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GEOLOGY OF LUBRECHT EXPERIMENTAL FOREST
MISSOULA COUNTY, MONTANA

by

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ABSTRACT

The Lubrecht Experimental Forest is located on the north slope of the Garnet Range, approximately 35 miles east of Missoula, Montana. The map area covers about 70 square miles, and is underlain by several thousand feet of Precambrian Belt metasediments, Cambrian strata, Tertiary basin deposits, and Quaternary glacial and alluvial deposits. Precambrian and Cambrian rocks were intruded by plutonic and hypabyssal igneous rocks during late Cretaceous-early Tertiary times.

The Belt rocks are all within the Missoula Group. The oldest rocks consist of about 2,000 feet of red, purple, green, and gray argillites and siltites of the Miller Peak Formation. Gradationally above this formation is the pink, purple, and gray feldspathic Bonner Quartzite, which has a minimum thickness of 1,500 feet. The McNamara Formation, which overlies the Bonner Quartzite to the west and south, has been faulted out. An undeterminable thickness of gray and greenish gray siltite and micaceous quartzite of the Garnet Range Formation is the youngest Belt unit exposed in the area.

An unconformity at the base of the Cambrian System represents a period of erosion. Cambrian rocks consist of about 1,000 feet of shale, limestone and marble representing the Silver Hill Formation, and possibly part of the Hasmark Formation. Younger Paleozoic and Mesozoic strata have been cut out by intrusion or removed by erosion.

Tertiary basin deposits consisting of poorly consolidated conglomerate, sandstone, siltstone, claystone, and volcanic tuffs and breccias, lie unconformably above the Belt rocks. The youngest sediments are the glacial and alluvial deposits of the Quaternary System.

Major structures in the area, the east-southeast plunging Elk Creek syncline, and the subparallel Cap Wallace fault, are attributed to Laramide deformation, which preceded intrusion of the igneous rocks.

Quartz monzonite intruded Belt and Cambrian rocks forming the Garnet stock and smaller plutons. Other igneous rocks include trachyte porphyry, andesite porphyry, and lamprophyre. These intrusions produced contact metamorphic marble and other rocks belonging to the albite-epidote hornfels facies.

At the present time, barite deposited in hydrothermal veins is the only mineral resource which is being exploited commercially in the area. Over $1,100,000 in placer gold has been recovered from Elk Creek and its tributaries since 1886, and a lesser value of gold, silver, copper, lead, and zinc has been recovered from the Coloma district in the southern part of the area. Limestone and gravel are potential mineral resources.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Lubrecht Experimental Forest, located on the north slope of the Garnet Range, covers about 45 square miles approximately 35 miles east of Missoula, Montana. The map area (Fig. 1) includes an additional 25 square miles which lie outside the political boundaries of the forest. The map area is bounded on the north by the Blackfoot River, on the east by the Missoula-Powell County line, on the south by latitude 46°50'N, and on the west by longitude 113°33'W.

This area is accessible via Montana Route 20, unpaved county roads, and logging roads. Some of the unmaintained logging roads are old and therefore serve only as trails. The area adjacent to Montana Route 20 is accessible throughout the year; however, due to heavy snowfall, other parts of the area are only accessible between May and November.

PREVIOUS WORK

Previous work in the Forest consists of a geologic reconnaissance map made by J. T. Pardee (1918) as part of a study of the ore deposits in the northwest part of the Garnet Range, and a master's thesis by P. N. Clawson (1957) dealing with the barite deposits in the Elk Creek area. This latter report includes a geologic map covering 3½

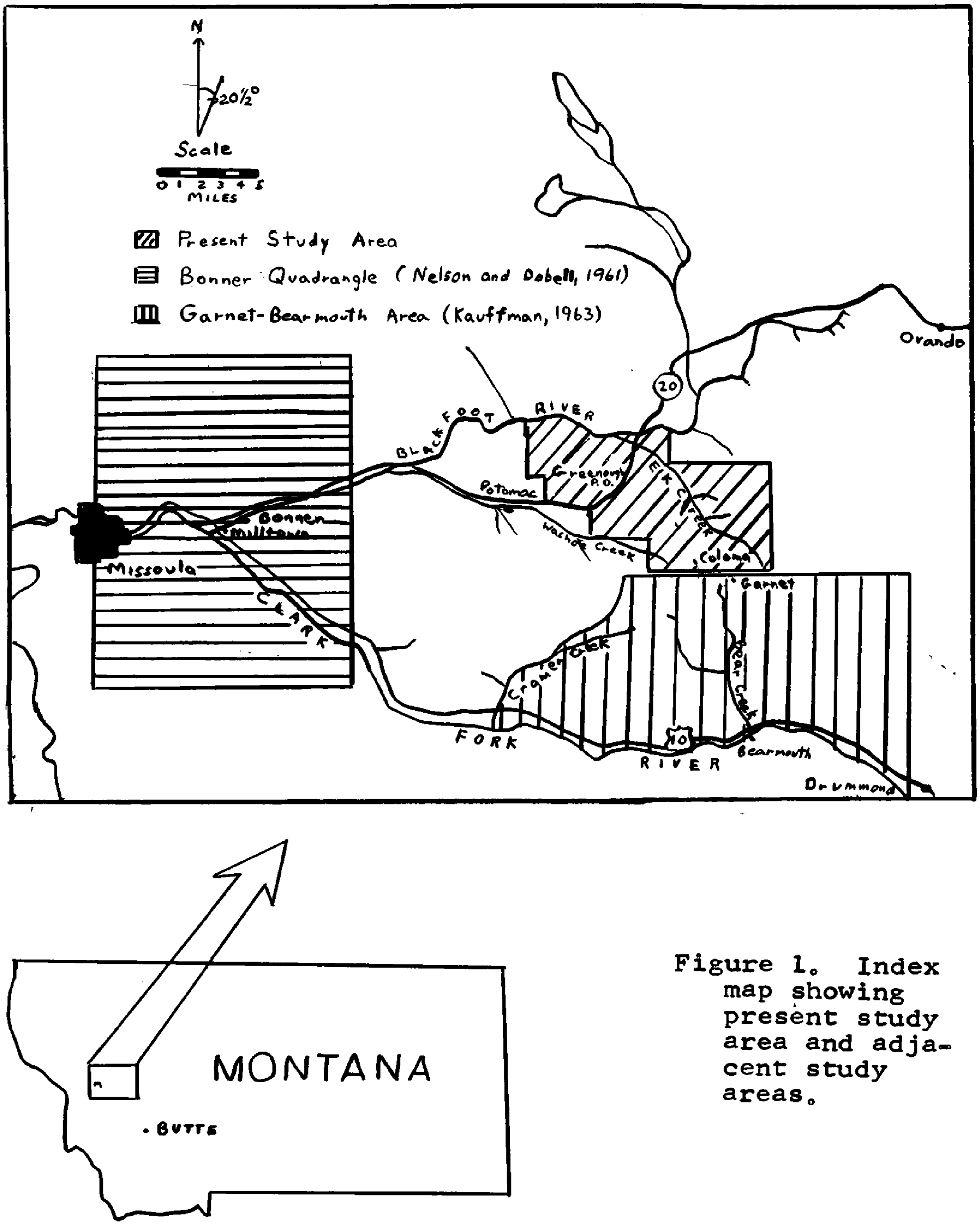

Figure 1. Index map showing present study area and adjacent study areas.

square miles of forest land surrounding the Greenough Barite Mine.

Some work has been done in surrounding areas. W. C. Alden (1953), examined the Blackfoot Valley while studying the glacial geology of western Montana. An unpublished master's thesis by M. M. Clapp (1936) covers the Belt stratigraphy and structure of the Ovando area, located to the northeast of the present study area. Recently, reports have been published by W. H. Nelson and J. P. Dobell (1961) on the Bonner quadrangle, and by M. E. Kauffman (1963) on the Garnet-Bearmouth area (Fig. 1).

At the present time J. P. Dobell is mapping the 15 minute northeast Bonner quadrangle which includes a small part of the western edge of the Forest.

PRESENT STUDY

The purpose of this investigation was: (1) to map and describe the rocks of the Lubrecht Experimental Forest as a basis for future soil and ecology studies, (2) to shed some light on the stratigraphy and structure on the north side of the Garnet Range, and (3) to study the various types of intrusive igneous rocks and their contact metamorphic effects on host rocks.

Sixty-three days were spent in the field between June 15th and September 15th, 1963, plus an additional three days in October, 1963, and six days during the spring and summer of 1964. The work was done under a research assistantship granted by the Montana Forest and Conservation Experiment Station, which also provided lodging, transportation, maps, and aerial photographs.

Geologic mapping traverses were done on foot. The planning of traverses, locating of stations, and plotting of geology were facilitated by 1:15,840 scale aerial photographs (United States Forest Service, August 23, 1952), and by eight inches to the mile planimetric section sheets prepared by the School of Forestry of Montana State University. The geologic data were transferred to advance proofs of the Bonner NE, and Drummond NE, NW, SE, and SW 7½ minute quadrangles, which have scales of 1:24,000 and 40 foot contour intervals.

Laboratory work consisted of study under the binocular and petrographic microscopes of all rock types encountered. One thousand point count modal analyses were made for all the granitic rocks. Uncovered thin sections were etched with hydrofluoric acid, and the potash feldspars were stained with a solution of sodium cobaltinitrate (Bailey and Stevens, 1960, p. 1025). Slabs of all feldspar-containing rocks were etched and stained in a similar manner, and several specimens of each of these rock types were studied under the binocular microscope.

ACKNOWLEDGEMENTS

The writer is grateful to the Montana Forest and Conservation Experiment Station for financial support and cooperation while undertaking this study. Special thanks are due Dr. Robert M. Weidman and the other faculty members of the Geology Department of Montana State University for their assistance. Helpful discussions with faculty members of the School of Forestry, forestry students, and graduate students in geology are greatly appreciated.

PHYSIOGRAPHY

CLIMATE

The following data have been published by R. W. Steele (1963, 1964) for the Greenough Post Office (elevation about 4,160 feet), where a weather station was established under his direction in 1956. The annual average temperature between 1956 and 1963 was 41.0°F. The lowest temperature recorded during this period was -41°F. in January, 1963, and the highest temperature recorded was 105°F. in July, 1960. Between 1959 and 1963, the annual precipitation averaged 15.64 inches. Annual precipitation is higher and diurnal temperature variations are less at higher elevations in the Forest (Steele, 1964, personal communication).

VEGETATION

Fertile soil and adequate precipitation have helped to produce heavily timbered valleys and north-facing slopes. On south-facing slopes, trees are sparse at low elevations. Douglas fir, ponderosa pine, western larch, and lodgepole pine are the dominant tree types in the study area. Ponderosa pine is found on dry, south-facing slopes almost to the exclusion of the other tree types. At elevations greater than 5,500 feet, Englemann spruce and other alpine vegetation occur. Because most of the Forest has been logged mainly during the periods 1904 to 1906, 1925 to 1935 (Cauvin, 1961, p. 7-10), and 1961 to 1962, much of the timber is second growth.

Sparsely timbered areas are vegetated for the most part by grass. Lichens and mosses grow wherever bare rock is exposed (Fig. 10, p. 45).

TOPOGRAPHY AND DRAINAGE

The Garnet Range has a west-northwest general trend, and is maturely dissected. The highest peak (elevation 6,403 feet) is in the northeastern part of the map area; the lowest elevation (3,560 feet) is on the Blackfoot River in the northwest corner of the map area. Locally the relief averages about 1,200 feet between ridge tops and adjacent stream valleys.

The drainage pattern is generally dendritic, and the direction of flow of some streams is controlled structurally. (See discussion under Structural Geology.) The streams in Lubrecht Experimental Forest flow northward and westward into the Blackfoot River, a tributary of the Clark Fork of the Columbia River. The Blackfoot River flows westward along the northern boundary of the map area, and has a gradient of about 16 feet per mile. Its longest tributary in the map area is Elk Creek, which has a gradient of from 250 feet per mile in its canyon, to 30 feet per mile where it crosses the Blackfoot Valley on its way to the river.

The streams which empty into Elk Creek have high gradients varying from 280 feet per mile to about 450 feet per mile.

GLACIATION

There is no evidence for glaciation on the north slope of the Garnet Range proper, but it appears that a glacial lake, probably an arm of glacial Lake Missoula, covered the Camas and Ninemile Prairies (Alden, 1953, p. 89). It is further suggested by Alden that the pre-Wisconsin Clearwater glacier moved over Hunter's Point from the northeast, and terminated in this lake. (See discussion under Quaternary deposits.)

GEOMORPHOLOGY

The Garnet Range has an apparent accordant summit level, which is quite evident as one approaches the Lubrecht Experimental Forest from the west on Montana Route 20 (Fig. 2). This level lies mainly between 6,000 feet and 6,500 feet, although a few ridges are slightly higher or slightly lower. Pardee (1918, p. 162-164) suggests that the Garnet Range is a rather flat, extensively dissected upland, and that a "peneplain," now 6,000 to 6,500 feet above sea level, was formed early in the Tertiary Period. High summits are interpreted as monadnocks on the upland surface, and passes across the range are interpreted as old stream valleys cut into this surface. Pardee interprets the occurrence of well rounded pebbles, cobbles, and boulders high above present stream levels as having been deposited by streams on this Tertiary upland surface. From relationships between the proposed erosional surface, lava flows, and truncated sedimentary formations, Pardee infers that the erosional surface developed between late Cretaceous (Colorado) and early Tertiary (Oligocene) times. His main line of evidence for the existence of an erosional surface is that all rock types regardless of structure, appear to reach the same maximum altitude. This observation appears to be true if one looks at the Garnet Range as a whole. Differential erosion of various rock types and structures obscure this relationship in any local area.

Figure 2. View looking south at the apparent accordant summit level of the Garnet Range.

Regional uplift followed the formation of the Tertiary upland surface. The evidence for this uplift in the Forest is the rejuvenation of Elk Creek and Washoe Creek, as shown by their transverse valley profiles. These valleys have gentle upper slopes, and steep, youthful lower slopes.

Regional uplift continued at least into the Pleistocene as indicated by the occurrence of two terrace levels along the south bank of the Blackfoot River (Fig. 3). The materials comprising these levels are reworked glacial and perhaps Recent fluvial deposits. (See discussion on Quaternary deposits.) Lateral planation combined with downcutting formed these terraces. Alden (1953, p. 68) attributes the

Figure 3. View looking east along the south bank of the Blackfoot River. Two terrace levels, one about five feet above the water level, the other about forty feet above the water level, can be observed.

formation of terraces to, "a nearly continuous period of regional uplift," during late Tertiary and Pleistocene times.

STRATIGRAPHY

GEOLOGIC SETTING

The north side of the Garnet Range consists mainly of broadly folded Precambrian metasediments, traditionally referred to as the Belt Series, and more recently as the Belt Supergroup (American Commission on Stratigraphic Nomenclature, 1961). An incomplete section of Paleozoic sediments occurs locally. Overlying these rocks unconformably are nearly horizontal strata of Tertiary and Quaternary sediments. These were probably more extensive than they are now, but have been partly removed by erosion leaving the older Precambrian and Paleozoic rocks exposed.

Major structural features of the Lubrecht Experimental Forest are the east-southeast plunging Elk Creek syncline, which occupies the southeastern half of the map area, and a roughly east-west striking fault, which separates this part of the area from a gentle south-dipping region to the north.

Mafic, salic, and intermediate intrusions are found scattered throughout the Precambrian and Cambrian rocks in and around the Lubrecht Experimental Forest. These intrusions have imposed varying degrees of contact metamorphism upon the Belt metasedimentary and Cambrian sedimentary rocks. The largest intrusion is the Garnet stock, which occupies the center of the Elk Creek syncline.

Several terms used to describe metasedimentary rock types are briefly defined below: Argillite refers to well indurated rock composed predominantly of clay-sized particles (diameters less than 1/256 mm.; Wentworth, 1922, p. 381). Siltite refers to well indurated rock composed predominantly of silt-sized particles (diameters between 1/256 mm. and 1/16 mm.). Quartzite refers to well indurated rock composed predominantly of sand-sized particles (diameters between 1/16 mm. and 2 mm.).

Stratification in the various rock units studied is described using the terminology of McKee and Weir (1953, p. 383). The description of rock color has been standardized by using the Geological Society of America Rock Color Chart (Goddard, et al., 1951).

PRECAMBRIAN BELT SUPERGROUP

Belt rocks cropping out in the map area belong to the Missoula Group, the youngest in the Belt Supergroup. An accurate estimate of the thickness of the Missoula Group is not possible from the present study, but Nelson and Dobell (1961, p. 189) estimate the thickness of this group to be about 14,300 feet in the Bonner quadrangle, twenty miles west of the Forest, and Kauffman (1963, p. 4) estimates the thickness of the Missoula Group to be between 10,300 feet and 11,800 feet on the south side of the Garnet Range.

Clapp and Deiss (1931, p. 678) divided the Missoula

Group into five formations which are from oldest to youngest, the Miller Peak, Hellgate, McNamara, Garnet Range, and Sheep Mountain Formations. A modification of this nomenclature by Nelson and Dobell (1961), resulting from their work in the Bonner quadrangle, has been generally accepted in the Missoula area, and is followed in this study. The formations presently recognized are from oldest to youngest, the Miller Peak, Bonner, McNamara, Garnet Range, and Pilcher.

The Belt rocks have undergone regional metamorphism which has transformed the original sediments into argillite, siltite, and quartzite. The grade of regional metamorphism is low, as indicated by the presence of sericite, the preservation of such sedimentary structures as stratification, cross-stratification, ripplemarks, and mud cracks, and the lack of mineral assemblages indicative of higher grades of metamorphism.

The rocks which comprise the Missoula Group were deposited in a shallow, marine environment as indicated by the presence of mud cracks, salt casts, and other shallow water, sedimentary structures throughout the section in the Forest and other areas in western Montana. Frequently, deposition of sand was punctuated by deposition of mud laminae, which were in some cases, torn up during storms, or cracked by dessication due to exposure to the atmosphere, and were redeposited as flakes of mud forming intraformational conglomerates. Carbonate units were deposited probably during times of submergence, when the source areas of clastics were relatively far away.

The tectonic setting for the Missoula Group is a questionable matter. Fenton and Fenton (1937, p. 1940) suggest that these rocks were deposited in a long, narrow, north-northwest trending geosyncline, which was shallow for the most part. Ross (1963, p. 98-99, 110) agrees with this suggestion. These suggestions seem to agree with the nature and sedimentary structures of Missoula Group rocks; however, as Harrison and Campbell (1963, p. 1425-1426) point out, an incongruity presents itself when we find shallow water, stable shelf type sediments, which have accumulated to geosynclinal thicknesses over a very large area without any apparent evidence of synchronous deformation. The solution to this paradox is yet to be found.

<u>Miller Peak Formation</u>: The Miller Peak Formation underlies much of the northern part of the map area. The thickness of this formation cannot be determined in this area due to the lack of an exposed lower contact. From the study of geologic cross-sections (Plate 2), it appears that about 2,000 feet of the siltites and argillites of the Miller Peak Formation underlies the northern part of the Forest. This formation consists of red, purple, green and gray argillite and siltite. Some of the green argillite contains carbonate.

Stratigraphically, the lowest outcrops of the Miller

Peak Formation in the map area occur on the north side of Hunter's Point in sections 29 and 30, T. 14 N., R. 14 W. They consist of about 150 feet of grayish yellow green (5GY 7/2), thinly laminated argillite. Fresh samples of this rock effervesce weakly on application of dilute hydrochloric acid. Weathered surfaces are moderate reddish orange (10R 7/6).

In thin section it can be seen that lamination is due to interlayering of fine silt particles and a mixture of carbonate, muscovite, and clay. The fine silt appears to be mostly quartz plus some twinned plagioclase, muscovite, and biotite. Muscovite found in the argillitic layers occurs in unorientated plates, and is probably metamorphic in origin. Muscovite and biotite plates in the coarse-grained laminae are crudely orientated, and are detrital.

Nelson and Dobell (1961, p. 197) describe the lower few hundred feet of the Miller Peak Formation as green argillite with a slightly different hue than the green argillite found higher in this formation. They report that this lowest unit is grayish yellow green (5GY 6/2) in color, and contains disseminated carbonate. It appears to the author that the rock described by Nelson and Dobell in the Bonner quadrangle is equivalent to that which occurs on Hunter's Point.

Bedding fissility is prominent through most of the 150 foot section on Hunter's Point. Close megascopic examination of slabbed hand specimens indicate that cross-laminations are common in this section.

West of Hunter's Point the Blackfoot River has exposed a section of about 100 feet of red interstratified argillite and siltite. Thick beds of pale red (5R 6/2) siltite are interbedded with beds of laminated, dusky red (5R 3/4) argillite. At irregular intervals thin-bedded sequences of mud cracked argillite are found. Much of the argillite and siltite exposed along the river is interlaminated, with individual laminae varying in thickness from 0.1 mm. to 1.0 mm. Other sedimentary structures noted include ripplemarks, cut and fill structures, cross-stratification (Fig. 4), and chips of argillite which form intraformational conglomerates. Argillite chips are round or eliptical in shape, vary in diameter from 5 mm. to 50 mm., and are less than 1 mm. thick (Fig. 5).

Microscopic examination of the siltite shows that quartz is the major constituent, with small amounts of feldspar and muscovite also present. Clay and fine hematite dust are interstitial to the silt-sized grains. Most of the quartz and feldspar grains average from 0.01 mm. to 0.04 mm. in diameter; some scattered quartz grains are as large as 0.3 mm. in diameter. Muscovite flakes reach a maximum length of about 0.4 mm.

Grains of silt-sized quartz are subangular to poorly rounded, and are predominately common quartz (Folk, 1961,

Figure 4. Cross-bedded siltite of the Miller Peak Formation along the south bank of the Blackfoot River.

Figure 5. Argillite chips in siltite of the Miller Peak Formation.

p. 68). These grains have many small inclusions, and straight to slightly undulose extinction. Some of the larger grains display uniaxial positive to biaxial positive interference figures with axial angles not greater than 5°. Slightly elongate grains are orientated parallel to bedding planes.

Microcline and plagioclase feldspars are both present in the siltite. In addition, some feldspar grains appear to be perthitic.

Muscovite flakes, apparently detritial in origin, are found orientated parallel to stratification planes, and most commonly border argillite laminae. Some of the silt-sized and fine sand-sized quartz grains are enveloped by muscovite, which is probably a result of a metamorphic reaction involving interstitial clay material which surrounds these larger grains.

South of the Blackfoot River, red siltite and argillite grade upward to a thick sequence of interbedded and interlaminated green, purple, and gray argillite and siltite. This sequence appears to comprise the upper 1,700 feet of the Miller Peak Formation. The greens vary from grayish olive green (5GY 3/2) to pale olive (10Y 6/2), with siltite tending to take on the darker shades, and argillite tending to take on lighter shades. These rocks commonly weather to dusky yellow (5Y 6/4). Interbedded with these green metasediments are interlaminated grayish red purple (5RP 4/2) argillite and medium light gray (N 6) siltite.

Bedding and lamination range in character from regular to irregular and mottled (Moore and Scruton, 1957). Cut and fill structures, where siltite fills cuts in argillite, closely resemble burrows (Fig. 6) produced by organisms in modern sediments, as pictured by Moore and Scruton (1957, p. 2541). This similarity suggests that burrowing organisms might have lived in Precambrian muds.

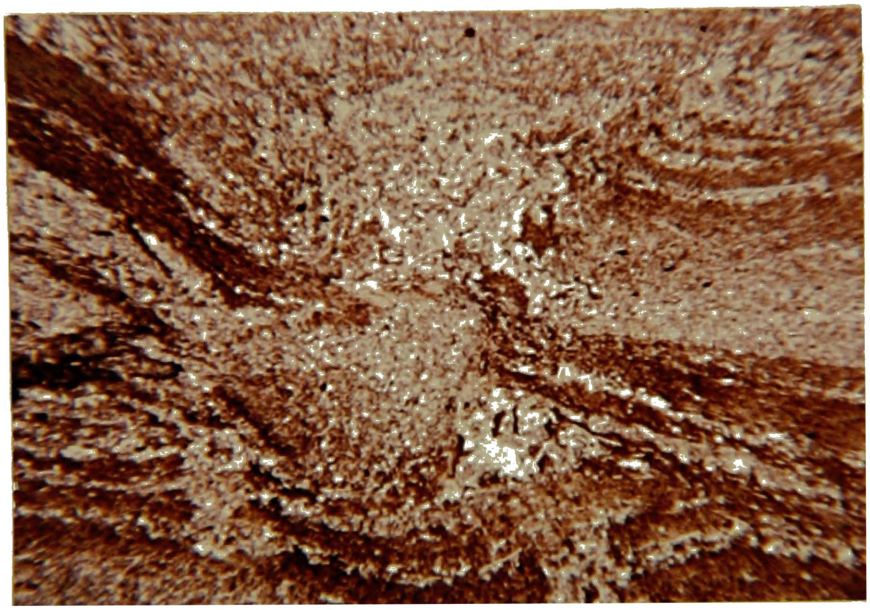

Figure 6. Photomicrograph of possible burrows in the Miller Peak (Plain light - x 20).

In thin section, the argillite consists of a mixture of sericite and clay. Chlorite occurs in green argillite. In the specimens studied, silt-sized quartz grains were not enveloped by muscovite as they are lower in this formation. Detrital muscovite occurs in flakes orientated parallel to planes of stratification.

The poorly exposed contact between the Miller Peak Formation and the overlying Bonner Quartzite can be seen in a road cut in the SE¼ of section 6, T. 13 N., R. 15 W., where the contact is gradational over a 50 foot interval. Purple and green argillites and siltites are interbedded with pink, feldspathic quartzite. The green and purple rocks gradually grade upward to interbedded pink, feldspathic quartzite and reddish purple argillite. The uppermost green bed was arbitrarily picked as the top of the Miller Peak Formation.

Bonner Quartzite: The Bonner Quartzite is predominantly a thick-bedded, medium-grained, feldspathic quartzite which overlies the Miller Peak Formation. The minimum thickness of the Bonner Quartzite as determined graphically (Plate 2) is 1,500 feet. For the south side of the Garnet Range, Kauffman (1963, p. 5) reports a thickness of 2,600 feet, and Nelson and Dobell (1961, p. 201) measured 1,500 feet of Bonner Quartzite on the north side of Mount Sentinel near Missoula.

Cross-bedding, interbedded dusky red (5R 3/4) argillite, and argillite chips are commonly found in the Bonner Quartzite. The quartzites and argillites occur in several different colors including: light gray (N 7), medium light gray (N 6), pinkish gray (5YR 8/1), pale red (10R 6/2), grayish pink (5R 7/2), dusky red purple (5RP 3/2), and greenish gray (5GY 5/1). Color variation appears to be lateral as well as vertical. In some cases indistinct pinkish gray blotches are surrounded by light gray quartzite; close megascopic examination does not yield any apparent difference either in grain size, or in feldspar content of the two differently colored rocks.

Nelson and Dobell (1961, p. 199) report that grayish pink of about (5R 7/2) is the most common color of the Bonner Quartzite. This appears to be the case in the western half of the Forest, but not in the eastern half of this area, where light gray (N 7) appears to be the most abundant color, and the pinks, reds and purples are less common.

In thin section very little difference is seen between the gray quartzites and those with reddish hues. The red hues appear to be the result of hematite and clay coatings on the quartz grains.

In specimens studied, about 80% of the quartzite is composed of quartz grains, most of which appear to be common quartz with biaxial positive interference figures having small axial angles and having average diameters of 1 mm. A few composite grains are found, the occurrence of which is considered by Folk (1961, p. 70) to be a diagnostic feature of recrystallized, metamorphic quartz. Pleochroic (light to dark green), plate-shaped inclusions occur in quartz grains. These small crystals have parallel extinction, masked interference colors, and one direction of cleavage. They could either be chlorite or green biotite.

Feldspar comprises about 15% of the quartzite in thin sections of specimens studied. This percentage varies, and is probably as low as 5% in some of the specimens studied megascopically. The feldspar consists of microcline and a small amount of sericitized plagioclase.

Trace amounts of garnet and black tourmaline occur in a matrix of clay, filling voids between quartz and feldspar sand grains. The garnet grains are recognized by their high relief and extremely weak birefringence. Tourmaline is recognized by its color, birefringence, biaxial negative interference figure, irregular fracture, and parallel extinction. The grains are irregular and somewhat rounded, and are interpreted as being detrital in origin.

The sizes of individual grains vary from fine sand-sized to pebbles with a maximum diameter of 15 mm. Pebble-sized particles are restricted in composition to quartz. Pebble conglomerate float was found on the north side of Cap Wallace Gulch. Conglomerates of this type have been found in the Bonner Quartzite at several localities in western Montana. In the Bonner quadrangle, Nelson and Dobell (1961, p. 200) report quartz pebbles up to 12 mm. in diameter. It appears that conglomerates occur in lenses within the Bonner Quartzite, and are not continuous beds.

Regardless of size, all quartz grains in the Bonner are well rounded, indicating extensive transportation or reworking of the sediments before deposition. Yet the presence of feldspar in significant quantities suggests that the source area was located near the place of deposition, or that the environments of erosion and deposition were such as to minimize the breaking down of feldspar. Cold temperature, lack of organic acids, arid climate, and high relief at the source areas, could have been factors which minimized feldspar decomposition. The apparent lateral continuity of this formation in western Montana suggests to the author that it transgresses time rather than representing a specific time interval. It seems doubtful that such a coarse sediment could be deposited synchronously over such a wide area.

The upper contact of the Bonner Quartzite is not exposed in the Forest.

McNamara Formation: The McNamara Formation does not crop out within the map area. It has evidently been faulted out by the Cap Wallace fault. In the central part of the map area, a significant amount of red, purple, and green argillite and siltite occurs with feldspathic quartzite float along the inferred trace of the Cap Wallace fault. This float could represent siltite and argillite beds in the Bonner Quartzite, or it could represent a small amount of the McNamara Formation which was left in place overlying the Bonner Quartzite on the upthrown block of the Cap Wallace fault, or which underlies the Garnet Range Formation on the downthrown block, or which was dragged into the fault zone.

Garnet Range Formation: The Garnet Range Formation consists of micaceous quartzite, siltite, and argillite forming the bedrock throughout a large portion of the Lubrecht Experimental Forest south of the Cap Wallace fault. There are only a few exposures of this formation in the area, and most of these show evidence of extensive deformation. In addition these rocks have been contact metamorphosed by several intrusions. As a result of these complexities, the thickness of the Garnet Range Formation cannot be determined in this area. Kauffman (1963, p. 5) reports a minimum thickness of 3,000 feet on the south side of the Garnet Range, and Nelson and Dobell (1961, p. 206) estimate the thickness of this formation at 1,800 feet in the Bonner quadrangle.

The consistency of the grayish green color of the Garnet Range Formation in the Bonner quadrangle (Nelson and Dobell, 1961, p. 204-205) and in other localities in western Montana does not hold true in the Forest. The colors observed in this area include: greenish gray (5GY 6/1), grayish yellow green (5GY 6/2), moderate grayish green (10GY 5/2), light gray (N 7), and dark gray (N 3). Light gray (N 7) and grayish yellow green (5GY 6/2) appear to predominate in the quartzite, and moderate grayish green (10GY 5/2) predominates for siltite and argillite. Quartzite commonly weathers to moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4), and occasionally to dusky yellowish brown (10YR 3/2). In a few isolated occurrences, dusky red purple (5RP 3/2) argillite chips and siltite laminae are interstratified with gray or greenish gray siltite and quartzite float.

The contact between the Garnet Range Formation and the overlying Cambrian rocks is covered in the Lubrecht Experimental Forest. On the west side of the Potomac Valley, about 500 feet of purple, red, and white Pilcher Quartzite overlies the Garnet Range Formation, and underlies Cambrian rocks (J. P. Dobell, 1964, personal communication). In that area, the contact between the Garnet Range Formation and the Pilcher Quartzite is gradational over an interval of about 20 feet. Further to the west, between 800 feet and 1,800 feet of Pilcher Quartzite was mapped by Nelson and Dobell (1961, p. 209-210) overlying the Garnet Range Formation. Kauffman (1963, p. 5) believes that only a remnant of the Pilcher Quartzite occurs in the western part of his area, and about 150 feet of the Flathead Formation (Middle Cambrian) overlying the Garnet Range Formation in the eastern part of his area. Lithology similar to that of the Pilcher Quartzite, and what appears to be a gradational contact with the underlying Garnet Range Formation on the north side of Deep Creek, south of Garnet, leads this writer to feel that Kauffman's "Flathead Formation" is equivalent to the Pilcher Quartzite.

On the limbs of the Elk Creek syncline, the Garnet

Range Formation underlies the Cambrian Silver Hill Formation. This same relationship exists in the northern part of Kauffman's map area. It appears that the Pilcher Quartzite has been removed by erosion, and that the Cambrian System lies unconformably above the Belt Supergroup. Poor exposures of the Precambrian-Cambrian contact, and only a slight angular discordance between these rocks, hamper detection of this unconformity and leave its existence in doubt in the minds of many geologists.

CAMBRIAN SYSTEM

Cambrian rocks, consisting of limestone, siltstone, marble and hornfels, rim the Garnet stock. The thickness of these rocks ranges from nothing near the axis of the Elk Creek syncline to over 1,000 feet south and west of Coloma. This variation is due to the irregular contact with the Garnet stock. Interbedded siltstone and limestone of the Silver Hill Formation (Calkins and Emmons, 1915) crop out west of the ghost town of Coloma.

Marble occurs in a contact metamorphic zone which surrounds the Garnet stock. Kauffman (1963, p. 6) has mapped this unit as part of the Hasmark Formation, which he describes as, "almost exclusively a medium crystalline dolomite." In the Forest, the marble reacts vigorously with dilute hydrochloric acid, and apparently has a high calcite content. Mutch (1961) reports that although the carbonates of the Hasmark Formation in the Flint Creek Range contain up to 95% dolomite, the marble derived from this formation in contact metamorphic zones contains up to 75% calcite. He attributes this change in composition to either the leaching of dolomite in preference to calcite, or to the replacement of magnesium with calcium.

Examination under the binocular microscope of marble slabs collected in the Lubrecht Experimental Forest and etched in dilute hydrochloric acid shows that about 20% of the rock is composed of dolomite crystals, and the remaining 80% being calcite. Two interpretations are possible: (1) the marble is contact metamorphosed dolomite from the Hasmark Formation and altered in such a way as to increase the calcite content to about 80% of the rock, or (2) most, if not all, of the marble was derived from the Silver Hill Formation which is predominantly a calcitic limestone. The author favors the latter interpretation because it accounts for the 671 feet of Silver Hill Formation that Kauffman (1963, p. 37) measured, and because it would not be necessary to map the Hasmark Formation in contact with the Garnet Range Formation implying a structural or stratigraphic complication which probably does not exist (Plate 1).

Silver Hill Formation: The thickest section of the Silver Hill Formation consists of more than 500 feet of limestone, siltstone and claystone along the road southwest of the ghost town of Coloma, near the Coloma barite pits.

The lowest part of the section is covered, and grayish black (N 2), shaly, interlaminated claystone and siltstone is stratigraphically the lowest Cambrian rock type observed. This part of the section appears to be rather thin, grading upward into a very thin-bedded siltstone and limestone unit. Beds are irregular and are on the average 1 cm. thick. Siltstone is grayish black (N 2), and the limestone is greenish gray (5G 6/1) and medium light gray (N 6) with yellowish gray (5Y 7/2) weathered surfaces. Differential weathering produces a mottled appearance. This appears to be a transitional sequence between the shaly claystone and siltstone below and the overlying, medium light gray (N 6) limestone. This massive, fine-grained limestone grades upward into a medium dark gray (N 4) marble.

In thin section, shaly claystone and siltstone of the Silver Hill Formation are composed of anhedral, fine silt-sized quartz grains, muscovite and biotite plates, and clay. Quartz grains have slight undulatory extinction and many inclusions. Biotite plates are pleochroic from pale green to yellowish green and are crudely orientated parallel to stratification planes. Muscovite also occurs in orientated plates; however, some of the biotite and muscovite plates are not orientated and appear to be a result of low grade contact metamorphism.

The study of a thin section of a specimen of interbedded limestone and siltstone under a microscope, shows the siltstone to be similar to the siltstone described above except for the addition of interstitial carbonate. Interlaminated with silt-sized quartz grains are layers of clay. The biotite studied in this specimen is pleochroic from reddish brown to colorless. Limestone beds have a conglomeratic appearance under the microscope. Calcite grains range in size from fine silt to medium sand. Quartz and a pyroxene, probably diopside, are found in trace amounts in these beds.

Cambrian Marble: Although this rock type should be discussed in the section dealing with metamorphic rocks, it seems appropriate to discuss it here in order to preserve sequential order. As mentioned above, there is some question as to whether the marble rimming the Garnet stock belongs wholly to the Silver Hill Formation, or partly to the Silver Hill Formation and partly to the Hasmark Formation.

Overlying the limestone of the Silver Hill Formation is a medium dark gray (N 4) marble. This is followed by a sequence of banded, very light gray (N 8) and medium dark gray (N 4) marble. In some places the marble is coarse-grained, while in other places it is fine-grained. The textures appear unrelated to both stratigraphic position and distance from the Garnet stock. Along the northern contact with the Garnet stock, much of the marble is very light gray (N 8). Higher in the section, fine-grained, moderate yellow green (5GY 7/3) hornfels beds averaging

1 cm. in thickness, are interbedded with very light gray (N 8) marble (Fig. 8, p. 42). This rock type crops out in the NE¼ of section 29, T. 13 N., R. 14 W., and occurs as float along Elk Creek near the Greenough Barite Mine, where Clawson (1957) has mapped a lenticular body of quartzite in the marble. It is probably the metamorphic product of the previously mentioned siltstone and limestone of the Silver Hill Formation.

TERTIARY BASIN DEPOSITS

Much of the Forest below 4,000 feet is underlain by poorly consolidated mudstone, sandstone, and conglomerate. These appear to be horizontally bedded and are interpreted as Tertiary basin deposits which accumulated to a thickness of about 1,000 feet and formerly covered a more extensive area. Only a few outcrops of this material were found within the map area, most of which are confined to road cuts of Montana Route 20. Study of these sediments under the binocular microscope indicates that they contain a large amount of detritus derived from acidic igneous material. In addition, outcrops of tuffaceous silts and sands occur in several places along Montana Route 20, both within the Forest and to the west. Most of the area, which is underlain by Tertiary basin deposits, is covered by an extremely clay-rich impermeable soil containing subangular argillite, siltite, and quartzite float which were originally derived from the Precambrian Belt Supergroup (mostly Missoula Group). Road cuts through this material expose spongy, puffed-up, clayey soil, indicative of bentonitic clays derived from decomposed volcanic glass.

Sandstone and conglomerate consist of well rounded, poorly sorted, poorly consolidated quartz and feldspar grains and flakes of biotite and muscovite; pebbles are composed exclusively of quartz. A large amount of clay is interstitial to the larger grains of quartz, feldspar, biotite and muscovite. The only outcrop of this material in the area is found along the Elk Creek road in the southwest corner of the NW¼ of section 5, T. 13 N., R. 14 W., where the rock is light yellowish orange (about 10YR 7/6), and weathers to a moderate yellowish brown (10 YR 5/4). Bedding is nearly horizontal.

Along Montana Route 20, in the NW¼ of section 12, T. 13 N., R. 15 W., is an exposure of volcanic rocks which were apparently intruded into the Tertiary basin deposits (Fig. 7A). These rocks consist of breccia and vitric felsite. The breccia is composed of angular fragments of argillite, siltite and quartzite derived from Belt rocks, and flow-banded felsite (Fig. 7B). The groundmass of the breccia is predominantly devitrified glass with microlites tentatively identified as feldspar and quartz. Vitric felsite has intruded the breccia; in one place it forms a steep, southwest-dipping dike,

A

B

Figure 7. (A) Tuffaceous breccia cropping out along Montana Route 20. (B) Close up of breccia showing variation in size of fragments and anglarity.

with a thickness of about 5 feet, and is flow-banded. This rock appears to be similar in composition to the breccia groundmass. It appears that the breccia was formed by a volcanic explosion, and is possibly part of a vent filling. The breccia was later intruded by magma, probably derived from the same vent.

Two exposures of deeply colored red soil can be seen on the north side of Montana Route 20 in the NE¼ of section 7, T. 13 N., R. 15 W., and in the NE¼ of section 1, T. 13 N., R. 15 W. In both exposures the soil is rich in clay, and has large, subangular pieces of Belt derived rock. These exposures could possibly represent remains of oxidized pre-Tertiary soil.

The nature of the Tertiary basin of deposition cannot be ascertained in this area due to lack of outcrops. These rocks and tuffaceous material appear to be similar lithologically to the deposits described by Gwinn (1961) in the Drummond, Montana, area. He believes that deposition took place in basins formed by subsiding lowlands during Tertiary times. Alden (1953, p. 26, 52) describes a buff, semi-indurated, sandy clay which contains small shells and concretions west of the Lubrecht Experimental Forest, near the town of Potomac. He suggests that the fossils and these beds are Miocene.

QUATERNARY DEPOSITS

In the Lubrecht Experimental Forest, Quaternary deposits consist of Pleistocene glacial deposits and Recent alluvium. In this report these deposits are mapped as one unit (Plate 1).

Glacial deposits: Glacial deposits, which are restricted to the northeastern part of the map area, consist of unstratified glacial drift and stratified lucustrine clay and silt. Unstratified glacial drift consists mostly of boulders, cobbles, and pebbles which were derived from Belt argillite, siltite, and quartzite, and assorted igneous rocks. Boulders reach a maximum diameter of about 10 feet, and range in shape from angular to subangular. Small pieces of rock are well rounded and difficult to distinguish from Recent alluvium deposits. Glacial striae or facets were not observed on any rocks.

Stratigraphically above these deposits is a sequence of horizontally stratified, lucustrine clay and silt, having an exposed thickness of at least 10 feet. A good exposure of clay and silt overlying unstratified glacial drift can be seen in a road cut on the southeast side of Montana Route 20, just north of the map area in the SE¼ of section 24, T. 14 N., R. 15 W. Stratified clay and silt underlie the upper terrace level, and poorly sorted, unstratified glacial drift underlies the lower terrace level along the south bank of the Blackfoot River.

Alden (1953, p. 89) reports that the western extent of the unstratified glacial drift in the Blackfoot Valley is in section 27, T. 14 N., R. 15 W. He suggests that at this point, the western front of a pre-Wisconsin glacier terminated in a lake, probably an eastern arm of glacial Lake Missoula. The lake apparently extended itself eastward as the glacier retreated, depositing clay and silt over the unstratified glacial drift.

Recent alluvium: Recent alluvium in the channel and flood plain of the Blackfoot River consists of reworked glacial deposits, and recently eroded Belt and igneous rocks. Because within the Forest the tributaries of the Blackfoot River were not glaciated, their stream beds consist of alluvium derived from recently eroded bedrock. The upper part of Elk Creek has quartz monzonite as well as Belt and Cambrian derived gravels in its stream bed. The gravels of several streams in the area, including Elk Creek, McGinnis Gulch, and Washoe Creek, contain placer gold deposits (see section on Economic Geology).

IGNEOUS ROCKS

QUARTZ MONZONITE

A stock, a few dikes, and several cupolas composed of quartz monzonite, intrude the Belt and Cambrian rocks in the eastern half of the Lubrecht Experimental Forest. The Garnet stock underlies about 13 square miles in the southeastern part of the map area, and an additional 15 to 20 square miles to the east and north (Ross, *et al.*, 1955). In the Forest the stock consists of quartz monzonite which varies somewhat in texture and composition (Table 1). Along the margin of the stock, the rock has a phaneritic texture and more hornblende than biotite. The width of the marginal zone is irregular, ranging from one-eighth of a mile in the NE¼ of section 13, T. 13 N., R. 14 W. to about one mile in the area northwest of McGinnis Gulch. In the interior of the stock, the quartz monzonite has a porphyritic texture, and biotite is more abundant than hornblende. The change in texture and composition appears to be gradational over a narrow zone.

Quartz monzonite of the Garnet stock marginal zone: The phaneritic quartz monzonite of the marginal zone of the Garnet stock consists of plagioclase, orthoclase, quartz, biotite, hornblende, plus minor amounts of muscovite-sericite, chlorite, epidote, sphene, apatite, ore (magnetite),

Minerals	Specimens 29	 32	 69	 76	 T
Plagioclase Feldspar	34.3	35.9	31.4	32.5	30.8
Potash Feldspar	28.9	30.8	36.7	32.1	33.4
Quartz	29.8	23.1	12.5	23.8	32.7
Biotite	5.1	3.6	----	3.9	2.5
Hornblende	1.4	5.3	15.3	6.2	trace
Ore	0.1	1.0	1.3	0.7	0.4
Muscovite-Sericite	0.2	0.1	0.6	trace	---
Sphene	0.2	0.1	2.2	0.8	trace
Apatite	trace	0.1	trace	---	trace
Zircon	trace	trace	---	trace	---
Chlorite	trace	trace	trace	trace	---
Epidote	trace	trace	trace	trace	---
Olivine	---	---	trace	---	---
Total	100.0	100.0	100.0	100.0	99.8

Sample Identification

29 = Quartz monzonite from the interior of the Garnet stock.

32 = Quartz monzonite from the marginal zone of the Garnet stock.

69 = Quartz monzonite dike

76 = Quartz monzonite cupola.

T = Toler's (1959) mode for the quartz monzonite at Lolo Hot Springs.

Table 1. Modal analyses of five occurrences of quartz monzonite

and zircon (Table 1, specimen 32). Plagioclase crystals average between 1.0 mm. and 1.5 mm. in diameter. They are generally zoned and display albite twinning. Using the Michel-Levy Method (Kerr, 1959, p. 257-260), the composition of the plagioclase in a specimen studied in thin section falls in the oligoclase-andesine range, with the cores of these crystals averaging about An_{44}, and the rims averaging about An_{17} in composition. The calcic cores are selectively altered to sericite. The potash feldspar crystals are megascopically pale orange pink, and have an average diameter of about 1.5 mm. In thin section, some of these crystals display Carlsbad twinning. Biaxial negative interference figures with large axial angles indicate that these crystals are orthoclase. Quartz crystals average about 1.2 mm. in diameter, and are relatively unstrained. Biotite occurs in pleochroic light to dark brown crystals which average about 0.8 mm. in diameter. Many of these crystals are partially altered to chlorite. Hornblende occurs in pleochroic light to dark green, prism-shaped crystals which average about 2 mm. in length.

The ore mineral found in this rock is metallic, blackish gray in reflected light, and is probably magnetite. It is found in association with both biotite and hornblende, and appears to be replacing these two minerals. The crystals are anhedral and average about 0.3 mm. in diameter. Sphene is found in both wedge-shaped, and anhedral crystals, averaging 0.2 mm. in diameter. Apatite forms slender, hexagonal prisms. Zircon crystals occur as small inclusions in biotite crystals. Epidote occurs in anhedral crystals which have moderate to strong birefringence, indicating a considerable iron content.

Quartz monzonite of the Garnet stock interior: In the interior of the Garnet stock, the megascopic texture of the quartz monzonite is porphyritic, with potash feldspar forming phenocrysts in a phaneritic groundmass consisting of plagioclase, potash feldspar, quartz, biotite, hornblende, plus minor amounts of chlorite, epidote, sphene, ore, muscovite-sericite, apatite, and zircon. Potash feldspar phenocrysts comprise about 25% of the rock. In addition to the textural difference, there is an increase in biotite content and a decrease in hornblende content in this rock as compared to the quartz monzonite in the marginal zone of the stock (Table 1, p. 38).

Potash feldspar crystals in the groundmass have an average diameter of about 1 mm., and phenocrysts of this mineral average about 10 mm. in diameter, commonly reaching diameters in excess of 25 mm. The composition of the zoned plagioclase crystals in a thin section of specimen 29 is approximately the same as that of the phaneritic specimen (32), but some of the plagioclase crystals have myrmekitic structure. Biotite crystals are somewhat larger in the interior of the stock than in the marginal zone, reaching diameters up to 2.5 mm. Some of these crystals are partially altered to chlorite.

Dikes and cupolas: A quartz monzonite dike about 3 feet thick is exposed in the NE¼ of section 29, T. 13 N., R. 14 W. (Fig. 8), where the host rock is an interbedded marble and hornfels derived from contact metamorphosed Cambrian rocks. The quartz monzonite dike rock is similar in composition to that of the marginal zone of the Garnet stock, except that hornblende is much more abundant in the dike, and biotite is absent (Table 1, p. 38, specimen 69). This rock has a fine-grained phaneritic texture. Chlorite inclusions occur in hornblende prisms, and could be an alteration product of hornblende, or biotite. Trace amounts of olivine and epidote also occur.

Clawson (1957, p. 19-20) describes a quartz monzonite dike which cuts a barite vein in the Greenough Barite Mine. This dike is enriched in biotite rather than hornblende.

Several irregular bodies of quartz monzonite occur in the vicinity of the Garnet stock, and appear to be cupolas. They range in outcrop area from a few tens of square feet, to several thousand square feet. Individual cupolas have both phaneritic and porphyritic textures, with most of the rocks having phaneritic textures. The composition of these cupolas is similar to that of the Garnet stock. A modal analysis of a specimen collected from a small cupola in the SW¼ of section 9, T. 13 N., R. 14 W. is given in Table 1

Figure 8. A quartz monzonite dike cutting across Cambrian marble and hornfels.

(specimen 76). The similarity in textures and composition between these cupolas and the Garnet stock, the spatial relationship between these bodies (Plate 1), and the similar degree of metamorphism of the host rocks, suggest that these bodies are all parts of the same pluton.

Aplite and pegmatite dikes: Aplite and pegmatite dikes cut through the Garnet stock in many places. They range in thickness from less than an inch to several feet.

A pegmatite dike cuts through hornfels derived from the Garnet Range Formation, about 300 yards north of the Greenough Barite Mine in the NW¼ of section 16, T. 13 N., R. 14 W. This dike is about 6 inches thick, and consists of a graphic intergrowth of potash feldspar and quartz, with small books of muscovite averaging 12 mm. in thickness and 25 mm. in diameter, occurring towards the interior.

Clawson (1957, p. 18, 20) describes thin, irregular pegmatite dikes which cut the main barite vein in the Greenough Barite Mine. One such dike in this mine appears to grade into a quartz monzonite dike.

Many aplitic and pegmatitic pieces of float are found scattered throughout the area of the Garnet stock. Concentration of float appears to be greatest near the margins of the stock. Although many thin dikes are well exposed in bold quartz monzonite outcrops, the presence of larger dikes are indicated only by the occurrence of aplitic and pegmatitic float. Thin dikes, such as those exposed on the north side of the North Fork of Elk Creek (Fig. 9), range in thickness from ½ inch to about 3 inches. They have very sharp boundaries with the quartz monzonite, and appear to be late fracture fillings.

Pegmatite float is chiefly composed of potash feldspar and quartz in a graphic intergrowth. Crystals as long as 6 inches have been found in float. More than one possible origin has been suggested for these rocks. Eutectic crystallization of potash feldspar and quartz could result in a graphic intergrowth of these minerals. Another possibility is that the origin of these rocks is similar to that of myrmekite (Williams, et al., 1954, p. 20; Turner and Verhoogen, 1960, p. 68), where potash feldspar is replaced by quartz. Williams, et al. (1954, p. 146) also suggests that many pegmatites appear to have been produced by replacement of aplites. Close spatial association of the two rock types, and the occurrence of both types in the same dike (hand specimen 10), support this last hypothesis for these rocks in the Forest.

Weathering of quartz monzonite: Spheroidal weathering of quartz monzonite outcrops is quite prominent in the Lubrecht Experimental Forest (Fig. 10).

On north-facing slopes, the soil on quartz monzonite is well developed. On south-facing slopes, abundant amounts of primary minerals in the upper levels of the soil indicate its youthful stage of development.

According to Grim (1953, p. 330-332), factors which influence the weathering processes are: parent rock, climate, topography, vegetation, and time.

Although a detailed petrographic and soil study of the quartz monzonite of the Garnet stock is yet to be done, it is of interest to mention the results obtained by Toler (1957) in a study done near Lolo Hot Springs, Montana. The parent rock that he studied has a composition similar to

Figure 9. Pegmatite dike cutting through quartz monzonite in the Garnet stock.

Figure 10. Outcrops of quartz monzonite in the Garnet stock. Note: jointing, spheroidal weathering, and lichen growth.

that of the Garnet stock (Table 1, p. 38), is located at about the same elevation and in a similar topographic setting, and has probably been exposed for a similar amount of time. The major difference in the two areas is precipitation, which is about 25 inches per year at Lolo Hot Springs as compared to only 15.6 inches per year at Greenough. Toler (1957, p. 31) found that the soil contains an abundance of primary minerals and a complex suite of secondary clay minerals including: metahalloysite, montmorillonite, mixed-layered chlorite-vermiculite, and fine particle size mica.

TRACHYTE PORPHYRY

Several dikes and sills plus a possible volcanic plug which cut the Precambrian Belt metasediments throughout the eastern half of the map area, have trachytic textures and compositions, and are interpreted as being hypabyssal intrusions. Field observations included discordant intrusive contacts, and a lack of extrusive igneous structures.

Cap Wallace Creek cuts through a trachyte pluton just east of its junction with Elk Creek. The outcrop pattern and nearly vertical flow structure suggest that this pluton might be a volcanic plug. Microscopic study of two specimens of this rock shows it to be composed of small phenocrysts in a felty groundmass.

The phenocrysts in Cap Wallace pluton are relatively small, reaching a maximum diameter of 2.0 mm. They consist of plagioclase feldspar, biotite, and a small amount of quartz, and account for about 25% of the rock. Plagioclase phenocrysts have poorly developed albite twinning with thin lamellae, and are a high temperature albite as determined by interference figure and refractive index. The edges of these phenocrysts are ill-defined due to alteration of the feldspar to clay and sericite. Biotite phenocrysts commonly have inclusions of an ore mineral, probably magnetite. In some places this mineral appears to be replacing biotite. Only a few small quartz phenocrysts were observed.

The groundmass consists of sanidine, oligoclase and biotite microlites, with some anhedral crystals of clino-pyroxene, hornblende, magnetite, and apatite. Clawson (1957, p. 16) identified hornblende, but not any pyroxene in the rocks of this pluton. The pyroxene crystals are colorless, have moderately high relief, two directions of cleavage which are almost at right angles, and extinction angles which reach 38° at a maximum. These crystals are definitely a clino-pyroxene, and most probably diopside. The composition of the feldspar microlites were determined using a statistical analysis involving extinction angles (Moorhouse, 1959, p. 55, 57).

An orientated specimen (#43) of this trachyte porphyry was collected. It was discovered that flow-banding controls jointing.

In contrast to the small phenocrysts in the trachyte at Cap Wallace, other trachytic plutons have phenocrysts with diameters in excess of 1 cm. The composition of a representative specimen from an intrusion in SW¼ of section 17, T. 13 N., R. 14 W. is similar to that of the Cap Wallace pluton, except for: (1) the presence of a greater amount of green hornblende, and (2) the absence of quartz and diopside. These differences could be particular to these samples, since quartz phenocrysts have been found in small quantities in some of the other trachytic intrusions.

Phenocrysts of a representative specimen (Fig. 11) consist of euhedral and subhedral plagioclase feldspar and

Figure 11. Photomicrograph of a zoned plagioclase phenocryst in a trachytic groundmass. Crude orientation of microlites suggests flow around phenocryst (X-nicols, x 20).

biotite. The plagioclase phenocrysts are zoned and display albite twinning. Using the Michel-Levy Method (Kerr, 1959, p. 257-260), it was determined that the outer zone of the plagioclase phenocrysts have a composition in the albite-oligoclase range, about An_{10}. The cores of these phenocrysts are in the calcic oligoclase range, about An_{29}. Biotite phenocrysts have magnetite inclusions which appear to be alteration products.

Around the peripheries of the larger phenocrysts, microlites in the groundmass are crudely orientated in such a manner as to suggest that this material flowed around the phenocrysts (Fig. 11).

ANDESITE PORPHYRY

Several dikes with andesitic composition crop out in the eastern half of the Lubrecht Experimental Forest. One of these dikes is cut by Elk Creek, between North Fork and Cap Wallace Creeks. Several others crop out along the Coloma road and the lower part of the Stinkwater road.

Megascopically, these rocks have a porphyritic texture, with large, white plagioclase feldspar phenocrysts and smaller, black pyroxene phenocrysts, which together account for about 40% of the rock. The groundmass is aphanitic and yellowish green. Plagioclase phenocrysts reach a maximum diameter of 20 mm., and the pyroxene phenocrysts reach a maximum diameter of 4 mm.

Microscopic study of a representative specimen from a dike in the SE¼ of section 13, T. 13 N., R. 15 W., shows that this rock consists of plagioclase, pyroxene and biotite phenocrysts in a felty groundmass composed of plagioclase, some biotite, and sphene. The composition of the plagioclase phenocrysts as determined from albite twinning, using the Michel-Levy Method (Kerr, 1959, p. 257-260), is about An_{30} in the rims and about An_{40} in the cores. Seritization is extensive, especially along cleavage traces and borders of the phenocrysts. The centers of some of these phenocrysts are hollow, and partially filled with hematite and clay minerals. They could represent pre-existing calcic cores which have been selectively altered to clay.

Pyroxene phenocrysts are augite, which shows wavy extinction, and have been partially altered to green hornblende. Biotite rims some of these phenocrysts, and occurs as bent laths in the groundmass.

LAMPROPHYRE

A lamprophyric pluton crops out over a one square mile area along the Coloma road, about a mile south of its junction with Montana Route 20. It consists of several rock types, with an olivine-pyroxene-rich lamprophyre appearing to be the most dominant. In hand specimen, this rock appears to be fine-medium-grained, dark gray, and holocrystalline. Pyroxene and olivine can be identified with the aid of a hand lens. Along the margins of the pluton, hornblende-rich lamprophyre occurs in significant quantities. This rock has a porphyritic texture megascopically, with phenocrysts of hornblende in a felsic groundmass. This pluton is cut by a porphyritic dike with phenocrysts of both hornblende and augite in a fine-grained mesocratic groundmass, and several veins of bull quartz.

In thin section, a specimen of the olivine-pyroxene-rich lamprophyre can be seen to consist of about 35% feldspars, 40% pyroxenes, 20% olivine, and lesser amounts of biotite, magnetite, apatite, and zircon. This rock has a microporphyritic texture with the phenocrysts consisting of olivine, augite, and some pigeonite (Fig. 12). Olivine occurs in subhedral crystals with diameters between 4 mm. and 6 mm. Two generations of augite and pigeonite are present. Euhedral phenocrysts of these two pyroxenes range up to 5 mm. in diameter, while smaller crystals in the groundmass are less than 1 mm. in diameter. Pyroxenes and olivine are partially replaced by magnetite and biotite. Anhedral magnetite crystals are rimmed with biotite. Boundary relationships between these two minerals suggest that biotite is replacing magnetite. The groundmass is predominantly calcic plagioclase with interstitial orthoclase (Fig. 12). In addition to olivine and pyroxenes in the groundmass, apatite is scattered throughout in the form of needle-shaped, hexagonal prisms. Zircon occurs as small inclusions surrounded by pleochroic halos in biotite crystals.

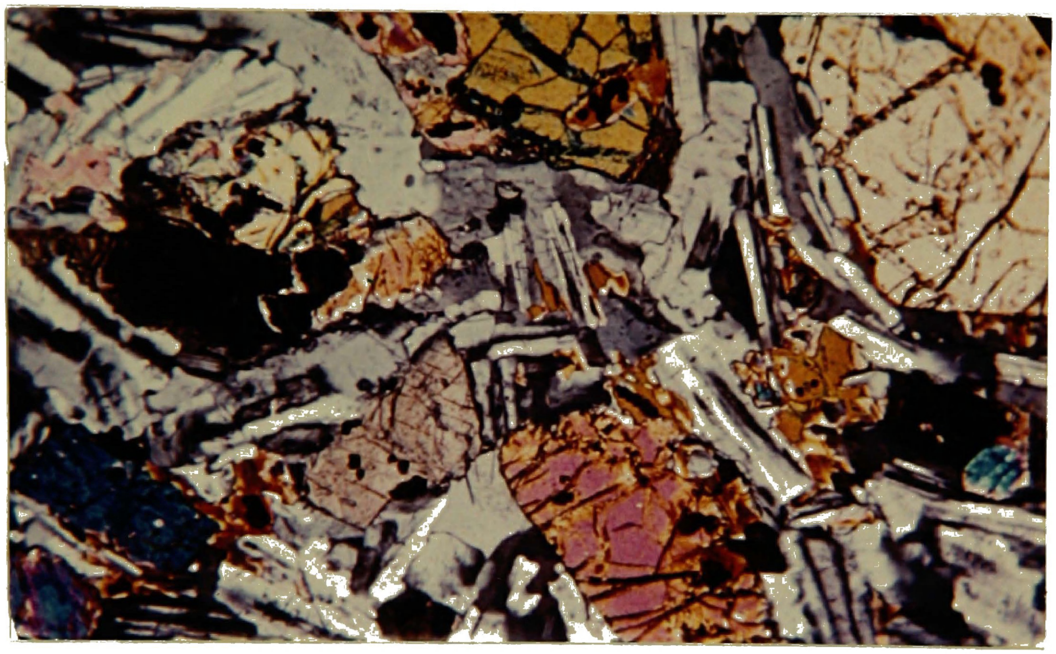

Figure 12. Photomicrograph of olivine-pyroxene-rich lamprophyre showing interstitial orthoclase (X-nicols, x 30).

In thin section, a specimen of the hornblende-rich lamprophyre consists of hornblende phenocrysts, which make up about 40% of the rock, in a groundmass which is predominantly plagioclase with interstitial quartz and orthoclase. Hornblende forms elongated phenocrysts which average about 4 mm. in length and 1 mm. in width, are pleochroic from yellowish green to dark green, and display polysynthetic twinning. Some of the hornblende phenocrysts have been partially altered to biotite and magnetite. The groundmass has an allotriomorphic-granular texture with plagioclase occurring as zoned laths which display albite twinning. Small crystals of hornblende, magnetite, biotite, and sphene are found in the groundmass in addition to the feldspars and quartz.

These two rock types appear intergradational; the olivine-pyroxene-rich rock is confined to the interior of the pluton and the hornblende-rich rock to the margins.

A porphyritic dike which cuts through the southern part of the pluton was traceable for about 100 feet in an east-west direction. This dike is about 15 feet thick, and consists of phenocrysts of hornblende and augite in a fine-grained, phaneritic groundmass of plagioclase, hornblende, augite, and some quartz. Much of the plagioclase is altered to sericite, and the pyroxene has a mottled appearance. The rock has an ophitic texture under the microscope.

AGE OF INTRUSIONS

The approximate age of intrusion and the relative ages of each intrusion to one another cannot be determined due to the lack of observable field relationships in the Forest. Host rocks in the area are restricted to the Belt metasediments and Cambrian rocks; however, similar intrusive rocks on the south side of the Garnet Range cut rocks as young as Cretaceous (Kauffman, 1963). Similar textures and compositions indicate that the andesite, trachyte, and granodiorite in Kauffman's area are probably genetically related to the andesite porphyry, trachyte porphyry, and quartz monzonite in the Forest. In view of this proposed correlation, and since the Tertiary basin deposits on the north side of the Garnet Range appear to be partially derived from these rocks, it can be said that these rocks were all emplaced during the Laramide orogeny (late Cretaceous-early Tertiary). This assumption seems plausible because of the similar compositions of the two suites of rocks, and their proximity to one another.

Clawson (1957, p. 14) states that the igneous rocks around the Greenough Barite Mine, with the exception of a porphyritic diorite (andesite porphyry) dike which he considers to be Precambrian in age, are of late Cretaceous or early Tertiary age. During a recent visit to this mine, the author found a small andesite porphyry dike cutting the main barite vein. Since Clawson (1957, p. 32) dates the barite as the same age as the quartz monzonite, an inconsistency arises. Either the andesite porphyry is Laramide rather than Precambrian in age, or the barite was deposited during Precambrian time. The author believes that the andesite porphyry is late Cretaceous or early Tertiary in age, and that the barite was either deposited after Laramide deformation began, but before the andesite prophyry was intruded, or that the barite was deposited before the Laramide orogeny.

Division of the Garnet stock into a marginal zone and interior portion suggests the possibility of two intrusions. The basis of this division is the phaneritic texture and excess of hornblende over biotite in the marginal zone as compared to the porphyritic texture and excess of biotite over hornblende in the interior of the Garnet stock.

In addition to the two intrusion hypothesis for the occurrence of two different quartz monzonites, another hypothesis is that the Garnet stock represents a single intrusion, and that the excess of biotite in the interior is due to increased water vapor pressure during crystallization of this part of the stock. Experimental studies by Tuttle and Bowen (1958, p. 92) indicate that amphiboles in granitic magmas are unstable at magmatic temperatures when the water vapor pressure reaches 1,000 kg./cm^2. As the marginal zone magma crystallized, a gradual increase in water vapor pressure in the interior of the stock would be expected. This would permit biotite to crystallize out of the magma in place of hornblende when the water pressure reaches 1,000 kg./cm^2. Difficulties arise when an explanation for the presence of orthoclase phenocrysts in the interior of the stock without associated plagioclase or quartz phenocrysts is attempted. Orthoclase would have to begin crystallizing before the other minerals in order to account for its occurrence as the only phenocrysts. Only a very rapid increase in water vapor pressure or temperature might allow orthoclase to crystallize independently from plagioclase and quartz (Turner and Verhoogen, 1960, p. 119-123). This appears to be unlikely, due to the lack of an easily explainable mechanism for a sudden increase in water vapor pressure or temperature.

Potash autometasomatism is another possible explanation for the presence of large orthoclase crystals (megacrysts). Heat and vapors from the interior of the Garnet stock could have promoted the growth of orthoclase porphyroblasts. Evidence in support of an autometasomatic origin for these megacrysts are: (1) the occurrence of inclusions along their margins; (2) the similar modes of the phaneritic and porphyritic (or porphyroblastic) quartz monzonites; and (3) the lack of associated large plagioclase and quartz crystals. Hyndman (1964, p. 135-136) describes a similar occurrence, where the quartz monzonite of the Lower Caribou Creek stock contains potash felspar megacrysts, and apparently has been affected by autometasomatism.

The lamprophyric nature of the pluton along the Coloma road south of Montana Route 20 suggests that there might be a genetic relationship between it and the Garnet stock. Lamprophyres commonly occur in close association with granitic or granodioritic plutons (Turner and Verhoogen, 1960, p. 251-252). Several hypotheses have been suggested for the origin of lamprophyres. Some of these ideas relate the origin of these rocks to the occurrence of nearby acid intrusions, either by assimilation of minerals from the acid rock by a basaltic magma, thus contaminating the basaltic magma, or by the derivation of both magma types from a common granitic magma (Turner and Verhoogen, 1960, p. 254-256). Although there is no completely satisfactory explanation of the origin of lamprophyres, it should be noted that if a genetic relationship should exist between the lamprophyric pluton and the Garnet stock, then this pluton would have to be at least as young as the stock. Assuming that the Garnet stock was emplaced during the Laramide orogeny, the lamprophyric pluton would not be older than late Cretaceous.

CONTACT METAMORPHISM AND HYDROTHERMAL ALTERATION

METAMORPHISM OF THE GARNET RANGE FORMATION

Several metamorphic effects are noted in the Garnet Range Formation. In Cap Wallace Gulch, where this formation is the host rock for a trachyte pluton, a dark gray spotted hornfels crops out near the contact. In thin section, clusters of quartz, green biotite, muscovite, clay, and magnetite form spots which average 1 mm. in diameter. The groundmass consists of fine silt-sized recrystallized quartz grains, mica flakes, and interstitial clay.

In contact zones near quartz monzonitic, andesitic, and basic intrusions, the dark spots are much larger, reaching maximum diameters of 5 mm. or more. In thin section, small porphyroblastic aggregates consist of minute crystals of biotite, quartz, muscovite, and magnetite. In one thin section, large porphyroblasts of limonite envelope cordierite, and octahedral crystals of magnetite are scattered throughout the rock (Fig. 13). Weathered specimens have limonite shells surrounding cordierite porphyroblasts.

In the area around the Elk Creek-North Fork junction, where the Garnet Range Formation is in contact with quartz monzonite, a biotite schist occurs. Intersecting plates of

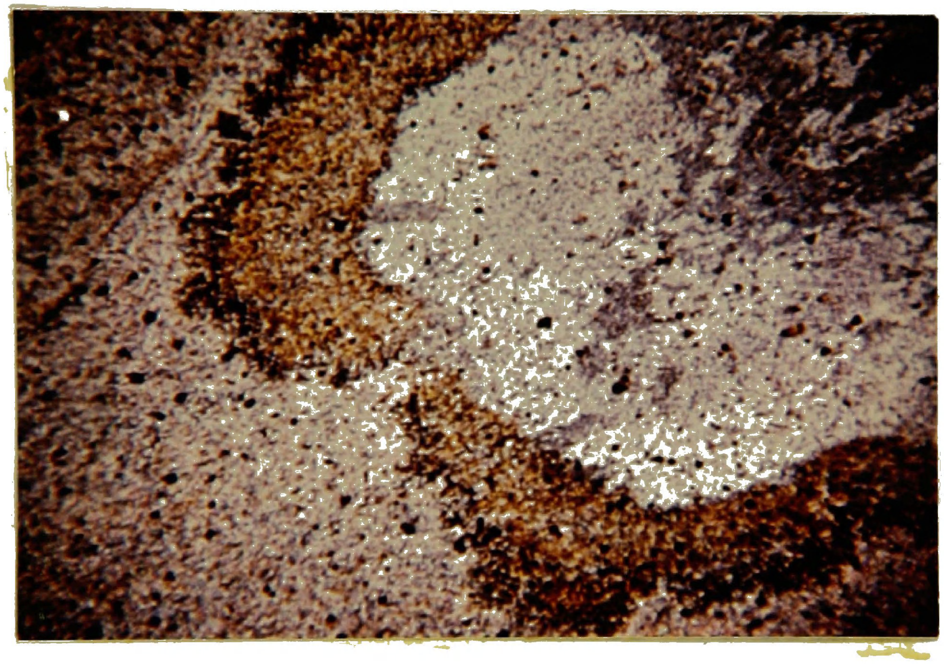

Figure 13. Cordierite porphyroblast with limonite shell around it. Magnetite crystals are scattered in the quartzitic hornfels (X-nicols, x 20).

pleochroic, pale olive green to dark olive green biotite and colorless muscovite alternate with quartz-rich layers. Quartz grains range from fine silt to fine sand-sized. These grains are anhedral, have nearly straight extinction, and contain many inclusions, some of which are biotite microlites. Green biotite laths have zircon inclusions with pleochroic halos around them. Scattered throughout the rock are small grains of well rounded garnet, which are believed to be of detrital origin. The tourmaline schorlite occurs as anhedral and hexagonal crystals in small amounts throughout the rock. Cordierite, which occurs in hexagonal sections and colorless, anhedral crystals displaying biaxial negative interference figures with large axial angles, are also found in small quantities in this rock.

The mineral assemblages in the rocks described above indicate that all belong to the albite-epidote-hornfels facies (Turner and Verhoogen, 1960, p. 510-511).

HYDROTHERMAL ALTERATION ZONE

Partially rimming the lamprophyric pluton described on p. 50, is a quartz, calcite and hematite-rich hydrothermal alteration zone. This zone consists of two rock types, one of which is siliceous and the other calcareous; both are rich in hematite.

The siliceous rock consists of chert, interstitial hematite, and fractures which are partly filled with quartz crystals. Fractures are locally very numerous and filled with red earthy hematite. In addition opal and agate filled cavities are common in this rock. In thin section, the quartz which fills fractures is typical vein quartz (Folk, 1961, p. 68-70), containing many inclusions, undulose extinction, biaxial positive interference figures with axial angles up to 10°, and phantom crystals.

A microscopic fracture network is observed within some of the chert specimens. These fractures are filled mostly with hematite, and cut through the quartz-filled veins. This relationship, along with the strained extinction of the vein quartz, indicates that this rock has undergone deformation after the primary fractures were filled with quartz.

The presence of a large amount of silica adjacent to a basic igneous body does not present any problem when one considers that the Garnet Range host rock is a highly quartzitic metasediment.

The other rock type, which occurs in large amounts, is composed of hematite, calcite, antigorite, and quartz. The calcite and antigorite fill fractures in the hematite-stained quartz. This rock is so thoroughly fractured that very little of the quartz still remains in the representative specimen studied. Antigorite occurs in fiberous aggregates of pale green crystals. The birefringence is very weak; first order gray is the highest inference color observed. Calcite occurs in anhedral, colorless crystals with irregular margins. Some of the quartz crystals are euhedral and display phantom crystals.

SKARN ZONE

Small pockets of intense mineralization are found in a skarn zone along the contact between the quartz monzonite of the Garnet stock and the Cambrian marble. These pockets are reflected on covered surfaces by the occurrence of orange, calcareous soil, and green, granitic soil. They are most prominent along the northern contact of the stock, in the North Fork drainage. Under the binocular microscope, the following minerals were identified from specimens collected from these pockets of mineralization: galena, bornite, azurite, malachite, pyrite, chalcopyrite, limonite, tourmaline, molybdenite, biotite, calcite, quartz, garnet, epidote, feldspar, and clay. After study of a thin section of one of these specimens, diopside and antigorite were added to the list. Antigorite appears to be an alteration product of diopside.

Skarn deposits, such as the ones that occur in the Lubrecht Experimental Forest, form in contact zones by reactions between limestone or dolomite and iron-rich, silica-rich solutions or gases from intrusive igneous bodies (Turner and Verhoogen, 1960, p. 572-573). The presence of diopside suggests that some dolomite was involved in these reactions. Ions that are found in small quantities in granitic rocks, such as iron, lead, and copper are concentrated in the residual fluids along with excess silica. These fluids reacting with the limestone produced the mineral assemblage listed above. In addition, hydrothermal deposition of sulfide minerals might have been superimposed upon this zone accounting for the sulfide-rich veins found in the skarn zone in the North Fork drainage (see section on Economic Geology).

STRUCTURAL GEOLOGY

STRUCTURAL SETTING

The major structural trends in the Garnet Range vary from about N 70° W to about N 60° E. Compressional stresses acted generally in a north-south direction, and on the south side of the Garnet Range, overthrusting took place from the south-southwest as expressed by the Bearmouth thrust (Kauffman, 1963, p. 20).

FOLDS

One major fold is found within the Lubrecht Experimental Forest, and minor folds occur on the limbs of this structure. The major fold is the east-southeast plunging Elk Creek syncline which occupies the southeastern half of the map area. This fold is truncated on the southeast by the quartz monzonite of the Garnet stock, which forms irregular, intrusive contacts with its host rocks. The symmetry of the Elk Creek syncline cannot be determined because of the irregular contacts of the Garnet stock, contact metamorphism of the host rocks, and deformation of these host rocks.

Minor folding appears to have resulted from two different mechanisms. The Cambrian marble, which is close to the Garnet stock, is contorted as indicated by frequent reversal of dips; the axes of the folds are inferred to be roughly parallel the contact with the stock. These folds are probably the result of compressional stresses created by the emplacement of the Garnet stock. The Garnet Range Formation is relatively incompetent, and is apparently extensively faulted and folded, accounting for the anomalous thickness of this formation west of the Garnet stock. Unfortunately, this cannot be demonstrated in the field because of the lack of outcrops. The Miller Peak Formation and the Bonner Quartzite are gently folded and perhaps also faulted in the western part of the area, but not to the same extent as is the Garnet Range Formation (Plate 2). The deformation of these three formations is probably due to north-south acting compressional forces during the Laramide orogenic period, or perhaps Laramide deformation superimposed over gentler Precambrian deformation.

FAULTS

Cap Wallace fault: The Cap Wallace fault trends in a general east-west direction through the map area, placing the Garnet Range Formation in contact with the Bonner Quartzite. The McNamara Formation, which in an unfaulted stratigraphic sequence occurs between the Bonner Quartzite and the Garnet Range Formation, has been faulted out in the Lubrecht Experimental Forest. The thickness of this formation, which is 2,800 feet on the south side of the Garnet

Range (Kauffman, 1963, p. 5), gives a rough approximation of the minimum vertical displacement of the Cap Wallace fault.

The north block of the Cap Wallace fault consists of Bonner Quartzite, and moved up in relation to the south block which consists of the Garnet Range Formation. Due to the lack of exposure of the fault and the scarcity of outcrops on either side of it, the dip of this fault and its branches cannot be determined from field observations. East of Elk Creek, the trace of the Cap Wallace fault trends along the bottom of the V-shaped canyon of Cap Wallace Gulch, which it structurally controls. The location of the fault is detected there by the occurrence of float exclusively from the Garnet Range Formation on the south slope, and float exclusively from the Bonner Quartzite on the north side of the canyon. The undulatory trend of the trace in relation to the topography in the area suggests that the fault zone dips steeply to the south in sections 11, 12, and 14 of T. 13 N., R. 14 W., and to the north from the NE¼ of section 14, T. 13 N., R. 14 W., westward until it leaves the Cap Wallace Gulch (Plate 1). The fault trace west of Elk Creek is only approximately located and can be inferred to dip at almost any angle in either direction.

Other faults: Two faults which branch from the Cap Wallace fault (Plate 1), apparently cause a wedge of Garnet Range Formation to crop out in the north block of the Cap

Wallace fault. The wedge is represented by one outcrop and an almost continuous cover of float from the Garnet Range Formation. This structure could be either a down-dropped block, or an up-thrown block (see discussion below). If these are high-angle faults, as they appear to be from their traces and the topography (Plate 1), then the simplest interpretation is that the wedge of Garnet Range Formation is a down-dropped block. Both fault traces strike, for the most part, between N 60° E and N 65° E, and are roughly parallel to the main barite vein in the Greenough Barite Mine (Clawson, 1957, p. 24), and to the inferred trace of the Cap Wallace fault west of Elk Creek. The parallelism of these structures suggests that they might be part of a set of en échelon faults.

Stinkwater Creek flows in nearly a straight line trending N 10° E into Elk Creek. Although there is no observable field evidence which could be used to indicate the presence of a fault, the prominent lineament expressed by the straight, steep-sided valley of Stinkwater Creek, and the occurrence of several parallel igneous intrusions (Plate 1), strongly suggest the existence of a fault within the Garnet Range Formation.

Clawson (1957, p. 22-23) observed several faults in the underground workings of the Greenough Barite Mine. These faults range in strike from due north to due east, and in dip from 30° to 90° in both northerly and southerly directions. Gouge zones and slickensides are associated with these faults, but Clawson did not observe any drag. Some drag is observed adjacent to a barite vein in an exploration trench west of Elk Creek, implying that the barite was deposited in a fault zone (see section on Economic Geology). All these faults are apparently within the Garnet Range Formation, and most are older than the barite veins. Clawson did, however, observe two faults which cut the main barite vein in the Greenough Barite Mine. One of them trends about N 60° E, roughly parallel to the vein, and cuts through the hanging wall, foot wall, and the vein itself. The other fault is a high-angle normal fault which cuts across the vein, but does not follow it. These two faults demonstrate that deformation took place after as well as before the deposition of barite.

Interpretation of Cap Wallace and related faults: The simplest explanation for the attitude of the Cap Wallace fault is that it dips steeply and is curved slightly, accounting for its irregular trace and apparent reversal in dip. This would necessitate the wedge of Garnet Range in the north block of the fault to be down-faulted. This interpretation is illustrated on Plates 1 and 2. An alternative interpretation is that the Cap Wallace fault is a low-angle, north-dipping thrust fault in the western part of the Forest, and is curved in such a way that it has a steep dip in upper Cap Wallace Gulch. This latter interpretation would allow the wedge of Garnet Range to represent an upthrown footwall block, requiring a vertical displacement in excess of 1,500 feet. Since neither interpretation can be proven or disproven, both are presented and the simplest illustrated.

JOINTS

The bold outcrops of quartz monzonite of the Garnet stock display prominent sets of near vertical joints (Fig. 10, p. 45). Two hundred joints were measured over a 4 square mile area in the stock (Plate 1). The poles of these joints were plotted on the lower hemisphere of an equal-area steronet, and were counted using an improved method introduced by Lowe (1946, p. 1215). It can readily be seen from the resulting contour diagram (Plate 3) that there is a prominent joint set which strikes about N 5° W, and dips almost vertically. A second, poorly defined set strikes in a general east-west direction and is also very steeply dipping. Because of the limited distribution of the data collected during the present study, a single interpretation cannot be assigned to the origin of these joints.

AGE OF FOLDING AND FAULTING

Folding in the Lubrecht Experimental Forest took place after the deposition of the Cambrian strata and before deposition of the Tertiary basin deposits. Faulting appears to have taken place after folding, since faulting prior to folding should be reflected by folded trends of faults. This does not appear to be the case (Plate 1).

Structural trends on the south side of the Garnet Range appear to be continuous with those on the north side of the Garnet Range in the Forest. The rocks involved in deformation on the south side range in age from Precambrian to early Cretaceous, indicating that deformation is late Cretaceous-early Tertiary (Laramide orogeny) in age (Kauffman, 1963, p. 18).

ECONOMIC GEOLOGY

METALLIC RESOURCES

The first gold discovery in the Lubrecht Experimental Forest was made in 1886 in the Elk Creek drainage (Lyden, 1948, p. 108). Between $1,000,000 and $2,000,000 in placer gold was recovered from this stream between 1886 and 1916. An estimated $105,000 worth of placer gold has been recovered since 1916. Between 1938 and 1940 portions of Elk Creek were dredged. Lyden (1948, p. 108) believes that significant, but not necessarily profitable amounts of placer gold are still within the gravels of the stream bed of Elk Creek. The placer gold of Elk Creek was derived from the south, near the crest of the Garnet Range in the First Chance and Top O'Deep districts, as well as the Coloma districts.

Discovery of gold in McGinnis Creek, a tributary of Elk Creek, and Washoe Creek took place at about the same time as the Elk Creek discovery. Lyden (1948, p. 108) estimates that over $100,000 in placer gold was recovered from these Creeks. Most of the mining along these streams was done before 1900.

In 1897, lode gold was first recovered in the Coloma district. Coloma is situated on the quartz monzonite-marble contact. The gold is found in quartz veins, which occupy fractures in the quartz monzonite and occur within one-half mile of the contact (Pardee, 1918, p. 196). These veins strike east-northeast, and dip approximately 30° to the south. The average size of these veins was 1 to 2 feet in width, about 500 feet in length, and about 500 feet in depth. Due to their relatively small size, development was confined to the upper, oxidized zone, where the leaching of soluble gangue minerals increased the concentration of the ore. Pardee (1918, p. 197) reported that the ore minerals in the quartz veins consist of pyrite, chalcopyrite, and tetrahedrite, for the most part. Silver, copper, lead, and zinc were recovered in small quantities.

Most of the metallic ore recovered in the Coloma district is credited to the Mammoth and Comet mines, according to Earll (in Kauffman, 1963, p. 27). The Mammoth shaft was located just north of the town of Coloma, and several hundred feet lower in elevation. This shaft and several others in and around the ghost town are flooded, or otherwise unsafe to enter at the present time.

There are several recent prospects in this district which can apparently become small producers, if the price of gold should rise significantly. Earll (in Kauffman, 1963, p. 27) collected samples at the Ness prospect, north of Coloma. Assay of these samples showed that a 12 inch section of a vein contains 1.185 ounces of gold (per ton), and 2.30 ounces of silver (per ton). A 5 inch zone of clay gouge contains 1.26 ounces of gold and 3.70 ounces of

Year	Gold (oz.)	Silver (oz.)	Copper (lb.)	Lead (lb.)	Zinc (lb.)	Value
1897-1916	12,000	9,000	5,000	---	---	$250,000
1917	---	---	---	---	---	---
1918	43	8,968	491	16,000	---	11,174
1919	70	50	100	---	---	1,526
1920	---	---	---	---	---	---
1921	40	40	100	---	---	866
1922-1926	---	---	---	---	---	---
1927	4	30	---	---	---	101
1928-1931	---	---	---	---	---	---
1932	112	71	333	---	---	2,367
1933	374	200	1,281	---	---	7,894
1934	978	628	1,700	---	---	34,721
1935	464	117	60	---	---	16,341
1936	327	315	43	565	---	11,733
1937	576	415	248	---	---	20,511
1938	536	464	541	739	---	19,149
1939	490	296	346	22	---	17,388
1940	361	249	460	---	---	12,864
1941	394	308	600	300	---	14,097
1942	281	291	---	---	---	10,042
1943	132	128	---	---	---	4,711
1944	90	114	400	---	---	3,285
1945	71	90	200	---	200	2,599
1946	16	10	---	---	---	568
1947	52	53	---	---	600	1,941
1948	14	10	---	---	---	499
1949	17	21	---	---	---	614
1950	10	10	---	---	---	359
1951	---	---	---	---	---	---
1952	4	71	---	1,230	---	402
1953-1955	---	---	---	---	---	---
1956	---	1	1,600	---	---	681
1957-1960	---	---	---	---	---	---
Total	17,456	21,950	13,503	18,856	800	$446,433

Table 2. Metal production of
the Coloma mining district
(from Kauffman, 1963, p. 27).

silver (per ton).

Table 2 shows the total metal production in the Coloma district from 1897 to 1960.

Two adits and several prospect pits have been dug along the quartz monzonite-marble contact zone in the North Fork drainage. Clawson (1957, p. 7) reports stories concerning the shipment of two carloads of ore from an adit located along the contact, about one mile east of Elk Creek, in NE¼ of section 15, T. 13 N., R. 14 W. The ore, which was primarily argentiferous galena, was removed by use of the adit, a crosscut, and a raise. The adit is located in quartz monzonite, and the raise reaches the surface in the marble. Clawson (1957, p. 35) observed the actual contact in the crosscut and describes it as, ".... a rather complex interfingering of quartz monzonite and marble." About one-half mile to the west, several prospect pits have been dug along a thin, copper-bearing quartz vein in the contact zone. Clawson (1957, p. 34) reports that no ore was uncovered to date. This prospect appears to have been untouched for several years.

NON-METALLIC RESOURCES

Barite is the chief non-metallic mineral resource in the area, and the only mineral resource being exploited commercially at the present time. Ground barite is used primarily to make "heavy" mud for use in oil well drilling. It has been mined in the Elk Creek-North Fork area since 1951, mostly in an underground mine, but also in several open pits. Barite was discovered near Coloma in 1955, and mined in an open pit until the operation was discontinued. The Baroid Division of the National Lead Company has been mining and milling all the barite in the map area since 1956.

Barite occurs in veins in the Garnet Range Formation. All such veins discovered to date lie within one mile of Garnet stock. The main barite-producing vein is being exploited through the Greenough Barite Mine, just north of the junction of North Fork and Elk Creek. This mine and the barite veins are the subject of an unpublished master's thesis by Clawson (1957), from which the following description was summarized. The vein forms a roughly tabular-shaped body with an approximate strike of N 60° E, and dip of about 70° SE. Although it shows characteristics of both replacement and cavity filling, Clawson believes that open space filling was the dominant process, and that replacement has played a minor role in the origin of this vein.

The barite vein southwest of Coloma appears to have been lenticular in shape. The vein strikes approximately N 80° E, and dips at a very steep angle. Open pits are located about one-half mile apart, at both the east and west ends of the vein in the SE¼ of section 31, T. 13 N., R. 14 W., and SW¼ of section 32, T. 13 N., R. 14 W. The maximum thickness at the west end appears to have been about 7 feet. At the eastern end, the pit was widened in order to facilitate mining operations, and therefore it is difficult to estimate the thickness of the vein which has since been removed. Along the eastern wall of this pit the vein pinches out upward (Fig. 14). There the barite is in contact with trachyte porphyry on the north side of the vein, and with

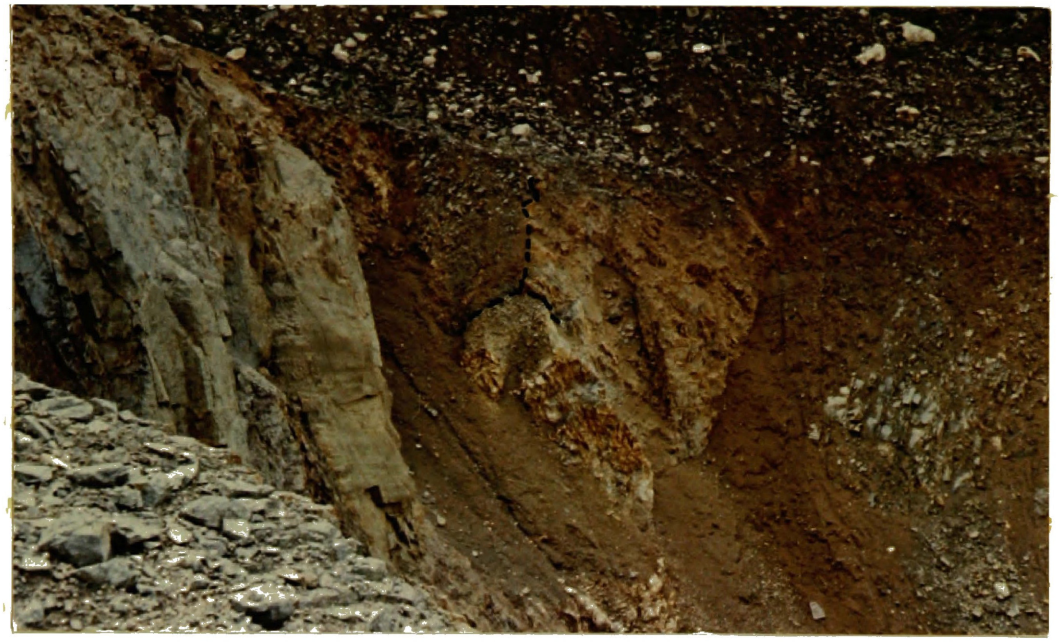

Figure 14. The eastern wall of the barite pit near Coloma showing the barite in contact with trachyte porphyry on the north (left) side and micaceous quartzite of the Garnet Range Formation on the south (right) side.

micaceous quartzite of the Garnet Range Formation on the south side. It appears that the trachyte porphyry preceded the barite, and that the porphyry-quartzite contact acted as a channel along which the barium sulfate-rich solutions passed. In the pit at the western end of the vein, the Garnet Range Formation is the wallrock on both sides of the barite.

Recently, a new barite discovery has been made in the Lubrecht Experimental Forest. It consists of a vein in the NE¼ of section 20, T. 13 N., R. 14 W. The vein strikes

N 63° W, and dips 60° N. It can be traced for at least one quarter of a mile. The vein ranges in thickness from 1 to 5 feet, and appears to be almost pure barite. Freshly cut exploration trenches allowed the author to get a first hand look at the barite-host rock contact. The host rock is spotted hornfels derived from the Garnet Range Formation. Original bedding preserved in the hornfels shows that this rock has been dragged in the vicinity of the barite vein, indicating that the barite was deposited in a fault zone. The contact metamorphism of the wallrock is probably due to the proximity of the Garnet stock, the contact of which is less than half a mile to the southeast.

The origin of these barite deposits is not clear at the present time. Clawson (1957, p. 32-33) believes that the barite in the Greenough Barite Mine was deposited by hydrothermal solutions emitted during the emplacement of a small quartz monzonite body in the vicinity of the mine. The barite is cut by both a quartz monzonite dike and a pegmatite dike which are believed to be offshoots of the Garnet stock. This deposit is related spatially, if not genetically, to the quartz monzonite emplacement. It is also possible that both the barium sulfate solutions and the quartz monzonite magma moved along the same structures, with the deposition of barite preceding the emplacement of quartz monzonite, but apparently postdating the trachyte.

In the SE¼ of section 29, T. 13 N., R. 14 W., a small amount of marble has been quarried out within the past year by the Crystal Sugar Company of Missoula. This rock was apparently used to make lime for the processing of sugar beets. Continued commercial use of this rock seems doubtful, since larger, more accessible outcrops of upper Paleozoic and Mesozoic limestones occur on the Clark Fork side of the Garnet Range.

Alluvial and glacial gravels are potentially commercial as road fill. These gravels occur in the Blackfoot Valley, in the northern part of the map area.

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APPENDIX A

TERMINOLOGY FOR STRATIFICATION IN SEDIMENTARY ROCKS

Stratification	Thickness	Splitting Property
Very thick-bedded	Greater than 120 cm.	Massive
Thick-bedded	120 cm. to 60 cm.	Blocky
Thin-bedded	60 cm. to 5 cm.	Slabby
Very thin-bedded	5 cm. to 1 cm.	Flaggy
Laminated	1 cm. to 2 mm.	Shaly (claystone, siltstone) Platy (sandstone, limestone)
Thinly laminated	2 mm. or less	Papery

After McKee and Weir (1953, p. 383)

APPENDIX B

THIN SECTION DATA

Section No.	Description	Location
17	Garnet Range Formation: gray quartzitic siltite with clusters of biotite laths forming dark spots.	T 13 N R 14 W sec. 16 NE¼
21	Mica schist derived from the Garnet Range Formation: containing biotite, muscovite and quartz in a foliated rock.	T 13 N R 14 W sec. 16 SE¼
29	Quartz monzonite from the interior of the Garnet stock: porphyritic texture, biotite is more abundant than hornblende. Myrmekitic intergrowths are common.	T 13 N R 14 W sec. 22 SE¼
32	Quartz monzonite from the marginal zone of the Garnet stock: phaneritic texture with hornblende more abundant than biotite. Myrmekitic intergrowths are common.	T 13 N R 14 W sec. 22 SE¼
39	Migmatite from the quartz monzonite-marble contact zone: containing quartz, feldspars, diopside and antigorite.	T 13 N R 14 W sec. 15 NW¼
42	Flow-banded trachyte porphyry: high temperature albite phenocrysts in a matrix of sanidine, biotite, and oligoclase microlites, and subhedral diopside crystals.	T 13 N R 14 W sec. 9 NW¼
43	Orientated section of flow-banded trachyte: A = strike of joints; C = up; jointing coincides with flow-banding.	T 13 N R 14 W sec. 9 NW¼

50	Garnet Range Formation: dark gray quartzitic siltite with small biotite clusters.	T 13 N R 14 W sec. 9 NW¼
66	Spotted hornfels derived from the Garnet Range Formation: cordierite porphyroblasts enveloped in limonite shells in a quartzitic rock containing biotite, muscovite and octahedral magnetite crystals.	T 13 N R 14 W sec. 29 SE¼
69	Quartz monzonite dike rock: containing a large amount of hornblende and no biotite. Hypidiomorphic-granular texture.	T 13 N R 14 W sec. 29 NE¼
76	Quartz monzonite cupola rock: more hornblende than biotite. Hypidiomorphic-granular texture.	T 13 N R 14 W sec. 9 SW¼
78	Migmatite: from quartz monzonite-Garnet Range Formation contact. Texture is poikilitic with feldspars altered to clay and abundant ore mineral.	T 13 N R 14 W sec. 8 SE¼
84	Trachyte porphyry: large zoned plagioclase phenocrysts and smaller biotite phenocrysts in a felty groundmass of sanidine, oligoclase and biotite microlites and magnetite crystals.	T 13 N R 14 W sec. 17 SW¼
103	Andesite porphyry: large zoned plagioclase and smaller biotite and augite phenocrysts in a felty groundmass of plagioclase and minor amounts of biotite and sphene.	T 13 N R 14 W sec. 18 SW¼
107	Spotted hornfels derived from the Garnet Range Formation: clusters of biotite, muscovite, and quartz. Relict cross-lamination preserved.	T 13 N R 15 W sec. 23 NE¼

108	Olivine-pyroxene-rich lamprophyre: augite, olivine, and pigionite phenocrysts in a matrix of plagioclase, pyroxene, olivine, biotite, magnetite, and interstitial orthoclase.	T 13 N R 15 W sec. 23 NW¼
113	Silver Hill Formation: shaly, interlaminated claystone and siltstone composed of anhedral, fine silt-sized quartz grains, biotite plates, and clay.	T 13 N R 14 W sec. 32 NE¼
114	Silver Hill Formation: very thin interbedded siltstone and limestone. Siltstone contains quartz with some biotite and clay. Limestone consists of calcite grains ranging in size from fine silt to medium sand.	T 13 N R 14 W sec. 32 NE¼
126	Hornblende-rich lamprophyre: consists of hornblende phenocrysts in a groundmass of plagioclase, hornblende, and interstitial orthoclase. Accessory minerals include sphene, quartz, biotite, and magnetite.	T 13 N R 15 W sec. 23 NW¼
128	Porphyritic pyroxene-hornblende-rich lamprophyre: phenocrysts of augite and hornblende in a groundmass of plagioclase, augite, hornblende, and interstitial orthoclase and quartz.	T 13 N R 15 W sec. 23 NW¼
130	Hydrothermal zone rock: hematite stained quartz (chert) with fractures filled with hematite and magnetite. Highly fractured.	T 13 N R 15 W sec. 22 NE¼
130a	Hydrothermal zone rock: hematite stained quartz (chert) with fractures filled with vein quartz.	T 13 N R 15 W sec. 22 NE¼

131	Hydrothermal zone rock: highly fractured, hematite stained quartz (chert), with fractures filled with calcite and antigorite (serpentine).	T 13 N R 15 W sec. 22 NW¼
139	Miller Peak Formation: interlaminated green argillite and siltite. Laminae are irregular and mottled. Siltite is primarily composed of anhedral quartz grains.	T 13 N R 15 W sec. 4 NW¼
145	Miller Peak Formation: interlaminated red argillite and siltite. Laminae are irregular. Siltite is composed of anhedral quartz grains with interstitial clay and hematite.	T 14 N R 15 W sec. 26 SE¼
146	Miller Peak Formation: interlaminated reddish purple argillite and gray siltite. Laminae are regular with cut and fill structures. Siltite is composed of anhedral quartz grains with interstitial clay and hematite.	T 14 N R 15 W sec. 32 SE¼
152	Miller Peak Formation: laminated grayish yellow green argillite. Laminae are regular, with some cross-laminations. Contains some carbonate material.	T 14 N R 14 W sec. 30 NW¼
158	Bonner Quartzite: gray, feldspathic quartzite. Feldspar is mostly microcline and makes up about 15% of the rock.	T 13 N R 15 W sec. 9 SW¼
163	Bonner Quartzite: pink, feldspathic quartzite. Feldspar is mostly microcline and makes up about 15% of the rock.	T 13 N R 15 W sec. 5 NE¼

182	Bonner Quartzite: massive, greenish gray argillite.	T 13 N R 14 W sec. 6 SE¼
CRS-1	Hornblende-rich lamprophyre: similar to #126. Collected on edge of pluton.	T 13 N R 15 W sec. 23 NW¼
CRS-3	Hornblende-rich lamprophyre: similar to #126.	T 13 N R 15 W sec. 23 NW¼
CRS-3a	Olivine-pyroxene-rich lamprophyre: similar to #108. Collected 10 feet west of #CRS-3.	T 13 N R 15 W sec. 23 NW¼

APPENDIX C

HAND SPECIMEN DATA

Specimen No.	Description	Location
4	Cambrian marble: white, medium-grained, calcareous (80% calcite) marble.	T 13 N R 14 W sec. 14 NE¼
10	Aplite-Pegmatite dike: one rock type grades into the other.	T 13 N R 14 W sec. 15 SE¼
13	Skarn zone rock: contains calcite, garnet, diopside, quartz.	T 13 N R 14 W sec. 15 NE¼
28	Phaneritic quartz monzonite from marginal zone of Garnet stock. Hornblende more abundant than biotite.	T 13 N R 14 W sec. 22 SW¼
34	Pegmatite: contains quartz, potash feldspar, plagioclase, from a dike in the Garnet stock marginal zone.	T 13 N R 14 W sec. 15 SW¼
39	Skarn zone rock: contains calcite, diopside, quartz, and antigorite.	T 13 N R 14 W sec. 15 NW¼
42	Trachyte porphyry: contains small biotite phenocrysts, and has prominent flow bands parallel to jointing.	T 13 N R 14 W sec. 9 NW¼
50	Spotted hornfels: derived from the Garnet Range Formation. Small porphyroblasts.	T 13 N R 14 W sec. 9 NW¼

54	Garnet Range Formation: fine-grained, gray, cross-bedded, micaceous quartzite.	T 13 N R 14 W sec. 17 SE¼
66	Spotted hornfels: derived from the Garnet Range Formation. Limonite enveloped porphyroblasts.	T 13 N R 14 W sec. 29 SE¼
69	Interbedded hornfels and marble: contact metamorphosed by quartz monzonite dike.	T 13 N R 14 W sec. 29 NE¼
76	Quartz monzonite: hornblende more abundant than biotite. From a small cupola.	T 13 N R 14 W sec. 9 SW¼
86	Trachyte porphyry: has large, white, plagioclase phenocrysts and smaller biotite phenocrysts. From hypabyssal dike.	T 13 N R 14 W sec. 18 NE¼
97	Tertiary basin deposit: sandy conglomerate.	T 13 N R 14 W sec. 5 NW¼
99	Porphyritic quartz monzonite: from interior of Garnet stock.	T 13 N R 14 W sec. 27 NE¼
103	Andesite porphyry: large, white, plagioclase phenocrysts in greenish groundmass. From hypabyssal dike.	T 13 N R 14 W sec. 18 SW¼
107	Spotted hornfels: derived from the Garnet Range Formation. Large cordierite phenocrysts.	T 13 N R 15 W sec. 23 NE¼
108	Olivine-pyroxene-rich lamprophyre: from interior of lamprophyric pluton.	T 13 N R 15 W sec. 23 NW¼

113	Silver Hill Formation (Middle Cambrian): shaly, interlaminated siltstone and claystone.	T 13 N R 14 W sec. 32 NE¼
114	Silver Hill Formation (Middle Cambrian): very thin-bedded siltstone and limestone.	T 13 N R 14 W sec. 32 NE¼
120	Tertiary basin deposit: light gray, flow-banded felsite.	T 13 N R 15 W sec. 12 NW¼
126	Hornblende-rich lamprophyre: from margin of lamprophyric pluton.	T 13 N R 15 W sec. 23 NW¼
130	Hydrothermal hematite stained chert: has hematite and magnetite filled fractures.	T 13 N R 15 W sec. 22 NE¼
130a	Hydrothermal hematite stained chert: has quartz filled fractures.	T 13 N R 15 W sec. 22 NE¼
131	Highly fractured, hematite stained quartz: fractures are filled with calcite and antigorite.	T 13 N R 15 W sec. 22 NW¼
139	Miller Peak Formation (Belt): green, interlaminated argillite and siltite.	T 13 N R 15 W sec. 4 NW¼
145	Miller Peak Formation (Belt): red, interlaminated argillite and siltite.	T 14 N R 15 W sec. 26 SE¼
146	Miller Peak Formation (Belt): interlaminated reddish purple argillite and gray siltite.	T 14 N R 15 W sec. 32 SE¼

152	Miller Peak Formation (Belt): laminated, green, calcareous or dolomitic argillite.	T 14 N R 14 W sec. 30 NW¼
158	Bonner Quartzite (Belt): gray, feldspathic quartzite.	T 13 N R 15 W sec. 9 SW¼
159	Bonner Quartzite (Belt): reddish purple, feldspathic quartzite.	T 13 N R 15 W sec. 9 SW¼
160	Tertiary basin deposit: white, volcanic, waterlain (?) clay.	T 13 N R 15 W sec. 16 SE¼
163	Bonner Quartzite (Belt): pink, feldspathic quartzite.	T 13 N R 15 W sec. 5 NE¼
CW-2	Bonner Quartzite (Belt): pinkish gray pebble conglomerate.	T 13 N R 14 W sec. 10 NE¼
CW-7	Garnet Range Formation (Belt): grayish green siltite.	T 13 N R 14 W sec. 3 SW¼