{47-55} as determined by the immersion method. The texture is similar to that shown in figure 27.

The exceptionally large size of the bytownite inclusions in specimen no. 1016 made possible the measurement of the optic orientation and the cleavage of the host andesine, its twinning lamellae, and the bytownite inclusions. The result of two such measurements is shown in figure 35. The pole of the basal pinacoid of the bytownite (An_{80}) inclusions, $(001)_3$ in diagram *a* of figure 35, makes an angle of 17° with the pole of the basal pinacoid of the host $(001)_{1,2}$, in the same diagram. The host consists of andesine (An_{45}) and is twinned according to the pericline law.

In diagram b of figure 35 cleavage (010) is common for the host and the inclusions (marked $(010)_{1,3}$), and the pole of the basal pinacoid of the host $(001)_{1,2}$, makes an angle of 16° with the pole of the basal pinacoid of the inclusions $(001)_3$. Both the andesine host and the bytownite inclusions are twinned according to the pericline law. In addition to the pericline twinning the host shows the albite twinning. Many of the twinning lamellae on the (001), face, or nearly so, seem to contine from the host to the inclusions (fig. 36) where they either turn parallel to the $(001)_3$ plane of the inclusion, or stop in the bytownite at a short distance from the contact of the two plagioclases. Some twinning lamellae go straight through a few small inclusions of bytownite. In some other grains measured, the poles of the (001) face of the host and the inclusions make an angle of 15° to 16°.

The tiny rounded inclusions in the larger bytownite inclusions and the groups of small bytownite grains (4 in fig. 36) included in andesine are oriented at random. The texture of the groups of small bytownite grains is similar to that of the bytownite which occurs between the large andesine grains. This similarity in texture suggests a common origin for all bytownite. The tiny inclusions and the irregularly shaped extensions from bytownite (3) into these groups of small grains (bytownite (4) on lower left corner of fig. 36) suggest that bytownite (4) represents an earlier phase that was, in part, replaced by bytownite (3). Thus, the bytownite (3) seems to represent recrystallized remnants of the fine-grained bytownite rock. The optic orientation of the bytownite (3) and the andesine suggest that the bytownite was reoriented and recrystallized during the formation of andesine.

Locally the massive anorthosite contains more hornblende than that described in the earlier paragraphs; the percentage of the dark constituents range from 3 to 20 percent. Hornblende and chlorite occur in clusters and form irregularly shaped dark patches. Under the microscope the hornblende is seen as subhedral prisms which are very light greenish with pleochroism X= colorless, Y=light green, Z=light bluish green; thus it is much like the hornblende in specimen no. 608 (table 12). The indices of refraction are $\alpha=1.646\pm0.001$, $\beta=1.657\pm0.001$, $\gamma=1.670\pm0.001$, $Z\wedge c=17°$, and 2V about 90°. Chlorite is light greenish with abnormal blue interference colors. Some epidote is included in chlorite. Sphene and ilmenite occur as accessories.

Chemical analysis of the hornblende-bearing anorthosite (table 11, no. 1015) shows that the composition is close to that of the light-colored variety except for some more iron and magnesium.

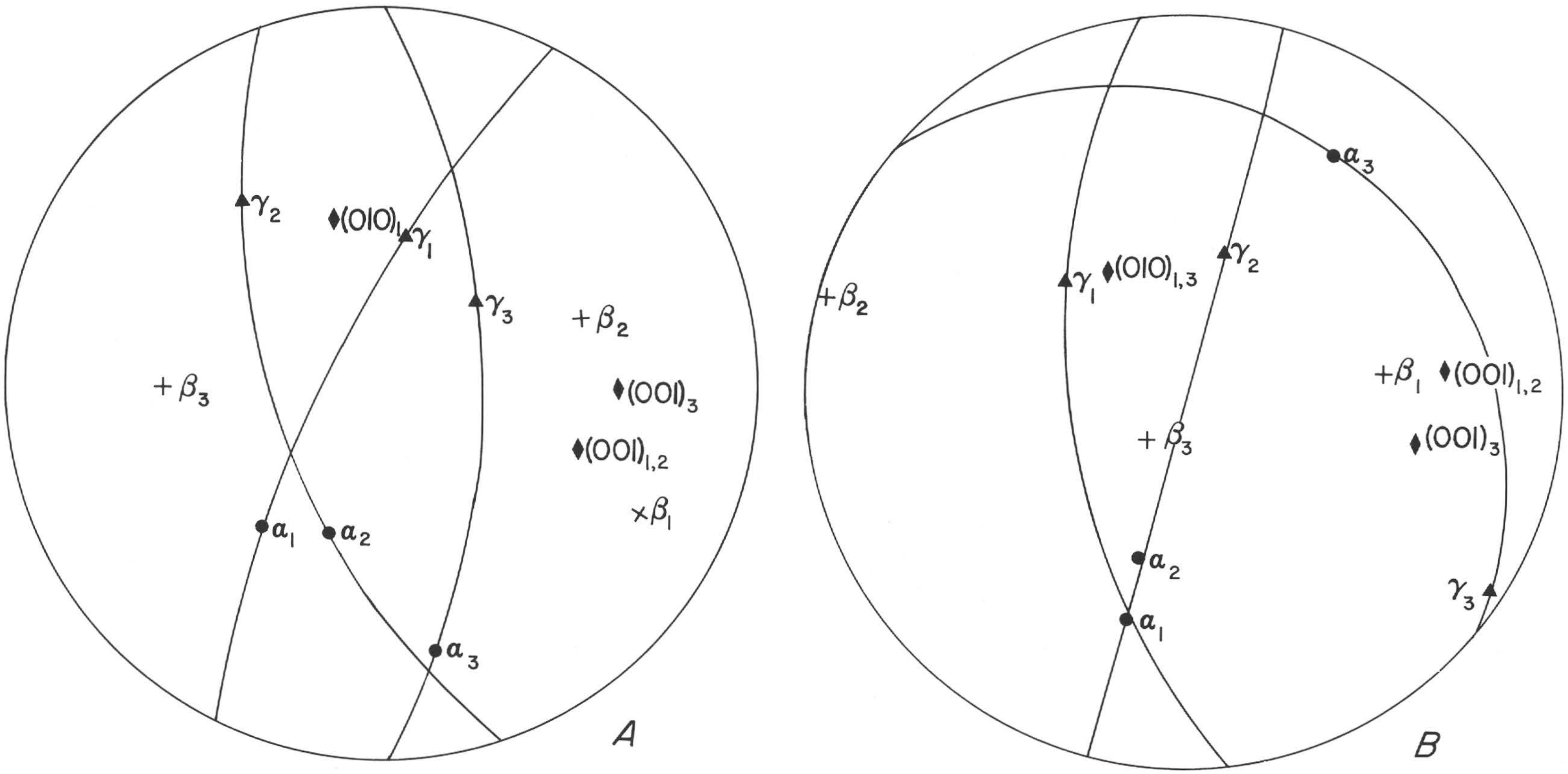

FIGURE 35.—Orientation of the inclusions of bytownite (3) in andesine (1) that shows pericline twinning lamellae (2). Subscripts refer to these three units. Where two subscripts appear, the face is common for two units; for example, $(001)_{1,2}$ is basal pinacoid for the host andesine (1) and its twinning lamellae (2). A and B are measurements of two separate andesine grains from the same thin section. Massive anorthosite southwest of Monumental Buttes (loc. 1016).

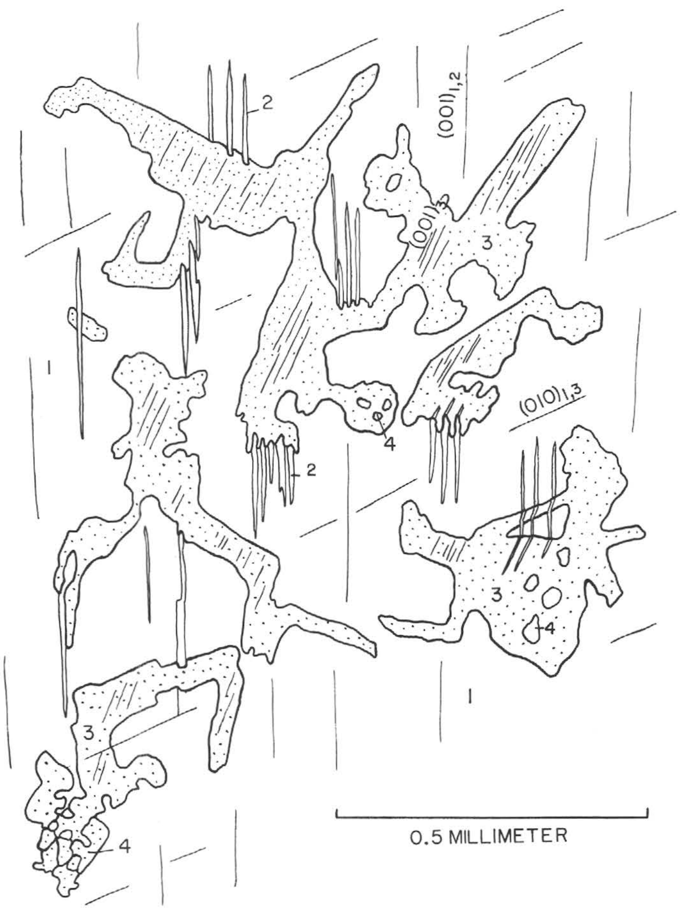

FIGURE 36.—Camera lucida drawing of bytownite inclusions (3) in the same andesine grain (1), the orientation of which is shown in figure 35. The pericline twinning lamellae are indicated by (2). The tiny inclusions of bytownite (4) are oriented at random. Massive anorthosite southwest of Monumental Buttes (loc. 1016).

HORNBLENDE-BEARING BANDED VARIETY

The part of the northernmost large anorthosite body that extends southward from Goat Mountain consists of banded plagioclase-hornblende rock, which resembles the thin-layered anorthosite along Cedar Creek. It is medium grained, has a gneissic structure, and contains from 2 to 20 percent hornblende. The hornblende prisms occur in paper-thin discontinuous laminae between layers of plagioclase 1 to 2 cm thick. A similar anorthosite occurs in many other localities; for example, near the garnet amphibolite body between Goat Mountain and Monumental Buttes, and locally along the borders and also in the center of the body. In localities 1021 and 1363 the banded anorthosite grades over to a dark gneissic variety that contains from 10 to 30 percent hornblende. Two types of plagioclase, andesine and bytownite, occur in both varieties, and the texture is similar to that of the thin-banded anorthosite exposed along the Little North Fork of the Clearwater River and along Cedar Creek. In many outcrops in the southern part of the body south of Goat Moutain the amount of hornblende varies, giving rise to a coarser banding that resembles differentiation layers in igneous rocks. Long layerlike bodies of amphibolite are included in anorthosite in this part of the body. Only the large ones are marked on the map, the others being from 10 to 50 cm thick. The amphibolite grades over to the anorthosite that contains discontinuous dark layers rich in hornblende. The rock in the two localities mentioned (nos. 1021 and 1363) may represent similar hornblende-rich layers. The occurrence of two kinds of plagioclase brings the mineral content of these layers close to that of the normal anorthosite; however, some quartz is common in them and the hornblende is a darker variety than is commonly found in the anorthosite. In these respects the mineralogy of these dark layers resembles that of the amphibolite.

A small outcrop along the road south of Goat Mountain (loc. 968) contains more hornblende than any of the anorthosite described earlier. It could be classified as a gabbroic anorthosite, but in addition to abundant hornblende it contains a few kyanite crystals and some chlorite, thus being mineralogically similar to the dark kyanite-bearing layers in the anorthosite along the Clearwater River.

Another locality where kyanite occurs in anorthosite rich in hornblende is south of Monumental Buttes just south of locality 1321. No outcrops were found in this locality but several small blocks contain layers, 5 to 10 cm thick, that are rich in hornblende, with $\gamma=1.666 \pm 0.001$ and $\alpha=1.643 \pm 0.001$, and contain numerous bluish prisms of kyanite (fig. 37). These prisms range from 1 to 5 cm in length and 1 to 5 mm in thickness and are oriented at random in the plane of foliation. The kyanite prisms have rounded corners, and they are shelled by a thin layer of alteration products. Among these, sericite could be identified, but most of the alteration products consist of fine-grained grayish material that has low indices of refraction and is dark under crossed nicols (probably clay minerals).

An intense wrinkling was found in a banded fine-grained light-colored border zone of the anorthosite west of Pinchot Creek (loc. 1744). In this rock paper-thin bytownite layers alternate with layers, ranging from 1 to 4 mm in thickness, that contain andesine and hornblende (fig. 38).

GARNETIFEROUS BORDER ZONE OF THE ANORTHOSITE

Much of the anorthosite in the northernmost large body near its southern edge east of Orphan Point is fine grained and locally shows a distinct planar structure (fig. 39). The plagioclase in this rock consists of labradorite (An_{52-57}), and the scarce dark constituents are hornblende, chlorite, and epidote. Layers rich in garnet and some other layers containing aluminum

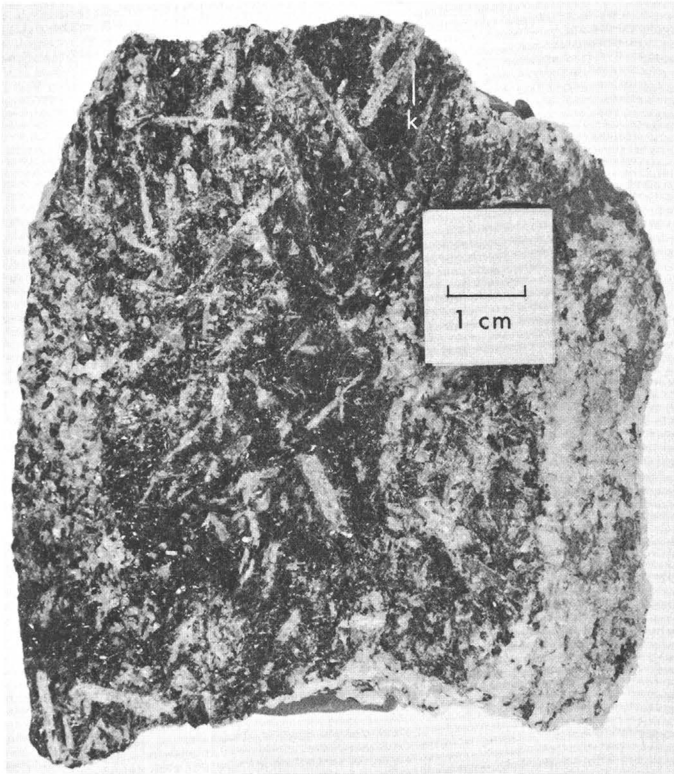

FIGURE 37.—Light-colored prisms of kyanite in a dark hornblende-rich layer in anorthosite south of Monumental Buttes, just south of location 1321.

silicates and biotite are interbedded with this fine-grained anorthositic rock.

Abundant garnet crystals ranging from 1 to 10 mm in diameter were found in the float along the road leading from Goat Mountain to Orphan Point. The blocks in which the garnet occurs consist of light-gray fine- to medium-grained plagioclase-rich rock that contains thin dark-colored micaceous layers. No outcrops were found in this locality, but the structure of the garnetiferous biotite schist and biotite quartzite exposed just west of this locality suggests that the garnetiferous rock occurs on the crest of a gentle anticline. The float of the garnetiferous and fine-grained anorthositic rock is structurally above this schist, and the massive anorthosite along Lund Creek and its tributaries is beneath the same schist. Neither exposures nor float, but light-colored soil suggesting an anorthositic bedrock was found just north of the garnet-bearing anorthositic float in the place where the structural continuation of the schist layer should occur. Several blocks of gray fine-grained plagioclase rock contain pink garnetiferous ellipsoidal lenses shelled by a darker red layer very rich in garnet. In some other blocks discontinuous layers of pink, greenish, and light-gray rock alternate in an irregular manner (fig. 40).

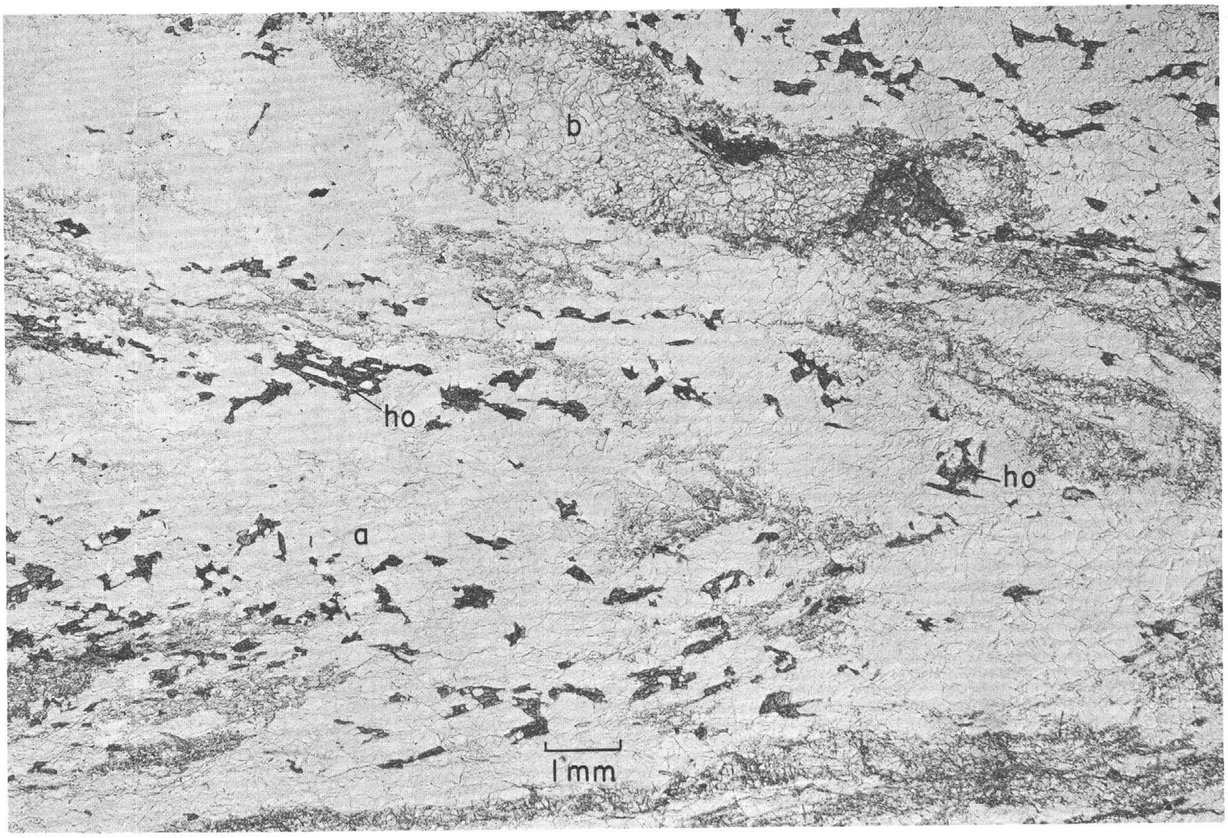

FIGURE 38.—A small fold in fine-grained layered anorthosite along the border south of Orphan Point (west of Pinchot Creek, loc. 1744). The grayish layers are bytownite (b). Hornblende (ho) occurs with andesine (a) in the light-colored layers. Plane-polarized light.

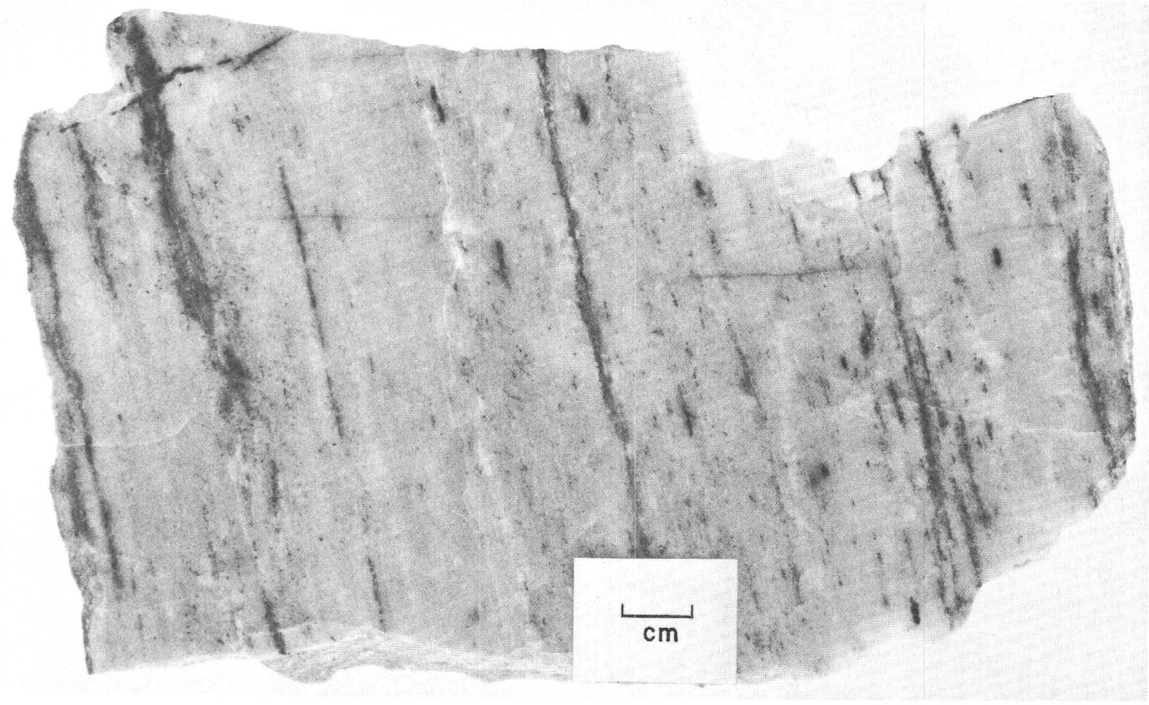

FIGURE 39.—A layered fine-grained anorthosite east of Orphan Point. The dark minerals are hornblende and chlorite; the gray part consists of labradorite (loc. 1353).

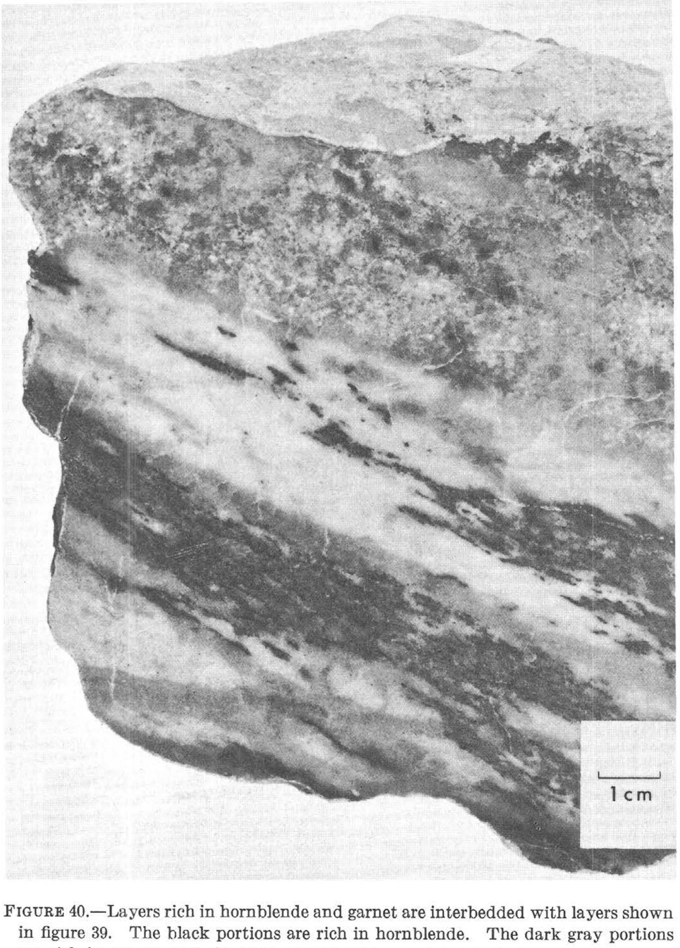

FIGURE 40.—Layers rich in hornblende and garnet are interbedded with layers shown in figure 39. The black portions are rich in hornblende. The dark gray portions are rich in garnet, and the light-colored parts consist of andesine.

Study under the microscope shows that andesine is the major constituent in the light-gray garnetiferous layers, which—in addition to abundant quartz, anadalusite, and biotite—contain some kyanite, sillimanite, muscovite, chlorite, and staurolite as minor constituents. Magnetite, ilmenite, apatite, and rutile occur as accessories. The micaceous minerals, small grains of quartz, and the sillimanite commonly surround the more or less oval or rounded grains of andesine and the crystals of garnet, andalusite, and kyanite; but they also occur as inclusions in andesine and garnet. The garnet tends to be euhedral with dodecahedral faces, and includes grains of quartz, biotite, and magnetite. The unit cell length was determined by F. A. Hildebrand and is $a_0=11.611\pm0.005$A. Index of refraction is $n=1.784\pm0.003$ and specific gravity of 3.93 ± 0.02. Chemical analysis (table 4, no. 1353) shows that this garnet consists of about 63.5 percent almandite, 13.5 percent pyrope, and 21.5 percent grossularite, it being similar to the garnet in the garnet-biotite-gedrite gneiss along the Little North Fork of the Clearwater River (table 4, no. 1225). The analyzed material contained some tiny inclusions of quartz. The garnet in garnet amphibolites contains a little more pyrope (22.5 percent) and less grossularite (14.0 percent) (Hietanen, 1962). For comparison the composition of a garnet from reaction rims in the Adirondack anorthosite was calculated from the analysis given by Kemp (1921, p. 41) with the following result: 61.5 percent almandite, 19.3 percent

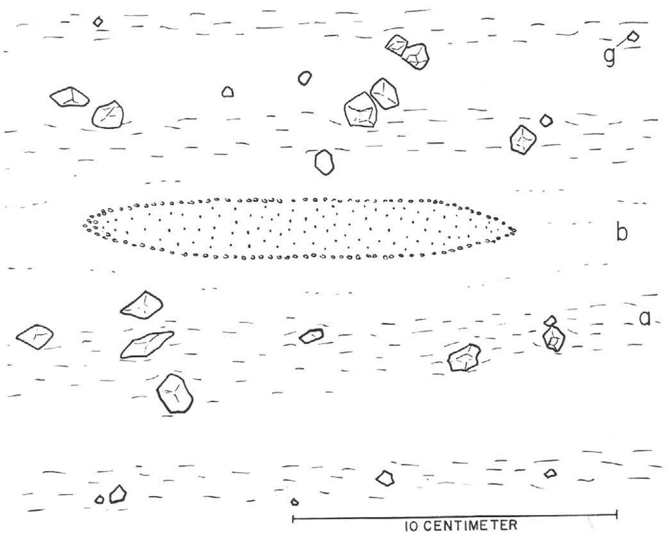

FIGURE 41.—A lens-shaped aggregate consisting of quartz, plagioclase, and garnet in garnetiferous anorthosite about 2 miles east of Orphan Point. *a*, layers consisting mainly of andesine and containing some biotite and bytownite. *b*, layers consisting mainly of bytownite with subordinate amount of andesine. Subhedral garnet crystals (*g*) are scattered throughout both layers.

pyrope, 17.2 percent grossularite, and 2.0 percent andradite. This garnet is chemically closest to the garnet in garnet-biotite-gedrite gneiss (table 4, no. 1225). All these garnets are in their composition close to those that occur in eclogites (compare Eskola, 1921).

The pink ellipsoidal lenses are embedded in a fine-grained gray plagioclase-rich rock that contains sporadic crystals of garnet and abundant quartz. The quartz in this calcic plagioclase rock occurs as elongated grains of medium size or as numerous tiny round inclusions. The sporadic crystals of garnet range from 3 to 10 mm in diameter. The pink lens-shaped aggregates, 2 cm thick and 15 to 20 cm long, resemble, in their mode of occurrence and shape, calcareous concretions (fig. 41) in metasedimentary rocks. Study under the microscope shows that they consist of small grains of calcic plagioclase, quartz, and garnet (fig. 42). The quartz grains are elongated parallel to the long dimension of the lenses and many of them are rimmed by tiny crystals of garnet. Garnet occurs also as numerous small inclusions in plagioclase, making the rock pink. The percentage of quartz in these pink lenses is larger than that in the host rock.

The irregular layering in the pink and green striped plagioclase rock is caused by the variation of the dark constituents. The pink layers contain numerous small garnet crystals, whereas the green layers contain zoisite and hornblende as their dark constituents. Zoisite in elongated grains with rounded edges is the major constituent in many light-gray layers.

The amount of quartz in the garnetiferous plagioclase rock is highly variable. Some layers consist of pure plagioclase, and some others of about 50 percent quartz and 50 percent plagioclase. Plagioclase is more calcic than it is in the anorthosite, ranging from An_{80} to An_{94}. Most of the quartz is as individual elongated grains or tiny inclusions in plagioclase, but in some layers thin bands or rows of grains of quartz occur in a manner similar to late vein quartz. There is every gradation from this quartz-rich rock to a normal anorthosite in which quartz is absent and, on the other hand, to a plagioclase-rich schist with aluminum silicates.

ANORTHOSITE IN SMALL BODIES

The anorthosite in most of the small bodies is fine to medium grained and banded, and either micaceous minerals or hornblende occur in it very much in the same way that they occur in the thin-banded variety in the large bodies. In a few outcrops, however, a granoblastic variety with some diopside was found. The diopside-bearing anorthosite is heterogeneous and contains grayish fine-grained lenticular spots surrounded by a somewhat coarser, lighter colored rock in which hornblende grains are clearly visible. The grayish fine-grained part contains small irregularly shaped grains of diopside. The hornblende is darker green than that in a normal anorthosite, and a few grains of orthoclase were found in one of the thin sections studied (no. 1393). This variety is very similar to the fine-grained biotite- and epidote-bearing parts in the anorthosite along the Little North Fork of the Clearwater River about 1 mile south of the mouth of Breakfast Creek (loc. 1299).

The small bodies near the mouth of Pinchot Creek (locs. 1681, 1683) consist of foliated fine-grained anorthosite with clusters of biotite and sillimanite. These clusters are about 1 mm thick and range from ½ to 2 cm in length. In addition to plagioclase (An_{54}) this rock contains a few small grains of quartz, some biotite, and sillimanite. Small flakes of biotite with tiny flakes of muscovite and small needles of sillimanite are scattered throughout the rock. The center of the largest body (specimen 1683) consists of pure light bluish gray massive anorthosite. Thin-section study of this anorthosite shows that it consists of irregularly shaped grains of plagioclase (An_{43}) that include many small round quartz grains. Epidote, chlorite, magnetite, sphene are sparse.

Another small body of anorthosite between Timber Creek and Pinchot Creek (loc. 1749) consists of fine- to medium-grained finely banded anorthosite which is intensely wrinkled in places. The fine banding is due to the alternation of thin layers consisting either of bytownite or of andesine with some hornblende. The

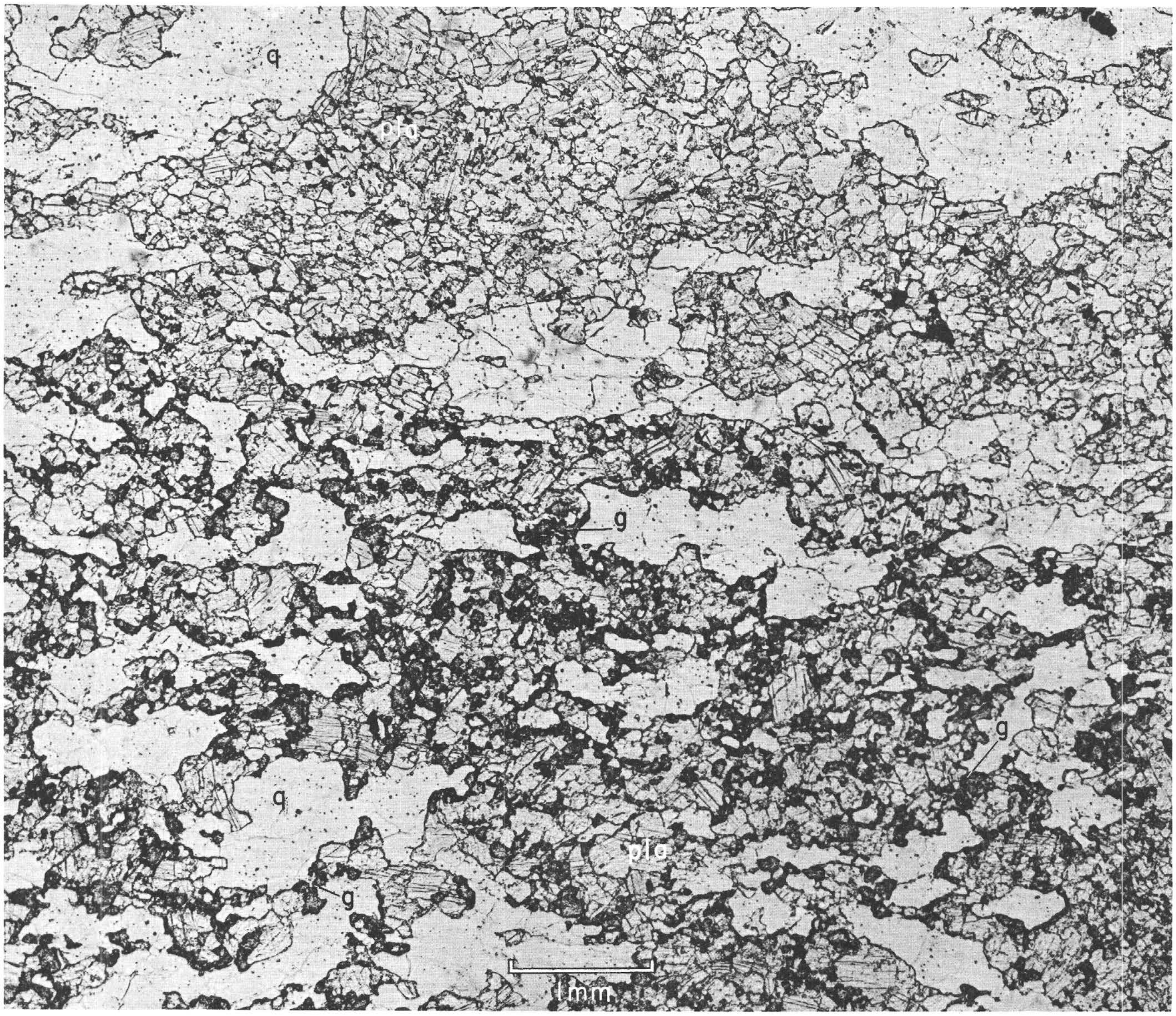

FIGURE 42.—Photomicrograph of a garnetiferous lens in calcic plagioclase-quartz rock. The rock in the upper part of the figure consists of quartz (*q*) and calcic plagioclase (*pla*). A part of an ellipsoidal lens is shown in the lower part of the figure where tiny garnet crystals (*g*) abound. Plane-polarized light.

bytownite layers are fine grained and about 1 mm thick, whereas the andesine layers are medium grained and 2 to 3 mm thick. In places about 25 percent of the rock consists of small prisms of hornblende oriented parallel to the bands.

Blocks of fine-grained garnetiferous pink and green banded anorthosite are strewn along the road south of Goat Mountain (loc. 956). In this rock layering is due to alternation of garnet-bearing layers (pink) with those containing diopside or hornblende (green). Most of the hornblende and diopside occur in separate thin layers, but some hornblende is with diopside. Abundant sphene in elongated grains or groups of grains, with ilmenite cores, is common in diopside-bearing layers. Hornblende-bearing layers contain spongelike plagioclase (An_{94}) grains with numerous round quartz inclusions. Large crystals of garnet include small grains of other minerals. Small garnet crystals occur between the quartz and plagioclase grains rimming many of the quartz grains in the pink layers.

Diopside-bearing anorthosite was also found at locality 1692 near its contact with amphibolite. Andesine in this anorthosite contains numerous tiny, round to oblong inclusions of quartz. Diopside is in clusters of irregularly shaped grains and include small plagioclase grains.

Remnants of a concordant sill-like body of dark hornblende-rich rock that can be classified as gabbroic anorthosite is folded with garnet mica schist on the ridge between Timber Creek and Pinchot Creek (loc. 1747). The schist in this locality is gently folded, the axis of folding plunging 15° east. Small remnants of gneissic plagioclase-hornblende rock, 3 to 7 cm thick, occur in small synclinal notches on the top of the schist on the highest part of an isolated outcrop. The anorthositic rock is gneissic and coarse grained. The mica schist in most parts of this outcrop is much finer grained and shows a lower grade of metamorphism than the schist in the outcrops nearby. However, the schist next to the anorthosite is recrystallized as a dark coarse-grained garnet-hornblende-chlorite rock. The thickness of this recrystallized contact zone is about 6 cm. The garnet crystals in it are 1 to 3 cm in diameter; the hornblende crystals are euhedral, and they decrease in number away from the contact. Small flakes of chlorite fill the interstices between the garnet and hornblende crystals. Quartz, which is a common constituent of the normal schist, is completely lacking. The mineral content indicates that this contact zone is greatly enriched in iron and magnesium and is impoverished in silicon and potassium.

Thin-section study of the gabbroic-anorthositic rock indicates that much of the anorthosite component of the plagioclase is altered to epidote minerals. Hornblende, which is the only dark constituent, is bluish green and contains numerous inclusions of plagioclase. The grains of medium size are clustered; thus the rock appears coarser grained than it really is. Epidote minerals also form clusters of small grains. Plagioclase (An_{60}) grains of medium size separate the hornblende crystals from the epidote clusters. The chemical composition (table 11, no. 1747), mineral content, and contact relations of this body differ strikingly from those of the other anorthosite bodies. It is possible that this thin body crystallized from a normal gabbro magma and that its anorthositic composition was attained by the migration of a part of the iron and magnesium to the country rock to form the garnet-hornblende-chlorite seam along the contact.

CHANGES IN THE COUNTRY ROCKS NEAR THE ANORTHOSITE

INCREASE OF PLAGIOCLASE AND ALUMINUM SILICATES TOWARD THE ANORTHOSITE

The composition and mineral content of the schist and quartzite near the anorthosite differ considerably from those found in the same rocks elsewhere. A gradual change in the amounts of the major constituents—quartz, aluminum silicates, micas, and plagioclase—is well demonstrated in several sections near Monumental Buttes, on the north side of the North Fork of the Clearwater River between Salmon Creek and Boehls Butte, and along Cedar Creek and its tributaries. In all these sections, the average amount of quartz decreases and that of the plagioclase, and commonly also that of the aluminum silicates, increase toward the anorthosite. In detail, the distribution of these various minerals in the schist around the anorthosite bodies is highly irregular, because some of the plagioclase and biotite and also some of the aluminum silicates are segregated to form monomineralic or highly concentrated clusters and masses.

Many good exposures on Monumental Buttes offer excellent material for a detailed study. A section from the anorthosite through schist to quartzite is exposed on the west slope of Monumental Buttes. The anorthosite in the center of the body is coarse grained and massive, but attains a gneissic thin-banded structure near the contact. Some sillimanite, muscovite, and chlorite appear as additional constituents in this banded fairly pure andesine-bytownite rock. The thickness of the banded zone ranges from 50 to 300 m. Abundant aluminum silicates—kyanite, andalusite, and sillimanite—appear in the schist next to the contact. The contact shows signs of stronger shearing than is apparent elsewhere in the formations. The sheared zone exposed is about 10 m thick, and the minerals in it are plagioclase, chlorite, kyanite, andalusite, and sillimanite. The schist outside of this sheared zone contains biotite and muscovite instead of chlorite, and some quartz appears among the andesine. A thick layer of aluninous schist is exposed on the uppermost part of the slope and on the top of the ridge. The trend is parallel to the ridge, and the same layer can be followed for 2 miles. Most of the schist is rich in plagioclase, which occurs in individual large grains and in clusters, but some of the schist contains only garnet and micas in addition to quartz. The change from the plagioclase-rich rock to this normal garnet-mica schist takes place across the bedding, as well as parallel to the bedding.

In detail the distribution of plagioclase in the plagioclase-rich parts also is rather irregular. The plagioclase occurs in individual scattered large round grains, in clusters, and small masses (fig. 43), all unevenly distributed throughout the schist. The roundness and whiteness of the sporadic andesine grains makes them conspicuous against the dark framework of the micaceous minerals. Where their number increases, the rock attains a coarsely granular texture, which is typical of micaceous layers of the anorthosite along the North Fork and the Little North Fork of the Clearwater River. The oblong masses of pure plagioclase in this plagioclase-mica schist range from a few centimeters to 10 m or more in length. These masses have a coarsely granular texture; some have the appearance of pegmatite, but the only constituent mineral in them is plagioclase,

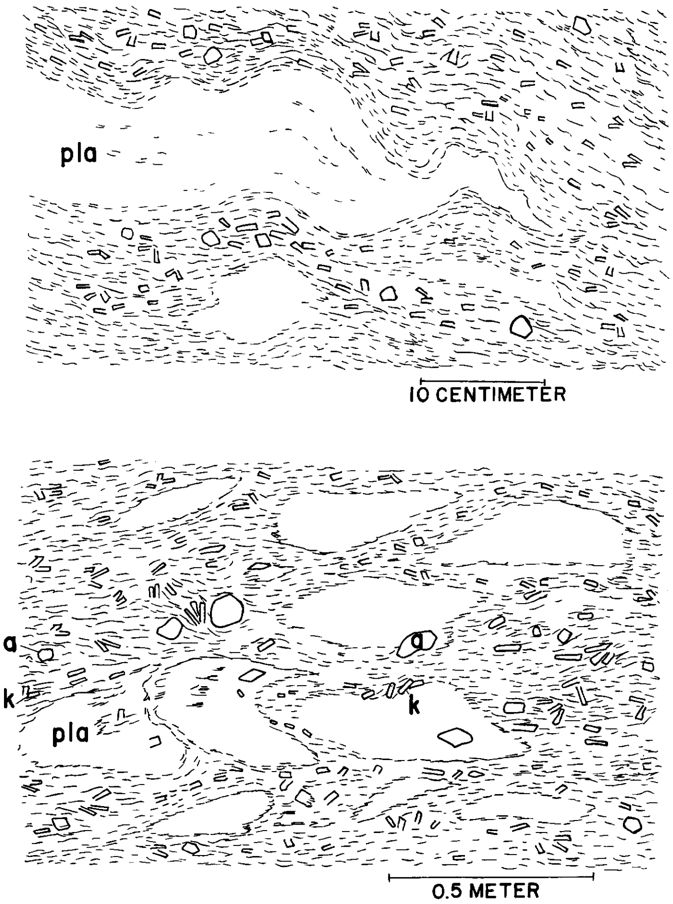

FIGURE 43.—Lens-shaped segregations of andesitic plagioclase (pla) in coarse-grained kyanite-mica schist rich in plagioclase. a, andalusite; k, kyanite. Horizontal surfaces on Monumental Buttes.

ranging in composition from An_{25} to An_{40}. More quartz instead of plagioclase occurs in the schist adjacent to the quartzite.

Much of the contact rock south of Monumental Buttes (south of loc. 1018) consists of fairly coarse-grained plagioclase-biotite rock with large kyanite crystals, as long as 10 cm, evenly distributed throughout the rock. These kyanite-rich layers alternate either with more micaceous layers or with fine-grained gneissic anorthosite that contains biotite. Large garnet crystals abound in some thicker mica-rich layers and also in many outcrops of plagioclase-biotite-kyanite rock; for example, just south of locality 1321, garnet crystals are 5 to 10 cm in diameter and include numerous small kyanite crystals.

The contact zones at Goat Mountain and along the North Fork of the Clearwater River consist of a plagioclase-rich kyanite-andalusite-sillimanite schist similar to that found on Monumental Buttes. Oligoclase-andesine is a major constituent in a zone whose thickness ranges from 50 to 300 m. On the south slope of Goat Mountain, huge kyanite crystals and large sporadic garnets are embedded in coarse-grained plagioclase-biotite rock that occurs next to the anorthosite. The chemical analysis of the plagioclase-biotite "groundmass" (table 13, no. 971) suggests that it is considerably richer in calcium and poorer in silicon than the normal schist. When the total composition of this rock is computed (no. 971a), the abundance of aluminum becomes apparent. The amount of iron is greater where large sporadic garnet crystals appear. Layers rich in biotite and aluminum silicates (table 13, no. 967), and containing small round grains of corundum, are interbedded with the plagioclase-rich schist. The biotite in these layers as well as in the plagioclase-rich parts of the rock is greenish and shows bright interference colors. The index of refraction is $\gamma = 1.610 \pm 0.001$. This mineral was separated and a clean fraction of a specific gravity between 2.809–2.910 was chemically analyzed. The result of chemical analysis (table 14) shows more than 21 percent alumina and a high percentage of magnesium oxide. The formula computed from the analysis is:

$$(H_{4.13}F_{0.01})_{\Sigma=4.14}(K_{1.62}Na_{0.18})_{\Sigma=1.8}(Mg_{3.55}Fe^{+2}_{0.96}Mn^{+2}_{0.02}Ti^{+4}_{0.03}Fe^{+3}_{0.13}Al_{1.05})_{\Sigma=5.74}(Si_{5.41}Al_{2.59})_{\Sigma=8.0}O_{24}.$$

This biotite is very similar to the green biotite in the cordierite gneiss on Smith Ridge (Hietanen, 1956, p. 7–8), showing an excessive amount of aluminum and a deficiency of potassium.

Muscovite abounds locally in the mica-rich layers but is rare in the plagioclase-rich rock. The habit and mode of occurrence of the muscovite in the rocks adjacent to the anorthosite differ from those of the muscovite in the normal schist of the Prichard formation. In the normal schist, muscovite forms large flakes (1 to 4 mm in diameter) that show all properties of normal muscovite, but in the schist adjacent to the anorthosite the muscovite occurs in groups of tiny, soft flakes that have a greasy feeling like talc when pressed between the fingers. The indices of refraction in specimen 971 are higher than those of the normal muscovite, $\beta = 1.594 \pm 0.001$, $\gamma = 1.600 \pm 0.001$. The alkali determination was done by L. N. Tarrant of the U.S. Geological Survey and shows 1.74 percent Na_2O and 8.67 percent K_2O. Quartzite and amphibolite adjacent to the plagioclase-rich schist do not contain secondary plagioclase in any locality studied.

Along the Little North Fork of the Clearwater River, on the north slope of Benton Butte, and along the tributaries of the West Fork of Cedar Creek, the contact rocks are more heterogeneous than those on Monumental Buttes and on Goat Mountain. The schist next to the contact contains abundant oligoclase-andesine, layerlike masses of biotite, and in places segregations of muscovite. Lens-shaped masses

TABLE 13.—*Chemical analyses, norms and modes of the schist next to the anorthosite*

Locality and specimen	630[1]	954[2]	967	971[2]	971a.
Rock type	Plagioclase-mica schist.	Biotite-plagioclase schist with aluminum silicates.	Biotite-plagioclase schist with cordierite and aluminum silicates.	Kyanite-bearing biotite-plagioclase rocks.[3]	Biotite-plagioclase rock 971 recalculated to include the large kyanite-andalusite prisms.
Location	Boehls	2½ miles northeast of Stocking Meadow Lookout.	South slope of Goat Mountain.	South slope of Goat Mountain.	South slope of Goat Mountain.
Weight percent					
SiO_2	51.65	56.00	46.04	56.47	52.55
Al_2O_3	26.42	27.16	29.20	25.44	32.97
Fe_2O_3	.15	.12	.73	.33	.33
FeO	1.89	2.67	4.35	1.44	1.16
MnO	.10	.03	.20	.04	.03
MgO	4.79	1.75	9.00	2.64	2.12
CaO	3.35	4.88	.68	4.12	3.30
Na_2O	4.41	4.34	2.99	6.73	5.40
K_2O	5.10	1.76	3.60	1.47	1.19
TiO_2	.12	.24	.24	.07	.06
P_2O_5	.01	.00	.00	.02	.00
CO_2	.01	.00	.01	.00	.00
H_2O+	1.85	.79	2.33	1.03	.83
H_2O-	.04	.10	.22	.07	.06
Total	99.89	99.84	99.59	99.87	100.00
Cation percent					
SiO_2	46.77	51.37	42.05	50.75	47.19
$AlO_{3/2}$	28.19	29.36	31.42	26.94	34.88
$FeO_{3/2}$	.10	.08	.51	.23	.23
FeO	1.43	2.05	3.32	1.08	.87
MnO	.08	.02	.15	.03	.02
MgO	6.46	2.39	12.24	3.54	2.84
CaO	3.25	4.79	.66	3.97	3.17
$NaO_{1/2}$	7.74	7.71	5.29	11.72	9.39
$KO_{1/2}$	5.88	2.06	4.19	1.68	1.36
TiO_2	.08	.17	.16	.05	.04
$PO_{5/2}$	.01			.01	.01
CO_2	.01		.01		
H_2O	(5.59)	(2.42)	(7.20)	(3.08)	(4.97)
	100.00	100.00	100.00	100.00	100.00
O	148.62	158.95	146.24	154.61	156.94
OH	11.18	4.84	14.19	6.17	4.97
Total anions	159.80	163.79	160.43	160.78	161.91
Molecular norm					
Q		8.23			5.07
Or	29.40	10.30	20.95	8.40	6.80
Ab	27.60	38.55	26.45	58.60	46.95
An	16.10	23.95	3.25	19.75	15.75
Ne	6.66				
C	8.13	10.01	20.64	5.64	17.83
En		4.78	14.92	1.28	5.68
Fs		3.72	3.72	.36	1.46
Fo	9.69		7.17	4.35	
Fa	2.07		1.80	1.14	
Ap	.03			.03	.03
Il	.16	.34	.32	.10	.08
Mt	.15	.12	.76	.35	.35
Cc	.02		.02		
Total	100.01	100.00	100.00	100.00	100.00
Molecular mode calculated from cation percent					
Quartz		8.41			
Plagioclase	An_{29} 54.80	An_{38} 62.50	An_{11} 29.70	An_{25} 78.35	An_{25} 60.59
Orthoclase		1.25			
Biotite	33.20	19.70	46.18	20.00	15.47
Muscovite	23.13				
Kyanite, Andalusite, Sillimanite		12.27	7.47	5.94	23.92
Cordierite			21.72		
Corundum			3.52		
Apatite	.03			.03	.02
Ilmenite			.20		
Magnetite			.76		
Calcite	.02		.02		
Total	111.18	104.13	109.57	104.32	100.00

[1] Analyst, Ruth H. Stokes, U.S. Geol. Survey
[2] Analyst, Faye H. Neuerburg, U.S. Geol. Survey
[3] Large kyanite crystals, which constitute estimated 20 percent of the rock, were not included in this analysis.

TABLE 14.—*Chemical analysis of biotite in kyanite-andalusite-plagioclase-biotite rock (no. 971c) on the south slope of Goat Mountain*

[Analyst, L. N. Tarrant, U.S. Geol. Survey]

Constituents	Weight percent	Molecular equivalent	Number of atoms		
SiO_2	37.85	6302	Si	5.41	8.00
Al_2O_3	21.61	2120	Al	2.59	
Fe_2O_3	1.21	76	Al	1.05	5.74
FeO	8.04	1119	Fe^{+3}	.13	
MnO	.13	18	Fe^{+2}	.96	
MgO	16.66	4132	Mn^{+2}	.02	
TiO_2	.32	40	Mg	3.55	
CaO	.00	--------	Ti^{+4}	.03	
Na_2O	.63	102	Na	.18	1.80
K_2O	8.89	944	K	1.62	
F	.03	16	F	.01	4.14
H_2O+	4.33	2403	H	4.13	
H_2O-	.12	--------	O	24.00	
	99.82	--------			
Less O for F	.01	--------			
Total	99.81	--------			

Sp gr=2.809–2.910

of pure andesine in the plagioclase-rich schist are common and many of them are several meters long. The anorthosite adjacent to the contact shows an irregular planar structure due to segregation of micaceous minerals and aluminum silicates into thin discontinuous layers or small lenticular masses.

A contact between fine-grained biotite quartzite and anorthosite is exposed along the West Fork of Cedar Creek. The anorthosite near the contact is fine grained and granular; its texture resembles that of quartzite. Small patches of light-gray to dark-gray rock occur in this white granular anorthosite. Thin sections show that these darker parts are fine grained and contain numerous small flakes of biotite and some epidote. The white portions consist of polygonal grains of andesine, many of which show reversed zoning. In addition, there are a few grains of hornblende and epidote and several large grains of allanite. Biotite-rich schlieren in this rock contain quartz. Elsewhere the quartzite and the lime-silicate rocks preserve their grain size, texture, and mineralogy up to the contact. The layer of bytownite rock that occurs next to the coarse-grained anorthosite along the West Fork of Cedar Creek is fine grained, hard, and unaltered as is also the other layer of bytownite rock that is interbedded with hornblende-biotite schist. No andesine was found in either layer. It seems that the occurrence of micaceous minerals greatly facilitated the development of andesine in the country rocks.

Near Boehls a coarse-grained phlogopite-andesine rock is between the anorthosite and the biotite schist. Chemical analysis (table 13, no. 630) shows that this schist is rich in aluminum and contains a considerable amount of calcium and magnesium.

The schist near the southern contact of the anorthosite along Cedar Creek contains abundant plagioclase and aluminum silicates. A part of this schist is recrystallized as a coarse- to medium-grained homogeneous light-gray plagioclase-biotite rock in which numerous slender blue prisms of kyanite 1 to 5 cm long are oriented at random.

The occurrence of garnet in the anorthosite along the contact between Orphan Point and Goat Mountain probably is a contact phenomenon comparable to the occurrence of aluminum silicates. The garnetiferous ellipsoidal lenticles and the abundance of quartz indicate the presence of abundant sedimentary material in this zone.

Thus, the distribution of plagioclase is not in all contact zones confined to bedding planes but is in places rather irregular, resembling then the feldspathization around metasomatic quartz diorite and tonalite bodies in the Headquarters quadrangle and vicinity (Hietanen, 1962). It seems that at least a part of the plagioclase in the schist near the anorthosite bodies crystallized late as a result of introduction of calcium and sodium and removal of excess silicon. The exchange of elements involved in the mineralogic changes around the anorthosite bodies can be well demonstrated by the chemistry of a cross section through the schist on the east side of Floodwood Creek to the anorthosite at Goat Mountain. Most of the schist along Floodwood Creek is a coarse-grained garnet-mica schist with abundant quartz and only a little oligoclase (compare with table 5, no. 1023). Near the mouth of Timber Creek (loc. 1690) and toward the north (loc. 1751) sillimanite and locally some staurolite appear in the schist. Thin sections show that the sillimanite replaces the biotite. Small grains of oligoclase or andesine occur with quartz. The amount of plagioclase varies but usually stays smaller than that of quartz. In the schist at the mouth of Timber Creek about 20 percent of the light minerals are plagioclase and 30 percent quartz (table 5, no. 1690). Toward the east, the beds rich in plagioclase become more common and the total amount of plagioclase in them increases. The amount of brown sillimanite also increases, and locally some kyanite and colorless needles of sillimanite are present. Near the contact of the anorthosite about 80 percent of the light constituents are plagioclase. Many outcrops in this zone consist of plagioclase-biotite rock with abundant aluminum silicates. Layers rich in micas and others rich in garnet are interbedded.

The gradual changes in mineralogy around the anorthosite bodies take place in an orderly manner and some of the changes indicate an introduction and removal of elements. In the outer zone where biotite is replaced by sillimanite, aluminum was introduced and potassium removed. The first local appearances of andesine in this zone indicate that in addition to aluminum some calcium was introduced. There is a definite increase of the total amount of calcium and aluminum and decrease of silicon and potassium toward the anorthosite. In the zone next to the anorthosite, calcic plagioclase abounds and the amount of quartz is small; the aluminum silicates constitute in places about 40 percent of the rock, with the average being about 15 percent. It is possible that much of the change in the total composition is depositional and that local rearrangements took place during the formation of anorthosite.

GROWTH OF GRAIN SIZE TOWARD THE ANORTHOSITE

The grain size of the minerals in the schist around the anorthosite bodies grows with the increase of plagioclase and aluminum silicates. The average grain size of quartz and biotite in the normal schist of the Prichard formation outside of the contact aureole is 0.01 to 1 mm and that of the garnet 1 to 5 mm. In many localities in the feldspathized schist, the biotite flakes reach a diameter of 1 to 3 mm and the andesine 0.5 to 5 mm. Kyanite crystals, as much as 30 cm long, were found in the schist next to the anorthosite. The grain size of the plagioclase in the anorthosite next to such coarse-grained feldspathized schist is of about the same magnitude as that in the schist, and the texture is coarsely granular. Thus, the growth of the grain size and the increase of plagioclase and aluminum silicates around the anorthosite bodies seem to be closely connected. It seems that the anorthosite bodies were centers of recrystallization and also centers of introduction of elements.

CONTACTS WITH AMPHIBOLITE

The contact of anorthosite with garnet amphibolite is exposed along the road north of Goat Mountain Lookout (loc. 1014). Anorthosite in this vicinity is medium grained, and dikes of similar anorthosite transect the garnet amphibolite. The garnet amphibolite has a good platy and linear structure. Thin sections show that numerous small grains and prisms of epidote and zoisite have crystallized in the anorthosite next to the garnet amphibolite. A few clusters of bluish-green hornblende occur as dark constituents in the anorthosite near the contact as well as farther from it. The garnet amphibolite next to the contact is very similar to the rest of this rock. The contact is sharp and both rocks preserve their grain size near it.

Numerous subhedral zoisite crystals were found in garnet amphibolite next to the anorthosite in a few blocks south of Goat Mountain. On the surface, the zoisite has weathered out, leaving double wedge-shaped cavities. Tiny subhedral garnet crystals have formed along the contact, which is sharp and along which the rock cleaves easily.

Inclusions of amphibolite were found in some large blocks of anorthosite south of Goat Mountain. The contact between these inclusions and the anorthosite is sharp.

The contact between the pyroxene-bearing anorthosite and the amphibolite in locality 1692 is quite different. The amounts of plagioclase and diopside decrease and that of hornblende increases gradually toward the amphibolite over a distance of 2 to 3 cm. Both dark constituents, diopside and hornblende, occur together in the contact zone. The plagioclase in the amphibolite is similar to that in the anorthosite except that the grains in the amphibolite are larger and contain small inclusions of hornblende. No garnet or biotite occurs in this amphibolite. This contact resembles the contact found between the intrusive hornblende gabbro and the inclusions of anorthosite southeast of Goat Mountain. No outcrops were found, but large blocks of hornblende gabbro on the southeast slope of Goat Mountain contain inclusions of fine- to medium-grained anorthosite. The contact is gradational over about 4 cm with the amount of hornblende decreasing toward the anorthosite. Numerous tiny round grains of quartz are included in plagioclase as well as in hornblende. Both of these latter minerals have complex interlocking boundaries resembling sutured texture. A similar relation between the anorthosite and hornblende-rich rock was found in blocks north of the forks of Cedar Creek just south of locality 1753. It seems that these contacts represent a contact between the anorthosite and a younger gabbroic rock. The hornblende-rich portion in the anorthosite 2 miles northeast of Stocking Meadow Lookout (loc. 947) probably represents a similar gradational zone between the anorthosite and hornblende gabbro.

CHEMICAL COMPOSITION OF THE ANORTHOSITE AND ITS COUNTRY ROCKS

The analyses of the anorthosite and of the country rocks were plotted in the QMF diagram (fig. 44) that was prepared in the following way: F is the total amount of feldspars in the molecular norm. Total of iron and magnesium is calculated as orthosilicates, the excess of aluminum oxide and magnetite from the molecular norm is added to this total and the sum used for the M coordinate. Q is free quartz after computation of F and M. The sum of $Q+F+M=100$. In this ternary diagram the plots for the anorthosite and feldspar-rich country rocks are scattered close to the F corner. The rocks of the intrusive quartz monzonite series, which were added for comparison, form a smooth curve near the F corner (nos. 1063, 1073, 1072, 301,

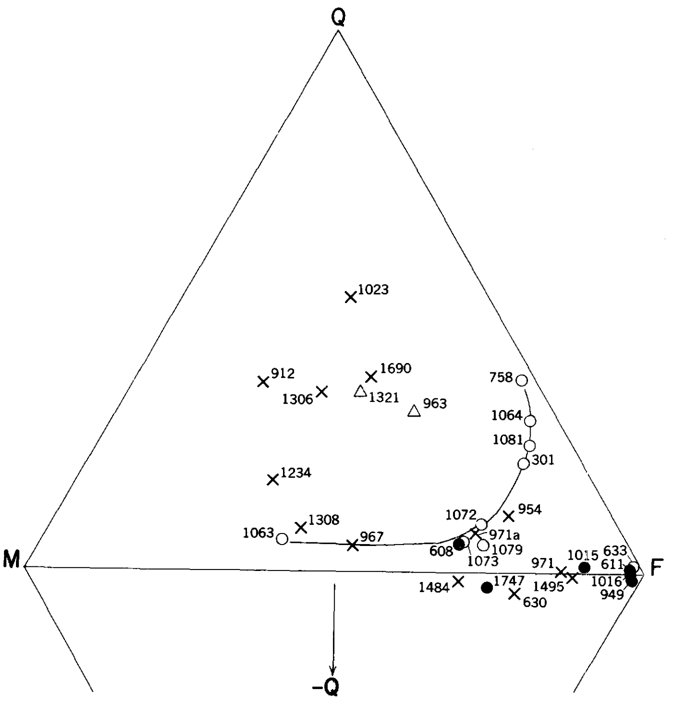

FIGURE 44.—QMF diagram for the anorthosite and its country rocks. (●), anorthosite; (X), country rocks; (Δ), amphibolite; (O), intrusive rocks. F, total amount of feldspars in the molecular norm. M, total of iron and magnesium calculated as orthosilicates to which is added corundum and magnetite from the molecular norm. Q, quartz in the molecular norm after calculation of M. Q+M+F=100. The analyses that are deficient in Q are plotted under the MF line. Numbers 1747, 949, 1016, 1015, 611, and 608 are anorthosites (table 11); nos. 630, 954, 967, 971, and 971a are schists next to the anorthosite (table 13); nos. 1023, 1690, 1234, 1306, and 1308 are rocks of the Prichard formation (table 5); no. 1484 is sericite-margarite schist (table 8); nos. 963 and 1321 are garnet amphibolite (table 10); no. 633 is orthoclase dike (table 9); no. 912 is cordierite gneiss (Hietanen, 1956, table 3); nos. 758, 1064, 1081, 301, 1072, 1073, 1079, and 1063 are rocks of the quartz monzonite series that were added for comparison.

1081, 1064, and 758). The plots for the metasedimentary rocks and amphibolites are scattered around the center of the diagram; these rocks have more iron-magnesium silicates and quartz and less feldspars than the anorthosite and its country rocks and the intrusive series. The plots for the country rocks of the anorthosite fall close to the curve for the igneous rocks and toward the F corner.

The ratio of the normative amounts of the three feldspars—orthoclase, albite, and anorthosite—is shown in figure 45. The plots for most varieties of anorthosite fall around An_{60}, but 80 percent of the normative feldspar in no. 949 and more than 90 percent in no. 1747 is anorthite. The plots for the rocks of the quartz monzonite series are connected with a curve for easier observation. The plots for most of the plagioclase-rich schist around the anorthosite fall close to this curve or toward the Ab corner. The position of the plots shows that the normative plagioclase of the country rocks is more albitic than that of the anorthosite. The normative feldspar in the lime-silicate rocks (nos. 1306 and 1308) is similar to that in the bytownite anorthosite (no. 949). The other anorthosites occupy a field between these lime-silicate rocks and the feldspathized schist that occurs next to the anorthosite.

In order to study the average amount of the major constituents in the anorthosite, its country rocks, and unaltered rocks of the Prichard formation, the averages of the ionic percentages in the rocks concerned were plotted in figure 46. In this figure *a* represents an average of cation percentages of 6 analyses of the anorthosite of table 11 and *c* the same average for 5 country rocks (table 13). These country rocks represent the composition of the schist in a zone as far as half a mile from the anorthosite. Number 1690 is a representative of a feldspathized schist about 1 mile from the anorthosite and no. 1023 is a typical unaltered schist of the Prichard formation. In the normal schist of the Prichard formation (no. 1023), 70 percent of the cations are silicon and 16 percent aluminum. In the feldspathized schist about a mile from the anorthosite the corresponding percentages are about 59 and 25. The average of the ionic percentage of silicon in the schist next to the anorthosite is 52.5 and in the anorthosite only 44.5. The corresponding percentages for aluminum are 28 and 31.5. Thus the amount of aluminum increases and that of silicon decreases considerably from the normal schist (no. 1023) through the feldspathized schist (no. 1690) and the country rock (c) to the anorthosite (a). Calcium and sodium show a considerable increase in the same direction, but the amounts of potassium and iron decrease.

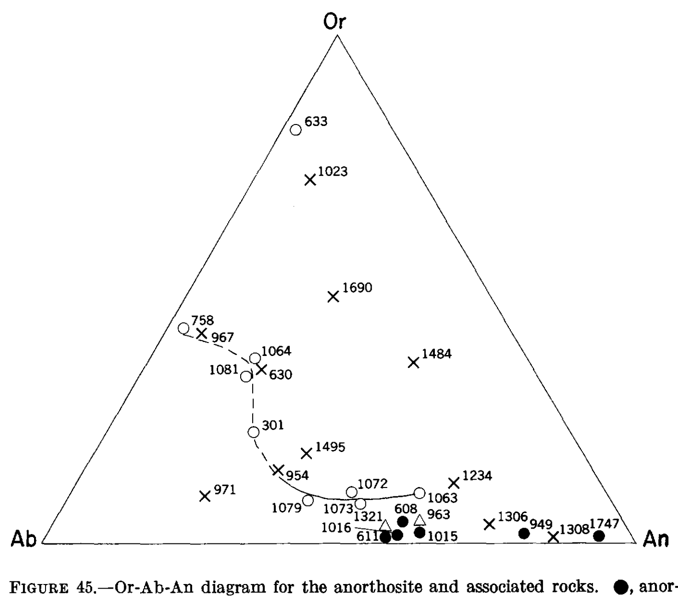

FIGURE 45.—Or-Ab-An diagram for the anorthosite and associated rocks. ●, anorthosite; x, country rocks; Δ, amphibolite; o, intrusive rocks. The amounts of orthoclase (Or), albite (Ab), and anorthite (An) from molecular norm was calculated to 100 and used for coordinates. The numbers refer to the same analyses as those in figure 44.

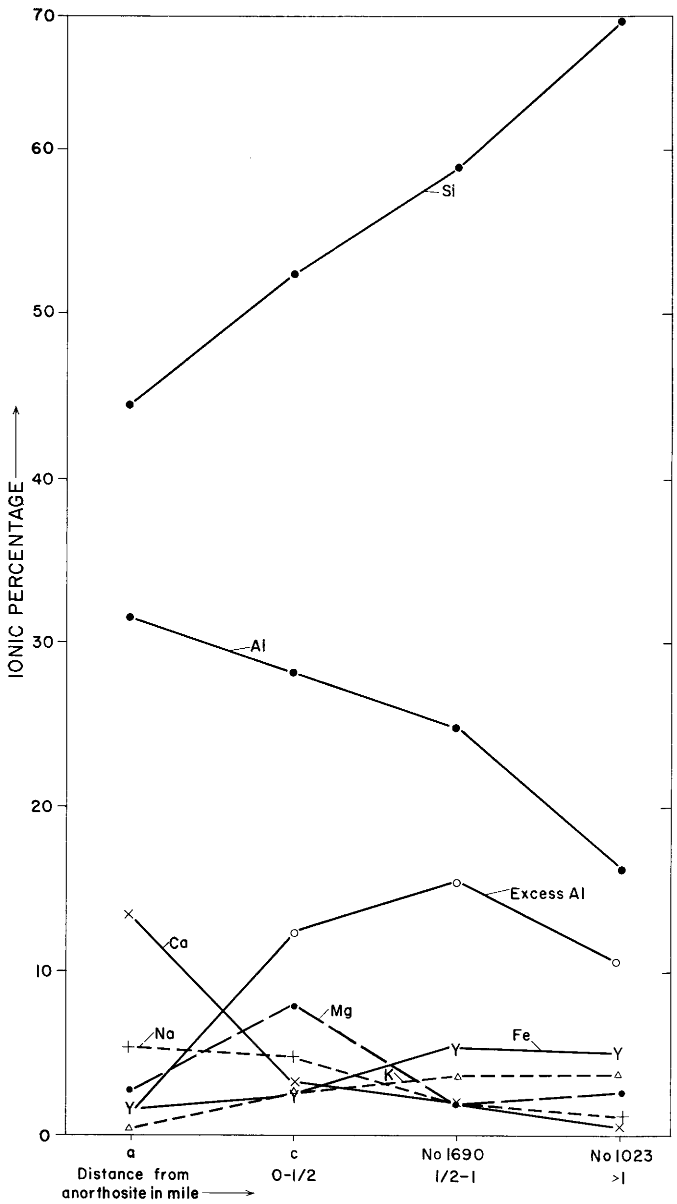

FIGURE 46.—Graph showing the average ionic percentages of silicon, aluminum, calcium, sodium, potassium, iron, and magnesium in anorthosite and its country rocks. The excess of aluminum after subtracting the amount combined with K, Na and Ca to form feldspars is also shown. a=average of the ionic percentages for anorthosites in table 11, c=average of the analyses of the country rocks in table 13, no. 1690 (table 5) represents a schist about a mile from the anorthosite, and no. 1023 (table 5) is a normal schist in the Prichard formation.

The feldspathized schist next to the anorthosite shows the highest concentration of magnesium. The average amount of this element in the anorthosite is slightly higher than that in the normal schist and that in the schist about a mile from the anorthosite (no. 1690).

The excess of aluminum after subtraction of the amount combined with K, Na, and Ca to form feldspars is largest in the schist about a mile from the anorthosite. Even though the total amount of aluminum is highest in the anorthosite, the excess is very slight because of the large amount of calcium and sodium present in this rock.

DISTRIBUTION OF MINOR ELEMENTS

Minor elements were determined spectrographically in those rocks and minerals which were analyzed chemically. In the anorthosite and its country rocks Ni, Co, Cr, Cu, V, Ga, Ba, and Sr were found (table 15); in the garnet amphibolite (table 16), and in various layers of the Prichard formation (table 17) Sc, Y, Yb, and Zr also are common. The two latter groups or rocks contain abundant garnet in which a part of these elements are contained (table 18). Also, tremolite and anthophyllite carry Sc, Y, Yb, and Zr. An appreciable amount of lithium was found in margarite. Beryllium, niobium, lanthanum, lead, and tin are scarce or completely lacking. Boron abounds in those schist layers which contain tourmaline. Ag, Au, Pt, Mo, W, Ge, As, Sb, Bi, Cd, In, Th, and U were looked for but not found.

To compare the average amounts of each element in garnet amphibolite, in anorthosite, and in its country rock, the mean concentration for each element in these three rock types was calculated and plotted in figures 47 and 48. Only a slight variation is seen in the amounts of Ni, Co, Cr, and Ga. In contrast to this Cu, V, Sc, Y, Zr, Ba, and Sr show definite concentrations in certain rock types.

Copper and vanadium are concentrated in the garnet amphibolite, with the anorthosite and its country rock containing only small amounts of these elements. In all rock types, the major part of vanadium is contained in garnet and in amphibole, but these minerals (nos. 1353 and 608a in table 18) in the anorthosite contain only about one-tenth of the amount that is contained in garnet and amphibole of the garnet amphibolite and the metasedimentary rocks (nos. 1225, 568, 1227, and 1306a in table 18). Most of the copper in the garnet amphibolite, however, is contained in chalcopyrite, which was found in some of the thin sections.

No scandium was found in anorthosite or in its plagioclase-rich country rock, whereas the various layers of the Prichard formation and the garnet amphibolite contain an appreciable amount of this element. Among the analyzed minerals (table 18) the garnet is a chief carrier of scandium; some of the amphiboles contain a moderate amount and the micas very little of it. It is noteworthy that the aluminous anthophyllite (nos. 813 and 1227) and the garnet occurring with it (nos. 813b and 1225) are rich in scandium, whereas the hornblende in the anorthosite (calcium-rich environment) and the calcium-rich garnet in skarn in an area nearby (31 miles southwest of Boehls, no. 568) show no trace of this element. Because the temperature of recrystal-

TABLE 15.—*Quantitative spectrographic analyses, in parts per million, of minor elements in anorthosite and its country rocks and in an orthoclase dike in the country rock*

[Analyst, Paul R. Barnett, U.S. Geol. Survey. Leaders indicate zero; Li was not determined]

Specimen	Ni	Co	Cr	Cu	V	Ga	Sc	Ba	Sr	Be	Y	Yb	La	Zr	B	Li	Pb
Anorthosite (see table 11)																	
1747	40	20	20	2	20	20	--------	30	4000	--------	--------	--------	--------	--------	150	--------	100
949	10	--------	4	50	20	7	--------	90	1000	--------	--------	--------	--------	--------	--------	--------	--------
1016	6	--------	5	10	8	6	--------	100	800	--------	--------	--------	--------	--------	--------	--------	--------
1015	100	30	10	20	10	7	--------	200	1000	--------	--------	--------	--------	--------	--------	--------	--------
611	--------	--------	3	8	8	10	--------	70	4000	--------	--------	--------	--------	--------	--------	--------	--------
608 [1]	200	30	20	4	20	10	--------	30	300	--------	--------	--------	--------	--------	--------	--------	--------
Average	60	13	10	16	14	10	--------	90	1867	--------	--------	--------	--------	--------	--------	--------	--------
Country rocks (see table 13)																	
630	--------	5	4	4	20	10	--------	2000	3000	--------	--------	--------	--------	--------	--------	--------	20
954	25	7	30	--------	30	15	--------	700	700	--------	--------	--------	--------	--------	--------	--------	--------
967	70	20	30	2	40	15	--------	600	200	--------	--------	--------	--------	--------	--------	--------	--------
971	--------	7	--------	4	8	15	--------	800	1000	--------	--------	--------	--------	--------	--------	--------	--------
Average	24	10	16	2	24	14	--------	1025	975	--------	--------	--------	--------	--------	--------	--------	5
Orthoclase dike (see table 9)																	
633	--------	--------	2	10	--------	7	--------	4000	400	--------	--------	--------	--------	60	--------	--------	--------

[1] Analyst, A. A. Chodos, U.S. Geological Survey.

TABLE 16.—*Quantitative spectrographic analyses, in parts per million, of minor elements in garnet amphibolite (table 10)*

[Analyst, Paul R. Barnett, U.S. Geol. Survey. Leaders indicate zero; Li was not determined]

Specimen	Ni	Co	Cr	Cu	V	Ga	Sc	Ba	Sr	Be	Y	Yb	La	Zr	B	Li	Pb
963	40	40	30	200	300	20	40	30	300	--------	70	5	--------	150	--------	--------	--------
1321	40	40	25	400	300	15	40	40	60	--------	70	6	--------	150	--------	--------	--------
Average	40	40	27	300	300	18	40	35	180	--------	70	5	--------	150	--------	--------	--------

TABLE 17.—*Spectrographic analyses of minor elements in the metasedimentary rocks* [1]

[Specimen 1690 analyzed quantitatively, and results are in parts per million; other specimens (see tables 5 and 8) analyzed semiquantitatively, and results are in percent, as explained in footnote. Analyst, Paul R. Barnett, U.S. Geol. Survey. Leaders indicate zero; Li was not determined]

Specimen	Ni	Co	Cr	Cu	V	Ga	Sc	Ba	Sr	Be	Y	Yb	La	Zr	B	Pb	Nb
1690	30	20	100	20	100	15	20	1000	100	--------	50	4	--------	150	500	--------	--------
1234	0.00x−	0.000x	0.00x	0.00x	0.00x	0.000x−	0.000x+	0.00x	0.00x+	--------	0.00x−	0.000x	--------	0.00x+	--------	--------	0.00x−
1306	.000x+	.000x	.00x	.000x+	.00x+	.000x+	.00x−	.000x−	.00x	--------	.00x−	.000x	--------	.00x+	--------	--------	.000x+
1308	.000x	.000x	.00x−	.00x+	.00x	.00x−	.00x−	.000x+	.0x−	--------	.00x−	.000x	0.00x	.00x+	--------	--------	.000x+
1495	.000x	--------	.00x−	.000x	.00x	.00x	.000x	.0x−	.0x−	--------	--------	--------	--------	.00x−	--------	0.00x+	--------
1484	.000x	--------	.00x+	--------	.00x+	.00x+	.000x	.0x	.0x−	0.000x	.000x+	.000x−	--------	--------	0.00x	.000x	--------

[1] The concentations of the elements as determined by semiquantitative spectrographic analysis are bracketed into groups each of approximately one-third of the order of magnitude, x+ indicates the higher portion (10–5 percent), x of the middle portion (5–2 percent), and x− the lower portion (2 to 1 percent). Comparisons of this type of semiquantitative results with those obtained by quantitative methods either chemical or spectrographic, show that the assigned group includes the quantitative value about 60 percent of the time.

TABLE 18.—*Quantitative spectrographic analyses, in parts per million, of minor elements in amphiboles, micas, and garnet from the rocks of Boehls Butte quadrangle and vicinity*

[Analysts: A. A. Chodos, no. 608a; Paul R. Barnett, nos. 1306a, 971c, 1484a; Harry Bastron, nos. 813a, 1227, 568, 813b, 1225a, 1225b, 1353, 13, 354; all of the U.S. Geol. Survey. Leaders indicate zero; Li was not determined]

Analysis	Ni	Co	Cr	Cu	V	Ga	Sc	Ba	Sr	Be	Y	Yb	La	Zr	B	Li	Pb	Tl [1]	Sn	Zn
608a	300	100	3	10	20	10	--------	5	20	--------			--------	--------	--------	--------	--------	--------	--------	--------
1306a	3	--------	70	3	150	2	15	150	15	--------	15	2	--------	30	--------	--------	15	(1,500)	--------	--------
813a	5	30	20	7	800	30	50	--------	--------	--------	30	6	--------	80	--------	--------	--------	--------	--------	1,000
1227	100	40	200	9	300	40	60	20	--------	--------	50	8	--------	100	--------	--------	--------	--------	100	--------
971c	40	50	4	6	30	30	--------	2,000	--------	--------	--------	--------	--------	--------	--------	100	--------	--------	--------	--------
1484a	7	3	150	15	70	70	3	150	700	7	--------	--------	--------	--------	30	1,500	30	(1,500)	--------	--------
568	--------	--------	--------	10	200	20	--------	--------	--------	--------	20	4	--------	50	--------	--------	--------	--------	--------	--------
813b	--------	30	9	20	100	10	300	--------	--------	--------	200	20	--------	80	--------	--------	--------	--------	--------	200
1225a	--------	20	80	20	200	--------	100	--------	--------	--------	200	30	--------	100	--------	--------	--------	(200)	--------	--------
1225b	--------	20	100	80	100	10	60	30	--------	--------	100	20	--------	200	--------	--------	--------	(1,000)	--------	--------
1353	--------	30	20	7	10	10	40	--------	--------	--------	30	9	--------	30	--------	--------	--------	--------	--------	--------
13	--------	40	300	60	80	20	300	--------	--------	--------	400	70	--------	400	--------	--------	--------	--------	--------	--------
354	--------	20	40	7	200	10	100	--------	--------	--------	60	10	--------	40	--------	--------	--------	--------	--------	--------

608a, Hornblende, table 12
1306a, Tremolite, table 6
813a, Aluminous anthophyllite (gedrite) from garnet-kyanite gedritite near Orofino (Hietanen, 1959)
1227, Aluminous anthophyllite (gedrite), table 3
971c, Biotite, table 14
1484a, Margarite, table 8
568, Grossularite from lime-silicate rock at Bruces Eddy near Orofino (Hietanen, 1962) [2]
813b, Garnet from garnet-kyanite gedritite near Orofino (Hietanen, 1959)
1225a, Garnet, table 4
1225b, Garnet, table 4
1353, Garnet, table 4
13, Garnet from garnet-biotite-plagioclase rock, Dent (Hietanen, 1962)
354, Garnet from garnet amphibolite, Orofino Creek (Hietanen, 1962)

[1] Tl probably introduced by heavy-liquid separation procedures.

[2] Composition in molecular percentages is: grossularite, 85.74; andradite, 12.52; almandite, 1.10; pyrope, 0.46; and spessortite, 0.18

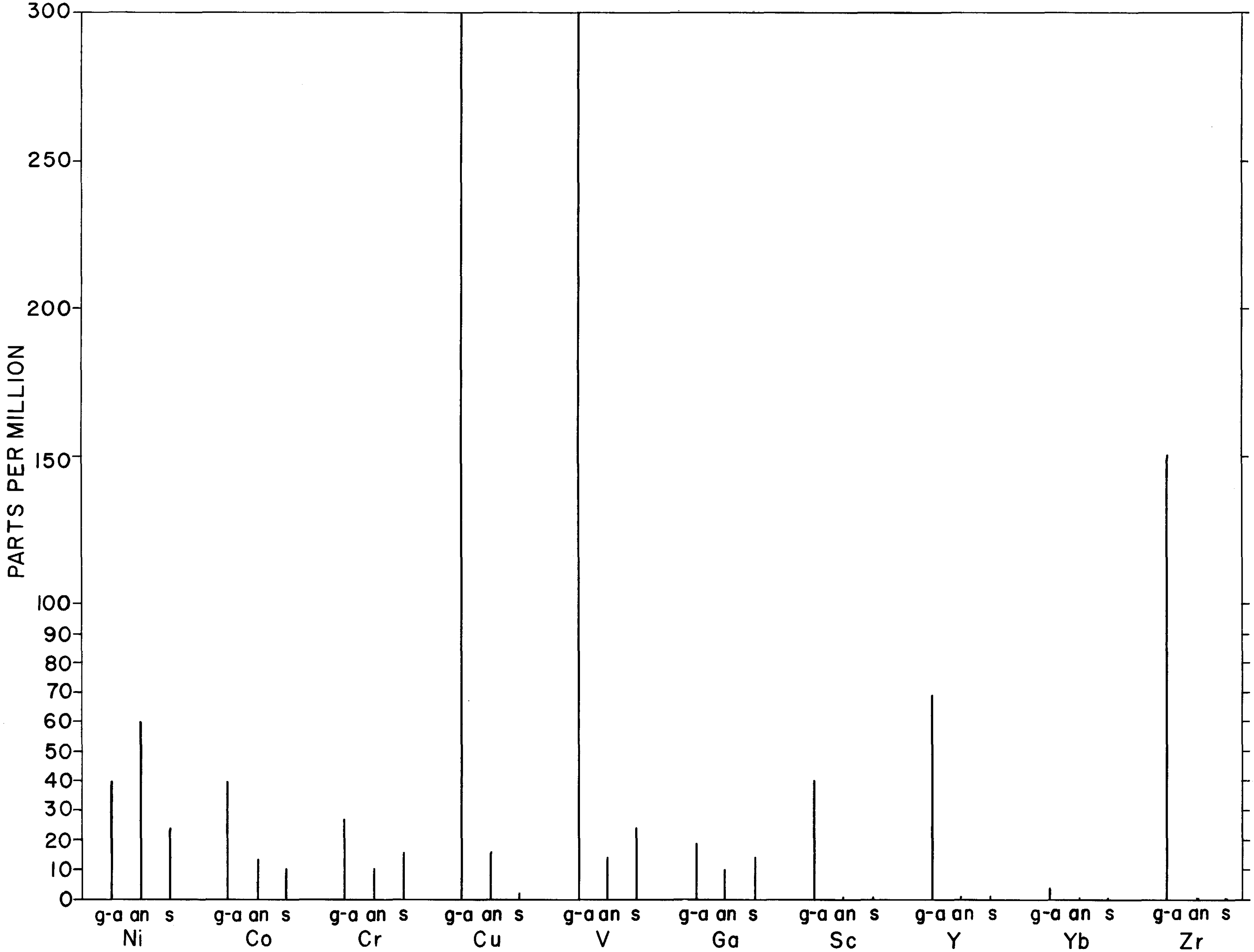

FIGURE 47.—Average concentration of Ni, Co, Cr, Cu, V, Ga, Sc, Y, Yb, and Zr in the garnet amphibolite (g–a), the anorthosite (an), and in the country rock (s).

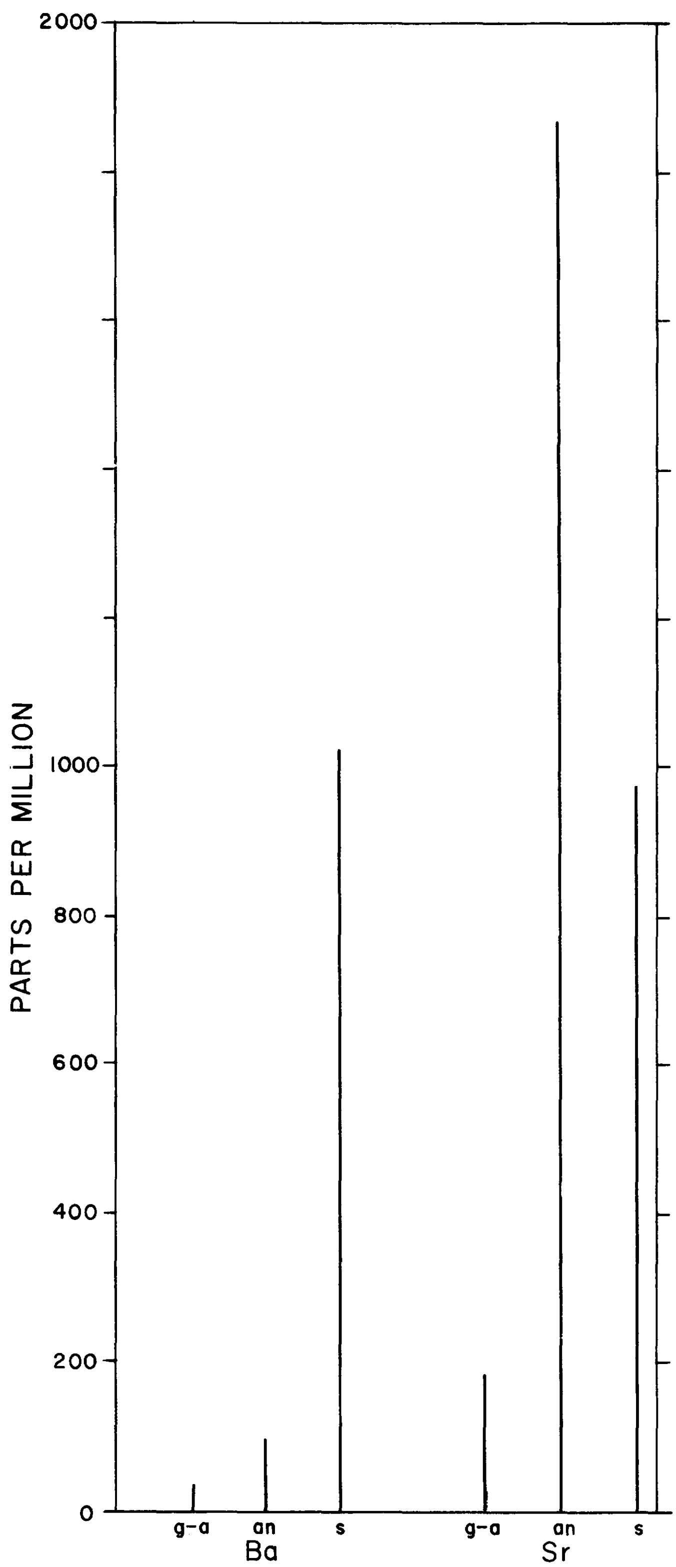

FIGURE 48.—Average concentration of barium and strontium in the garnet amphibolite (g-a), the anorthosite (an), and in the country rock (s).

lization was about the same for all rocks analyzed, this distribution suggests that the enrichment of scandium depends much on the chemical environment. It was earlier found that most micas of this region do not contain scandium (Hietanen, 1962); the present study confirms that the garnet is its chief carrier, the almandine of the garnet-biotite-plagioclase rock (no. 13) and the pyrope of the garnet gedritite being richest in this element.

The pattern of distribution of yttrium, ytterbium, and zirconium follows closely to that of the scandium. The highest concentrations are found in the garnet-amphibolite, and the anorthosite and its country rocks are void of these elements. Study of the minerals suggests that garnet and amphiboles are the chief carriers. However, a few small zircon crystals occasionally are found in the garnet amphibolite.

Barium and strontium are concentrated in anorthosite and in its country rocks, the other rocks of the area containing much less of these elements. In the anorthosite, the amount of strontium is about ten times higher than that of barium, whereas in the country rocks these two elements occur in equal amounts. The highest concentration of barium is found in the orthoclase dike,' the muscovite-rich schist (no. 630) being the second in order. It was found earlier that muscovite contains three times as much barium as the biotite in the same rock (Hietanen, 1962). Orthoclase in specimen no. 633 has 4,000 ppm barium, thus twice the amount contained in biotite (no. 971c). The calcium mica (the margarite no. 1484a) contained 700 ppm strontium and only 150 ppm barium. Thus barium is concentrated in the rocks and minerals rich in potassium, whereas strontium accompanies calcium and is contained mainly in plagioclase.

The distribution of the minor elements has a pattern similar to that found in the area south of Boehls Butte quadrangle (Hietanen, 1962). Strontium is concentrated with calcium in the plagioclase-rich rocks, as in anorthosite and its country rocks. Barium follows closely the distribution of minerals rich in potassium, such as orthoclase, muscovite, and biotite. High concentrations were found in the country rocks of the anorthosite.

Copper, vanadium, zirconium, yttrium, and ytterbium are concentrated with magnesium and iron in the garnet amphibolite that represents the basic rocks of the area and can be correlated with the accumulations of ferromagnesium minerals in the area south of the Boehls Butte quadrangle.

COMPARISON OF THE OCCURRENCES OF ANORTHOSITE

On the basis of the above descriptions of the anorthosite in the Boehls Butte quadrangle, it is evident that there are a few similarities but also several marked differences between the anorthosite in the Boehls Butte quadrangle and the occurrences of anorthosite described in the literature.

The mode of occurrence and the shape of anorthosite bodies in the Boehls Butte quadrangle are, in some respects, comparable with those of the Jay mass within the Adirondacks anorthosite area as described by Buddington (1939, p. 25). He writes: "The curved shape of the Jay mass, the foliation of the outer border, and the shape and foliation of the prong of the main anorthosite massif to the south will suggest that it is a folded sheet on the nose of a north-pitching anticline." The petrology of the anorthosite and that of the associated rocks in the Boehls Butte quadrangle, however, are quite different. The Adirondack anorthosite contains only one type of plagioclase, usually andesine or labradorite (Barth, 1930), and the mafic constituents in it tend to increase toward the contact zones. No aluminum silicates of such an extent as present in the Boehls Butte quadrangle have been reported from the Adirondacks or any other anorthosite area. Only corundum has been reported earlier in some rare hornblende-bearing anorthosites (Miller, 1899, p. 279–280, Rosenbusch and Osann, 1922, p. 243) and in oligoclase pegmatites (Barth, 1927, p. 98).

Pyroxenes are common mafic constituents in most anorthosites described in the literature, suggesting a dry environment (Suter, 1922; Chatterjee, 1929). In contrast to this, hornblende and chlorite are the regular dark constituents of the anorthosite in the Boehls Butte quadrangle, suggesting a wet environment. Biotite, which is rare in other anorthosites, is common in most of the anorthosite under discussion. No block structure or cataclastic textures that are common in the Adirondacks (Balk, 1931, p. 357–358) and in Nain, Labrador (Wheeler 1942, p. 619) were found in the anorthosite in the Boehls Butte quadrangle. Large crystals of plagioclase that are common in the Marcy anorthosite and in similar coarse-grained dark anorthosite of Morin Heights, near Montreal, are rare in the Boehls Butte quadrangle where the grain size and color of the coarse-grained massive anorthosite are closest to those of the light-gray, coarse-grained anorthosite at San Gabriel Mountains, California. On the other hand, the hornblende-bearing gneissic variety resembles the Whiteface facies in the Adirondack area except that garnet is rare in this type in Idaho and the layering is more pronounced.

A gradation to a gabbroic anorthosite, gabbro, and norite is common in most anorthosite areas described in the literature (Buddington, 1939; Harrison, 1944; Wheeler, 1942; Michot, 1955, 1957) but very rare in the area under discussion. No normal syenitic rocks, as are common elsewhere, are associated with anorthosite in the Boehls Butte quadrangle. The only potassium-rich rock found is the orthoclase dike (table 9) near Boehls. The associated intrusive rocks are quartz diorite and quartz monzonite, the latter being younger than the anorthosite.

In the Boehls Butte quadrangle, the floors of most anorthosite bodies are exposed, but the mafic rocks, amphibolite, and garnet amphibolite rarely occur along this lower contact zone. Rather, the associated mafic rocks occur as small concordant lenses in the country rocks above as well as below the anorthosite, or are included in the anorthosite bodies. These mafic bodies are richer in silicon and aluminum than the normal gabbros. Many bodies contain abundant biotite and garnet and grade over to garnet-mica schist. Most are concordant but a few dikelike discordant bodies were found. Some of the mafic bodies in anorthosite are older than the anorthosite; a few next to the anorthosite bodies seem contemporaneous or younger.

The distribution of mafic rocks and garnet amphibolite in the same general area where anorthosite occurs suggests a genetic relationship. They form the only group of basic rocks that can be complementary to the anorthosite. The fine-grained gabbro with diabasic texture occurs as sill-like bodies and is definitely younger than the anorthosite. In general, the mafic rocks of this area range in age from pre-anorthosite to post-anorthosite, only the youngest group being true gabbro. The volume of the mafic rocks exposed is subordinate and quite inadequate to give a gabbroic composition if added to the anorthosite. However, the amount of the mafic constituents is larger than the geologic map (pl. 1) shows, because some of the surrounding schist is enriched in ferromagnesian minerals such as garnet, biotite, and cordierite. The enrichment of the country rocks in aluminum silicates is, however, far more striking and one of the unique features of the anorthosite area in the Boehls Butte quadrangle.

The association of the anorthosite with metasedimentary rocks rich in aluminum is comparable to that of the anorthite rocks described briefly by Lacroix (1939) from Madagascar. These rocks, called "sakenites" by Lacroix, are found as layers as much as 12 m thick with paragneiss rich in sillimanite, cordierite, and almandine. The other associated rocks are pyroxenites and amphibolites of various kinds. The sakenites are bluish or greenish white, medium to coarse grained, saccharoidal, resembling marble in their appearance. Some samples show indistinct banding. Anorthite or some other plagioclase close to anorthite in composition is the main constituent; the additional minerals are spinel, sapphirine, corundum, and leucaugite rich in aluminum. Some light-colored phlogopite or chlorite occurs in places. In some layers corundum is a major constituent. The description is too brief to give a full picture of these rare types of calcic plagioclase rocks or of the associated rocks. Their mode of occurrence in rather thin layers in the metasedimentary strata (paragneiss) seems to suggest that they are of sedimentary origin and are probably so considered by French geologists.

GENESIS OF THE ANORTHOSITE

As pointed out in the introduction, the igneous origin of anorthosite is generally accepted, and the discussions are centered around the possible composition of the parent magma and around the mechanism of differentiation and intrusion or possible later modifications through metamorphic and metasomatic processes. The contact relations, structure, texture, and mineralogy of the anorthosite in the Boehls Butte quadrangle make an intrusive origin for these particular bodies questionable. Some of the layers in the metasedimentary rocks consist of about 90 percent calcic plagioclase (bytownite), giving rise to a thought of a possible sedimentary origin. On the other hand, the widespread enrichment of country rocks in elements like aluminum and calcium suggests that metasomatic processes played an important role in the formation of these anorthosite bodies. In the following discussion each possible explanation is summarized and weighed.

POSSIBILITY OF IGNEOUS ORIGIN

The massive coarse-grained anorthosite that is common in the central parts of the two northernmost large bodies and that also occurs locally elsewhere has the appearance of an intrusive rock. However, the presence of two plagioclases—andesine and bytownite—and their peculiar texture are difficult to explain on the basis of our present knowledge about the crystallization of the albite-anorthite series. It is apparent that anorthosite of this composition and texture could not be formed through a simple crystallization differentiation from a gabbroic or gabbroic-anorthositic magma as has been suggested for the anorthosite in general. Magmatic origin must be questioned unless it can be shown that in certain physico-chemical conditions andesine and bytownite will crystallize contemporaneously from a liquid and form separate grains, or that a later exsolution of labradoritic plagioclase would yield a mixture of andesine and bytownite. Moreover, the physico-chemical conditions that prevailed during such crystallization or exsolution must be consonant with the geology of the area.

The occurrence of sillimanite and muscovite together in the schist and in the schistose inclusions in the anorthosite suggests that the temperature was under 650°C (Yoder and Eugster, 1955). There was enough water present to prevent the crystallization of pyroxenes. If it is assumed that the associated amphibolites are differentiates of the same magma as the anorthosite, the composition of such magma should have been similar to the composition of the anorthosite no. 1015 (table 11). It is clear that a magma of this composition could not be liquid under 650°C. The presence of abundant volatiles could have prevented freezing of the small amount of liquid needed to facilitate an intrusion of a mush of plagioclase crystals. However, there are no signs of such an extensive protoclasis as would be expected to result from an intrusion of fairly solid crystal mush. The small grains of bytownite between the larger grains of andesine resemble the granulated texture, but the composition of the two plagioclases refutes such a theory. If the granulated small grains crystallized from the residual liquid, they should be more sodic than the large crystals. The banded structure along the border zones of the anorthosite is an alternation of thin layers of andesine and bytownite and, therefore, cannot be considered to result from the granulation alone.

If it is assumed that a very large amount of volatiles were present to keep the plagioclase in the solution at a temperature close to 650°C, such a solution is no longer a magma, but rather resembles a pneumatolytic or hydrothermal solution, and a rock deposited from such a solution is not magmatic in its strict sense.

The other possibility would be a later exsolution of andesine and bytownite from an originally labradoritic plagioclase and a later low-temperature metamorphism. The mineral associations found now would be the result of a recrystallization of the primary constituents in a low-temperature field. If this were the case, one would expect to find some traces of the earlier high-temperature minerals; one should also find a similar exsolution in many other areas in the world where plutonic rocks have been subjected to a low-temperature metamorphism. However, there are no reports of such an exsolution. Moreover, it would be difficult to explain why parts of the border zones contain exclusively bytownite, whereas only andesine is found in the plagioclase-rich schist. The common occurrence of minerals that are typical of rocks of sedimentary origin (kyanite, andalusite, sillimanite, staurolite, biotite, garnet) and of the beddinglike structure in the anorthosite, the gradational contacts between the anorthosite and the schist, and the substitution of andesine for the quartz in the schist next to the anorthosite, are further features that refute the hypothesis of igneous origin of these anorthosite bodies.

The anorthosite was found to change over to a gabbroic anorthosite only in one locality and to amphibolite in two localities. One would expect to find such a change in many places if the anorthosite were a differentiate of a gabbroic-anorthositic magma.

POSSIBILITY OF ISOCHEMICAL METAMORPHIC ORIGIN

Many of the contact relations, the mineralogy, and the structure of the anorthosite resemble those found in the rocks of sedimentary origin. The distribution of the various rock types in the Belt series is lenticular, and it is possible that a plagioclase-rich sediment was desposited in the lower part of the Prichard formation. No such distinctly discordant contacts as described from the vicinity of Dent, about 20 miles southwest of Boehls (Hietanen, 1962), were found in the present area. Therefore, the possibility of sedimentary origin must be carefully considered. This possibility is strengthened by the occurrence of the lime-silicate rocks, some of them rich in bytownite, and andesine-phlogopite schist in the lower quartzite unit of the Prichard formation as described earlier in this report. Both of these rocks are rich in calcium and contain a considerable amount of aluminum (table 5, nos. 1234, 1495). The mode of occurrence, texture, and mineralogy of the two bytownite rock layers along the West Fork of Cedar Creek suggest a sedimentary rather than an igneous origin for the bytownite anorthosite. Paper-thin layers of bytownite interbedded with thin layers of quartzite and lime-silicate rock were found in two other localities. Some of these thin beds have a peculiar texture; bytownite occurs in grains of medium size and includes numerous tiny round quartz grains. This kind of texture is typical of metamorphic rocks. It is scarcely possible that the paper-thin laminae of bytownite in this rock were crystallized as a result of introduction of elements. The layering is more likely due to the alternation of dolomitic, limy, shaly, and sandy layers. The bytownite rocks may represent thicker layers of pure plagioclase in a similar sequence. As pointed out earlier, one of these bytownite layers is interbedded with fine-grained bedded hornblende-biotite schist, originally probably a calcareous clay.

It is more difficult to explain the occurrence of bytownite in the kyanite-andalusite-bearing anorthosite that contains inclusions of aluminous schist. If the bytownite in the anorthosite with excess of aluminum were of sedimentary origin, these sediments should have been calcareous shales exceptionally rich in aluminum and very poor in iron and magnesium. No such sediments are known to occur elsewhere in the Beltian strata, nor have descriptions of such sediments been found in the literature. The only reference that has some bearing on the subject is the short description by Lacroix (1939) of a corundum-bearing anorthite rock layer in a paragneiss in Madagascar. In the Idaho area the aluminous schist farther from the anorthosite bodies is poor in calcium, and most of the calcareous layers and masses in this schist are rich in iron and magnesium. Hence, during metamorphism the calcareous rocks gave rise to the formation of amphibolites and lime-silicate rocks rich in diopside or in amphiboles of the tremolite-actinolite series.

The general aspect and mineralogy of the lime-silicate rocks along Cedar Creek are very different from those of the anorthosite. The bedding in the lime-silicate rocks and in the phlogopite-andesine schist is definitely more distinct and more regular than the beddinglike structure in the anorthosite. The sedimentary phlogopite-andesine schist along the Little North Fork is very similar to the fine-grained thin-bedded gray biotite quartzite with which it is interbedded, whereas most of the anorthosite is coarse grained and the centers of the bodies are massive. The lime-silicate rocks along Cedar Creek have varied mineralogy, and none of the layers studied is similar to the anorthosite. The lime-silicate rocks contain abundant pyroxene, amphibole, and other silicates rich in lime; quartz is always present and constitutes about 30 percent of most layers. Graphite is a typical accessory mineral in the lime-silicate rock but is completly lacking in the anorthosite. Phlogopite is common in the lime-silicate rocks, but in the anorthosite the micaceous minerals are biotite and muscovite. Moreover, the lime-silicate rocks contain only one type of plagioclase, the composition of which varies from An_{25} to An_{85}, whereas the anorthosite has two types of plagioclase. The lime-silicate rocks do not contain aluminum silicates that are common in a part of the anorthosite. If the anorthosite represented isochemically metamorphosed limy layers, one would expect to find every gradation from the metasedimentary rocks rich in lime to the anorthosite, but this is not the case.

In many respects the mineralogy of the anorthosite shows a closer resemblance to the surrounding schist than to the lime-silicate rocks. Biotite, muscovite, and the aluminum silicates are common additional constituents in large parts of the anorthosite.

The occurrence of two plagioclases together in the anorthosite is another feature that would be difficult to understand if it is assumed that no migration of material were involved. One might suggest that andesine crystallized first including some calcite, aluminum-silicates, and quartz, and that during a later phase a higher temperature gave rise to the reaction between andesine and included minerals producing bytownite.

This theory includes the assumption that the sedimentation had accidentally produced a bulk composition that was just right for the formation of anorthosite. Thus, there should have been a sudden facies change from a normal sedimentary sequence of schist and quartzite to an anorthositic composition.

The gradation of the anorthosite to a plagioclase-rich shist along the concordant contacts can be interpreted to be depositional, but it is more difficult to explain the fairly abrupt interfingering contact between the anorthosite and the schist of the Prichard formation poor in feldspar east of Widow Mountain. In this locality the schist ocurring just west of the coarse-grained massive anorthosite is fine-grained biotite schist typical of those layers which elsewhere are found just above the quartzite units of the Prichard formation. This schist is separated by a fault from the upper quartzite unit at Widow Mountain and by a narrow zone of anorthosite from the lower quartzite unit in the north. In this locality the anorthosite seems to have a similar discordant contact with the schist layers of the Prichard formation as shown on a small scale in figure 20.

Between Widow Mountain and Lund Creek the anorthosite lies conformably under a thin layer of light-gray medium-grained quartzite that becomes thicker east of Lund Creek. In three localities between Lund Creek and Monumental Buttes the contact seems discordant, in each case moving down in the stratum. Near Monumental Buttes a layer of schist, about 100 m thick, separates the anorthosite from the quartzite. Thus, the northeastern contact of the anorthosite between Widow Mountain and Monumental Buttes cuts slightly discordantly from the beds of the major quartzite layer to the schist under the quartzite.

A similar slightly discordant contact can be traced between Stocking Meadow Lookout and Cedar Creek. The southwestern contact between the anorthosite and the schist between the heads of Pinchot Creek and Timber Creek also seems to cut across the beds; northeast of the head of Pinchot Creek the schist lies above the anorthosite that is exposed just north of it along the tributaries of Lund Creek but dips under the anorthosite toward the east.

A slightly discordant contact between amphibolite and a small body of anorthosite exposed along the logging road that follows the Little North Fork of the Clearwater River toward Cedar Creek has been described earlier (fig. 21). This anorthosite is a very coarse-grained pegmatitic variety and may represent a part of a dikelike body. Contacts of this kind are common in concordant intrusive bodies but would not be expected to occur between various beds of a sedimentary formation. Moreover, a discordant dike consisting of about 99 percent labradorite (An_{52}) was found south of the Boehls Butte quadrangle (Hietanen, 1962).

It would be difficult to understand many other field relations if it were assumed that no migration of material was involved but that the anorthosite is a product of isochemical metamorphism; for example, the massive coarse-grained variety is found next to a fine-grained schist and quartzite in many localities near Orphan Point. It would be difficult to understand how some beds (the anorthosite) recrystallized as a coarse-grained rock, losing all their original sedimentary structures, while the neighboring beds show only a moderate recrystallization and a well-preserved bedding. Thus the hypothesis of the sedimentary origin alone does not explain all the facts seen in the field.

POSSIBILITY OF METASOMATIC ORIGIN

It has been pointed out that the hypothesis of igneous origin and that of sedimentary origin each fails in certain respects. The mainly concordant and gradational contacts and the feldspathization of the country rocks resemble closely the field relations found around the metasomatic granite bodies with the exception that instead of alkali feldspars, the newly crystallized mineral in the area under discussion is andesine (An_{45-48}) in the anorthosite and oligoclase-andesine (An_{25-45}) in the country rocks.

In general, it is possible to find both types of contacts, discordant and concordant, between the metasomatic rocks and their host rocks. The distribution of andesine in the area south of the Boehls Butte quadrangle was found to be lenticular on a large scale, but when the contacts were studied in detail both concordant and discordant contacts were found. Also, the contact between a metasomatic rock and the host rock can be either sharp or gradational. The gradational contacts have been described from many granitized areas and are considered by many petrologists to be typical of metasomatic rocks. Sharp contacts were found in the vicinity of Dent (Hietanen, 1962).

The beddinglike structure that is pronounced in many localities and the sheetlike inclusions of schist in the anorthosite can be explained as relict structures. Both of these structures are parallel to the bedding of the country rocks. The distribution of the outcrops that contain remnants of the schist is rather irregular, and the schistose layers are seen to fade out gradually when followed parallel to the structure. The schistose layers in the anorthosite contain abundant aluminum silicates just as does the schist that surrounds the anorthosite bodies.

Abundant calcic plagioclase and hornblende were crystallized in the schists and gneisses south of the Boehls Butte quadrangle (Hietanen, 1962). This calcic plagioclase and hornblende replace mainly quartz in the schist, and quartz and diopside in the diopside-plagioclase gneiss. In some localities, the calcic plagioclase was found as dikes and veinlets cutting a gneissic diorite and a feldspathized schist. This shows that an anorthositic rock can be derived through an accumulation of calcic plagioclase during a metasomatic introduction of Mg, Fe, Ca, Al, and possible Na. These dikes and veinlets range only from a few centimeters to about 1 m in width; the question arises whether or not a similar segregation during the metasomatism could be responsible for the formation of bodies which are as much as 20 km in length and 2 km in thickness. Such a segregation would require an extensive exchange of material and a large-scale migration of cations such as Ca, Al, Fe, and Mg which are not so easily detached from the mineral structures and some of which are heavy (Ca, Fe). The question of the formation of the anorthosite is further complicated by the occurrence of two plagioclases.

Only that hypothesis which is capable of explaining all the facts seen in the field and found in the laboratory should be accepted in explaining the origin of the anorthosite. A closer study of the features suggesting metasomatic origin may contribute to the solution.

EVIDENCE OFFERED BY THE MINERALOGY OF THE ANORTHOSITE

First it is necessary to find out which of the constituent minerals of anorthosite crystallized late and are responsible for the features that suggest metasomatic origin. Two mineralogic features of the anorthosite, the occurrence of two types of plagioclase together and the abundance of the minerals of the country rocks in the anorthosite, are strong evidence of metasomatic processes in formation of the anorthosite. The two compositional varieties of plagioclase should react and form labradorite at metamorphic temperatures. Their case is comparable with those of the other pairs of incompatible minerals. Usually in such cases, one is older and preserved only because it was protected by a shell of some other composition, or because the rock was cooled so rapidly that there was no time for the reaction between the minerals to take place. In the rocks under discussion, the bytownite is not protected but occurs between the andesine grains and forms small inclusions in the andesine. The contact relations between the andesine and the interstitial bytownite (fig. 27) and those between the andesine and its inclusions (fig. 36) strongly suggest that bytownite is an earlier mineral than, and is partly replaced by, andesine. Peculiarly, the bytownite grains next to the andesine and most of the inclusions in the andesine seem to have partially recrystallized and reoriented, forming larger grains and groups of inclusions that have a parallel optic orientation. Thus, the andesine grains seem to have been centers of recrystallization representing a later phase than the crystallization of interstitial bytownite. Sodium must have been added during this phase because the newly formed mineral is considerably more sodic. Silica needed for the formation of andesine may have been present as quartz.

The coarse-grained anorthosite in the massive parts of the large bodies generally contains only tiny platelike inclusions of bytownite. More rarely, interstitial bytownite is found in this variety. Hornblende fills some of the interstices between the large labrodorite grains in this rock. It is possible that the reaction between the earlier bytownite and the added sodium has proceeded farther in these localities.

The common occurrence of the aluminum silicates—kyanite, andalusite, and sillimanite—and of garnet, staurolite, biotite, and muscovite in many layers in the anorthosite suggests that the anorthosite contains abundant sedimentary material. Kyanite was found with hornblende in some layers. Petrologists have pointed out the incompatibility of these two minerals. Their occurrence together in the anorthosite is easily explained if it is assumed that the kyanite originated in the schist that was gradually replaced by plagioclase to form anorthosite. Thus, the kyanite would be a relict mineral, whereas some of the elements that formed hornblende were introduced during the formation of anorthosite.

EVIDENCE OFFERED BY METASOMATIC CHANGES IN THE COUNTRY ROCKS

A closer study of the mineralogic changes in the schist around the anorthosite bodies suggests an extensive exchange of material in a zone whose width ranges from a few meters to several kilometers. The occurrence of numerous large grains and small masses of andesine, or of oligoclase-andesine instead of quartz in the schist around the anorthosite bodies is comparable with the feldspathization of the schist near Dent (Hietanen, 1962), and can be explained as a result of introduction of calcium and sodium into and removal of silicon from the schist.

The schist next to the three largest anorthosite bodies contains considerably more aluminum silicates than the same schist a little farther from the anorthosite. As described earlier by the author (Hietanen, 1956), all three modifications of Al_2SiO_5 occur together in this contact zone. Their occurrence together was attributed to a fluctuation of the temperature around the triple point where all three aluminum silicates can exist in equilibrium. In a wide area around the mouth of Timber Creek, thus in a zone a little farther from the contact of anorthosite, a replacement of biotite by the brown sillimanite was observed. The replacement of biotite by the sillimanite suggests that at least some of the aluminum was introduced and potassium removed from this zone. Plagioclase is less abundant and occurs as smaller grains in this outer zone than in the zone next to the large anorthosite bodies. Considerably more aluminum silicates occur in those parts of the stratum in which plagioclase abounds (fig. 46), suggesting a metasomatic addition of aluminum in these parts also.

EVIDENCE OF POSSIBLE PARENT ROCKS

Numerous remnants of the older rocks in the anorthosite give best evidence of rock types that originally occupied the parts of the area where anorthosite occurs now. In the southernmost body, most of the inclusions and ghostlike remnants of older rocks consist of an aluminum-rich schist similar to that found around the body. Amphibolite is included in the anorthosite north of Benton Butte, and shadowy remnants of quartzite and diopside-plagioclase gneiss south of Boehls. Layers and lenticles rich in bytownite were found along the contacts of the northernmost and the middle anorthosite bodies. In the upper parts of these two bodies, schist inclusions are common and some inclusions consisting of amphibolite, quartzite, and lime-silicate rock were found. Thus, it seems possible that most of the original rocks in the part of the area now occupied by the southernmost anorthosite body were of the same composition as those found in the surroundings of the anorthosite. Aluminum-rich schist may have been the major rock type and quartzitic and calcareous layers and masses were interbedded with it. This schist contained lenticular bodies of amphibolite as does the schist surrounding the anorthosite.

The fine-grained bytownite rock that was found as layerlike bodies in the northern part of the middle anorthosite probably was an earlier rock type in a much wider area than now exposed, and was transformed to the andesine-bytownite anorthosite by a later introduction of sodium and possibly silicon if no excess quartz was present. If this was the origin of the massive anorthosite, bytownite rock should have occupied large areas and a question about its origin forms a vital part of the problem concerning the ultimate origin of the anorthosite.

ORIGIN OF BYTOWNITE

The bytownite must have originated in one of these three ways: (1) bytownite is of igneous origin, crystallizing from a melt; (2) bytownite results from the metamorphism of sedimentary material; (3) bytownite is of metasomatic origin.

IGNEOUS

The first way would mean that the layers of bytownite rock would by metamorphosed fine-grained bytownite anorthosite and that most of the bytownite would be of igneous origin. The massive anorthosite would represent larger masses of igneous calcic anorthosite transformed to a more sodic variety by metasomatic introduction of sodium. The layered anorthosite with aluminum silicates would represent either thin layers of igneous anorthosite in the schist or metasomatic contact aureoles of the larger igneous masses. One could think that first bytownite crystallized in the country rocks in a manner similar to the alkali feldspars in the surroundings of many igneous granite bodies. During the introduction of sodium, andesine crystallized as a result of reaction between the sodium and this earlier bytownite. If the volume stayed unchanged, a part of the calcium was removed from the bytownite-bearing rocks. This calcium, together with sodium that was introduced and aluminum and silicon that were present in the schist, formed oligoclase-andesine in the schist next to the bytownite-bearing contact aureoles. The sodium metasomatism could have obliterated all traces of the high temperature that should have accompanied intrusion of bytownite anorthosite.

However, the gradational contacts and especially the thin micaceous laminae in many small anorthosite bodies near Timber Creek cast doubt on an igneous origin of bytownite. It is scarcely possible that the paper-thin laminae of micaceous material that should originate in the schist would be preserved during an igneous intrusion of bytownite anorthosite and remain as parallel inclusions in it. Rather these thin bodies are comparable with the aluminum silicate-bearing parts of the large bodies, in which the bytownite and andesine are either both metasomatic or else the bytownite is of sedimentary and the andesine of metasomatic origin.

METAMORPHIC

The bytownite rock contains about 16 percent CaO, more than 30 percent Al_2O_3, and only about 1 percent combined FeO and MgO. This composition is quite abnormal for a sediment. The content of calcium is too high for an argillaceous sediment and that of aluminum too high for a calcareous sediment. Therefore it seems highly questionable that bytownite rocks would be products of isochemical metamorphism of sediments. There is, however, another possibility. The lens-shaped garnetiferous bodies in the bytownite layers along the lower contact of the northernmost anorthosite body are, in all probability, metamorphosed calcareous concretions suggesting a sedimentary origin for these bytownite layers. The neighboring layers consist of andesine anorthosite rich in aluminum silicates and micas, the abundance of these minerals indicates that the original sediment in these layers was rich in aluminum. Thus the original sedimentary strata in this locality consisted of calcareous layers interbedded with clayey layers, both poor in iron and magnesium. During the metamorphism, bytownite crystallized in the calcareous layers from calcium, silicon, and sodium present in these layers and the aluminum provided by the neighboring clayey layers. A small fraction of calcium probably migrated in the opposite direction, forming bytownite in the aluminum-rich layers.

The two layers of the bytownite rock at Cedar Creek most likely have a similar modified sedimentary origin. Also here the aluminum probably was provided by the neighboring aluminum-rich sediments. The lack of aluminum silicates in the massive anorthosite can be considered as an indication of the prevalence of calcareous sediments in these parts of the area. However, the crystallization of the albite component of the andesine may have used some aluminum, according to the following equation:

$$\underset{\text{Kyanite}}{Al_2O_3 \cdot SiO_2} + \underset{\text{quartz}}{5SiO_2} + \underset{\text{sodium rich solutions}}{Na_2O} \longrightarrow \underset{\text{albite}}{Na_2O \cdot Al_2O_3 \cdot 6SiO_2}$$

Thus the older rock may have contained aluminous layers in all localities where micaceous layers are now common, even if no aluminum silicates are found. The pronounced layering in the anorthosite containing aluminum silicates and micas suggests a strong compositional variation that may be due to the original sediment. Comparison of analyses nos. 611 and 608 in table 11 shows that the main difference between the dark- and light-colored layers is a larger amount of iron and magnesium and a smaller amount of calcium and sodium in the dark layers. In the micaceous layers the amount of potassium would be higher (compare analysis no. 630, table 13). The content of Al_2O_3 in the anorthosite shows remarkably little variation, being about 27 percent in the dark micaceous and in the hornblende- and kyanite-bearing layers, and about 29 percent in the pure plagioclase layers. The range in the variation of the calcium content is much larger. The bytownite rock has about 16 percent calcium oxide, the common anorthosite about 11 percent, and the dark-colored layers about 8 percent.

The occurrence of abundant banded hornblende-bearing anorthosite south of Goat Mountain is another feature that differs from the general aspect of the large bodies. This part of the body contains very little aluminum silicates, even if the country rocks are aluminous schists and a large sheetlike inclusion of schist occurs in the center. A sheetlike inclusion of amphibolite is above the schist inclusion, and the anorthosite above this amphibolite contains more hornblende than is found elsewhere. The field relations conform with the possibility of igneous origin, the basic rock occuring under the anorthosite and the anorthosite containing thin layers and lenticles of hornblende-rich rock.

The abundance of the hornblende in this gneissic anorthosite, however, can have another explanation; it may originate in the older amphibolite. The mode of occurrence of the hornblende is comparable with that of the biotite and aluminum silicates along the West Fork of Cedar Creek and along the North Fork of the Clearwater River. The only difference between the mode of occurrence of the hornblende and that of the micaceous minerals in the anorthosite is the greater regularity of the hornblende-bearing bands. This difference, however, may be a result of the more pronounced and straight platy and linear structures in the amphibolites as compared with the wavy bedding planes in the schist.

The mineralogy and texture of the hornblende-rich anorthosite at localities no. 947, 968, and 1753 are in accordance with the suggestion that the abundance of hornblende in some parts of the anorthosite may be due to the abundance of this mineral in a parent rock.

It is noteworthy that all inclusions show a metamorphism and metasomatic transformation similar to that of the country rocks. The lime-silicate rock included in the anorthosite between the forks of Cedar Creek is similar to some layers of lime-silicate rock south of the anorthosite. Abundant graphite occurs in the inclusion as well as in the main occurrence of lime-silicate rocks. No graphite, however, was found in the bytownite rock along the West Fork of Cedar Creek. The inclusions of quartzite are granoblastic and finer grained than the schist inclusions. They show feldspathization only in a fairly narrow zone (10 cm to 2 m) next to the anorthosite, just as the quartzite between Stocking Meadow Lookout and Cedar Creek does. In contrast to these fairly well-preserved inclusions of quartzite and lime-silicate rock, the inclusions of schist are strongly feldspathized. Very little quartz is found, but instead there are numerous sporadic large round grains and clusters of andesine in the inclusions just as is in the surrounding schist adjacent to the anorthosite. It seems that the schist was less resistant to the feldspathization than were the quartzite and the lime-silicate rock. Some layers of the lime-silicate rock contain about 30 percent plagioclase, but the elements to form this plagioclase were contained in the original sediment. The plagioclase occurs as interlocking grains of medium size with quartz and pyroxene. The texture is sutured or granoblastic, similar to the texture in the metamorphic rocks of this area in general.

This mode of occurrence and the texture of the primary plagioclase are in contrast to those of the large round grains of secondary andesitic plagioclase in the schist. In most of the bytownite rocks, the texture is granoblastic. Large grains of bytownite with tiny round inclusions of quartz were found in only one locality.

METASOMATIC

The third possibility includes an assumption that not only sodium but also calcium came from outside sources. Bytownite would have crystallized either from aluminum and silicon present in the sedimentary strata and calcium introduced later into it; or all elements to form bytownite were introduced. This mode of origin of bytownite could be correlated with the feldspathization of schist near Dent, about 20 miles south-southwest of the area under discussion. Near Dent, plagioclase (An_{50}) locally replaces quartz in a fairly homogeneous garnet-biotite-sillimanite schist. During the study of these rocks, the author came to the conclusion that the crystallization of andesine (An_{50}) was accompanied by an addition of calcium, sodium, and some other elements from outside sources, probably from the quartz dioritic magma that gave rise to the formation of the quartz dioritic border zone of the Idaho batholith. This conception was supported by the fact that the elements to form andesine and hornblende were found to have been mobile during the latest phase of crystallization of the quartz dioritic magma and to have caused an extensive dioritization and feldspathization of schist and quartzite. Only a few fairly thin veins of anorthosite were formed by segregation during this metasomatism. Near Dent the plagioclase of metasomatic origin has, as a rule, the same composition as the plagioclase in the quartz diorite (An_{35-50}) nearby. Secondary plagioclase around the granitic bodies is generally albite or oligoclase, thus in composition close to the plagioclase in the intrusive body that caused the metasomatism.

The intrusive rocks near the anorthosite bodies are mainly granite, quartz diorite, and quartz monzonite with plagioclase (An_{25-40}). The amphibolite bodies with labradoritic plagioclase would be better representatives of the intrusive rock that could be a source of bytownite than the rocks of the quartz diorite and quartz monzonite suite. Most of these amphibolite bodies, however, contain garnet, biotite, and quartz in large quantities, and are probably themselves products of metasomatic replacement. No suitable igneous source rock for the bytownite is thus exposed, but we might assume that a magma capable of sending large amounts of elements of bytownite could exist underneath the present erosion surface. This same hypothetical magma could have been a source for the iron and magnesium that accumulated around the anorthosite bodies to form garnet amphibolite. A later introduction of sodium would, as in the other cases, be responsible for the crystallization of andesine at the expense of earlier bytownite.

The ratio between the amounts of ferromagnesian minerals and bytownite in the anorthosite-amphibolite group would suggest that the composition of the hypothetical magma below the present surface should have been of gabbroic-anorthositic composition. Buddington (1939) suggested this composition for the parent magma of the anorthosites in general, and later (Buddington, 1943) suggested that this magma type would have a global extension just above the basaltic layer. Also Michot (1956, 1957) has suggested that an anorthositic layer would have a global extension underneath the granitic layer. According to him, the formation of the anorthositic magma would be a result of an assimilation of pelitic sediments by basaltic magma. This assimilation would reverse the order of the crystallization so that plagioclase would crystallize earlier than the ferromagnesian minerals. Large amounts of anorthosite would be formed through anatectic processes, principally by selective elimination of excess of ferromagnesian minerals from leuconoritic material. The upper limit of the front of such an anorthositization would represent the discontinuity found by seismic methods under the granitic layer of the continents. This discontinuity (called Sical by Michot for principal ingredients, Si, Ca, and Al) would be at the depth of about 20 km during the time of its formation and could be exposed in tectonically suitable places by a later erosion. At this depth, anorthosite would be formed contemporaneously through metasomatic, anatectic, and magmatic processes. The ferromagnesian minerals would be removed by selective resolution in eutectic ratios and would be precipitated around the residual anorthosite body, forming a basic front to which the ilmenitic iron ores would belong.

It is possible that in the area under discussion, the garnet amphibolite around the anorthosite bodies is a result of such a selective removal of ferromagnesian minerals from the area now occupied by anorthosite, but it seems less likely that the anorthosite itself is a modified igneous rock. The formation of the garnet amphibolite is essentially earlier than the crystallization of andesine and is probably connected with the formation of bytownite. The evidence in favor of a modified sedimentary origin of most of the bytownite rocks found in the present area is more weighty than that for such a modified igneous and metasomatic origin as suggested by Michot (1956, 1957) for the Egersund area and for anorthosite in general. Only the small occurrence of gabbroic anorthosite (no. 1747, table 11) that occurs in a fine-grained mica schist southeast of Orphan Point and is shelled by a layer of coarse-grained chlorite-hornblende-garnet rock may have attained its present composition by elimination of a part of the iron and magnesium from an igneous rock. Elsewhere some iron and magnesium may have been removed from the metasedimentary strata in which bytownite crystallized during the metamorphism. A more detailed discussion of the rearrangement of material around the anorthosite bodies will give a clearer picture of the processes leading to the formation of anorthosite in Idaho.

REARRANGEMENT OF MATERIAL AROUND THE ANORTHOSITE BODIES

There is no doubt that a considerable rearrangement of material was necessary during the formation of the anorthosite under discussion. Short-distance migration of calcium and aluminum was pointed out in the discussion of a sedimentary mode of origin. The occurrence of abundant aluminum silicates in many layers of the two southern bodies suggests a metasomatic origin at least for a part of the bytownite. The crystallization of bytownite in the aluminum-rich sediment would require an addition of calcium, the source of which could be a sedimentary rock nearby. Furthermore, the bytownite rock layers, such as those found along the West Fork of Cedar Creek, probably crystallized from calcareous shale, acquiring additional aluminum from the clayey layers nearby. These calcareous layers were poor in iron and magnesium, as shown by the scarcity of diopside and hornblende in all bytownite rocks; or else a part of the iron and magnesium was removed during the metamorphism. The reaction may have proceeded as follows:

$$4CaCO_3 + NaAlSi_3O_8 + 8SiO_2 + 4Al^2O^3 \longrightarrow 5(Ab_{20}An_{80}) + 4CO_2$$

Calcite + albite + quartz	+ aluminum	→ bytownite	+ carbon dioxide
from calcareous shale	from the clayey layers nearby		

The total composition of the present anorthosite is about $Ab_{40}An_{60}$, one-third of its plagioclase consisting of bytownite (An_{80}) and two-thirds of andesine (An_{50}). Thus, two-thirds of the original bytownite may have been changed to andesine by a later sodium metasomatism according to the following reaction:

$$5(Ab_{20}An_{80}) + 4SiO_2 + Na_2O \longrightarrow 6(Ab_{50}An_{50}) + CaO \quad (2)$$

bytownite + quartz	+ sodium-rich solutions	→ andesine	+ calcium-rich solutions
in metasediment			

The calcium released in this reaction probably was the source for the calcium introduced into aluminum-rich layers nearby where it reacted forming bytownite according to the following equation:

$$4Al_2O_3 + 8SiO_2 + NaAlSi_3O_8 + 4CaO \longrightarrow 5(Ab_{20}An_{80})$$

Further introduction of sodium would give rise to the formation of andesine at the expense of this bytownite according to reaction (2) and the resultant rock would have a composition and structure of the aluminum-rich border phase that is common in the southernmost anorthosite body and in the southern part of the middle body. The layering in these parts of the anorthosite would be a relict structure inherited from the original aluminum-rich sedimentary rock.

The calcium released during the formation of andesine in the layered border phase would migrate into the neighboring schist layers and be combined there with aluminum, silicon, and introduced sodium to form oligoclase-andesine. In this way, the calcium would gradually migrate from the calcareous layers and masses into the surrounding aluminum-rich layers, forming first bytownite and later, during the metasomatic introduction of sodium, andesine in the inner zone next to the anorthosite and oligoclase in the outer zones. Thus it seems that the introduction of sodium gave rise to the recrystallization and rearrangement of earlier minerals and gave to the anorthosite and its country rocks their present composition and texture.

The recrystallization and homogenization have proceeded farthest in the massive parts of the large anorthosite bodies. The heterogeneity becomes conspicuous toward the border zones because of two reasons: presence along the borders of more remnants of the original sedimentary rocks, and the regrouping of ions during the formation of the anorthosite. Owing to the regrouping and segregation, the salic and femic constituents of the border zone crystallized in different layers, giving rise on one hand to lens-shaped and layerlike bodies of pure plagioclase, and on the other hand, to segregations of biotite and hornblende with or without garnet. This differentiation may have started during the crystallization of bytownite, in which case it is comparable with the metamorphic differentiation as suggested by Eskola (1932). However, the major part of all rearrangements in this area seems to be a result of sodium metasomatism and the differentiation should be more properly termed as "metasomatic differentiation."

A tendency to a metasomatic differentiation on a large scale is clearly manifested in the country rocks in a zone, 1 to 3 miles wide, outside the anorthosite bodies. The extraordinarily large amount of aluminum silicates and plagioclase in the schist found only around the anorthosite bodies suggests a genetic relationship. The abundance of plagioclase in this contact zone can in part be tied to the introduction of sodium. It remains uncertain whether all of the aluminum was contained in the original sediment or whether some of it was introduced with the sodium. Regardless of its original source, the aluminum shows a definite concentration in the schist next to the anorthosite. Moreover, this concentration is not confined to beds but follows closely the same pattern as does the feldspathization. The fact that the same zone is impoverished in potassium and silicon suggests a considerable exchange of material. In the outermost parts of the contact aureole, where biotite is replaced by sillimanite, iron is precipitated as magnetite, but potassium and magnesium are removed from the system according to the following equation:

$$\underset{\text{biotite}}{H_4K_2Fe_3Mg_3Al_2Si_6O_{24}} \longrightarrow \underset{\text{sillimanite}}{Al_2SiO_5} + \underset{\text{magnetite}}{Fe_3O_4} + \underset{\text{quartz}}{5SiO_2} + \underbrace{K_2O+3MgO+H_2O+H_2}_{\text{removed in solution}}$$

In the normal regionally metamorphosed rocks the reaction leading to the formation of cordierite and potassium feldspar from the biotite and muscovite is common (Eskola, 1939, p. 354). In the area under discussion, cordierite is a common additional constituent, but potassium feldspar is absent in the schist. Crystallization of plagioclase instead of potassium feldspar suggests an exchange of alkalies subsequent to the reaction that led to the replacement of biotite and muscovite by sillimanite and cordierite. The orthoclase in the dike found near the anorthosite south of Boehls (table 9) may represent a segregation of the potassium that was removed from the surrounding feldspathized schist. The magnesium removed during the replacement of biotite by sillimanite was precipitated in the schist nearby, where it formed magnesium-rich biotite and hornblende.

The secondary plagioclase in the schist around the anorthosite bodies contains a considerable amount of calcium, and a question arises as to whether this calcium was originally present in the sediment or introduced with the sodium. Most of the schist in the Prichard formation contains very little calcium, and there may have been a metasomatic addition in the parts that carry plagioclase. This suggestion is strengthened by the occurrence of abundant calcium mica, margarite, instead of sillimanite in some of the schist of this area. The mode of occurrence and the appearance of the margarite are similar to those of sillimanite; so margarite may be a pseudomorph after sillimanite. The reaction,

$$2\text{ sillimanite} + CaO + H_2O \longrightarrow \text{margarite},$$

requires an addition of calcium and suggests that the calcium was mobile during the recrystallization. The reaction sillimanite⟶margarite also requires an addition of water and indicates (together with its occurrence next to a pegmatitic dike) that the calcium may have been introduced in water solutions. When calcium and sodium were introduced into the schist, they would form andesine with aluminum silicates and quartz, according to the following reaction:

$$2Al_2SiO_5 + CaO + Na_2O + 6SiO_2 \longrightarrow 2NaAlSi_3O_8 + CaAl_2Si_2O_8.$$

This reaction would use much of the aluminum present in the schist, and the amount of aluminum silicates in the feldspathized schist should be less than it is in the normal schist; instead, the feldspathized parts of the schist contain more aluminum silicates than the normal schist in the same layer. Therefore it seems likely that at least a part of the aluminum in the contact zone was introduced metasomatically.

The source of this excess aluminum could be either the aluminum-rich layers of the sediments transformed to anorthosite or an outside source, the same as that of the introduced sodium.

TEMPERATURE AND PRESSURE DURING THE FORMATION OF ANORTHOSITE

On the basis of the above discussion, it is clear that in the formation of anorthosite two phases have to be considered: (1) metamorphism leading to the formation of bytownite in the anorthosite; (2) metasomatism leading to the crystallization of andesine in the same rock. The temperature-pressure conditions during the crystallization of bytownite in a shaly limestone with aluminum-rich clayey layers were those of amphibolite facies. The typical mineral assemblages were bytownite and diopside in limy layers and kyanite and biotite in clayey layers. Crystallization of kyanite instead of andalusite is in accordance with the conclusion that metamorphism took place during the period of folding.

The crystallization of andesine has obscured the foliation and bedding of the metamorphic rocks in many places; this obscuring indicates that andesine crystallized after the deformation. The inversion of kyanite to andalusite probably is due to a change from kinematic to static conditions. It is not necessary to assume any change in temperature during this inversion (Hietanen, 1956). Crystallization of hornblende instead of diopside during this phase may be due merely to the presence of water in the sodium-rich solutions that altered much of the bytownite to andesine. The occurrence of sillimanite with muscovite proves, according to the experiments made by Yoder and Eugster (1955), that the temperature did not exceed 650 °C. Michot (1956, 1957) places the upper limit of anorthositization (discontinuity sical) to the depth of 20 km and assumes temperatures of 660°C and higher. According to Adams (1924) the temperature at this depth would be between 450°C and 500°C, thus lower than estimated by Michot.

Barth (1956) has shown that the ratio of the distribution of the albite molecule between potassium feldspar and plagioclase crystallized in equilibrium may serve as a geologic thermometer. Using his method, one can estimate the temperature of formation of the orthoclase dike near Boehls (table 9). In this dike, plagioclase of composition $Ab_{78}An_{22}$ crystallized with orthoclase $Or_{88}Ab_{12}$, which gives the ratio of distribution k=0.15 and a temperature of about 420°C.

The occurrence of epidote with labradorite (An_{55}) in some parts of the anorthosite would suggest temperatures around 430°C (Ramberg, 1949).

The varying rate of homogenization of the two plagioclases (andesine and bytownite) in different parts of the anorthosite bodies suggests that the physico-chemical conditions were locally approaching those necessary for the formation of true anorthosite with only one kind of plagioclase, labradorite (An_{55-58}). It is also possible that the time factor plays an important role in this respect and that in all parts of the area, labradorite anorthosite would have been formed instead of andesine-bytownite rock provided that there was enough time for the reaction leading to the homogenization. In either case, the present area provides an example of formation of metamorphic-metasomatic anorthosite and of the upper limit of metasomatic anorthositization. The next step after the homogenization would be a partial remelting and mobilization that could result in an intrusion of anorthosite.

REFERENCES

Adams, F. D., 1896, Report on the geology of a portion of the Laurentian area lying to the north of the Island of Montreal [Quebec]: Canada Geol. Survey Ann. Rept., v. 8, rept. J, p. 1–184.

Adams, L. H., 1924, Temperatures at moderate depths within the earth: Washington Acad. Sci. Jour., v. 14, p. 459–472.

Balk, Robert, 1930, Structural survey of the Adirondack anorthosite: Jour. Geology, v. 38, p. 289–302.

——— 1931, Structural geology of the Adirondack anorthosite, a structural study of the problem of magmatic differentiation: Mineralog. petrog. Mitt., neue Folge, v. 41, no. 3–6, p. 308–434.

Barth, T. F. W., 1927, Die Pegmatitegänge der kaledonischen Intrusivgesteine im Seiland Gebiet: Norske Vidensk.-Akad. Oslo, Mat.-Naturv. Kl., Skrift. no. 8, p. 1–123.

——— 1930, Mineralogy of the Adirondack feldspars: Am. Mineralogist, v. 15, p. 129–143.

——— 1952, Theoretical petrology: New York, John Wiley & Sons, Inc., 387 p.

——— 1956, Studies in gneiss and granite: Norske Vidensk.-Akad. Oslo, Mat.-Naturv. Kl., Skrift. no. 1, p. 1–35.

Bowen, N. L., 1917, The problem of the anorthosites: Jour. Geology, v. 25, p. 209–243.

Buddington, A. F., 1936, Origin of anorthosite in the Adirondacks and in general: Am. Geophys. Union Trans. 17th Ann. Mtg., pt. 1, p. 255–256.

——— 1939, Adirondack igneous rocks and their metamorphism: Geol. Soc. America Mem. 7, 354 p.

———1943, Some petrological concepts and the interior of the earth: Am. Mineralogist, v. 28, p. 119–140.

Chatterjee, S. C., 1920, A preliminary note on the anorthosite near Raniganj, Bengal: Geol., Mining and Metall. Soc. of India, Quart. Jour., v. 2, no. 2, p. 65–86.

Clapp, C. H., 1917, Sooke and Dunkan map areas, Vancouver Island: Canada Geol. Survey Mem. 96, 445 p.

Cooke, H. C., 1919, Gabbros of East Sooke and Rocky Point: Canada Geol. Survey Mus. Bull. 30, p. 1–48.

Cushing, H. P., 1917, Structure of the anorthosite body in the Adirondacks: Jour. Geology, v. 25, p. 501–509, 512–514.

Davidson, C. F., 1943, The Archaean rocks of the Rodil district, south Harris, Outer Hebrides: Royal Soc. Edinburgh Trans., v. 61, p. 71–112

Dresser, J. A., and Denis, T. C., 1944, Geology of Quebec, v. 2 Descriptive geology: Quebec Dept. of Mines, Geol. Rept. 20, 544 p.

Eckermann, H. von, 1938, The anorthosite and kenningite of the Nordingrå-Rödö region: Geol. Fören. Stockholm Förh., v. 60, no. 413, p. 243–284.

Eskola, Pentti, 1921, On the eclogites of Norway: Vidensk. Kristiania, Skrift. I, Mat.-Naturv. Kl. no. 8, p. 1–118.

——— 1932, On the principles of metamorphic differentiation: Comm. Geol. Finlande, Bull. 97, p. 68–77.

——— 1939, Die Entstehung der Gesteine: Berlin, Springer, 422 p.

Fowler, K. S., 1930, The anorthosite area of the Laramie Mountains, Wyoming: Am. Jour. Sci., 5th ser., v. 19, p. 305–315, 373–403.

Francis, G. H., 1956, Facies boundaries in pelites at the middle grades of regional metamorphism: Geol. Mag., v. 93, p. 353–368.

Goldschmidt, V. M., 1916, Geologisch-petrographische Studien im Hochgebirge des südlichen Norwegens. IV. Übersicht der Eruptivgesteine im kaledonischen Gebirge zwischen Stavanger und Trondhjem: Vidensk. Kristiania Skrift. I, Mat.-Naturv. Kl. no. 2, p. 1–140.

———1922, Stammestypen der Eurptivgesteine: Vidensk. Kristiania Skrift. I, Mat.-Naturv. Kl. no. 10, p. 1–12.

Grout, F. F., 1928, Anorthosite and granite as differentiates of a diabase sill on Pigeon Point, Minnesota: Geol. Soc. America Bull., v. 39, p. 555–577.

Harrison, J. M., 1944, Anorthosite in southeastern Ontario, Canada: Geol. Soc. America Bull., v. 55, p. 1401–1430.

Hietanen, Anna, 1956, Kyanite, andalusite, and sillimanite in the schist in Boehls Butte quadrangle, Idaho: Am. Mineralogist, v. 41, p. 1–27.

———1959, Kyanite-garnet gedritite near Orofino, Idaho: Am. Mineralogist, v. 44, p. 539–564.

———1961, Superposed deformations northwest of the Idaho batholith: Internat. Geol. Cong., 21st, Copenhagen, 1960, v. 26, p. 87–102.

———1962, Metasomatic metamorphism in western Clearwater County, Idaho: U.S. Geol. Survey Prof. Paper 344–A, p. 1–116.

Kemp, J. F., 1921, Geology of the Mount Marcy quadrangle, Essex County, New York: New York State Mus. Bull. nos. 229–230, 86 p.

Kolderup, C. F., 1903, Die Labradorfelse des westlichen Norwegens: Bergens Mus. Aarbog 12, p. 1–129.

———1914, Egersund: Norges Geol. Undersökelse, no. 71, 60 p.

———1936, The anorthosites of western Norway: Internat. Geol. Cong., 16th, U.S.A., 1933, v. 1, p. 289–296.

Lacroix, Alfred, 1939, Sur un nouveau type de roches métamorphiques (sakénites) faisant partie des schistes cristallins du sud de Madagascar: Acad. Sci. Paris Comptes rendus, v. 209, p. 609–612.

Mawdsley, J. B., 1927, St. Urbain area, Charlevoix district, Quebec: Canada Geol. Survey Mem. 152, p. 1–58.

Michot, Paul, 1939, Les anorthosites de la région d'Egersund (Norvège): Acad. royale Belgique, Bull. cl. sci., 5th ser., v. 25, p. 491–503.

———1955, Anorthosites et anorthosites: Acad. royale Belgique, Bull. cl. sci., 5th ser., v. 41, p. 275–294.

———1956, La géologie des zones profondes de l'éncorce terrestre: Soc. Geol. Belgique Ann., v. 80, p. 19–59.

———1957, Phenomenes géologiques dans la catazone profonde: Geol. Rundschau, v. 46, no. 1, p. 147–173.

Miller, W. J., 1899, Notes on the corundum-bearing rocks of eastern Ontario, Canada: Am. Geologist, v. 24, p. 276–282.

———1914, Magmatic differentiation and assimilation in the Adirondack regions: Geol. Soc. America Bull., v. 25, p. 243–264.

———1918, Adirondack anorthosite: Geol. Soc. America Bull., v. 29, p. 399–462.

———1929, Significance of newly found Adirondack anorthosite: Am. Jour. Sci., 5th ser., v. 18, p. 383–400.

———1931, Anorthosite in Los Angeles County, California: Jour. Geology, v. 39, p. 331–344.

Mouta, Fernando, and O'Donnell, H., 1933, Carte géologique de l'Angola: Republica Portuguesa, Ministerio das Colonia, Colonia de Angola, 87 p.

Osborne, F. F., 1949, Coronite, labradorite, anorthosite, and dykes of andesine anorthosite, New Glasgow, P.Q.: Royal Soc. Canada Trans., 3d ser., v. 43, p. 85–112.

Pardee, J. T., 1911, Geology and mineralization of the upper St. Joe River basin, Idaho: U.S. Geol. Survey Bull. 470, p. 39–61.

Polkanov, A. A., 1937, On the genesis of the labradorites of Volhynia: Jour. Geol. (Acad. Sci. of Ukrainian SSR), v. 3, p. 51–82.

Ramberg, Hans, 1949, The facies classification of rocks—a clue to the origin of quartzo-feldspathic massifs and veins: Jour. Geology, v. 57, p. 18–54.

Ransome, F. L., and Calkins, F. C., 1908, The geology and ore deposits of the Coeur d'Alene district, Idaho: U.S. Geol. Survey Prof. Paper 62, 203 p.

Retty, J. A., 1944, Lower Romaine River area, Saguenay County: Quebec Dept. Mines Geol. Rept. 19, p. 1–31.

Rosenbusch, H., and Osann, A., 1922, Elemente der Gesteinslehre: Stuttgart, E. Schweizerbart'sche, 346 p.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the State of Idaho: U.S. Geol. Survey and Idaho Bur. Mines and Geology.

Schaller, W. T., and Glass, J. J., 1942, Occurrence of pink zoisite (thulite) in the United States: Am. Mineralogist, v. 27, p. 519–524.

Selwyn, A. R. C., 1892, Summary reports on the operations of the Geological Survey for the year 1891: Canada Geol. Survey Ann. Rept., v. 5, pt. A, p. 39–44.

Smith, I. F., 1922, Genesis of anorthosites of Piedmont, Pennsylvania: Pan-Am. Geologist, v. 38, p. 29–50.

Suter, H. H., 1922, Zur Klassification der Charnockite-anorthosite provinzen: Schweiz. Mineralog. petrog. Mitt., v. 2, p. 307–330.

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

Vogt, J. H. L., 1924, The physical chemistry of the magmatic differentiation of igneous rocks: Vidensk. Kristiania, Skrift. I., Mat.-Naturv. Kl. no. 15, p. 1–132.

Wagner, P. A., 1924, On magmatic nickel deposits of the Bushveld complex in the Rustenburg district, Transvaal: South Africa Geol. Survey Mem. 21, p. 1–181.

Wagner, W. R., 1949, The geology of part of the south slope of St. Joe Mountains, Shoshone County, Idaho: Idaho Bur. Mines and Geology Pamph. 82, p. 1–48.

Wheeler, E. P., 1942, Anorthosite and associated rocks about Nain, Labrador: Jour. Geology, v. 50, no. 6, pt. 1, p. 611–642.

Winchell, A. N., and Winchell, Horace, 1951, Elements of optical mineralogy—an introduction to microscopic petrography, 4th ed., pt. 2, Description of the minerals: New York, John Wiley & Sons, Inc., 551 p.

Winchell, N. H., 1899, The geology of Minnesota: Minnesota Geol. and Nat. History Survey, v. 4, 630 p.

Yoder, H. S., and Eugster, H. P., 1955, Synthetic and natural muscovites: Geochim. et Cosmochim. Acta, v. 8, p. 225–280.

INDEX

[Major references are in italic]