Geology of the Curlew Quadrangle Ferry County Washington

By RAYMOND L. PARKER *and* JAMES A. CALKINS

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A study of metamorphic, intrusive, and volcanic rocks, geologic structure, and mineral deposits

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GEOLOGY OF THE CURLEW QUADRANGLE, FERRY COUNTY, WASHINGTON

By Raymond L. Parker and James A. Calkins

ABSTRACT

The Curlew quadrangle encompasses an area of about 200 square miles in the mountainous region of northeastern Washington. It is drained mainly by the Kettle River and Curlew Creek. Relief is moderate; altitudes range from about 1,750 to 5,500 feet.

The oldest rocks in the quadrangle are the metamorphic rocks of Tenas Mary and St. Peter Creeks. They are pre-Permian in age and are probably mostly late Paleozoic, though some of them may be as old as Precambrian.

The Tenas Mary Creek rocks consist of well-layered metamorphosed sedimentary and igneous rocks and have a minimum thickness of about 17,000 feet. They have been correlated with the Grand Forks Schist in Canada and with other high-grade metamorphic rocks in the general region surrounding the Curlew quadrangle. The Tenas Mary Creek rocks have been subdivided into the following stratigraphic units: orthoclase-quartz-oligoclase gneiss, marble and related rocks, quartzite, hornblende schist, quartz-plagioclase gneiss, schist, and phyllite. The rocks show a generally low-dipping gross structure and a gradual decrease in degree of metamorphism, which ranges from the amphiloblite facies in the lower units to the greenschist facies in the upper units. The upper unit, the phyllite, is overlain by Permian and Triassic greenstone without evident unconformity or metamorphic discontinuity.

The St. Peter Creek rocks are similar in lithology and metamorphic grade to the Tenas Mary Creek rocks and are tentatively correlated with them.

Permian and Triassic rocks consist of metamorphosed basic tuffs and flows and lesser amounts of limestone, argillite, graywacke, chert, and conglomerate. The metamorphic grade lies in the greenschist facies. The thickness of these rocks is unknown. They enclose bodies of serpentine that were intruded possibly in the Late Triassic and in part were moved later as diapiric intrusions.

Probably in the Late Jurassic or Cretaceous the Tenas Mary Creek rocks, the St. Peter Creek rocks, and the Permian and Triassic rocks were deformed and metamorphosed in the process of batholithic intrusion related to the Nelson batholith of British Columbia. Northwest trending structures were formed at this time. The Tenas Mary Creek rocks were intruded by granodiorite, and the Permian and Triassic rocks in the northern part of the Republic graben were intruded by syenite porphyry and other alkalic rocks; all these intrusive rocks probably represent phases of the batholith.

Tertiary rocks range in age from Eocene(?) to Oligocene; they are nonmarine and dominantly volcanic in character. The oldest, the O'Brien Creek Formation (Eocene(?)), consists of tuffaceous sandstone, shale, and

conglomerate and rests unconformably on Permian and Triassic rocks. It is overlain by the Sanpoil Volcanics (Eocene(?)), which consists mostly of latite and rhyodacite flows. The Sanpoil Volcanics is overlain unconformably by the Klondike Mountain Formation (Oligocene), which consists of pyroclastic rocks, tuffaceous sedimentary rocks, and glassy flows.

The Sanpoil Volcanics and older rocks are cut by Eocene or Oligocene intrusions. The Scatter Creek intrusive rocks were the earliest and were followed by the batholithic quartz monzonite of Long Alec Creek.

The quadrangle contains three main structural elements, the Republic graben and the relatively raised blocks on either side. The graben contains Permian and Triassic, Cretaceous(?), and Tertiary rocks, and the raised blocks expose mostly pre-Permian metamorphic rocks and Cretaceous(?) and Tertiary intrusive rocks.

Block faulting and the initiation of the graben structure began in the early Tertiary and continued through part of Oligocene time to possibly Miocene time. The rocks within the sagging graben became broken along numerous north-trending faults. Continued subsidence resulted in tilting of the subblocks generally toward the center of the graben and also caused some blocks within the graben to be raised relative to their neighbors. The earlier rocks within the graben are the most steeply tilted. Subsidence was least along the edges of the graben and in the area north of Curlew.

Known mineral deposits are in the Danville and Curlew mining districts in the northern part of the quadrangle. Copper, gold, and silver have been produced from the Lone Star, Morning Star, and Comstock mines, and a small amount of lead ore has been shipped from the Lancaster and Morning Star mines. Minor amounts of tungsten have been reported from the Morning Star mine, and minor concentrations of chromite occur as small pods in the serpentine east of the mine. Incomplete past-production figures for the Danville and Curlew mining districts indicate an output of more than 2,000,000 pounds copper, 6,500 ounces gold, and 20,500 ounces silver.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The Curlew quadrangle is in northeastern Washington in northern Ferry County, 8 miles north of Republic and about 90 miles northwest of Spokane (fig. 1). It is bounded by meridians 118°30′ W. and 118°45′ W. and parallels 48°45′ N. and 49° N. (international boundary) and covers an area of about 200 square miles.

Curlew (population about 100), Malo, and Danville are the only settlements in the quadrangle. Republic, the county seat, and Grand Forks, British Columbia, 4 miles northeast of Danville, are the nearest towns.

Despite the sparse population, most parts of the quadrangle are accessible by paved, graded, or unimproved roads. Logging roads of varying quality follow most of the creeks.

Ranching and lumbering are the main industries at the present time, although mining was active until 1946. Sawmills at Malo and Curlew are supplied by logs cut from the large stands of timber nearby.

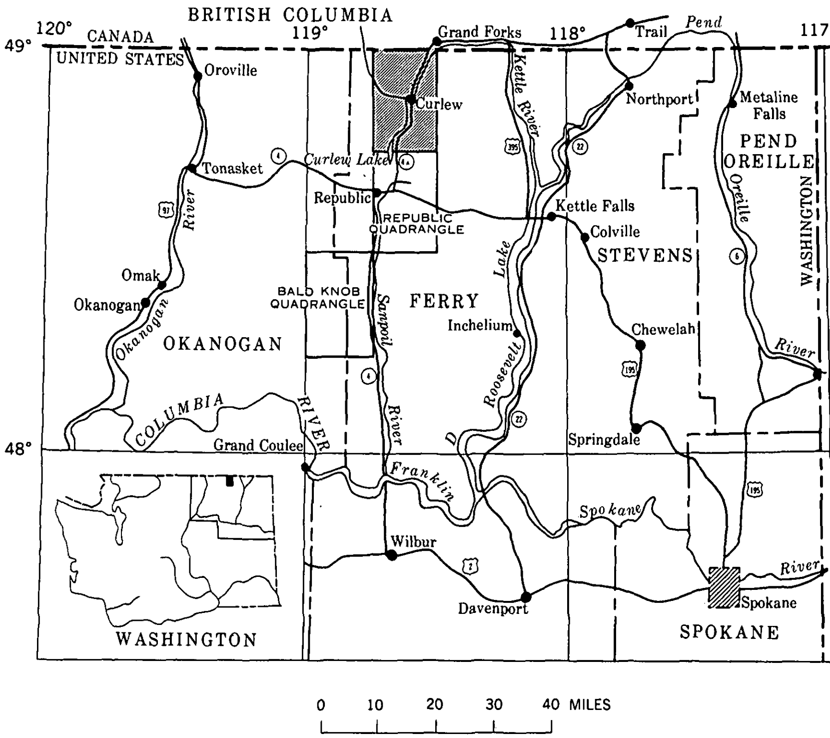

FIGURE 1.—Index map showing location of the Curlew quadrangle, Washington.

PHYSICAL FEATURES

The region covered in this survey is part of the Okanogan Highlands (Pardee, 1918, p. 14; Fenneman, 1931, p. 202), the mountainous area bounded by the Columbia and Okanogan Rivers (fig. 1). This area and its extension into Canada was called the Columbia System by Daly (1912, p. 37), but the term has not come into general usage in the United States.

Within the Curlew quadrangle, the dominant topographic features are the valleys of the Kettle River and its tributary, Curlew Creek. The Kettle River, a part of the Columbia River drainage, is a fast-flowing stream bordered on both sides by rugged mountains. Curlew Creek flows north from Curlew Lake and joins the Kettle River at Curlew. Its small size is quite out of proportion to the large valley in which it flows. The valley itself is characterized by such glacial-fluvial features as eskers, kame terraces, and kettles.

Mountainous country rises on both sides of the Kettle River and Curlew Creek. The rugged character of the topography is due to deep dissection by streams and to modification of this dissection by glacial ice. The ice, through scouring action, formed many deep north-south-trending declivities which commonly cut across the general stream pattern. Features of alpine glaciation, such as cirques and serrated ridges, are generally absent.

Occupying the eastern part of the quadrangle are the foothills of the Kettle River Range, a rugged north-trending range whose crestline lies from 1 to 6 miles to the east at elevations reaching 6,300 feet. The north and south forks of St. Peter Creek head on Mount Leona, a peak which lies on the crestline 1 mile east of the quadrangle boundary.

The highest point in the quadrangle is 5,553 feet on White Mountain, 1 mile south of the international boundary. The lowest point is Danville at an elevation of 1,745 feet.

PREVIOUS WORK

Geologic reports on parts of the Curlew quadrangle include brief descriptions of the Danville mining district by Bancroft (1914), a report on the Comstock property by McLaughlin (1919), and a geologic map and report by Dobell [1] of a narrow strip along the northwestern part of the Curlew quadrangle.

Geologic reports on nearby areas were made by Umpleby (1910) and by Lindgren and Bancroft (in Bancroft, 1914) for the Republic district, and by Pardee (1918) for the Colville Indian Reservation. One of the earliest geologic studies in this region was made by Brock (1903, 1905) in the Boundary Creek mining district, British Columbia, which borders the Curlew quadrangle on the north. This work was largely incorporated by Daly (1912) in his report on the geology along the 49th parallel. More recent mapping studies in this area were completed by Little (1957) on the 1-degree quadrangle Kettle River-East Half, British Columbia. Mapping in the Curlew quadrangle was conducted concurrently with mapping by S. J. Muessig in the Republic and Wauconda quadrangles, which adjoin the Curlew on the south. Mapping by Staatz (1964) in the Bald Knob quadrangle farther south was also done at this time.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork in the Curlew quadrangle was done during the summers of 1956, 1957, 1958, and part of the summer of 1959. Fieldwork during the first year was done by Alan E. Disbrow and Calkins, and that in the remaining years by Parker and Calkins.

[1] Dobell, J. P., 1955, Petrology and general geology of the Kettle River—Toroda Creek district of northeastern Washington: Washington Univ., unpub. Ph. D. thesis.

Geologic field data were plotted mainly on aerial photographs and transferred to the topographic map of the Curlew quadrangle by means of a stereoscope-type instrument based on the camera-lucida principle. Some data were recorded directly on the topographic map by use of planetable and open-sight alidade and the Brunton compass and altimeter.

The authors are indebted to many people for the completion of this study. Messrs. Arthur Cameron, James Davis, Sr., and A. R. Patterson of Republic extended many courtesies. Mr. Evan Oscarson allowed the use of his notes and maps of the Morning Star mine, and Dr. D. F. Kidd furnished data on the Lone Star mine. Dr. Heward W. Little of the Geological Survey of Canada contributed greatly to the authors' knowledge of the adjacent area in Canada through numerous written communications and a visit in the field. Alan E. Disbrow mapped a large part of the metamorphic complex in the northwestern quarter of the quadrangle and was largely responsible for the subdivision of the complex into map units.

The authors are especially grateful for the help of their colleagues, S. J. Muessig, J. J. Quinlan, M. H. Staatz, and R. C. Pearson, with whom many aspects of this study were discussed at length.

GENERAL GEOLOGY

The Curlew quadrangle is underlain by sedimentary, metamorphic, and igneous rocks that range in age from pre-Permian (probably late Paleozoic) to Recent.

The principal geologic structure in the Curlew quadrangle is a northeast-trending graben, named the "Republic graben" by Muessig (1962) for its excellent exposure in the adjoining Republic quadrangle. Boundary faults of large cumulative vertical displacement mark the edges of the graben but, although the graben has a known length of over 50 miles, it is not conspicuous on topographic maps or aerial photographs.

Contrasting rock types outline the graben structure. In general, high-grade metamorphic rocks and deep-seated batholithic intrusive rocks are exposed in the relatively upthrown blocks on either side of the graben, whereas the graben is underlain mainly by greenstone and associated rocks of Permian and Triassic age together with sedimentary, volcanic, and intrusive rocks of Tertiary age.

PRE-PERMIAN ROCKS

METAMORPHIC ROCKS OF TENAS MARY CREEK

The metamorphic rocks of Tenas Mary Creek occupy about 45 square miles in the northwestern part of the quadrangle (pl. 1).

Tenas Mary Creek flows westward across them. The Tenas Mary Creek rocks consist of well-layered, regionally metamorphosed sedimentary and igneous rocks that have a thickness of about 17,000 feet. They show gradual decrease in degree of metamorphism, ranging from orthoclase-quartz-oligoclase gneiss [2] in the lower part along the Kettle River, to schist and phyllite in the upper part on White Mountain near the northern border of the quadrangle. Phyllite, the uppermost unit, extends 1 mile north of the international boundary where it is overlain with apparent conformity by greenstone and associated rocks considered to be Permian and Triassic in age. The top of the Tenas Mary Creek rocks is regarded somewhat arbitrarily as the contact between the phyllite and the greenstone, inasmuch as no fossils have been found for dating these rocks.

Within the Curlew quadrangle, the Tenas Mary Creek rocks are bounded by a northeast-trending fault in the northwestern corner of the quadrangle and by the Bacon Creek fault and the granodiorite body on the east. Along most of the eastern boundary the Tenas Mary Creek rocks are in sharp contrast to the greenstone rocks of lower metamorphic grade east of the Bacon Creek fault. Northward, however, this contrast becomes less distinct as successively lower grade units of the Tenas Mary Creek rocks abut the fault; north of Goosmus Creek the phyllite is indistinguishable from some rocks mapped with the Permian and Triassic rocks east of the Bacon Creek fault.

Although evidence for sedimentary bedding is abundant, regional metamorphism has destroyed primary features that would indicate the tops of beds. It is assumed however, without direct evidence, that the Tenas Mary Creek rocks are top side up. The Tenas Mary Creek rocks consist of the following units, in assumed ascending stratigraphic order: (1) orthoclase-quartz-oligoclase gneiss, (2) marble and related rocks, (3) quartzite, (4) hornblende schist, (5) quartz-plagioclase gneiss, (6) schist, and (7) phyllite.

The Tenas Mary Creek rocks, particularly in the upper part of the sequence, are cut by dikes and irregular bodies of grandiorite of Tertiary age assigned to the Scatter Creek Formation.

ORTHOCLASE-QUARTZ-OLIGOCLASE GNEISS

GENERAL FEATURES

Orthoclase-quartz-oligoclase gneiss, the lowest unit of the Tenas Mary Creek rocks, is well exposed on the bold rocky spurs that rise from both sides of the Kettle River. Its thickness is about 3,500

[2] In naming the metamorphic rocks in this report, the last-named mineral is the most abundant one.

feet. The orthoclase-quartz-oligoclase gneiss is intruded by a dioritic facies of the Cretaceous(?) granodiorite batholith along most of its eastern and southeastern border. The intrusive character of the contact is well shown at several places along the contact in sec. 8, T. 39 N., R. 33 E. The gneiss is commonly swirled and contorted in the vicinity of the contact.

The contact between the gneiss and the overlying marble is marked by a transition zone as much as 100 feet thick in which the gneiss gradually gives way upward to thin biotite-rich layers. This contact closely follows the trend of the foliation and appears to be conformable.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The orthoclase-quartz-oligoclase gneiss is light-colored and medium to coarse-grained. Foliation is defined by subparallel streaks and lenses of feldspar, quartz, and accessory biotite and by foliated layers and lenses of pegmatitic material. Pink garnet is commonly a conspicuous accessory mineral. The texture tends to be porphyroblastic; porphyroblasts of oligoclase, orthoclase, and some garnet are as large as 1 inch. (See fig. 2.) South of the Kettle River the gneiss is coarse-grained and the foliation is not conspicuous.

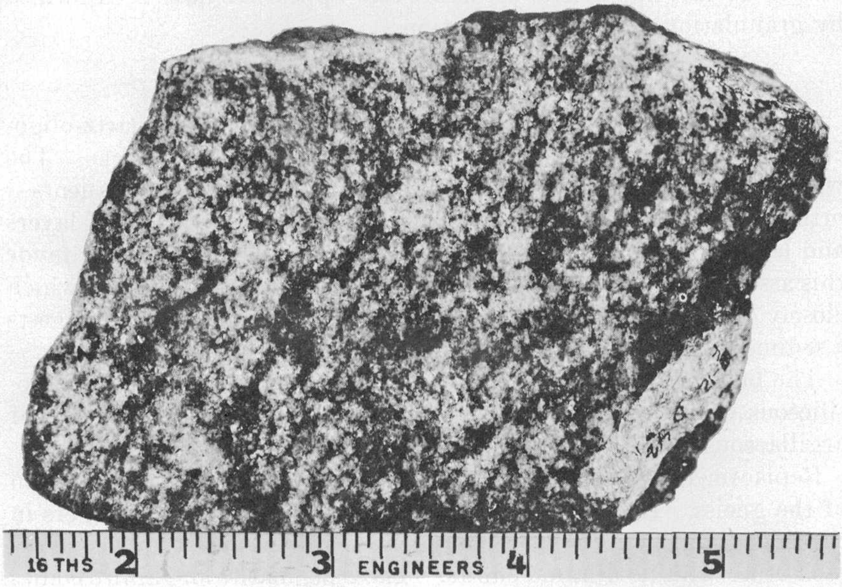

FIGURE 2.—Orthoclase-quartz-oligoclase gneiss. Foliation is marked by thin irregular layers of biotite and lenticular masses of quartz and feldspar. Specimen is from sec. 12, T. 39 N., R. 32 E.

Foliated pegmatite bodies, in streaks, lenses, and irregular crosscutting masses, are abundant and in places make up a large part of the rock. They consist of orthoclase, quartz, minor garnet, and sparse biotite and muscovite and range in size from thin stringers to masses several feet thick. These pegmatites, including the crosscutting ones, are foliated, and the foliation is parallel to that in the gneiss. They grade into the gneiss along indefinite contacts. Aplite dikes of similar habit are present also but are less abundant than the pegmatites.

Conformable lenticular bodies of dark- and light-colored schist and gneiss and minor layers of calc-silicate rocks occur in the orthoclase-quartz-oligoclase gneiss. The darker layers are a result of the higher concentration of biotite and range in thickness from a fraction of an inch to several inches. Commonly these layers contain conspicuous porphyroblasts of feldspar forming augen gneiss.

Under the microscope, orthoclase-quartz-oligoclase gneiss is seen to be variable in mineral composition. It consists essentially of about 50–70 percent oligoclase, 15–50 percent quartz, and traces to 15 percent orthoclase. Reddish-brown biotite, hornblende, zircon, rutile, apatite, magnetite, and rare allanite are accessories. Deformed mineral grains are common; quartz displays undulatory extinction, and a few plagioclase twin laths are bent. In some of the gneiss the large grains are rimmed by fine-grained aggregates of quartz, plagioclase, and orthoclase in a mortar structure that appears to have been formed by granulation and recrystallization.

ORIGIN

The available evidence indicates that the orthoclase-quartz-oligoclase gneiss most likely was formed from sedimentary rocks. The wide variation in the proportions of the main mineral constituents—orthoclase, plagioclase, and quartz—as well as the presence of layers and lenses of biotite schist and some calc-silicate rocks seems to favor this assumption. The upper contact with the overlying marble, which closely follows the trend of the bedding in the marble, also suggests a sedimentary origin.

The bulk of the unit probably represents metamorphosed alumino-siliceous beds, perhaps a graywacke containing scattered interbeds of argillaceous and calcareous material.

Replacement processes probably were important in the formation of the gneiss. The pegmatite and aplite dikes, pods, and stringers in the gneiss appear to be of replacement origin because they crisscross each other with no dilation effects. These pegmatite and aplite bodies predate the intrusion of the adjacent batholith because they are foliated like the gneiss and are an integral part of it. However, it is not known if the pegmatites represent addition of material from an outside source or a redistribution of components of the parent rock.

MARBLE AND ASSOCIATED ROCKS

GENERAL FEATURES

A unit of marble and associated siliceous beds occupies a narrow zone along the cliffs and steep slopes above the orthoclase-quartz-oligoclase gneiss. This unit ranges in thickness from about 800 feet on the west to a narrow but persistent zone, 10–20 feet thick, along the south flanks of Little Vulcan Mountain. The foliation dips gently to the north, averaging from 10° to 25° and is almost parallel to the bedding. The lower contact is gradational into the underlying orthoclase-quartz-oligoclase gneiss. The upper contact is drawn at an abrupt change from calcareous to quartzose rocks.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The marble unit consists of alternating beds of marble, calc-silicate rocks, biotite schist, quartzite, and layers and lenses of foliated pegmatites. Thin layers of sillimanite-quartz schist occur near the top of the unit. Sill-like bodies of gneissic quartz monzonite, some as thick as 40 feet, are common. Marble beds actually make up less than 25 percent of the mapped unit, but their bold white outcrops are a distinctive feature of the unit as a whole.

The texture of the marble and associated rocks ranges from granoblastic in the marble and calc-silicate beds to schistose in the biotite-rich beds. The alternation of beds of different composition is characteristic. Individual beds range in thickness from a fraction of an inch to more than 20 feet, and many beds grade into adjacent ones. Laminated structures are produced mainly by compositional layering, but also by drawn-out quartz grains, subparallel micas, and foliated pegmatite.

The marble is white and coarsely crystalline and ranges in thickness from thin laminations to 20-foot layers. Thick bodies of marble are both massive and thin bedded, the thin bedding usually marked by impure calcareous interlayers. Marble beds are everywhere speckled with the accessory silicate minerals—hornblende, green diopside, phlogopite, and biotite. More feldspathic layers intercalated in thin-bedded marble are medium-grained granoblastic gneiss containing andesine, orthoclase, quartz, and reddish-brown biotite. Pink garnet is an accessory.

Calc-silicate rocks consist of layers rich in calc-silicate minerals together with intercalations of biotite schist, quartz-feldspar gneiss, and foliated pegmatite in varying proportions. Textures commonly are granoblastic. Some layers are rich in garnet and diopside. Other layers contain principally diopside and scapolite; considerable calcite forms the matrix. Epidote and clinozoisite occur sparingly as inclusions in diopside, along fractures, and in well-formed crystals along crude layers. Quartz, orthoclase, phlogopite, muscovite, reddish-brown biotite, and sphene are common accessories in the calc-silicate rocks. Wollastonite was not found in rocks containing free quartz and calcite but is reported by Dobell (p. 51; see footnote 1, p. 4) from the adjacent Bodie Mountain quadrangle in rocks that probably belong to the marble unit.

The bodies of gnessic quartz monzonite have in general been emplaced parallel to the layering in the enclosing rocks and are called sills, although their margins exhibit crosscutting and embayment relations on a small scale. The foliation in the sills is parallel to that of the enclosing marble rocks. The sills may represent intrusives that were emplaced prior to or during the metamorphism of the Tenas Mary Creek rocks, or they may represent arkosic beds that locally were mobilized during the metamorphism.

ORIGIN

The marble and associated rocks represent a well-bedded sequence of limestone and siliceous limestone, with interbeds of sandy and argillaceous material. Original bedding is reflected by the compositional layering. Obvious foliation is parallel to these layers and hence to the original bedding. Foliated pegmatite bodies, which are identical to those in the underlying gneiss, probably represent material that was formed during the intense metamorphism and which partly replaced the calcareous rocks. The presence of foliation in the pegmatites indicates that they predate the intrusion of the nearby granodiorite batholith, because only unfoliated pegmatites are definitely associated with the batholith.

QUARTZITE

GENERAL FEATURES

Quartzite occurs in a wide belt north of the Kettle River. It extends from the western edge of the quadrangle across Little Vulcan Mountain and thence northward to Little Goosmus Creek. The same rocks occur also on the south side of the river at the western border of the quadrangle. In general, the quartzite forms bold outcrops, and on the steeper slopes, such as north and south of Cottonwood Creek, it forms small cliffs 15–20 feet high.

The foliation dips gently in a northward direction, and its trend follows a curving arcuate pattern which reflects the broadly folded structure of the Tenas Mary Creek rocks as a whole. Foliation is parallel to the bedding both in the outcrop and in the regional trend. The quartzite is about 3,200 feet thick and appears to be comfortable with the underlying marble unit and the overlying hornblende schist. Both contacts are gradational over narrow zones 10–20 feet thick and apparently represent changes in the original conditions of sedimentation. In the vicinity of Cottonwood Creek the lower part of the quartzite is intruded by granodiorite of Cretaceous(?) age.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The quartzite consists of vitreous quartzite and interlayers of mica-quartz schist, marble, and layers of calc-silicate minerals. Foliated pegmatite, so abundant in the underlying marble and granodiorite gneiss, is scarce in the quartzite except in a few places near the base of the unit. Sills of foliated quartz monzonite, similar to those in the underlying marble, occur throughout the unit.

On fresh surfaces the quartzite is white, light tan, or faintly pink, and is granular and vitreous. Weathered surfaces are commonly somewhat stained light reddish brown by iron oxide. The quartzite is massive to medium bedded. Bedding is marked by subtle color differences, by thin micaceous partings, and to some extent by differences in grain size.

Under the microscope the quartzite consists principally of fine- to medium-grained quartz with granoblastic texture. Quartz makes up 85–95 percent of the rock, orthoclase and andesine 5–15 percent. Accessory minerals include reddish-brown biotite, muscovite, sillimanite, magnetite, and rare cordierite. In places, feldspar is sufficiently abundant to form feldspathic layers. Foliation is produced by elongate quartz grains and subparallel biotite, muscovite, and feldspar. Biotite and muscovite are also arranged in a less pronounced preferred orientation along lines that intersect the principal foliation at small angles.

Schist beds occur throughout the quartzite unit and are estimated to constitute 25–35 percent of the unit. They are composed of alternating dark mica-rich and light quartz-rich layers which grade into one another. Individual layers range in thickness from a fraction of an inch to 3 inches. Matted sillimanite, easily seen in hand specimen, is commonly present, and garnet and green hornblende occur locally. Apatite, zircon, sphene, magnetite, and ilmenite are minor accessories.

Highly aluminous schists, characterized by abundant sillimanite and very little quartz, are widespread as thin interbeds throughout the quartzite unit. This type of schist is well foliated and fine grained and consists essentially of orthoclase, biotite, and sillimanite. Green

735–724 O—64——2

pleochroic tourmaline in subhedral prisms is a characteristic accessory mineral.

ORIGIN

The quartzite and related rocks represent a metamorphosed series of well-bedded quartzose sandstone and argillaceous beds. Original bedding is displayed by layers of different composition. Mica-quartz schist layers, many containing accessory sillimanite, represent original argillaceous material with variable amounts of quartz. Thin layers of marble, calc-silicate rocks, and quartz-sillimanite-orthoclase schist represent, respectively, original limestone, siliceous limestone, and beds with a high content of potassium and aluminum.

HORNBLENDE SCHIST

GENERAL FEATURES

Hornblende schist is well displayed along the cliffs and steep slopes above the Kettle River in the northwestern part of the quadrangle. The maximum thickness is about 700 feet near the western edge of the quadrangle. The hornblende schist thins in an eastward direction and disappears north of Little Vulcan Mountain. The eastern part of the hornblende schist is not well exposed because of a thick mantle of glacial debris and poorly exposed outcrops along the upper, more densely wooded slopes of the Vulcan Mountain area.

The hornblende schist is well foliated, and the foliation is parallel to well-defined layers that are interpreted to represent original bedding. Along the cliffs in the western part of the area, the lower and upper contacts appear to be gradational. The eastward thinning of the hornblende schist may be a result of lateral thinning in the original sedimentary deposits or a result of an angular unconformity at the top of the schist.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The hornblende schist consists largely of fine-grained equigranular schist. Different proportions of the main constituents produce contrasting layers in various shades of gray, though the overall appearance is dark gray because of the hornblende content. The layers range in thickness from a fraction of an inch to 2 inches. The boundaries, which are sharp between some layers and gradational between others, are remarkably persistent and are interpreted to be stratification planes of the original sedimentary rocks. Intercalated with the hornblende schist are a few bands of pure quartzite, ranging in thickness from 2 to 8 inches, and at least one layer of anthophyllite-andesine schist 2 feet thick.

Under the microscope the hornblende schist is seen to be extremely variable in composition. The dominant minerals are hornblende (5–70 percent), andesine (30–60 percent), and quartz (4–35 percent). Accessories include sphene, zircon, apatite, magnetite, and occasional calcite.

A small part of the hornblende schist is fine-grained augen gneiss, which is spotted with augen of feldspar and lacks the pronounced layered structure that characterizes the hornblende schist unit as a whole. This rock constitutes most of the upper 90 feet of the hornblende schist unit in the western part of the outcrop area and also forms layers 5–15 feet thick in a few places near the base of the unit. The essential minerals are labradorite and hornblende. Sphene, ilmenite, and apatite are accessories. The augen, which may reach 9 mm in length, are labradorite crystals partially recrystallized around their edges and along cracks to a fine-grained mosaic. They probably represent original phenocrysts that have been completely granulated and drawn out parallel to the foliation.

ORIGIN

The hornblende schist probably represents a well-bedded series of dolomitic shale units possibly containing some intermixed mafic tuffaceous material. As in the underlying marble and quartzite units, original bedding is indicated by layers of different composition and thickness that reflect variations in the original sedimentary rocks.

The augen gneiss, probably represents original mafic flows or sills. This origin is suggested by the presence of labradorite instead of andesine, the absence of distinct banding, and the presence of augen, which are interpreted to represent original phenocrysts.

QUARTZ-PLAGIOCLASE GNEISS

GENERAL FEATURES

A wide belt of felsic gneissic rocks, here called quartz-plagioclase gneiss, occupies the western flanks and the upper, rounded slopes of the Vulcan Mountain area. This belt of gneissic rocks extends from the northwestern part of the quadrangle, where it is terminated by a major northeast-trending fault zone, to the vicinity of Little Goosmus Creek on the east, where it is also terminated by a major fault, the Bacon Creek fault. Except on the western slopes of the mountain, the rocks are poorly exposed because of dense timber and widespread cover of glacial debris. The thickness of the quartz-plagioclase gneiss varies from about 5,300 feet along the western margin of the quadrangle to 1,700 feet east of Vulcan Lookout.

Locally the gneiss is concordant with underlying rocks, although on a regional basis an unconformity may be indicated by the fact that the base of the unit rests on hornblende schist in western exposures and on quartzite in eastern exposures. The upper contact of the quartz-plagioclase gneiss is the least certain of any of the contacts between units of the Tenas Mary Creek rocks. This doubt arises because the quartz-plagioclase unit becomes finer grained and more schistose in its upper part and therefore looks like parts of the overlying schist. North of Catherine Creek the upper contact with green actinolite schist of the overlying schist is sharply defined. On the spur west of Vulcan Lookout, however, the quartz-plagioclase gneiss passes gradually into fine-grained quartz-biotite schist, and the contact is uncertain at this place.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The quartz-plagioclase gneiss consists mainly of fine- to medium-grained gneiss whose dominant minerals are quartz and plagioclase. (See fig. 3.) Varying amounts of biotite and hornblende are everywhere present. The rocks are various shades of gray, depending upon the relative abundance of dark minerals. Weathered surfaces are commonly stained shades of red.

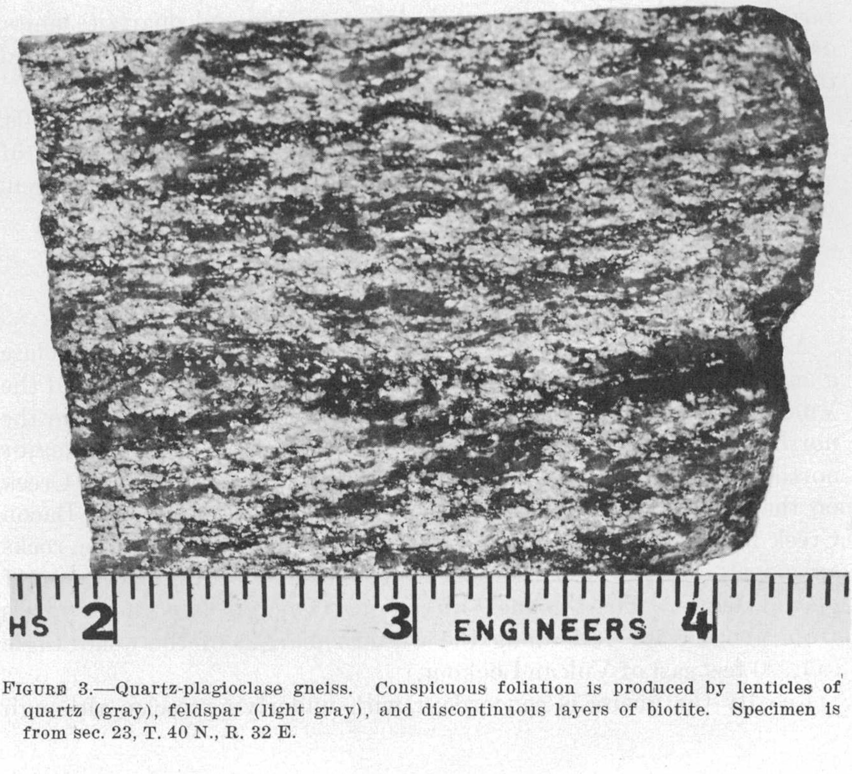

FIGURE 3.—Quartz-plagioclase gneiss. Conspicuous foliation is produced by lenticles of quartz (gray), feldspar (light gray), and discontinuous layers of biotite. Specimen is from sec. 23, T. 40 N., R. 32 E.

The most abundant variety is medium-grained quartz-oligoclase, or oligoclase-quartz gneiss containing varying amounts of hornblende and brown and green biotite. Apatite, sphene, zircon, and magnetite are accessories, and orthoclase is locally present in small amounts. Layers rich in biotite or hornblende occur in subordinate amounts, but layered structures are not characteristic of the unit as a whole. Instead, the rock generally displays a distinct mottled appearance because of the tendency for the felsic and the mafic minerals to become segregated from each other in streaks and lenses. The mineral streaks produce well-defined lineation in most outcrops. Some finer grained varieties contain only traces of dark minerals, mostly chloritized biotite which imparts a greenish color to the rock.

Other locally occurring rock types that are intercalated with the typical quartz-plagioclase gneiss include: almost pure quartzite, garnet-cummingtonite-andesine-quartz schist, garnet-epidote-andesine-quartz gneiss, and biotite-hornblende-quartz-andesine schist. The cummingtonite-bearing schist is found near the top of the unit. Some dikes and lenses of garnet-bearing foliated aplite and pegmatite occur, but they are not as abundant as in lower units of the Tenas Mary Creek rocks.

Amphibolite layers, 5–30 feet thick, are common throughout the quartz-plagioclase gneiss, especially in the western part. The rock is black, medium grained, and characteristically spotted with white knots of plagioclase, which are interpreted to be relict phenocrysts. The knots of plagioclase are set in a recrystallized groundmass of hornblende and labradorite. The rock contains about 40 percent labradorite and 60 percent hornblende. Sphene, zircon, apatite, and magnetite are accessories. The plagioclase phenocrysts reach lengths of 4 mm and consist of partly crushed twin laths rimmed by recrystallized granular plagioclase; some have been completely crushed and recrystallized. (See fig. 4.)

ORIGIN

The quartz-plagioclase gneiss probably represents a thick series of metamorphosed graywacke and shale in which original bedding is marked by layers of various thicknesses and composition. Layers rich in garnet, epidote, and cummingtonite probably were originally calcareous and dolomitic beds, whereas layers rich in biotite and hornblende probably were argillaceous graywacke beds.

A small percentage of the quartz-plagioclase gneiss may be intrusive in origin. These rocks are weakly foliated and medium grained, and have the composition of granite. Gneiss of this type occurs 1½ miles northwest of Little Vulcan Mountain in sec. 30, T. 40 N., R. 33 E.

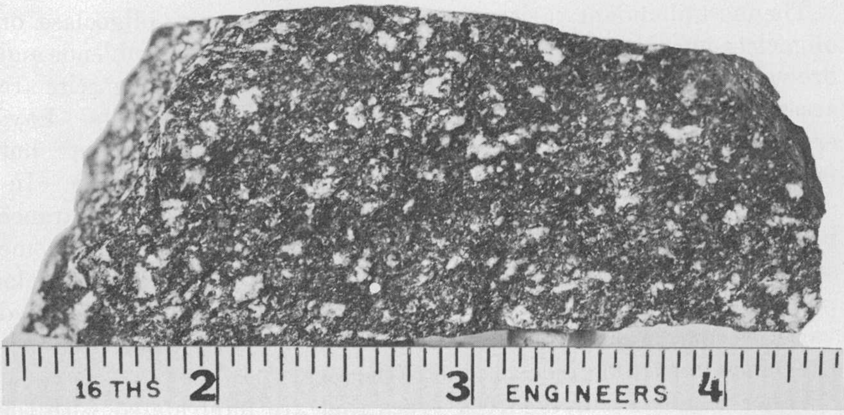

FIGURE 4.—Amphibolite from layer within quartz-plagioclase gneiss. Knots of plagioclase, which have been partly crushed and recrystallized, are interpreted as relict phenocrysts in original mafic hypabyssal intrusive rock. Specimen is from sec. 11, T. 40 N., R. 32 E.

Most of the spotted amphibolite layers are probably sills. Their contacts are generally parallel to the foliation and layering in the gneiss, but they show jagged irregularities in detail. At one place a 30-foot layer branches into two thinner layers. In addition, the amphibolite layers display fine-grained border zones 1–2 feet thick in which the knots of plagioclase are absent. These zones probably represent chilled borders of the original mafic sills. Possibly some amphibolite layers represent mafic volcanic flows.

SCHIST

DISTRIBUTION AND THICKNESS

The Schist is exposed in an area of about 4 square miles north and south of Catherine Creek along a mile-wide belt that extends northwestward from the vicinity of Vulcan Lookout to the major fault zone in the northwest corner of the map. It probably extends eastward also from Vulcan Lookout to the Bacon Creek fault, but its exact position is concealed by a deep mantle of glacial debris. In this area only a few isolated outcrops of schist and rocks of adjacent formations are present to indicate roughly its distribution.

The schist is about 2,500 feet thick on the south slope of White Mountain, but it apparently thins to less than 1,800 feet in the area east of Vulcan Lookout.

STRATIGRAPHIC RELATIONS

The schist overlies the quartz-plagioclase gneiss and underlies the phyllite, which is the uppermost unit of the Tenas Mary Creek rocks. The basal contact of the schist may represent an unconformity between the gneiss and the schist, a relationship that is suggested by the marked difference in thickness of the gneiss between its easternmost and westernmost exposures. The attitude of the foliation, however, which in most places in the Tenas Mary Creek rocks is parallel to the original bedding planes, is nearly parallel in the schist and gneiss; hence no angular discordance between them is apparent.

The contact with the overlying phyllite is sharp and in most places is clearly defined. Locally the contact appears conformable, but the presence of different varieties of schist along the contact, the striking contrast of rocks on either side of the contact, and the eastward thinning of the formation beneath the phyllite suggest that the schist and phyllite are unconformable. Foliation in both the schist and the overlying phyllite, however, is virtually parallel.

The schist contains numerous sills and dikes of amphibolite, mostly less than a few tens of feet thick, and a few large irregular discordant bodies of amphibolite. For the most part, these rocks are confined to the schist, but locally they intrude the overlying phyllite. The abundance of amphibolite in the schist in the western part of the area may be the reason for the thickening of the unit in that area. Because of their similarities to the contiguous schist, the amphibolite bodies have not been mapped separately.

The schist is cut by many north-northeast-trending dikes that range in composition from quartz monzonite to granodiorite. These dikes have not been metamorphosed and are considered to be equivalent to the Scatter Creek Formation of Eocene or Oligocene age.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The unit consists of several varieties of schist, which represent original stratified rocks, and amphibolite, which represents former mafic intrusive bodies. The schist includes biotite-quartz schist, feldspar-quartz schist, chlorite schist, and schistose quartzite and conglomerate.

Most of the schist comprising the unit is fine grained and has lepidoblastic or nematoblastic textures. The preferred orientation of platy and prismatic minerals imparts a strong schistosity to the rock.

Biotite-quartz schist, with andesine or oligoclase commonly present, is the most common type. Chlorite, sericite, actinolite, hornblende, cummingtonite, cordierite, and garnet, present singly or in various proportions and combinations, characterize several subvarieties of locally conspicuous biotite-quartz schist. Minor accessories are apatite, zircon, sphene, magnetite, and tourmaline.

Biotite-cordierite-quartz schist is conspicuous in the middle of the schist unit on the south slope of White Mountain in the SW¼ sec. 7, T. 40 N., R. 33 E. (also noted by Dobell, p. 38; see footnote 1, p. 4. It contains poikiloblastic crystals of cordierite in prominent light-colored knots ¼ to 2 inches in diameter. The cordierite knots contain abundant inclusions of quartz, lesser amounts of sericite, and scarce plagioclase and biotite. The schist surrounding the knots is composed of quartz, biotite, sericite, and plagioclase. Thin layers of mica, together with minute layers composed of quartz and plagioclase of various grain size impart a prominent layering to the rock. This layering is interpreted to represent original bedding. The cordierite knots contain very little biotite, contrasting strongly with the biotite-rich matrix. Cordierite has apparently formed at the expense of the biotite.

Andesine-cummingtonite-quartz schist with little or no biotite is common in the lower part of the schist unit. This rock type contains 20–40 percent cummingtonite in closely spaced prisms averaging 0.2 mm in length. Quartz and andesine, present in about equal amounts, are the other major constituents. Actinolite, chlorite, garnet, and magnetite occur in minor amounts.

Feldspar-quartz schist is conspicuous locally in the middle of the schist on the south slope of White Mountain above the cordierite-bearing schist. It is only weakly foliated and consists of a fine-grained crystalloblastic aggregate of quartz and less abundant andesine and orthoclase. Orthoclase contains abundant patches of fibrous sericite. Aggregates of chlorite and hematite are grouped at the site of former iron-rich minerals. Locally, the feldspar-quartz schist is richer in brownish-green biotite and is more strongly foliated.

Distinctive rocks at the top of the schist unit consist of chlorite schist, biotite-quartz schist, and beds of quartzite and metamorphosed conglomerate. The conglomerate is composed of cobbles of quartzite and quartz-feldspar rocks in a matrix of biotite-quartz schist. These rocks are more than 300 feet thick.

Amphibolite occurs as sills, dikes, and irregular discordant bodies in the schist. The sills and dikes tend to be coarse grained, and the irregular bodies fine grained. In general, foliation is parallel to that of the adjacent schist, although in places it is not parallel, especially in dikelike bodies where it tends to parallel the walls of dikes. The latter occurrence suggests that original structures and mineral orientations in part controlled the later orientation of recrystallized minerals. Some bodies seem devoid of mineral orientation.

The amphibolite that forms irregular discordant bodies in the schist unit contains abundant, finely crystalline bladed actinolite crystals set in a granoblastic mosaic of andesine. Relict porphyritic texture is preserved by aggregates of chlorite, epidote, and plagioclase, though schistosity, produced principally by the orientation of actinolite crystals, is well developed. One such irregular body of amphibolite occurs in the northeastern corner of sec. 11 and northwestern corner of sec. 12, T. 40 N., R. 32 E. It is about 5,000 feet long and 2,000 feet wide, and trends northwest. Another discordant body, generally circular in shape and roughly 2,000 feet in diameter, occurs along the north-south section line between sec. 12, T. 40 N., R. 32 E., and sec. 7, T. 40 N., R. 33 E. One small intrusive body of amphibolite in the south-central part of sec. 1, T. 40 N., R. 32 E., contains a selvage and scattered inclusions of garnet-epidote-diopside-oligoclase skarn. The skarn is probably the result of contact metamorphism by the original mafic intrusion.

Coarse amphibolite that forms dikes and sills is composed principally of hornblende, andesine, and epidote. Hornblende forms anhedral blue-green poikiloblastic grains as large as 5 mm. These crystals tend to be equant, a feature that may be inherited from original pyroxene grains. Andesine forms a fine-grained granoblastic mosaic between the hornblende crystals. Epidote is distributed in both andesine and hornblende as a very fine granular aggregate. Chlorite, magnetite, and apatite are accessories. Some varieties consist principally of large poikiloblasts of hornblende set in an aggregate of granular epidote, bladed hornblende, calcite, and minor amounts of relict augite.

ORIGIN

The schist probably represents a series of sedimentary, volcanic(?), and intrusive rocks that were quite variable in composition. No doubt exists as to the parentage of the quartzite and conglomerate at the top of the formation; however, the origin of the various schists in the remainder of the unit is less certain.

A large proportion of the schist, which is rudely layered, contains quartz as the predominant mineral; this quartz suggests that the original rocks were quartz-rich clastic or pyroclastic rocks. Schist that now contains abundant cummingtonite was iron-and magnesium-rich rocks, possibly fine-grained dolomitic or tuffaceous rocks. Schist that is characterized by cordierite or chlorite, biotite, and sericite probably represents an original series of interbedded fine-grained aluminous rocks, possibly siliceous dolomitic shale or fine tuff, in which the amount of femic constituents varied among the beds.

That amphibolite bodies represent original basic intrusions is indicated by their crosscutting relationships, by the presence of contact-metamorphosed rocks along their borders, and by the relict augite.

PHYLLITE

DISTRIBUTION AND THICKNESS

Phyllite crops out in an area of about 12 square miles at the northern border of the quadrangle and underlies a large part of White Mountain and Vulcan Mountain. It is bounded on the east by the Bacon Creek fault and on the west by the fault zone at the northwest corner of the quadrangle. It also underlies an area of several square miles in the adjacent parts of Canada to the north (Brock, 1905) and an area of unknown extent immediately east of the quadrangle in the northwestern part of the Togo Mountain quadrangle.

The thickness of the phyllite cannot be determined with assurance because the upper contact is not exposed in the area mapped and possibly the phyllite has been repeated by folding. A thickness of 2,500 feet or more, not considering the possible repetition of beds, has been estimated from the map.

STRATIGRAPHIC RELATIONS

The phyllite is the youngest unit of the Tenas Mary Creek rocks. It is underlain unconformably by the schist and is overlain by greenstone that is believed to be Permian and Triassic in age. The phyllite it cut by porphyry sills and small felsic porphyry bodies of unknown shape that were sheared and metamorphosed at the same time as the phyllite. It is also complexly intruded by north-northeast-trending dikes and irregular bodies of unmetamorphosed granodiorite and quartz monzonite.

The contact with the underlying schist, as previously described, is considered to be unconformable. The upper contact of the phyllite lies 1 mile north of the quadrangle boundary. Reconnaissance reveals that the contact follows a northwest-southeast direction along the top of Rusty Mountain in Canada about a mile north of the quadrangle and the international boundary. At this place the phyllite is overlain by greenstone and chert lithologically similar to and continuous with Permian and Triassic rocks east of the Bacon Creek fault. Linear structures (crinkling and rodding) are parallel in both the phyllite and greenstone and follow the same general northwest-southeast trend as those in other Tenas Mary Creek rocks of higher grade to the south.

Although an unconformity between the phyllite and greenstone may well exist, no major structural or metamorphic discontinuity is apparent. The conclusion thus imposed is that greenstone was deformed and metamorphosed at the same time as the phyllite and other Tenas Mary Creek rocks.

Sills and small bodies of felsic porphyry, which are mostly a few tens of feet thick, though not abundant, are widely distributed in the phyllite unit; however, they have not been distinguished separately on the map.

LITHOLOGY, INTERNAL STRUCTURE, AND PETROGRAPHY

The phyllite is characterized by very fine grained quartz-rich rocks in which sericite, chlorite, and biotite occur in various combinations and proportions. Other less common minerals are actinolite, albite-oligoclase, epidote, and, at the base of the unit, grunerite and garnet.

The principal rock types are dark-gray lustrous phyllite, some of which is knotted, and gray fine-grained micaceous quartzite that grades into the phyllite. Other lithologic types, which are present only in minor amounts, are black graphitic limestone, greenstone, grunerite-garnet rock, and felsic porphyry. The lithologic succession in the unit is not clearly defined, and in detail differs from place to place, probably because of folding and other structural complexities.

The rocks are extensively recrystallized, though their stratified character is preserved in intricate layers of slightly different composition and grain size. Relict features are also preserved in the porphyry sills and in the coarser grained clastic rocks. Foliation in the phyllite is generally well developed and in most places is parallel to the original bedding planes. Locally the phyllite is thrown into small-scale folds, but the extent to which these folds and other complicating internal structures have caused repetition of beds and have affected the stratigraphic thickness of the phyllite is unknown. Minute corrugations, crinkles, and pencil structures form lineations that are parallel to the axes of minor folds in the phyllite and parallel to the lineation in the more highly metamorphosed Tenas Mary Creek rocks. A lineation formed by the streaking of biotite, however, lies at acute angles to the fold axis.

Dark-gray phyllite is aphanitic and homogeneous in hand specimen, though in places it contains lighter gray laminae that commonly are more silty than the adjacent darker gray laminae; it characteristically weathers to shades of brown. The parallel alinement of minute scales of sericite, biotite, and chlorite produces a well-developed foliation and a silky luster to the rock. The microscope reveals that the phyllite is composed of very fine contorted laminae a fraction to several millimeters thick. Adjacent laminae are distinguished by their different grain size and mineral composition. The laminae are composed of sericite, chlorite, incipient biotite, and quartz grains in varying proportions that range in diameter from 0.2 to 0.05 mm. Some contain mostly fine granular quartz with minor amounts of micaceous minerals. The micas are oriented both parallel to the laminae and along fractures that parallel the axial planes of microfolds.

The knotted phyllite, which consists principally of biotite and sericite and less abundantly of quartz and plagioclase, is spotted with ovoid-shaped knots 0.5 to 1 mm in diameter. These knots contain one or several poikiloblastic grains strongly charged with sericite. They are believed to be cordierite, but are too small to be identified with certainty.

The fine micaceous quartzite has granoblastic texture and is made up of 95 percent quartz grains that range in diameter from less than 0.05 to 0.2 mm. Minor amounts of actinolite, chlorite, and plagioclase are also present. Apatite, sphene, and opaque minerals are accessories.

Dark-gray limestone, greenstone, and metamorphosed graywacke (?) are locally present in the unit. The limestone occurs as thin lenticular, highly deformed bodies near the base of the unit on the south slope of White Mountain. It is fine grained and laced with veinlets of pyrite. On weathered surfaces it is sooty black and mottled with brown iron stains derived from the oxidation of the pyrite. The greenstone is dense, massive, and only weakly foliated. Faint ill-defined, lighter colored areas are believed to represent phenocrysts of the original porphyritic rock. Most of the greenstone contains abundant disseminated calcite. It strongly resembles the Permian and Triassic greenstone found east of the Bacon Creek fault and north of the international boundary.

Beds of metamorphosed graywacke(?) occur locally within the phyllite. The rock is dark gray and fine grained, and contains clearly perceptible angular fragments of quartz, chert, and rock chips in a dense green matrix. As seen under the microscope, it is strongly sheared and contains anguler fragments of quartz, albite, chert, slate, and igneous rock chips, ranging in size from 0.05 to 2 mm, and set in a matrix of sericite, greenish-brown biotite, chlorite, and microcrystalline quartz. Magnetite and hematite are present in small amounts. The matrix forms about 50 percent of the rock.

A fine- to medium-grained rock composed principally of grunerite and garnet occurs discontinuously along a pyrite-rich zone at the base of the unit on White Mountain and below Vulcan Lookout. The optical properties of the grunerite, as determined by P. L. Weis, are: $n\alpha = 1.674$, $n\beta = 1.684$, $n\gamma = 1.694$; $(-)2V \sim 80°$; the index of refraction of the garnet is 1.800. A similar rock containing accessory tourmaline is also found at the base of the unit about a mile east of Danville in the adjoining Togo Mountain quadrangle. Fibrous radiating grunerite and abundant disseminated garnet are clearly visible in hand specimens. The miscroscope reveals an intergrown aggregate of grunerite in fibrous radiating crystals (as long as 0.5 mm), and fractured isotropic garnet (as large as 2 mm). Granular epidote and quartz occur in small amounts. The rock is rich in iron and magnesium and may have been produced from a cherty ferruginous carbonate rock or a ferruginous dolomitic shale, or perhaps the rock was derived from a weathered zone that had developed on top of the schist unit. The extensive occurrence of this rock type at the base of the phyllite unit may be due to widespread distribution of the parent strata, or weathered zone.

The numerous felsic porphyry sills that are found in the phyllite are very distinctive but constitute only a minor part of the unit. Although the rock is metamorphosed and considerably deformed, the original porphyritic igneous texture is clearly preserved. The sills were probably hypabyssal intrusives of felsic or intermediate composition. They are characterized by abundant phenocrysts of plagioclase reaching lengths of more than 10 mm and weathering white in strong contrast to the light-green fine-grained matrix. Under the microscope, large phenocrysts of plagioclase are enclosed in a matrix of microcrystalline quartz, sericitized feldspar, clusters of actinolite, and minor chlorite. The phenocrysts have been partly crushed and converted to oligoclase and sericite but are still clearly recognizable.

A more silicic variety of porphyry is grayish pink to light gray and contains abundant relict phenocrysts of quartz and plagioclase, most of which are 2–3 mm long but some are as much as 6 mm. The matrix consists of microcrystalline feldspar of low index of refraction, quartz, and less abundant chlorite. Sericite and minor biotite are formed along shear planes.

AGE AND CORRELATION

The upper age limit of the Tenas Mary Creek rocks is considered to be pre-Permian because greenstone of Permian and Triassic age overlies these rocks 1 mile north of the international boundary. At least the upper units of the Tenas Mary Creek rocks are thought to be late Paleozoic in age because greenstone overlies them without apparent structural or metamorphic discontinuity. No age limits are assignable to lower units on the basis of our data. Rocks similar in lithology to the phyllite and parts of the schist units occur in the Wauconda quadrangle. S. J. Muessig (written commun., 1960) concluded that these rocks are probably only slightly older than the overlying greenstone rocks that he has designated as Permian in age.

The lower part of the Tenas Mary Creek rocks is most likely correlative with rocks of similar lithology and gross structure that occupy several square miles in the vicinity of Grand Forks, British Columbia, 4 miles northeast of Danville. These rocks were called the Grand Forks Schist by Daly (1912, p. 378) and the Monashee and Grand Forks Groups by Little (1957). Little considered these rocks to be "pre-Pennsylvanian and presumbably Precambrian in age." These rocks include granite gneiss, marble, hornblende schist, and foliated granitic sills; they have the same gently dipping gross structure as the Tenas Mary Creek rocks. On Boundary Mountain, 1 mile east of

Danville in the adjoining Togo Mountain quadrangle, the southern continuation of the Grand Forks Group consists of sillimanite-bearing quartzite and other high-grade types. These rocks dip gently south and are overlain by rocks that are identical to the schist unit of the Tenas Mary Creek rocks. The schist in turn is overlain by a thick section of phyllite. Thus it appears that the same general lithologic sequence occurs in both the Grand Forks Group and the Tenas Mary Creek rocks.

The Tenas Mary Creek rocks also resemble the high-grade schist and gneiss in the Orient area 12 miles east of the Curlew quadrangle that Bowman[3] postulated as being Precambrian in age. These rocks appear to be continuous with the Grand Forks Group of Little.

The Tenas Mary Creek rocks are similar in many respects to rocks in British Columbia, collectively called the Shuswap terrane, which occupy large areas in a broad belt between Okanogan Lake and Arrow Lakes and from the international boundary at least as far as Aiken Lake, 600 miles to the northwest. Various ages have been assigned to Shuswap rocks in widely separated areas, and they have been given many local names because of the uncertainties of correlation.

That the age of the Shuswap rocks and the time of their metamorphism is not yet fully agreed upon is shown by the opposite views expressed in summary articles by Cairnes (1940b) and Reesor (1957, p. 172–175). The Tenas Mary Creek rocks are probably equivalent in age to at least some of the Shuswap, but not enough information is available to make definite correlations.

METAMORPHIC ROCKS OF ST. PETER CREEK

GENERAL FEATURES

The metamorphic rocks of St. Peter Creek underlie an area of about 8 square miles in the southeastern part of the quadrangle. They extend for an unknown distance to the east in the adjoining Togo Mountain quadrangle and for about half a mile to the south in the Republic quadrangle. These rocks are well exposed in the drainage of St. Peter Creek.

The St. Peter Creek rocks are high-grade metamorphic rocks consisting predominantly of mica-quartz schist, calc schist, marble, and quartzite. These rocks form broad northwest-trending folds along which dips of the beds are commonly moderate, but locally as steep as 75°.

The metamorphic rocks of St. Peter Creek are bounded on the north and west by the quartz monzonite of Long Alec Creek and on the south

[3] Bowman, E. C., 1950, Stratigraphy and structure of the Orient area, Washington: Harvard Univ., unpub. Ph. D. thesis.

in the Republic quadrangle by quartz monzonite believed to be continuous with that of Long Alec Creek. In the central part of the outcrop belt the metamorphic rocks are in fault contact on the west with Permian and Triassic and Tertiary rocks. Thus the St. Peter Creek rocks are isolated by faults and by the quartz monzonite, and direct relations with other rocks in the quadrangle cannot be determined.

The St. Peter Creek rocks are intruded and locally contact metamorphosed by both coarse inequigranular and medium-grained equigranular varieties of the quartz monzonite of Long Alec Creek, considered to be Oligocene in age. In the divide area between Tonasket and Long Alec Creeks, complexly swirled migmatite in the St. Peter Creek rocks is cut by dikes of these intrusive rocks which were injected along fracture and joint planes. The joint and fracture planes are undeformed, and consequently they and the associated intrusive rocks are clearly younger than the contorted migmatite.

Bodies of calc-silicate minerals have been produced locally along the contact between calcareous parts of the St. Peter Creek rocks and the intrusive rocks of Long Alec Creek. Specific occurrences are along the northern contact near the divide between Tonasket and Long Alec Creeks and at the western contact in the valley of the North Fork of St. Peter Creek.

LITHOLOGY AND PETROGRAPHY

The succession of rocks comprising the metamorphic complex of St. Peter Creek is not clear because of the small part of it exposed in the quadrangle and because of structural complexities. Only a marble unit has been separately distinguished on the map.

The northern belt of marble is in fault contact with adjacent metamorphic rocks on the northeast. The stratigraphic relationships of rocks on either side of the fault are unknown. The rocks which underlie the marble southwest of the fault are principally graphite-bearing calc schist, minor quartzite, and mica-quartz schist. Those north of the fault are mostly quartzite and mica-quartz schist which grade into migmatite in the northernmost exposures. The schist occurs both as interbeds in the quartzite and as thick layers. Although similar rock types occur on both sides of the fault, the northern rocks are characterized by an abundance of quartzite; this quartzite exceeds 1,500 feet in thickness on the north side of the valley of the North Fork of St. Peter Creek. Pegmatites are scattered in quartzite and schist on both sides of the fault but are most abundant in the zone of migmatite on the north.

The marble is white to light gray and finely to coarsely crystalline. It is highly deformed and marked by drawn-out and contorted streaks that probably represent bedding planes of the original limestone. It is partly dolomitic; the dolomitic parts are irregularly distributed and apparently represent zones of dolomite replacement rather than bedded dolomite.

Calc schist that underlies the marble is medium to dark gray and fine grained; few grains exceed 1 mm in diameter and most are 0.2 mm or less. Its principal minerals are diopside, calcic plagioclase, quartz, orthoclase, brown biotite, graphite, magnetite, and calcite. The schist is very finely laminated, the laminae, which are as thin as a fraction of a millimeter, probably represent original beds. Some laminae are biotite rich and have lepidoblastic texture and well-developed schistosity; others contain little biotite and have granoblastic texture and weakly developed schistosity. Shades of gray are due to concentration of graphite in the rock.

Fine-grained gray quartzite, in minor amount, that is interbedded with calc schist is also impregnated with graphite, and contains, in addition to quartz, minor amounts of other minerals that make up the adjacent calc schist.

Typical mica-quartz schist in the rocks below the marble and south of the fault has lepidoblastic texture and is composed principally of brown biotite, quartz, and plagioclase and less abundant diopside, hornblende, and orthoclase. Rudimentary layered structure is marked by concentrations of well-oriented biotite that produces strong schistosity. A few elliptically shaped biotite crystals reach lengths of 3 mm, but most other grains range in length from 0.05 to 0.4 mm. Some mica schist contains irregular porphyroblasts of cordierite as long as 5 mm that are largely altered to sericite. Commonly these porphyroblasts also contain flamboyant clusters of sillimanite crystals along with grains of quartz and feldspar.

The quartzite north of the fault is white, pink, and tan and medium bedded. It is composed of 90 percent, or more, quartz grains which are elongated in the plane of foliation and reach lengths of 1 mm. The grain boundaries are strongly sutured. Clusters of orthoclase grains and scales of biotite are widely disseminated in the rock. Relicts of cordierite(?) are indicated by polygonal nests of fibrous sericite. Scattered grains of sphene, zircon, apatite, and opaque minerals are accessories.

Typical schist that is interlayered with the quartzite is fine grained and contains about 60 percent granular quartz, 15 percent orthoclase in ragged clusters, 20 percent cordierite-sericite, 5 percent biotite, and minor plagioclase, zircon, apatite, and opaque minerals. Some schist layers have a much higher proportion of biotite and plagioclase, and some, especially those that grade into migmatite, contain abundant sillimanite inclusions in the cordierite.

ORIGIN

The St. Peter Creek rocks represent sedimentary rocks that have been metamorphosed to the level of the almandine-amphibolite facies of regional metamorphism (Fyfe, Turner, and Verhoogen, 1958). These rocks, now represented by quartzite interlayered with schist, mica-quartz schist, calc schist and quartzite, and marble, are interpreted to represent original quartzose sandstone and interbedded shale, siliceous shale, calcareous shale and sandstone, and limestone. Graphite-bearing rocks originally had a high content of carbonaceous material.

AGE AND CORRELATION

No age assignment or correlation of the St. Peter Creek rocks with other rocks can be made with assurance because of the isolated position, the metamorphosed condition, and the limited areal extent of the rocks in the quadrangle. Metamorphic grade and internal structure of these rocks are very similar to the lower part of the metamorphic complex of Tenas Mary Creek; both the St. Peter Creek and the Tenas Mary Creek rocks probably have had similar metamorphic histories.

The St. Peter Creek rocks probably are the southward extension of the Grand Forks Schist (Daly, 1912, p. 378; Little, 1957), although these two similar rock assemblages are now separated by a septum of quartz monzonite just east of the Curlew quadrangle. Prior to the intrusion of the quartz monzonite, the Grand Forks Schist and the St. Peter Creek rocks probably were continuous.

PERMIAN AND TRIASSIC ROCKS

GENERAL FEATURES

Permian and Triassic greenstone, limestone, and other rock types occur in three main areas of the Curlew quadrangle: (1) north of Curlew, (2) along the eastern margin of the Republic graben, and (3) in the vicinity of Granite Mountain. All these rocks have been metamorphosed to the greenschist facies, and for the purposes of discussion this rock assemblage is occasionally referred to simply as greenstone, the predominant rock type. The various types of greenstone are tuffs, flows, or intrusives, depending upon the kinds of rocks they were originally. In many places these rocks have been so thoroughly engulfed by Tertiary intrusive rocks that they appear mostly as inclusions or isolated remnants.

It was not feasible to map separately the Permian and the Triassic rocks because of their similar lithology, the scarcity of fossils, and the scanty nature of the outcrops. These rocks are so complexly engulfed

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by intrusive rocks and are so faulted and tilted that their structural and stratigraphic relationships are known only to a limited extent.

In general, rocks of known Permian age consist predominantly of greenstone and minor amounts of lenticular limestone, in contrast to rocks of known Triassic age which are represented by well-bedded limestone and calcareous shale and lesser amounts of greenstone.

A belt of greenstone along the eastern margin of the Republic graben is probably Permian in age. This belt, which is continuous with the Permian rocks in the adjoining Republic quadrangle (Muessig and Quinlan, 1959), extends northward at least to the head of Art Creek, where fusulinids of Early Permian age occur. Scattered outcrops of greenstone between Art Creek and Curlew also may be of Permian age. This belt of rocks is faulted against quartz monzonite along most of its length, although the quartz monzonite intrudes the Permian rocks in a few places. At the southeastern corner of the quadrangle the Permian belt is faulted against the O'Brien Creek Formation of Tertiary age.

Triassic rocks are represented by the limestone belt that straddles the Kettle River north of Curlew, but whether the adjacent and neighboring greenstone is Triassic or Permian in age is not known. One mile north of Drummer Mountain, limestone of probable Triassic age is overlain unconformably by Tertiary rocks. Well-exposed Triassic rocks that are complexly cut by Tertiary intrusive rocks are found along the railroad track north of Curlew and along the main highway on the west side of the Kettle River.

In the Granite Mountain area, the greenstone rocks are intruded by numerous small stocks of quartz monzonite of Cretaceous(?) age. The greenstone is also cut by numerous dikes of porphyritic andesite related to the Klondike Mountain Formation, and in a few places by small bodies of Scatter Creek Formation. The greenstone, as well as the quartz monzonite rocks, is brecciated in many places, especially on Granite Mountain and in the area north and south of Empire Creek. The brecciation is not related to the contact with the younger rocks, nor to linear shear zones. Instead, the brecciation is scattered randomly throughout the greenstone and the quartz monzonite. In the greenstone area south of Empire Creek, brecciation is so thorough that an outcrop of solid rock is hard to find. The widespread brecciation is considered to be the result of gravity-sliding processes and fault block adjustments, both of which are related to the formation of the graben.

LITHOLOGY AND INTERNAL STRUCTURE

The Permian and Triassic rocks consist of greenstone, limestone, chert, argillite, graywacke, and conglomerate—all of which have undergone low-grade metamorphism equivalent to the greenschist facies.

SOUTHEASTERN BELT

The Permian rocks in the southeastern part of the quadrangle are chiefly greenstone and limestone. Minor amounts of limestone conglomerate and black argillite are in places associated with the limestone. Greenstone represents metamorphosed basic tuffs, flows, and some intrusive bodies. Limestone, containing chert bands and nodules, occurs as discontinuous lenses and beds in greenstone. Bedding is generally poorly developed. Fusulinids of Early Permian age were obtained from a lenticular body of gray limestone in sec. 9, T. 38 N., R. 34 E. These fossils were studied by Helen Duncan of the U.S. Geological Survey who reported as follows (written commun., 1959):

> * * * Thin sections made for fusuline studies contain a good deal of bryozoan debris. Most of this is not generally determinable owing to poor orientation and the scrappy nature of the material. The following categories can be recognized: Fistuliporoids, stenoporoids, *Rhomboporella* sp. indet., and fenestrate types. The fusulinids suggested the age was probably Leonard.

R. C. Douglass, also of the U.S. Geological Survey, reported on the fusulinids from the same specimens as follows (written commun., 1958):

> *Schwagerina*, sp.
> *Parafusulina* spp.

> None of the forms in this sample are easily assignable to described species. One of the species of *Parafusulina* bears some similarity to the form described as *P. armstrongi* by Thompson and Verville, 1950. Their specimens were from the Upper Cache Creek and they concluded the age was upper Leonard or lower Guadalupe. The general aspect of * * * [the forms] * * * suggests a slightly older age, probably Leonard, but probably not Guadalupe. Bryozoans are also present in the sample.

The origin of the Permian limestone bodies is uncertain but their general lack of bedding, podlike character, and frequent association with limestone conglomerate suggest that they may be reef complexes, though some may represent bedded limestone.

GRANITE MOUNTAIN AREA

The Permian and Triassic rocks in the area around Granite Mountain are made up primarily of greenstone that represents basic lava flows. Minor amounts of calcareous greenstone tuff, limestone masses, graywacke conglomerate, and chert are also present.

Flows are dark green, generally massive in outcrop, and the texture is commonly porphyritic with a fine-grained groundmass. Phenocrysts consist of saussuritized plagioclase and augite. Augite is partially recrystallized to actinolite and chlorite, and plagioclase is partly altered to sodic oligoclase, chlorite, epidote, zoisite(?), clinozoisite, and sericite. The groundmass consists mainly of chlorite, epidote, zoned plagioclase, and sphene. Ilmenite, rimmed with sphene, is a minor accessory.

Tuff, which is intercalated with the flows, is distinguished by its laminated structure and lighter green color. It is commonly contorted, more or less calcareous, and occasionally encloses small ragged inclusions of pure limestone. Limestone pods and lenses, most of them too small to show on the map, occur in the greenstone on the north flank of Granite Mountain. Larger bodies of limestone occur about a mile south of Franson Peak.

AREA NORTH OF CURLEW

The Permian and Triassic rocks between Curlew and the international boundary contain less greenstone and proportionately more limestone, chert, and argillite than these rocks in the southeastern belt and in the Granite Mountain area. The limestone crops out on both sides of the Kettle River in a continuous belt about 2 miles wide.

A Late Triassic age is established for two limestone localities within the limestone belt, and the whole limestone belt may be of Triassic age. The stratigraphic relations between the Triassic limestone and the greenstone and associated rocks north of Curlew are uncertain. Limestone on the east side of the Kettle River projects under greenstone on the west side of the Kettle River at the mouth of Goosmus Creek, and the same limestone beds apparently overlie greenstone 2 miles southwest of Danville. Because of the complex structure and the discontinuous nature of the outcrops, the sequence of beds is not well understood; the greenstone north of Curlew may be either Triassic or Permian in age.

The base of the Permian and Triassic greenstone is nowhere exposed in the Curlew quadrangle, but it is present on Rusty Mountain, 1 mile north of the international boundary west of the Bacon Creek fault. Here, greenstone, which is directly continuous with the Permian and Triassic greenstone east of the Bacon Creek fault, rests on the top unit of the Tenas Mary Creek rocks with no apparent structural (or metamorphic) discontinuity. If an unconformity exists between the phyllite of the Tenas Mary Creek rocks and the overlying greenstone, it is not conspicuous. This contact is provisionally considered to mark the base of the Permian and Triassic rocks, although no fossils have been found in the immediate vicinity.

In the Curlew quadrangle, black argillite and calcareous argillite that crop out in sec. 11, T. 40 N., R. 33 E., strongly resemble some rocks in the phyllite west of the Bacon Creek fault and may likewise lie near the base of the greenstone section. Here, also, structural continuity is indicated by the fact that linear structures in the black argillite are parallel to those in the phyllite west of the Bacon Creek fault.

The limestone of the Triassic limestone belt is medium to thin bedded; individual beds range from thin laminations to 3 feet in thickness. The limestone ranges from shades of gray and blue gray to black. Thin interbeds of shale and calcareous shale and thin lenses and layers of conglomerate are common associates. Many limestone beds contain black chert nodules and sparse quartz pebbles, and a few contain abundant fossil debris derived from crinoid stems, brachiopods, and gastropods, which stands out white on the weathered surface in contrast to the blue-gray or black calcite matrix.

A collection of fossils containing pelecypods and ammonites of Late Triassic age was obtained from calcareous shale interbeds in limestone 2 miles southwest of Danville in sec. 17, T. 40 N., R. 34 E. Determinations by N. J. Silberling of the Geological Survey are quoted as follows (written commun., 1956):

> * * * The pelecypods are unquestionably of the genus *Halobia* indicative of an early or medial Late Triassic age. Several small, generally indeterminate ammonites are also present in the collection.

Another collection, obtained from a limestone bed that crops out in a railroad cut in sec. 31, T. 40 N., R. 34 E., was studied by J. T. Dutro of the U.S. Geological Survey, who reported as follows (written commun., 1958):

> * * * This report covers one collection containing many small brachiopod fragments and crinoid columnals. The material was processed for fusulinids but none were observed. Etching with hydrochloric acid produced the brachiopods representing genera that occur, in the Pacific Northwest, in rocks of Late Triassic age. Precise relationships between this brachiopod faunule and the *Halobia*-bearing beds to the north are not known. They may be of about the same age.
>
> The genus *Spondylospira* was described, originally, from specimens collected from Upper Triassic beds in Nez Perce County, Idaho. The specimens from the Curlew quadrangle seem to represent a new species of this genus. Other spiriferoid brachipods are like associated species found elsewhere in faunas of Late Triassic age.
>
> Collection contains:
>
> Crinoid columnals, indet. (perhaps *Pentacrinus*?)
> *Spondylospira* sp. (new species)
> *Psioidea*? sp.
> *Spiriferina*? sp.
> Terebratuloid brachiopod, indet.

Small scattered lenses of limestone that occur in areas east of the Lone Star mine, south of Snow Peak, and on both sides of Little Goosmus Creek may be either Triassic or Permian in age. Their massive, somewhat recrystallized nature is more characteristic of the Permian limestone than of the well-bedded limestone of known Triassic age.

Beds of graywacke conglomerate associated with limestone and greenstone occur sparsely throughout the area north of Curlew. The rocks are massive, and bedding is displayed only by a few sandstone interbeds. Some individual conglomerate layers exceed 30 feet in thickness. Snow Peak is composed almost entirely of massive conglomerate, with a few sandstone interbeds that dip steeply to the west.

The conglomerate consists primarily of poorly sorted, sharply angular to subrounded pebble-sized fragments of quartzite, chert, limestone, greenstone, and phyllite in a greenstone groundmass. The fragments commonly range in size from a fraction of an inch to 1 inch; a few are as large as 8 inches. Some of the chert and quartzite pebbles are well rounded.

Tuff and subordinate black argillite and calcareous argillite are abundant west and southwest of Danville and along the ridge between Goosmus and Little Goosmus Creeks. They range from shades of green and dark green to almost black and are characteristically thinly laminated. The laminations consist of alternating layers and lenses of fine-grained quartz, calcite, chlorite, and sericite in various proportions. Sphene, largely altered to leucoxene, is an abundant accessory. Albite or sodic oligoclase, chlorite, sericite, and sphene, tend to occur together as individual lenses and laminae. Preferred orientation of the platy minerals produces a marked schistosity which in most places is parallel to the laminations. The calcite content varies widely and produces rocks ranging from calcareous tuff to rocks composed chiefly of calcite with only minor chloritic partings. As indicated by the variation in composition, many of these rocks are sedimentary tuffs with variable amounts of argillaceous and calcareous material. A few are felsic, very pale green, thinly laminated rocks consisting of ovoid quartz grains in a sericite-rich groundmass. The abundant sericite and minor chlorite give the rocks a waxy luster.

Black argillite and calcareous black argillite, which are found in minor amounts west and south of Danville, strongly resemble parts of the phyllite unit of the Tenas Mary Creek rocks. These rocks commonly display the linear structures of small-scale folds, stretched calcite pebbles or lenses, and crinkling.

Flows and flow breccias, containing minor tuff beds, are found just southwest of Danville on the northwest side of the Kettle River and between the Kettle River and the serpentine body east of the Morning Star mine. The most abundant and most striking variety is massive volcanic breccia composed of angular blocks as much as a foot across, in a greenstone matrix. The rock as a whole is pistachio green because of the abundance of epidote. The blocks are spotted by black mafic phenocrysts that range from 1 to 4 mm and that are partially altered to actinolite, epidote, and sparse chlorite and calcite. Granular aggregates of epidote are conspicuous throughout the blocks. The greenstone matrix consists of a crisscross network of acicular actinolite, fine granular epidote, interstitial albite or sodic oligoclase, and quartz. This rock is well exposed in roadcuts on the main highway 1 mile south of Danville. A few dark-green aphanitic flows occur with the volcanic breccia and with the tuff.

Dikes, sills, and small irregular bodies of metamorphosed mafic and felsic rocks occur locally. A typical mafic intrusive rock, probably originally a gabbro, occurs as a narrow sill-like body along the railroad cut 1 mile southwest of Danville. It is dark colored and medium to coarse grained. The original mafic minerals have been largely altered to fine-grained actinolite and chlorite, and the plagioclase has been altered to sodic oligoclase, chlorite, epidote, and clinozoisite. Epidote and clinozoisite are intergrown, the clinozoisite commonly forming polysynthetic twins. Calcite, pyrite, and sphene are present in small amounts.

Metamorphosed felsic rocks probably represent original intrusive or extrusive(?) rocks of intermediate composition. They are porphyritic and display a light pale-green color and waxy luster owing to their content of sericite and scattered chlorite. Phenocrysts of quartz and sodic oligoclase, as large as 5 mm, are embedded in a fine-grained mosaic of quartz, plagioclase, and sericite. The feldspars are altered to calcite, chlorite, sericite, epidote, clinozoisite, and sodic oligoclase. Sericite is abundant in the groundmass, and its preferred orientation imparts a weak to moderate foliation to the rock. These rocks commonly contain scattered pyrite and chalcopyrite, and at the Lone Star and Morning Star mines they seem to have been favorable rocks for ore deposition.

Chert and minor amounts of phyllite and argillite form the steep slopes on both sides of July Creek, 2 miles west of Danville. These rocks are overlain by tuff and minor amounts of argillite, which occupy the areas to the west and south. Most of the rocks are highly contorted, and the regional attitude is difficult to determine. Chert and black argillite underlie most of the area between the serpentine and the eastern border of the map area. These rocks are composed of alternating chert and phyllite layers, or chert and black argillite layers in various proportions. Some of these rocks consist mainly of contorted chert beds with only thin phyllite partings. Others are dominantly black argillite but contain scarce chert beds and lenses. There are all gradations between rocks composed principally of chert and those composed almost entirely of black argillite. In places the chert has been recrystallized to a fine-grained quartz aggregate.

Laminated chert and argillite occur also in the area west of the Comstock mine where they have been partly recrystallized and converted to hornfels.

CONDITIONS OF SEDIMENTATION

The Permian and Triassic rocks consisting of greenstone (mainly mafic tuffs and flows), limestone, bedded chert, graywacke, and argillite are typical eugeosynclinal deposits. Similar assemblages are represented throughout the Paleozoic and earlier Mesozoic sequences along the Pacific border region from California to Alaska. This belt, called the Fraser Belt by Kay (1951, p. 36), is especially characterized by basic volcanic flows and tuffs.

In the area of the Curlew quadrangle, nearby volcanos contributed abundant tuff and volcanic flows to the subsiding geosynclinal trough. During lapses in volcanic activity, limestone, black shale, and chert were deposited. Some limestone may have been formed as reef complexes. Mafic ash falls mingled with carbonate and shale deposits to form layers of calcareous tuff, tuffaceous shale, and other mixed types. At times, local tectonic highlands or islands contributed coarse conglomerate, perhaps fanglomerate, which consists mainly of chert and phyllite pebbles.

AGE AND CORRELATION

The greenstone and associated rocks are considered to be of Permian and Triassic age on the basis of fossils found at three localities. Inasmuch as no lower limit for the Permian beds and no upper limit for theTriassic beds are definitely established, some beds of Pennsylvanian or older age and some beds as young as Jurassic may also be included. It was not possible to draw a boundary between the Permian rocks and the Triassic rocks in the Curlew quadrangle because the lithologies of the two systems are nearly the same and the exposures are inadequate.

Rocks of Permian age crop out in the southeastern part of the quadrangle and extend at least to the head of Art Creek, where Early Permian fossils were found, and possibly almost to Curlew. These rocks are continuous with the belt of Permian rocks in the adjoining Republic quadrangle. In the Colville Indian Reservation, 15 miles south of Republic, parts of the Covada Group (Pardee, 1918) are probably equivalent to the Permian rocks of the Curlew quadrangle.

The belt of limestone that crops out on both sides of the Kettle River north of Curlew is of Late Triassic age. The age of the greenstone and associated rocks west and north of the limestone is not precisely known because no fossils were found in these rocks and their stratigraphic relations to the Triassic limestone are uncertain. These rocks may be Triassic or Permian in age.

The greenstone that overlies the phyllite unit of the Tenas Mary Creek rocks a mile north of the quadrangle boundary west of the Bacon Creek fault probably marks the base of the Permian and Triassic section. (See also page 20.) No fossils were found at this locality to establish the age with certainty; hence some beds of Pennsylvanian or older age may be included.

Permian and Triassic rocks similar to the greenstone in the Curlew quadrangle are widespread in southern British Columbia between Okanogan Lake and Nelson. The Anarchist Series of Daly (1912), which occupies the area between Grand Forks and Midway, British Columbia, is of probable Permian age, but may include some beds of Pennsylvanian and Triassic age (Little, 1957). The Anarchist Series is continuous with the Permian and Triassic rocks of the Curlew quadrangle and includes the upper part of the phyllite which extends 1 mile north of the quadrangle boundary.

Other correlative or partly correlative formations or groups in southern British Columbia include: the Mount Roberts Formation (Pennsylvanian and (or) Permian), the Slocan and Kaslo Groups (Triassic) and the Ymir Group (Triassic? and earlier) between Christina Lake and Nelson (Little, 1956, 1957); the Cache Creek Group (Pennsylvanan and Permian), and the Nicola Group (Triassic) in the Princeton and Nicola map areas (Rice, 1947; Cockfield, 1948).

Similar rocks of Permian and Triassic age occur in the Okanogan Valley north and south of the international boundary (Waters and Krauskopf, 1941; Cairnes, 1940a).

Upper Palezoic rocks ranging from Mississippian through Permian ages also occur east of the Kettle River Range 40 miles east of Curlew. The Churchill Formation in the Orient area is considered by L. G. Henbest (in Bowman, p. 48; see footnote 3, p. 24) to be of probable middle Permian age because it contains *parafusulina*. A series of greenstone, graywacke, and limestone also crops out in the Kettle Falls-Colville area. A collection of parafusulinids from sec. 17, T. 36 N., R. 38 E., just north of Kettle Falls is considered by R. C. Douglass to be of late Permian age, "probably late Leonard or possibly even younger" (written commun., 1958). Helen Duncan, in her study of the same collection, concluded that the bryozoans are characteristic of later Permian faunas (written commun., 1959).

TRIASSIC(?) ROCKS

SERPENTINE

Several bodies of serpentine are associated with the Permian and Triassic rocks north of Curlew. The largest body, which extends from Danville south to Skiffington Creek, is about half a mile wide and 2½ miles long. Several smaller bodies are along the ridge between Goosmus Creek and Little Goosmus Creek, and others occur a mile north of Drummer Mountain and a mile west of Danville.

The contact between the serpentine bodies and the adjacent rocks is not seen in most places. In the area between Goosmus Creek and Little Goosmus Creek, rocks of the Scatter Creek Formation intrude the serpentine bodies and are darker in color along the contact zone, possibly a result of the assimilation of serpentine.

The western contact of the large serpentine mass south of Danville is steeply dipping and strongly sheared. In the vicinity of the Morning Star mine this sheared contact is carbonatized and mineralized, and just south of the mine in the center of sec. 16, T. 40 N., R. 34 E., the western sheared margin of the serpentine is in contact with a lens-shaped body of the Scatter Creek Formation. The contact at this place dips 70° E. One-half mile east of Danville, unaltered limestone is in contact with serpentine, and in other places the western margin of the serpentine is in sheared contact with greenstone.

Along the road above the Morning Star mine magnesite(?), talc(?), dolomite, and other minerals have replaced serpentine near the contact. This sheared contact of the serpentine mass evidently is a control for gold-copper mineralization, for the workings of the Morning Star mine and several prospects are principally along this contact. The serpentine along the eastern contact of the mass also is strongly sheared.

The serpentine in the interior of the body is mostly massive. It is dark green to black and weathers readily to shades of pale green and brown. The serpentine contains accessory chromiferous iron spinel that is easily seen on the pale-green weathered surface. Locally small pods of spinel containing sufficient chromium to be termed "chromite" occur in the serpentine.

The serpentine is interpreted as having originated from an ultramaffic intrustive. This origin is suggested by the presence of relict outlines of original pyroxene crystals and the presence of accessory chromiferous magnetite and of pods of chromite.

Direct evidence for the age of the serpentine in the Curlew quadrangle was not obtained, except that it is intruded by the Scatter Creek Formation of Eocene or Oligocene age. Data from other areas in this region indicate that a Late Triassic age is likely.

Leech (1953, p. 39) believes that the Shulaps ultramafic rocks of southwestern British Columbia were intruded during the Late Triassic orogeny. The main ultramafic mass cuts Upper Triassic strata, and detrital chromite is found in Lower(?) Jurassic strata. These relations suggest that the ultrabasic mass was unroofed prior to Early Jurassic time.

In the Aldrich Mountains south of John Day, Oreg., Upper Triassic pillow lava, volcanic graywacke, and andesitic tuff lie on a basement of Paleozoic metavolcanic rocks and serpentine (Thayer and Brown, 1960, p. 302). Commonly, however, the exposed serpentine in the John Day area is in sheard contact with Upper Triassic rocks, and these bodies are considered to be diapiric intrustions, that is, intruded in the solid state by plastic flow and, hence, later than the original intrusions. The serpentine bodies in the Curlew quadrangle exhibit sheared contacts, and they also may be diapiric intrusions.

CRETACEOUS(?) ROCKS

GRANODIORITE

GENERAL FEATURES

A batholith consisting of granodiorite and related rocks occupies most of the extreme western part of the quadrangle south of the Kettle River. It is bounded on the east by the Bacon Creek fault and on the northwest by the metamorphic rocks of Tenas Mary Creek, which the batholith intrudes. Several small bodies of granodiorite, apparently a continuation of the main intrusive mass, are exposed on the southeast slope of Little Vulcan Mountain and in the vicinity of Cottonwood and La Fleur Creeks. Numerous small stocks of fine- to medium-grained quartz monzonite, which intrude the Permian and Triassic rocks in the Granite Mountain area, are also mapped with the Cretaceous(?) granodiorite; however, they may be related to the quartz monzonite of Long Alec Creek (Oligocene).

The batholith is faulted against, or overlain by, Tertiary rocks about 3 miles west of the quadrangle. It extends southward through the Republic quadrangle (Muessig and Quinlan, 1959) and the Bald Knob quadrangle (Staatz, 1964) for a known length of about 60 miles.

In the Curlew quadrangle the batholith is composed chiefly of coarse-grained granodiorite and lesser amounts of medium-grained quartz monzonite. Other related rock types are also present in small amounts. Granodiorite and quartz monzonite are intimately associated, but their age relations are not definitely known. The quartz monzonite is light colored, even grained, and speckled with accessory biotite. The granodiorite is light gray or pink and mottled by dark mafic minerals. Local dioritic types are dark gray because of their higher percentage of mafic minerals. In hand specimen, typical granodiorite is massive and porphyritic to equigranular, and consists of quartz, plagioclase, orthoclase, biotite, and hornblende. (See fig. 5.) Sphene is a common accessory, easily seen with the hand lens. In some specimens, orthoclase is pink and easily distinguished from white plagioclase. Quartz is commonly smoky.

Rocks west of Trout Creek in the southwestern corner of the quadrangle are porphyritic granite which consists of phenocrysts of orthoclase as long as 1 inch set in a coarse-grained groundmass of quartz, plagioclase, orthoclase, and accessory biotite.

Dark-colored quartz diorite is found south of the Kettle River in the vicinity of the contact with the granitic gneiss. Mafic streaks and subparallel feldspar crystals impart a weak lineation and foliation to the rock. These structural features are swirly and have no consistent direction and are interpreted to be primary flow features near the border of the intrusive mass. Rounded and ovoid-shaped clots also occur in the quartz diorite as far as a half a mile from the contact. They are composed of hornblende and plagioclase and are as much as 2 feet across. It is not known whether they are partially resorbed inclusions of country rock or mafic segregations.

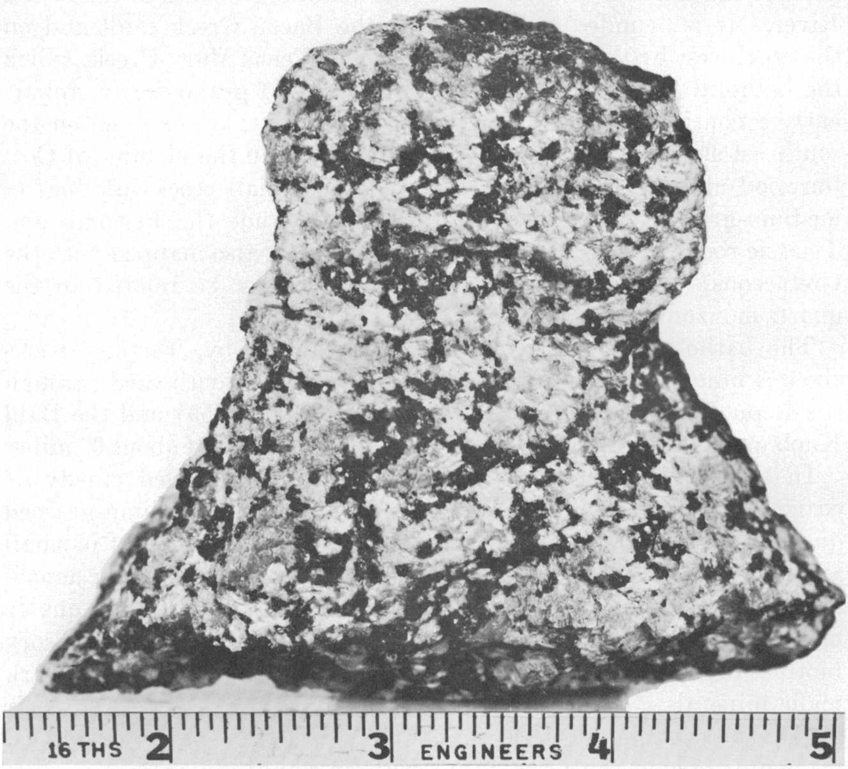

FIGURE 5.—Cretaceous(?) granodiorite, showing coarsely crystalline texture. Principal minerals are white plagioclase, pink orthoclase, quartz, and dark biotite and hornblende. Rock borders the Republic graben on the west in sec. 13, T. 38 N., R. 32 E.

The intrusive relations between the diorite phase of the batholith and the granitic gneiss are well displayed in sec. 8, T. 39 N., R. 33 E., north of the Kettle River. In this area the diorite and several apophyses from it cut the granitic gneiss. The apophyses are as much as 100 feet thick and trend northeast parallel to the foliation of the gneiss. In general the contact between the batholith and the gneiss is a zone of mixed rocks ranging from as little as a few inches to a complex border zone of more than 200 feet in width. In a few places the mixed zone is absent and the contact is knife-edge sharp. This zone of mixed rocks is principally irregularly swirled migmatite consisting of varying proportions of diorite and unfoliated granitic pegmatitic material complexly intermixed with streaks, schlieren, and irregular fragments of biotite-rich schist. In places the diorite in this border zone contains randomly oriented fragments of gneiss and biotite schist in various stages of digestion. Coarse-grained unfoliated granite pegmatites are abundant in the contact zone. They are considered to have been implaced during the time of intrusion of the batholith because of their unfoliated character and their spacial association with the batholith, especially at the contact. Pegmatites related to the batholith cut the diorite and the granitic gneiss and appear to have replaced the gneiss to a certain extent. Unfoliated pegmatite bodies ranging from 5 to 10 feet in thickness commonly separate the zone of mixed rocks from relatively uncontaminated gneiss. Pegmatites related to the batholith are unfoliated, and the orthoclase is pink; those related to the granitic gneiss are foliated, and the orthoclase is almost white. The foliated pegmatites were discussed on page 8 of this report.

Flow structures in the diorite border zone are somewhat swirled, although they tend to parallel the contact in its immediate vicinity. When the contact is sharp and uncomplicated by a mixed zone, the flow structures in the diorite are parallel to the contact but dip nearly vertically, almost at right angles to the slightly dipping foliation in the gneiss.

A few inclusions of country rock occur in the interior of the batholith. They consist of elongate blocks of quartzite, biotite schist, and marble and range in length from 30 to more than 1,000 feet. None of them have been shown on the map. Original limestone inclusions are extensively altered to calc-silicate minerals. In a small area north of Lake Butte, inclusions are numerous enough to constitute a contaminated zone in which both medium- and coarse-grained phases of the batholith enclose remnants of country rock and are themselves irregularly enriched in biotite. The distribution of inclusions shows no relation to the contact with the metamorphic rocks of Tenas Mary Creek, and their source is uncertain.

Narrow aplite dikes and stringers are abundant in the batholitic rocks, but few pegmatite dikes and alaskite bodies occur except in the vicinity of the contact with the gneiss.

PETROGRAPHY

Microscopically, the granodiorite and related rocks have medium- to coarse-grained granitic textures. The essential minerals are andesine (An_{30-45}), orthoclase, and quartz, and various amounts of hornblende, biotite, and augite as the characterizing mafic minerals. Accessory minerals include sphene, apatite, zircon, epidote, magnetite, and muscovite.

Coarse-grained granodiorite and medium-grained quartz monzonite are the main rock types, but granite, monzonite, and quartz diorite are also represented. All these types are recognizable in the field, but they were not mapped separately. Chemical and modal analyses of granodiorite taken from a roadcut on the south side of the Kettle River half a mile east of bench mark 1809 are given in table 1.

Andesine or oligoclase in subhedral laths as large as 4 mm makes up about 50 percent of the various rock types. The crystals are zoned with more sodic borders. The orthoclase content ranges from 50 percent in quartz monzonite to traces in quartz diorite. It forms irregular poikilitic grains as large as 6 mm and small patches and stringers in the interstices and along grain boundaries. Quartz, in rounded grains, constitutes 10–20 percent of most rocks. Strained quartz and a few bent plagioclase laths indicate slight deformation of the rock fabric during or after solidification, but the deformation has not been sufficient to produce a preferred orientation of the minerals.

TABLE 1.—*Chemical and modal analyses of granodiorite*

[Chemical analyses by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack]

Chemical analysis (percent)		Mode (point count)		
Constituent	G17C-177	Mineral	G17C-177[1]	G31C-189[2]
SiO_2	62.4	Quartz	18	11
Al_2O_3	16.2	Plagioclase	[3]48	[4]45
Fe_2O_3	1.6	Orthoclase	16	22
FeO	3.4	Augite }		
MgO	3.1	Hornblende }	17	22
CaO	5.0	Biotite }		
Na_2O	3.9	Others	1	<1
K_2O	3.0			
H_2O	.70			
TiO_2	.70			
P_2O_5	.28			
MnO	.09			
CO_2	.21			
Total	100.58			

[1] Mode is based on point count of 850

[2] Mode is based on point count of 738.

[3] An_{40}.

[4] An_{43}.

G17C-177. From roadcut on south side of Kettle River, NW¼ sec. 17, T. 39 N., R. 33 E.
G31C-189. From NW¼ sec. 31, T. 39 N., R. 33 E.

AGE AND CORRELATION

Information from the southward continuation of the batholith in Wauconda quadrangle (Muessig and Quinlan, 1959) and Bald Knob quadrangle (Staatz, 1964) indicates that the time of intrusion of the batholith was after the late Paleozoic but before the Eocene—probably in the Cretaceous. In the Wauconda and Bald Knob quadrangles, the granodiorite intrudes rocks of probable late Paleozoic age and is cut by dikes similar to the Scatter Creek Formation of Eocene or Oligocene age. In the Republic quadrangle, granitic boulders in the O'Brien Creek Formation (Eocene?) presumably were derived from the granodiorite batholith.

The granodiorite is the northern extension of an intrusive mass called the "Colville granite" by Pardee (1918, p. 34), from its exposures on the Colville Indian Reservation 30 miles to the south. Pardee concluded that it was of Mesozoic and probably Cretaceous age. The granodiorite batholith may correlate with other granitic intrusive bodies in northeastern Washington and southern British Columbia whose ages are uncertain but are considered to be of late Mesozoic age. Possible correlatives are the batholith studied by Waters and Krauskopf (1941) on the east side of the Okanogan Valley, 40 miles west of the Curlew quadrangle, the Nelson intrusions of Cretaceous(?) age lying a few miles to the north in Canada (Little, 1957; Smith and Stevenson, 1955), and the Kaniksu batholith east of the Columbia River, 60 miles to the east (Park and Cannon, 1943).

INTRUSIVE ROCKS OF SHASKET CREEK

GENERAL FEATURES

Several bodies of alkalic intrusive rocks occur 2 miles south and southwest of Danville along a narrow zone that crosses the Republic graben in a west-northwest direction. These rocks are referred to informally as the alkalic rocks of Shasket Creek. Two rock units are distinguished on the geologic map (pl. 1): syenite porphyry and a rock unit of variable composition ranging from monzonite through nepheline(?) syenite to shonkinite.

Syenite porphyry occurs in two small elongate pluglike bodies at the north and south borders of the largest of the three principal intrusive bodies. The northern body is about ¾ mile long and ½ mile wide and the southern body is about ½ mile long and ⅛ mile wide. These bodies also are alined parallel to the west-northwest trend of the alkalic complex.

Syenite porphyry dikes that originate in the alkalic complex and which are evidently offshoots from the pluglike syenite porphyry bodies intrude other facies of the complex and penetrate the enclosing

Permian and Triassic rocks. Most of these dikes, though not all, are nearly vertical and trend west-northwest, parallel to the trend of the alkalic complex.

The alkalic rocks intrude Permian and Triassic sedimentary rocks and greenstone and in turn are intruded by dikes and irregular bodies of fine-grained quartz monzonite that are considered to belong to the Scatter Creek Formation. The intrusive relations are most clearly shown at the contact of the largest intrusive body of alkalic rocks. Along the south side of the body the syenite porphyry has intruded limestone beds of Late Triassic age, and along the contact the limestone beds have been converted through thermal metamorphism to white, coarsely crystalline marble. In places the marble contains one or more of the following minerals: fibrous wollastonite, phlogopite, actinolite, brown garnet, and vesuvianite. Elsewhere along the borders of the body, greenstone and argillite have been metamorphosed to dense dark biotite hornfels and lime silicate hornfels in an aureole extending several hundred feet from the contact. Some rocks that are believed to have been greenstone containing abundant contorted chert laminae have been converted to hornfels containing thin quartz laminae.

In secs. 7 and 18, T. 40 N., R. 34 E., the alkalic rock complex is cut by younger quartz monzonite of the Scatter Creek Formation. Rocks of both the main intrusive mass and the syenite porphyry dikes are cut by this quartz monzonite.

LITHOLOGY AND PETROGRAPHY

The alkalic complex is composed of several related rock types which are classed as monzonite, hornblende syenite, nepheline(?) syenite, shonkinite, and syenite porphyry. These rocks vary in major constituents from place to place and, with the exception of the syenite porphyry, the several types are considered textural and mineralogic variants of the main mass, not separate intrusives. The syenite porphyry, because of its contrasting texture and felsic composition and because of the injection of its dikes into rocks of the complex and into surrounding country rocks, is believed to be a slightly later differentiate of the main mass. The mineral composition of the principal rock types in the complex is given in table 2.

Monzonite constitutes a large part of the complex. It is light gray and medium grained, and has a distinctive trachytoid texture. Under the microscope it is seen to consist of about 50 percent plagioclase (oligoclase-andesine), 30 percent perthitic orthoclase and microcline, and 10 percent hornblende; many minor accessory minerals, especially sphene and magnetite, make up the remainder of the rock. (See table 2.) Plagioclase, in subparallel laths mostly 1–2 mm long, produces the trachytoid texture. It is commonly rimmed with clear albite and partly altered to sericite and either epidote or clinozoisite. Orthoclase forms a few laths, but most of it is interstitial between the plagioclase laths. Hornblende is bluish green, is commonly poikilitic, and contains inclusions of feldspar and relict cores of augite. Quartz in minor amounts is interstitial to orthoclase and other minerals.

Notable features that are not common to other monzonite and quartz monzonite rock types in the quadrangle are the presence of microcline, the large size and greater abundance of sphene, the poikilitic nature and blue-green pleochroism of hornblende, and the pronounced trachytoid texture.

Hornblende syenite, nepheline(?) syenite, and shonkinite are gray medium-grained rocks with a high proportion of mafic constituents. In the outcrop these rocks look like diorite and gabbro.

Hornblende syenite contains perthite, in anhedral grains averaging 0.3 mm in length, and subordinate amounts of hornblende, epidote, and albite. Magnetite, apatite, and brownish-green biotite are accessories. The grains are mostly anhedral and give the rocks an allotriomorphic granular texture. The hornblende is bluish green to yellowish green, and much of it occurs in poikilitic grains that form parts of larger skeletal crystals, some of which reach lengths of 7 mm. Epidote occurs both in granular aggregates and in disseminated grains.

The nepheline(?) syenite consists of dominant orthoclase in subhedral prismatic crystals, very minor sodic plagioclase, abundant pale green pyroxene and deep bluish green, strongly pleochroic

TABLE 2.—*Modal analyses of some alkalic rocks of Shasket Creek*

[X indicates presence of minor quantities]

Mineral	B12P-219	A8C-190b	A8C-259	A8C-190a	A17P-264
Quartz	<1	----	----	----	----
Plagioclase	54	7	X	----	10
Orthoclase Microcline	} 28	57	46	16	64
Amphibole	9	10	} 29	31	15
Pyroxene	X	----		50	----
Nepheline	----	----	20[1]	----	6[1]
Magnetite	2	5	1	3	2
Sphene	2	X	1	X	X
Garnet	----	----	3	----	3
Epidote	X	19	----	X	X
Apatite	X	X	X	X	X
Calcite	X	X	----	X	X
Zircon	X	----	X	----	X
Biotite	----	X	----	----	----
Chlorite	----	X	----	X	----
Clinozoisite	X	----	----	----	----
Sericite	X	----	----	----	----

[1] Pseudomorphic aggregates probably altered from nepheline.

B12P-219. Monzonite from NW¼ sec. 12, T. 40 N., R. 33 E.
A8C-190b. Hornblende syenite from SW¼ sec. 8, T. 40 N., R. 34 E.
A8C-259. Nepheline(?) syenite from south central sec. 8, T. 40 N., R. 34 E.
A8C-190a. Shonkinite, same locality as A8C-190b.
A17P-264. Syenite porphyry from NW¼ sec. 17, T. 40 N., R. 34 E.

735-724 O—64——4

amphibole, light brown garnet, aggregates of sericite, and minor accessories, apatite, magnetite, and zircon. The orthoclase is clear and unaltered, and its weak orientation imparts trachytoid texture to the rock. The pyroxene, probably augite near hedenbergite ($2V(+) \sim 60$, $Z \wedge c \sim 48°$) is rimmed by strongly pleochroic amphibole, thought to be a sodic hornblende ($2V(-) \sim 60°$; $Z \wedge c \sim 23°$; $n\alpha$-$n\gamma$ 0.015; X=yellowish green, Y=green, and Z=dark bluish green). The hornblende also occurs in large anhedral poikilitic skeletal crystals. Brown garnet likewise occurs in poikilitic skeletal grains. The aggregates of sericite that have completely replaced an earlier formed anhedral mineral (nepheline?) are molded about orthoclase. Minor accessories are magnetite, apatite, and zircon.

The shonkinite in the complex is a local dark-gray variant with marked porphyritic texture. It is composed principally of augite and subordinate amounts of hornblende and perthite. Minor constituents are magnetite, sphene, calcite, chlorite, epidote, and apatite. Augite occurs in green-tinted, weakly pleochroic euhedral crystals that are closely packed together. Perthite, in ragged anhedral grains, encloses and occupies the space between augite crystals. Both augite and perthite grains range in width from 0.2 to 1 mm. Hornblende forms poikilitic brownish-green to pale yellowish-brown phenocrysts, some of which are as long as 8 mm. Inclusions in these phenocrysts are augite, perthite, sphene, magnetite, and apatite as well as epidote, calcite(?), and chlorite after another former mafic mineral. Magnetite is more abundantly disseminated in this rock than in the lighter colored varieties.

The most felsic variety of rock in the complex is syenite porphyry which occurs as irregular pluglike intrusive bodies and as dikes. The porphyry has been distinguished separately from other Shasket Creek rocks on the geologic map (pl. 1).

Syenite porphyry is light pinkish gray to mauve and consists principally of tabular euhedral perthitic orthoclase crystals whose alinement gives the rock a pronounced trachytoid texture. (See fig. 6.) The orthoclase crystals range from less than 1 mm to more than 50 mm and are alined parallel to the walls of dikes and intrusive contacts. Both phenocrysts and matrix crystals generally are smaller in the dikes than in the larger pluglike bodies. Interspaces between the large orthoclase crystals are filled principally with anhedral perthitic orthoclase, pleochroic biotite (pale yellow to dark green), pleochroic hornblende (yellowish green to bluish green), brown poikilitic garnet, and minor plagioclase (oligoclase-andesine).

The orthoclase crystals are more perthitic along their borders, and in many places the patches of albite are sufficiently large to show polysynthetic twinning. The hornblende has been altered partly to biotite, chlorite, calcite, and epidote. Magnetite and sphene are the most abundant accessory minerals; others are apatite and zircon.

Polygonal aggregates (1 mm or less in width) of fibrous natrolite(?), calcite, and sericite are concentrated principally along the borders of orthoclase crystals, though some of these aggregates are enclosed in garnet grains and a few are contained in hornblende or biotite crystals. In thin section it can be seen that these pseudomorphic aggregates are mostly in the form of hexagons, a fact which suggests that the original mineral probably was a feldspathoid, possibly nepheline.

AGE AND CORRELATION

A provisional age of Cretaceous(?) is assigned to the Shasket Creek rocks. They are younger than the limestone of Late Triassic age, which they intrude, and are older than the Eocene or Oligocene Scatter Creek Formation which intrudes the syenite porphyry dikes as well as other rocks of the complex. The Shasket Creek rocks are believed to predate the formation of the Republic graben, the early phases of which probably began prior to the Eocene(?). Dikes and other intrusive bodies of the complex follow a west-northwest trend across the graben, a direction that is a prominent structural trend in the older metamorphic rocks bordering the graben and which is normal to most linear structural features related to the formation of the graben.

Alkalic rocks similar in composition and occurrence to the Shasket Creek rocks have been described in several localities in British Columbia northwest, north, and northeast of the Curlew quadrangle. Cairnes (1940a), in the Osoyoos Lake region to the northwest, included

FIGURE 6.—Syenite porphyry, showing large tabular orthoclase crystals in subparallel arrangement. Dark minerals in the interspaces between orthoclase crystals are biotite, hornblende, garnet, and magnetite.

alkalic intrusives with rocks that he called Okanogan intrusives. He assigned an age of Jurassic or later to these rocks. Campbell (1939), who studied some of these rocks in greater detail, distinguished malignite, felsic nepheline syenite, femic nepheline syenite, and porphyritic alkaline syenite. These rocks are very similar to those of Shasket Creek. Just north of the Curlew quadrangle in the Boundary district, British Columbia, LeRoy (1912) described augite syenite and syenite porphyry dikes which he related to the granodiorite batholith. He assigned them an age of Jurassic(?). Also mentioned by LeRoy are pulaskite porphyry dikes (alkaline syenite porphyry) that are the youngest intrusive rocks in the district. At the Franklin Mining Camp, 37 miles north of the quadrangle, Drysdale (1915) found a suite of alkalic intrusive rocks that he classed as porphyritic syenite, shonkinite-pyroxenite, augite syenite, and monzonite. He considered these rocks to be Miocene in age because they intrude rocks mapped as the Kettle River Formation and are similar in composition to trachyte flows of the Midway Volcanic Group of Daly (1912), of which they supposedly are feeders. Younger pulaskite dikes cut the trachyte and older rocks. Farther to the northeast near Ymir, McAllister (1951) distinguished pulaskite, basic syenite, and shonkinite, which are younger than the Nelson batholith and presumably are Tertiary.

TERTIARY ROCKS

O'BRIEN CREEK FORMATION

GENERAL FEATURES

The O'Brien Creek Formation is Eocene(?) in age and contains the oldest Tertiary layered rocks in this area. It forms a north-trending belt of isolated outcrops extending from the southeastern part of the quadrangle to about 1 mile south of Curlew. Another smaller area occurs in a shallow syncline 2 miles north of Drummer Mountain. In the Republic and Curlew quadrangles, the O'Brien Creek Formation is exposed only within the Republic graben. As is a large part of the Permian and Triassic rocks, the fragmentary outcrops of the O'Brien Creek Formation are regarded as roof pendants in the enclosing Scatter Creek Formation. More continuous sections occur in the adjoining Republic quadrangle, where the formation was named and fully described by Muessig (1962).

In most places the beds dip steeply west and with few exceptions strike northeast. The consistent attitudes indicate that the O'Brien Creek rocks have been little disturbed by the extensive Scatter Creek intrusions. If it is assumed that the present distribution of the roof pendants marks the extent of the formation prior to the intrusion of the Scatter Creek rocks, then the O'Brien Creek Formation is about

6,000 feet thick near the southeastern boundary of the quadrangle. With a few exceptions in the area between St. Peter Creek and Art Creek, graded bedding indicates that the tops of the beds are everywhere to the west.

Between St. Peter Creek and Art Creek, the belt occupied by the O'Brien Creek Formation is 13,000 feet wide. The reason for such great width is not completely understood, but it may be due to the combined effects of local folding and movement along the Drummer Mountain fault. In a small area 2 miles north of Drummer Mountain, the formation is only about 250 feet thick. At this place it lies with angular unconformity on Triassic(?) limestone and is overlain by the Sanpoil Volcanics with apparent conformity. Thus it seems probable that the O'Brien Creek Formation thins markedly to the north.

In most places the upper and lower contacts of the formation are obliterated by younger intrusive rocks. The lower contact is a fault against Permian rocks at the southern border of the area.

LITHOLOGY

The O'Brien Creek Formation consists primarily of tuff, tuffaceous sandstone, shale, and conglomerate. Black argillite chips oriented parallel to the bedding are perhaps the most distinctive feature of the unit as a whole. Both well-bedded and massive rocks are found within the formation. Coarse detritus ranges in size from pebbles to boulders and commonly is highly variable over small intervals. Tuffaceous material is abundant in most types, but there are variations from pure crystal tuff through lithic tuff to graywacke in which the tuff fraction is negligible.

Tuffaceous conglomerate contains black argillite and phyllite chips and rounded to highly angular felsic volcanic rock fragments as large as 2 inches, in a light- or dark-colored tuffaceous matrix of quartz and feldspar. Other lithic fragments include quartz, quartzite, chert, phyllite, greenstone, granite, and rare limestone.

Two miles north of Drummer Mountain in secs. 28 and 29, T. 40 N., R. 34 E., a basal conglomerate, consisting mainly of limestone boulders as large as 2 feet in a tuff matrix, unconformably overlies Permian and Triassic limestone.

Tuffaceous sandstone and siltstone are abundant in the O'Brien Creek Formation. These are greenish gray to buff and medium to thin bedded, and locally display graded bedding. Some of the beds are almost pure crystal tuff consisting of feldspar, and rounded blebs of quartz, and a few lithic fragments.

A small part of the formation consists of thinly laminated black tuffaceous shale and siltstone, which in some places contain plant debris.

The O'Brien Creek Formation in the Curlew quadrangle differs somewhat from the type exposures in the Republic quadrangle by having a greater fraction of lithic material, darker color, and a larger content of volcanic fragments.

CONDITIONS OF SEDIMENTATION

The rocks of the O'Brien Creek Formation represent a rapid accumulation of tuffaceous and detrital material in a subsiding intermontane basin, possibly an early stage in the development of the Republic graben. Uplifted blocks on each side of the basin contributed coarse, poorly sorted material. Explosive volcanic activity blanketed the region with ash falls which were reworked by stream action and deposited in the basin. Detrital material from the uplands mingled with the tuff during transport and the result was deposits of tuffaceous shale, sandstone, and conglomerate. Some tuffaceous conglomerate beds are probably volcanic mudflows. Some laminated shale and fine sandstone beds containing scattered plant debris mark short intervals of slow, orderly deposition. Some fine ash settled in the standing water of the basin to form white tuffaceous mudstone.

AGE AND CORRELATION

The stratigraphic relations of the O'Brien Creek Formation are not easily determined in the Curlew quadrangle because of the scarcity and discontinuous nature of its outcrops. However, 2 miles north of Drummer Mountain, the O'Brien Creek Formation is overlain by the Sanpoil Volcanics and unconformably overlies limestone probably of Late Triassic age. Plant fossils collected from the O'Brien Creek Formation in the adjoining Republic quadrangle are considered by R. W. Brown to be of Eocene(?) age (Muessig, 1962, p. D57).

The extent of the O'Brien Creek Formation outside the Republic graben is incompletely known. It is probable that several structural basins existed in the northwest during Eocene time and that correlative rocks were deposited in them. The O'Brien Creek Formation is probably correlative with the Kettle River Formation that occurs between Grand Forks and Rock Creek just north of the international boundary (Daly, 1912, p. 394–397). The Kettle River Formation near Phoenix, British Columbia, has the same characteristic lithology and stratigraphic position as the O'Brien Creek Formation.

SANPOIL VOLCANICS

GENERAL FEATURES

The Sanpoil Volcanics has been formally named after the Sanpoil River which cuts through extensive exposures of these rocks in the adjoining Republic quadrangle (Muessig, 1962).

In the Curlew quadrangle the Sanpoil Volcanics extends from the southern border of the quadrangle east and west of Curlew Lake, northward on both sides of Curlew Creek, as far as Rincon Creek, 3 miles north of Curlew. The eastern margin of this belt is extensively intruded by the Scatter Creek Formation. Because the two formations are difficult to separate owing to their similar appearance, a mixed zone containing both rock types is shown on the map along the eastern margin of this volcanic unit. The Sanpoil Volcanics also underlies smaller areas 2 miles west of Mount Elizabeth, in the vicinity of Lundimo meadows, and 2 miles north of Drummer Mountain. Volcanic rocks in the extreme northwest corner of the quadrangle are also probably Sanpoil.

The Sanpoil Volcanics overlies the O'Brien Creek Formation and underlies the Klondike Mountain Formation. Contact relations with the O'Brien Creek Formation are largely masked by the intrusions of Scatter Creek Formation. The nature of the upper contact is also obscure, but in the Republic quadrangle the Sanpoil Volcanics is is overlain with angular unconformity by the Klondike Mountain Formation.

No reliable estimate of the thickness of the Sanpoil Volcanics can be made because the details of its internal structure are unknown. If we assume that the volcanic rocks along the southern border of the quadrangle dip steeply to the west, as do the underlying O'Brien Creek rocks, the thickness would be several thousand feet. On Klondike Mountain in the Republic quadrangle, the thickness of the Sanpoil Volcanics is reported to be about 4,000 feet; both top and bottom contacts are exposed (Muessig, 1962).

LITHOLOGY AND INTERNAL STRUCTURE

The Sanpoil Volcanics consists mainly of porphyritic flows that fall in the range quartz latite-rhyodacite (Johannsen, 1932, p. 309–310, 356–358). In hand specimen it resembles andesite, but in thin section is seen to be more felsic than normal andesite because of the content of quartz and potassium feldspar in the groundmass. Amygdaloidal and vesicular structures, as well as pyroclastic types, are rare, and sedimentary or tuffaceous interbeds occur only in a few places. Flowage structure is common, but its trends are irregular and do not appear to reflect the gross structure of the formation. Individual flows are seldom distinguished and cannot be traced far.

These volcanic rocks weather in shades of brown, reddish-brown, gray, purple, and, in places, green. They are porphyritic, containing phenocrysts of plagioclase, hornblende, and biotite that are set in an aphanitic to glassy-appearing groundmass. The feldspar phenocrysts are white or pale yellow, and in the rocks that have flowage structure they tend to lie in subparallel arrangement.

PETROGRAPHY

These volcanic rocks contain phenocrysts of andesine and lesser amounts of augite, hornblende, and biotite. Phenocrysts of hypersthene as well as rounded quartz occur in some rocks. The groundmass, which is commonly microcrystalline, consists mostly of an irregular patchwork of feldspathic material and small plagioclase laths, quartz, biotite, and dusty material composed of magnetite and microlites. In some rocks the groundmass is pilotaxitic textured having subparallel plagioclase laths arranged in flow lines around phenocrysts.

Thin sections stained with sodium cobaltinitrate suggest that much of the groundmass consists of an irregular interstitial intergrowth of quartz and potassium feldspar. The potassium feldspar is selectively stained to canary yellow and stands out in marked contrast to unstained quartz and plagioclase. The grain size of the groundmass ranges from 0.1 mm to a few microns. In the smaller range, definite crystals are not determinable, but aggregate polarization shows that the groundmass is not glass. In many rocks the grain size of the groundmass lies somewhere between the above extremes. In these middle-range types, abundant quartz can be identified, but the granules that are selectively stained to canary yellow are not optically identifiable, though they are believed to be potassium feldspar.

Chemical analyses of two specimens of the Sanpoil Volcanics from nearby areas are shown in table 3. These analyses correspond closely to the analysis of average dacite listed by Nockolds (1954), though the Sanpoil rocks are slightly more potassic.

AGE AND CORRELATION

The Sanpoil Volcanics is considered to be Eocene(?) in age (Muessig, 1962). It overlies the O'Brien Creek Formation of Eocene (?) age and is overlain unconformably by the Klondike Mountain Formation of Oligocene age. It is intruded by the Scatter Creek Formation. Volcanic rocks near Midway, British Columbia, which extend into the northwest corner of the Curlew quadrangle, were included in the Midway Volcanic Group by Daly (1912, p. 398–400). These rocks were called the Phoenix Volcanic Group by Little (1957), who reported that they overlie the Kettle River Formation (a formation probably equivalent to the O'Brien Creek Formation) with apparent unconformity and in places contain fossil plants of Paleocene or Eocene age.

SCATTER CREEK FORMATION

DISTRIBUTION

The Scatter Creek Formation (Scatter Creek Rhyodacite of Muessig, 1962) is one of the most widespread formations in the Curlew quadrangle. Most exposures are found within the Republic graben, but some occur also in the fault zone in the extreme northwest corner of the quadrangle. The exposures in the Republic graben are continuous with those of the adjoining Republic quadrangle to the south. A separately distinguished facies of the Scatter Creek Formation occurs in the Vulcan Mountain area west of the Bacon Creek fault and in the adjacent area in Canada.

TABLE 3.—*Chemical analyses and norms, in percent, of Sanpoil Volcanics*

[Analyses: sample 1, by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack; sample 2, by D. F. Powers. Norms computed by J. O. Berkland]

	1	2
Chemical analyses		
SiO_2	62.0	63.08
Al_2O_3	15.9	15.58
Fe_2O_3	3.3	2.81
FeO	1.9	1.61
MgO	2.7	2.55
CaO	4.4	4.56
Na_2O	3.9	3.94
K_2O	2.7	2.65
H_2O	1.5	----------
H_2O-	----------	.98
H_2O+	----------	.90
TiO_2	.71	.67
P_2O_5	.24	.26
MnO	.09	.08
CO_2	<.05	.06
Total	99.39	99.73
Norms		
Ilmenite	1.37	1.37
Magnetite	4.41	4.18
Hematite	.32	----------
K-feldspar	16.12	15.57
Albite	33.01	33.01
Anorthite	17.79	17.24
Diopside	3.24	4.10
Hypersthene	----------	4.70
Olivine	3.64	----------
Quartz	19.74	17.76
Total	99.64	97.93

1. Flow from SW¼ sec. 24, T. 35 N., R. 34 E., in the Republic quadrangle, Washington.
2. Flow from area just east of Long Lake in the Bald Knob quadrangle, Washington.

GEOLOGIC RELATIONS

The Scatter Creek Formation occurs as multiple sills, dikes, and ill-defined intrusive bodies. It complexly intrudes the Permian and Triassic rocks, the O'Brien Creek Formation, and the Sanpoil Volcanics, and in a few places cuts the alkalic rocks of Shasket Creek. In most parts of the Republic graben the Scatter Creek intrusive rocks have so invaded the older rocks that only isolated roof pendants remain. These roof pendants range in length from less than 100 feet to several thousand feet.

The Scatter Creek rocks intrude the Sanpoil Volcanics along a mile-wide zone extending from St. Peter Creek to Alkali Creek, about 2 miles north of Curlew. Because these two rock units at this place are difficult to distinguish owing to their similar composition and lithology, a mixed zone containing both types is shown on the map along the contact.

The intrusion of the Scatter Creek rocks apparently caused little disturbance of the country rocks because bedding structures in the roof pendants for the most part maintain consistent trends.

The separately distinguished Scatter Creek rocks in the northwest corner of the quadrangle west of the Bacon Creek fault complexly intrude the metamorphic rocks of Tenas Mary Creek as northward-trending intersecting dikes and irregular intrusive bodies. These intrusive rocks enclose isolated roof pendants of country rock in much the same habit as the Scatter Creek rocks in the Republic graben. The phyllite of Tenas Mary Creek is the most extensively intruded unit, though many dikes penetrate the schist and quartz-plagioclase gneiss, and one dike intrudes the basal granodiorite gneiss.

Contact metamorphism associated with the intrusion of the Scatter Creek rocks is slight and local. Most roof pendants in the Scatter Creek, even those only a few feet in length, show little evidence of contact metamorphism. Locally, calc-silicate hornfels is formed in impure limestone and calcareous greenstone in the NW¼ sec. 28, T. 38 N., R. 34 E., in the southeast corner of the quadrangle, and in impure limestone beds near the center of sec. 19, T. 40 N., R. 34 E. Contact metamorphic rocks occur in a few narrow zones in the phyllite of Tenas Mary Creek along the contact with fine-grained granodiorite. These contact rocks consist principally of dense dark biotite hornfels or calc-silicate hornfels.

The Scatter Creek is intruded by the quartz monzonite of Long Alec Creek on the north side of West Deer Creek west of Drummer Mountain and on the south side of Long Alec Creek 2 miles southeast of Curlew. (See p. 54). It is cut also by numerous dikes of quartz latite porphyry, which are related to the Long Alec Creek intrusive rocks, and by numerous dikes that have not been classified separately in the mapping, termed "undivided dikes."

LITHOLOGY AND PETROGRAPHY

The Scatter Creek Formation in the Curlew quadrangle consists of mostly fine-grained quartz monzonite and granodiorite porphyry, although it varies in texture and composition from place to place. Locally some of these rocks are sufficiently fine-grained to be indistinguishable from rhyodacitic volcanic rocks, and in a few places they approach the composition of syenite and diorite.

Typical fine-grained quartz monzonite is light-gray to medium-gray and is strongly porphyritic, containing abundant white prismatic plagioclase crystals, biotite crystals, and irregular masses of chlorite that have altered from original hornblende and augite crystals. The matrix consists of locally varying proportions of finely crystalline chlorite, biotite, feldspar, and quartz.

Under the microscope, most of the Scatter Creek rocks are porphyritic and have a felted, or orthophyric, or microgranitic groundmass. In general, phenocrysts reach lengths of 3 mm, and the groundmass minerals range in size from less than 0.1 to 0.5 mm. Plagioclase phenocrysts and crystals in the groundmass in most of these rocks are andesine and constitute 30 to 60 percent of the total minerals. Commonly the plagioclase is zoned. Orthoclase, which forms 20 to 50 percent of the rock, is confined to the groundmass and commonly forms graphic intergrowths with quartz. Quartz, which also is largely restricted to the groundmass, forms from less than 5 to 20 percent of the rock. Biotite is a common accessory, and many varieties of these rocks contain augite and hornblende or actinolite. Minor accessory minerals are apatite, sphene, magnetite, and zircon.

Commonly, though not in all Scatter Creek rocks, augite and hornblende crystals have been deuterically(?) altered to an aggregate of chlorite and carbonate and minor amounts of leucoxene, sphene, and magnetite. In some rocks, augite has been partly converted to uralitic hornblende or actinolite, as shown by relict cores of augite in the amphibole crystals. The plagioclase commonly is incipiently altered to sericite, and in many rocks plagioclase crystals are rimmed or partly replaced by orthoclase.

Some Scatter Creek rocks in the area north of West Deer Creek contain a higher proportion of mafic constituents and a lower proportion of orthoclase than quartz monzonite and are close to granodiorite in composition. Other variants, which are locally distributed and of minor occurrence, are biotite-augite syenite and hornblende gabbro.

Rocks west of the Bacon Creek fault that are assigned to the Scatter Creek Formation range from quartz monzonite to granodiorite. In composition and in texture they are similar to some Scatter Creek rocks that occur east of the fault. The Scatter Creek rocks west of the Bacon Creek fault typically are medium gray, fine grained, and porphyritic. Phenocrysts of plagioclase, biotite, and hornblende contrast strongly with the more finely granular groundmass. Commonly, irregular clots of dark-green mafic minerals as large as 10 mm in diameter are widely disseminated.

In thin section most of the Scatter Creek rocks west of the Bacon Creek fault are porphyritic and have a micrographitic groundmass. Andesine, as phenocrysts and groundmass crystals, exceeds the amount of orthoclase. Quartz, which occurs in the interstices of other groundmass minerals, is variable in proportion but forms at least 10 percent in all rocks studied. As much as 15 percent hornblende is present as bladed crystals, as long as 10 mm, and as stubby crystals which apparently were originally augite. The clots of mafic minerals so characteristic of these rocks in hand specimen are seen to be composed of fibrous amphibole (probably actinolite), biotite, magnetite, and minor chlorite.

AGE

The Scatter Creek Formation intrudes the O'Brien Creek Formation and the Sanpoil Volcanics of Eocene(?) age and older rocks, and is overlain unconformably by the Klondike Mountain Formation of Oligocene age. It is probably either Eocene or Oligocene in age.

QUARTZ MONZONITE OF LONG ALEC CREEK

DISTRIBUTION

A large intrusive body of quartz monzonite underlies about 20 square miles in the east-central part of the quadrangle between the South Fork of Day Creek on the north and the South Fork of St. Peter Creek on the south. It extends to the Summit Guard Station more than 5 miles to the east in the adjoining Togo Mountain quadrangle and is the principal rock type in the West Deer Creek and Long Alec Creek drainages. The southern continuation of the quartz monzonite forms a narrow, highly sheared belt in the southeastern part of the quadrangle. This belt is apparently continuous with the large mass of similar batholithic rock that occurs east of the Sherman fault in the adjoining Republic quadrangle to the south.

GEOLOGIC RELATIONS

The quartz monzonite of Long Alec Creek intrudes the Scatter Creek Formation of Eocene or Oligocene age and remnants of the older rocks (Permian and Triassic) contained in the Scatter Creek. Locally, rocks bordering the intrusion are thermally metamorphosed. About half the contact of the quartz monzonite exposed in the quadrangle is intrusive; the remainder is tectonic, consisting of faults along the east side of the Republic graben.

Intrusive relations are clearly established along the northern contact of the quartz monzonite on the north side of West Deer Creek between the Kettle River and Drummer Mountain. Here a fine-grained granodiorite of the Scatter Creek Formation and the remnants of Permian and Triassic rocks contained in it are sharply truncated by the more coarsely crystalline quartz monzonite of Long Alec Creek. Remnants of Permian and Triassic limestone that were little altered by the granodiorite (of the Scatter Creek Formation) have been converted to marble and calc-silicate hornfels along contacts with the quartz monzonite of Long Alec Creek. The Scatter Creek, however, is not noticeably changed at the contact with quartz monzonite, and the contact is of knife-edge sharpness. Similar relations occur on the south side of Long Alec Creek in sec. 19, T. 39 N., R. 34 E., except that greenstone remnants in the Scatter Creek have been converted to biotite-magnetite-rich hornfels along the contact with the Long Alec Creek rocks.

With the exception of the intrusive contacts described above, the western margin of the quartz monzonite consists of normal faults that bring greenstone and Scatter Creek rocks into juxtaposition with the quartz monzonite. In the extreme southeastern part of the quadrangle, a brecciated zone of quartz monzonite defines a major fault zone and is restricted to it.

In the divide area between Long Alec Creek and Tonasket Creek, the quartz monzonite of Long Alec Creek complexly intrudes migmatite of the metamorphic rocks of St. Peter Creek. The quartz monzonite clearly intrudes the migmatite along fracture or joint planes which were formed later than the migmatite. The margins of the quartz monzonite contain randomly oriented blocks of metamorphic rocks; these inclusions suggest that magmatic stoping or forceful intrusion was effective during emplacement of the quartz monzonite.

Bodies of calc-silicate minerals that occur locally in the St. Peter Creek rocks along the quartz monzonite contacts are believed to represent contact metamorphic effects caused by the quartz monzonite.

LITHOLOGY AND PETROGRAPHY

The Long Alec Creek intrusive rocks are mostly quartz monzonite, though quartz latite porphyry and minor granodiorite are also included. Chemical analyses and modes of the principal rock varieties are given in table 4.

The quartz monzonite occurs mainly in two varieties, a coarse-grained porphyritic variety (fig. 7) and a medium-grained equigranular variety (fig. 8). Other minor varieties of slightly different textures are present also but are not characteristic. Quartz latite porphyry occurs as dikes and small irregular bodies. It is included with the Long Alec Creek rocks because in places it grades imperceptibly into the coarse-grained porphyritic quartz monzonite and hence is genetically related to these rocks. (See fig. 9.)

TABLE 4.—*Chemical analyses, modes, and norms of quartz monzonite of Long Alec Creek*

[Chemical analyses by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack; norms computed by J. O. Berkland]

	H9P-119	H9P-120	H6C-184
Chemical analyses (percent)			
SiO_2	66. 1	70. 3	65. 3
Al_2O_3	16. 5	16. 1	15. 2
Fe_2O_3	1. 7	. 7	1. 4
FeO	1. 5	1. 4	2. 2
MgO	1. 0	. 96	2. 1
CaO	2. 5	1. 9	3. 0
Na_2O	4. 1	4. 3	3. 5
K_2O	4. 8	3. 5	5. 2
H_2O	. 89	. 72	1. 1
TiO_2	. 49	. 32	. 54
P_2O_5	. 16	. 06	. 24
MnO	. 04	. 03	. 06
CO_2	. 39	. 08	. 31
Total	100. 17	100. 37	100. 15
Mode (volume percent)			
Quartz	14	24	------------
Plagioclase	43	45	------------
Orthoclase	33	24	------------
Biotite	7	6	------------
Others	3	1	------------
Total	100	100	------------
Norms (percent)			
Apatite	0. 3	------------	------------
Ilmenite	. 9	3. 0	0. 9
Magnetite	2. 6	------------	2. 1
Hematite	------------	. 6	------------
Rutile	------------	1. 7	------------
K-feldspar	28. 4	20. 6	30. 6
Albite	34. 6	36. 2	29. 3
Anorthite	11. 7	9. 4	10. 6
Diopside	------------	------------	3. 6
Hypersthene	3. 0	2. 4	5. 7
Quartz	17. 3	26. 5	15. 7
Corundum	. 3	1. 8	------------
Total	99. 1	102. 2	98. 5

H9P-119. Coarse-grained, porphyritic quartz monzonite from SE¼ sec. 4, T. 39, N., R. 34 E.
H9P-120. Medium-grained, equigranular quartz monsonite from same locality as H9P-119.
H6C-184. Quartz latite porphyry from NW¼ sec. 6, T. 39 N., R. 34 E.

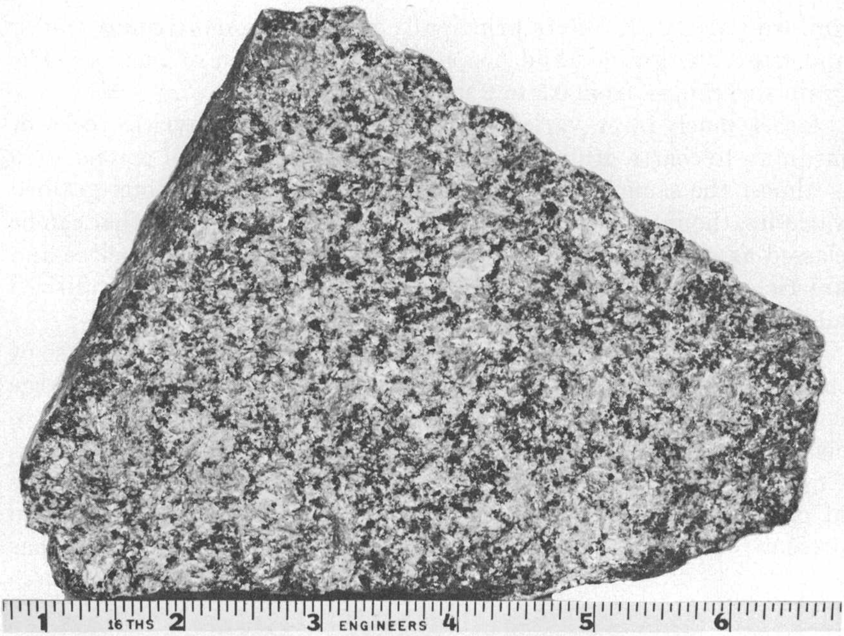

FIGURE 7.—Coarse-grained quartz monzonite of Long Alec Creek, showing pronounced porphyritic texture formed by large phenocrysts of pink orthoclase. Rock of this type occurs both within and without the Republic graben in a wide area east of Curlew. Specimen is from sec. 4, T. 39 N., R. 34 E.

The coarse-grained variety is in most places distinctly porphyritic; it contains large subhedral to anhedral phenocrysts of pink orthoclase that reach maximum lengths of 25 mm. Some orthoclase is poikilitic, enclosing smaller crystals of plagioclase and biotite; some large crystals have relict cores of plagioclase. Oligoclase crystals, which form about 45 percent of the rock, are subhedral and range from 0.6 to 5 mm in length. Commonly they are zoned, having more calcic cores (about An_{30}) and more sodic borders (about An_{20}). Quartz, which forms about 15 percent of the rock, is anhedral and fills interstices between other minerals and partly replaces them; some crystals are poikilitic and some exhibit undulatory extinction between crossed nicols. In hand specimen the quartz is smoke colored and contrasts distinctly with white plagioclase. Biotite, the most abundant accessory mineral, occurs in subhedral crystals, which in places are partly altered to chlorite. Less abundant hornblende is almost completely altered to chlorite and carbonate. Sphene, apatite, zircon, magnetite, and allanite are accessory minerals.

The medium-grained variety of quartz monzonite is light gray and equigranular. Under the microscope it is similar to the coarse-grained variety; it differs principally in that it is more equigranular and more fine grained and has a higher proportion of quartz. The grain size ranges from 0.5 to 2 mm.

Other much rarer varieties are fine-grained porphyritic rocks or medium- to coarse-grained equigranular rocks. Mineral composition is almost the same as in the coarse porphyritic and medium-grained varieties, though the rare medium- to coarse-grained rocks that can be classed as granodiorite contain a lower proportion of orthoclase and are richer in the mafic minerals, biotite, hornblende, and uralitized augite.

Quartz latite porphyry, which is considered a hypabyssal phase of the quartz monzonite, is grayish orange pink in overall hue. Large euhedral phenocrysts of pink orthoclase and white plagioclase (oligoclase-andesine) reaching lengths of more than 10 mm are abundant. Crystals of augite and hornblende, which are mostly altered to clots of chlorite and carbonate, and euhedral crystals of biotite are also present. The phenocrysts are set in a fine-grained matrix that has

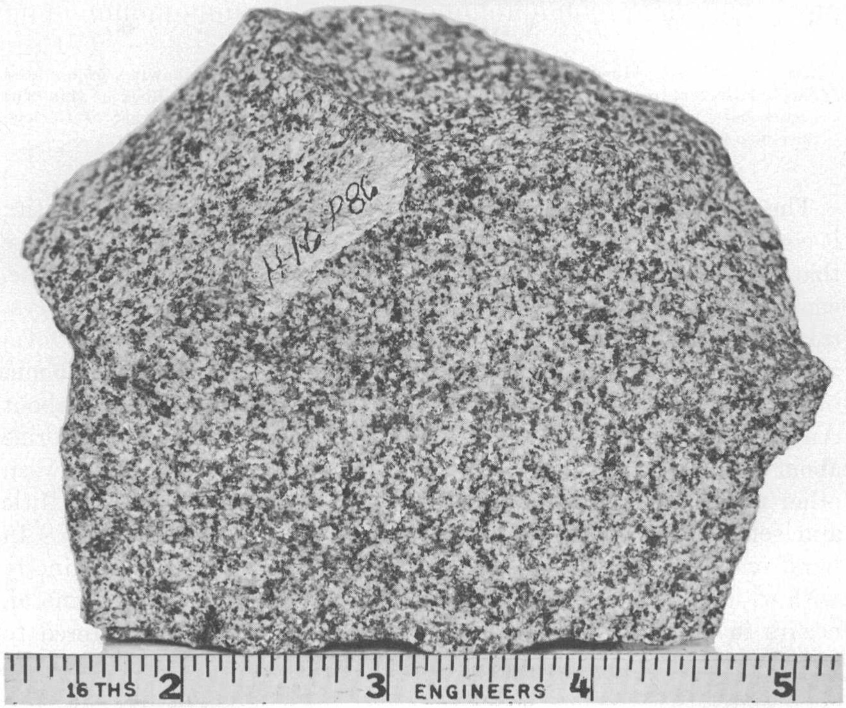

FIGURE 8.—Medium-grained quartz monzonite of Long Alec Creek, showing medium-grained equigranular texture. Specimen is from sec. 16, T. 39 N., R. 34 E., but similar rock occurs both within and outside the Republic graben in a wide area east of Curlew.

orthophyric texture. The matrix is composed principally of tiny, closely packed prisms of orthoclase, which are less than 0.1 mm long, and less abundant interstitial quartz which displays optical continuity in patches as much as 0.6 mm across. Minor accessories are apatite, magnetite, and zircon.

Minor variations in the porphyry occur from place to place. In some bodies abundant prismatic orthoclase crystals that reach lengths of 0.5 mm occur in the matrix, and in some large plagioclase crystals are rimmed by orthoclase. As the crystal size of the groundmass minerals increases, the porphyry grades into coarse-grained porphyritic quartz monzonite.

AGE AND CORRELATION

The quartz monzonite of Long Alec Creek is younger than the Scatter Creek Formation of Eocene or Oligocene age and older than the Klondike Mountain Formation of Oligocene age. The quartz mon-

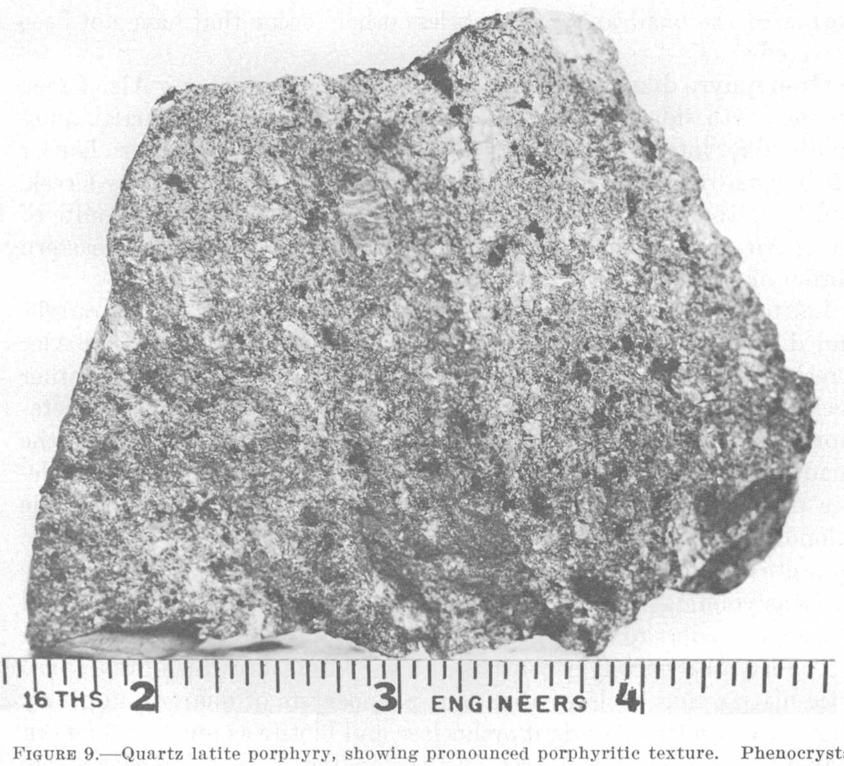

FIGURE 9.—Quartz latite porphyry, showing pronounced porphyritic texture. Phenocrysts are orthoclase, oligoclase-andesine, and biotite. Rock forms abundant dikes in the Republic graben and is related to the quartz monzonite of Long Alec Creek.

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zonite intrudes the older Scatter Creek Formation on the north side of West Deer Creek and on the south side of Long Alec Creek.

The quartz monzonite of Long Alec Creek is considered to be equivalent to the quartz monzonite of Herron Creek (Muessig and Quinlan, 1959). It is probably equivalent to parts of the quartz monzonite mass east of the Sherman fault in the Republic quadrangle which has been assigned a Cretaceous and Tertiary age by Muessig. All these rocks have the same general lithology and exhibit the same general field relations.

DIKES, UNDIVIDED

Many felsic, intermediate, and mafic dikes have not been distinguished separately on the geologic map, and relative ages are not precisely known. Dikes included are rhyolite and rhyolite porphyry, granophyre, and quartz monzonite, latite, andesite, and basalt. Descriptions of occurrences follow.

A single dike of rhyolite porphyry intrudes Permian and Triassic greenstone on Granite Mountain at the head of Empire Creek. A rhyolite dike intrudes the Sanpoil Volcanics in the extreme northwest corner of the quadrangle. Doubtless others occur that have not been detected.

Granophyre dikes intrude the quartz monzonite of Long Alec Creek on the north side of West Deer Creek near its mouth. Quartz monzonite dikes intrude the Scatter Creek Formation at the eastern border of the quadrangle on the north side of the North Fork of Day Creek, and some that are not shown on the map cut the quartz monzonite of Long Alec Creek on the south side of Long Alec Creek at the eastern border of the quadrangle.

Latite, andesite, and basalt dikes are scattered over the quadrangle, and dikes of these types intrude the quartz monzonite of Long Alec Creek, the Scatter Creek Formation, the Sanpoil Volcanics, and other rocks. Especially prominent is a latite dike that cuts the metamorphic rocks of Tenas Mary Creek at the western border of the quadrangle on the south side of the Kettle River valley. Many andesite dikes resemble the porphyritic andesite dikes that intrude the Klondike Mountain Formation. The andesite and the porphyritic andesite dikes, as well as some dikes of latite and basalt which intrude rocks as young as the quartz monzonite of Long Alec Creek, may well represent feeders to flows in the Klondike Mountain Formation.

The rhyolite porphyry consists of a very light brownish gray aphanitic matrix that encloses abundant phenocrysts of quartz and glassy oligoclase and less abundant orthoclase and biotite as much as 3 mm in diameter. Under the microscope the matrix is a microcrystalline intergrowth composed principally of orthoclase and less abundant sodic plagioclase and quartz (?). The rhyolite is similar to the rhyolite porphyry except that phenocrysts are much less abundant; the rhyolite contains spherulites.

The granophyre is pale gray to pale pinkish gray and visibly granular though very fine grained. A few phenocrysts of oligoclase, quartz, and biotite, all less than 1 mm long, are contained in a matrix consisting principally of a granophyric intergrowth of quartz and orthoclase. Minor constituents are tiny grains of epidote and widely scattered aggregates of carbonate and chlorite that are pseudomorphic after a former mafic mineral.

The quartz monzonite dikes are very light gray and are visibly granular. They differ from the granophyre in their more obvious porphyritic texture and in their groundmass texture as seen under the microscope. The granophyric intergrowth is absent and in its place is a granular quartz-orthoclase intergrowth in which quartz is commonly in optical continuity over several grains. Phenocrysts of oligoclase and quartz are mostly less than 2 mm across. The plagioclase is serictized, and former biotite and hornblende have been altered to chlorite, carbonate, and minor leucoxene.

The latite dikes are characteristically porphyritic and commonly are shades of light greenish gray and light brownish gray. The groundmass of most latite is aphanitic, but some is very finely granular. The most abundant phenocrysts are plagioclase (oligoclase or oligoclase-andesine) which in most occurrences is partly altered to sericite. Some former mafic phenocrysts, including some biotite, have been altered to chlorite and a carbonate mineral. The groundmass of the latite, as seen under the microscope, is composed of abundant plagioclase laths that display a trachytoid texture or show a rudimentary parallelism. Interstices of the laths are filled with finely crystalline orthoclase and quartz. Minor accessories disseminated in the rock are magnetite, sphene, epidote, and apatite. The latite dikes are indeed similar in lithology to latite and quartz latite flows in both the Sanpoil Volcanics and the Klondike Mountain Formation.

Andesite and basalt dikes are dense aphanitic rocks, some of which contain phenocrysts of mafic minerals that have been partly or completely altered to aggregates of chlorite, calcite, and magnetite. Phenocrysts of plagioclase are less conspicuous. Some dikes contain orthopyroxene crystals, which are clustered together to produce glomeroporphyritic texture, and some rocks contain pseudomorphs of serpentine and chlorite after former euhedral olivine crystals. The aphanitic groundmass of these rocks is characterized by closely spaced plagioclase laths whose arrangement gives a felty texture. Interstices are filled with granules of mafic minerals which in most occurrences are partly or wholly altered to chlorite and carbonate. Magnetite dust is abundantly dispersed.

KLONDIKE MOUNTAIN FORMATION

GENERAL FEATURES

The Klondike Mountain Formation (Muessig, 1962) is the youngest bedrock formation in the Curlew quadrangle. It underlies a large part of the mountainous area between the Bacon Creek fault and Curlew Creek in the southern two-thirds of the quadrangle. The lower part of the formation is composed of coarse to fine clastic and pyroclastic material and minor flows. The upper part of the formation, which prominently caps Mount Elizabeth and Franson Peak, consists principally of dark glassy flows containing minor clastic and pyroclastic material. These parts of the formation have been separately distinguished on the geologic map (pl. 1).

The Klondike Mountain Formation rests unconformably on the Sanpoil Volcanics and on older rocks where these volcanics are absent. The unconformity, though nowhere well exposed, is clearly indicated by the overlapping nature of the formation on various older rocks—Permian and Triassic greenstone and limestone, Cretaceous(?) intrusive rocks, and Sanpoil Volcanics. The various elevations along the base of the Klondike Mountain Formation also indicate that these volcanic rocks were deposited upon a surface of high relief. The older rocks are more highly deformed than the volcanic rocks of the Klondike Mountain Formation.

An unconformity of unknown magnitude occurs within the formation between the lower, dominantly clastic and pyroclastic unit and the upper, dominantly flow unit. Evidence of an unconformity can be seen on the south slope of Mount Elizabeth, where relief on the base of the upper unit is approximately 1,000 feet in a lateral distance of only a mile. This unconformity is probably not indicative of a great time break; the upper and lower members have certain lithologic similarities, and both are probably related to the same general volcanic episode. The possibility exists, however, that the unconformity is a major one.

In general the formation is little deformed. In most places the beds of the formation dip gently; however, on the east slope of Franson Peak, beds are inclined as much as 70°, probably owing to drag along a fault concealed by glacial deposits in the valley to the east. The Bacon Creek fault and parallel faults along the west side of the area of outcrop also cut the formation. The outcrops pattern shown by members of the formation, especially south of Mount Elizabeth, indicates a shallow synclinal structure trending northward through Mount Elizabeth (pl. 2).

LITHOLOGY AND PETROGRAPHY

The Klondike Mountain Formation has been separated into lower and upper units for purposes of mapping and description. A thin bed of black glass that occurs at the base of the lower unit also has been separately mapped in order to bring out the gently dipping character of the beds.

LOWER UNIT

The lower unit is variable in thickness; it is at least 2,000 feet thick on the east side of Mount Elizabeth, but nearby, at the 3,250-foot contour on the northeast side of Mount Elizabeth, the lower unit is only about 50 feet thick. Evidently the flows were desposited upon a surface of considerable relief. In addition to the black glass at the base, the lower unit consists of poorly sorted tuff-breccia and volcanic conglomerate and well-bedded tuffaceous conglomerate, sandstone, and mudstone. It contains also a few minor interspersed flows principally of porphyritic latite.

The dominant lithologies in the lower half of the lower unit are tuff-breccia and volcanic conglomerate, in contrast to the lithologies of the upper half where these materials are much less abundant. These rocks form massive, indistinctly bedded layers which grade into one another. The principal difference between layers is the degree of roundness or angularity of their contained fragments. Individual layers are colored mostly in pastel shades of green and purple and contain fragments ranging from tiny grains to blocks and boulders that exceed a foot in diameter. The fragments, principally light brownish gray, pale green, and shades of purple, are mostly porphyritic latite, though fragments of tuffaceous sandstone and mudstone, some of which were deformed prior to their complete lithification, are sparsely distributed. The matrix consists of closely packed crystal fragments and latite particles that in some layers are water sorted and streaked out into lenses; slight stratification is thus imparted to the rock. Near the top of the lower unit, layers of tuff breccia contain fragments of olive-colored, vaguely porphyritic or aphanitic rock in a tuffaceous matrix of disintegrated volcanic material of nearly the same color. In places this rock is laced with veinlets of chalcedony.

Interbedded tuffaceous conglomerate, sandstone, and mudstone form most of the upper half of the lower unit, as well as a few lenses in the lower half. These rocks are dusky yellow to grayish olive and are massive bedded to thin bedded. Tuffaceous sandstone beds are composed of angular grains of plagioclase, fragments of volcanic rock and chert, shreds of biotite, and a few grains of quartz. Sandstone beds commonly grade upward into thin layers of mudstone, which in some places contain fragments of fossil plants.

Tuffaceous conglomerate varies in composition from place to place depending on the terrane that furnished the detritus. Some conglomerate beds in the upland area west of Curlew Lake contain abundant well-rounded pebbles of quartzite, phyllite, chert, and quartz in a matrix composed of abundant white rhombic feldspar fragments, rock particles, and quartz grains. Conglomerate along the western edge of the area of outcrop a mile west of Mount Elizabeth, which more aptly should be termed "breccia" because of the preponderance of angular fragments, contains fragments of greenstone, phyllite, quartzite, chert, argillite (Permian and Triassic), coarse-grained intrusive rocks (Cretaceous?), porphyritic volcanic rock (Sanpoil(?) Volcanics), and sandstone and pebble conglomerate (O'Brien Creek(?) Formation). These fragments, some of which exceed a foot in diameter, are enclosed in a matrix of olive-colored clayey material that is weakly resistant to weathering.

Thin flows of porphyritic latite, which are similar in lithology to many flows in the underlying Sanpoil Volcanics, are sparsely distributed. Near the top of the lower unit a few amygdular flows, possibly more mafic than latite, are interlayered with the tuffaceous sandstone and tuff-breccia.

Most of the tuff-breccia and volcanic conglomerate is believed to have originated as volcanic mudflows. This interpretation is based on the presence of both rounded and angular fragments in these rocks, on their massive, poorly sorted, poorly bedded structure, on the presence of local water-sorted lenses, and on the deformed nature of some included mudstone fragments thought to have been plastic at the time of formation and to have been distorted by the flowing of the mass.

The tuffaceous conglomerate, sandstone, and mudstone certainly were water laid. Well-bedded conglomerate, sandstone, and mudstone were deposited in bodies of water, as suggested by the degree of sorting and the presence of graded bedding in some layers. Poorly sorted conglomerate and breccia may have been deposited in alluvial fans or may have been deposited rapidly in bodies of water near the source of the material.

UPPER UNIT

The upper unit is extremely variable in thickness from place to place. It is at least 1,200 feet thick on Mount Elizabeth, about 700 feet thick on Franson Peak, and about 200 feet thick on Granite Mountain.

It is composed principally of mafic flows and flows of intermediate composition and contains small quantities of tuff-breccia.

The flow rocks are mostly aphanitic and glassy and have only a small proportion of phenocrysts; some are extremely vesicular. Flow rocks range from dark gray or black in glassy types, to yellowish gray or brownish gray in the crystalline and stony types. The glassy rocks predominate.

Under the microscope typical glassy rocks are seen to consist of about 85 percent light-brown glass which contains abundant needle-like microlites of plagioclase (andesine-labradorite). The remaining 15 percent of the rock is composed of phenocrysts and microphenocrysts of labradorite, enstatite, brown hornblende, magnetite, and minor augite.

The index of refraction of the natural glass is slightly less than 1.54 and that of artificial glass, fused from a sample of the rock, about 1.55. These data, if applied to the curves of George (1924) and Mathews (1951), roughly indicate a silica content of 55–60 percent. On the basis of the phenocrysts and the silica content the rock is tentatively classed as calcic andesite.

A microcrystalline rock typical of thick flows on the south side of Mount Elizabeth is almost devoid of phenocrysts; only a few microphenocrysts of biotite and augite are present. The rock is composed principally of needlelike microlites of oligoclase in an arrangement which produces a felty texture. Irregular-shaped concentrations of light yellowish-brown granules and tiny unidentified mafic microlites form less than 15 percent of the rock. Magnetite and hematite(?) dust are abundant and well disseminated.

The index of refraction of fused samples of this rock is about 1.52, which, according to the curves of Mathews (1951), indicates a silica content in the range of 64 to 67 percent. Such a silica content supported by the sodic nature and abundance of the plagioclase tentatively classifies the rock as dacite.

Minor tuff-breccias are interlayered with flows in the upper part of the formation in the area west of Mount Elizabeth. They are similar in composition and texture to tuff-breccias in the lower part of the formation.

AGE AND CORRELATION

The Klondike Mountain Formation is continuous with exposures of the formation in the adjoining Republic quadrangle on the south. Plant fossils in the Tom Thumb Tuff Member (Muessig, 1962) were identified as Oligocene in age by R. W. Brown. The Tom Thumb Member, a basal member, is not present in the Curlew quadrangle.

In the Curlew quadrangle, fragmentary plant fossils were obtained from tuffaceous mudstone at the top of the lower unit on the east slope of Mount Elizabeth (west-central part of sec. 16, T. 38 N., R. 33 E.). These plant fossils were identified by Brown as follows (written commun., 1958):

Metasequoia occidentalis (Newberry) Chaney
Pinus sp.
Comptonia columbiana Dawson

Brown commented: "Most of the specimens in this lot are *Comptonia columbiana*, but this species and other fragments are duplicated in the collections from Republic and vicinity. My opinion, therefore, is that the age is Oligocene."

The upper part of the Klondike Mountain Formation has yielded no fossils. It may be Oligocene or younger in age, depending largely on the time interval represented by the unconformity at its base.

Similar pyroclastics and flows, in Canada, have been assigned by Daly (1912) and by Drysdale (1915) to the Midway Volcanic Group, which also includes older rocks correlative with the Sanpoil Volcanics of this report. Little (1957) called the Midway Volcanic Group the Phoenix Volcanic Group. Possibly some of the flows in the upper part of the Klondike Mountain Formation are correlative with the widespread Columbia River Basalt of Miocene and Pliocene(?) age. The Klondike Mountain rocks are generally similar in lithology and stratigraphic position to flows (including black glass) and coarse to fine clastic rocks that were described by Bowman (p. 85–97; see footnote 3, p. 24) in the Orient area about 20 miles east of Curlew.

PORPHYRITIC ANDESITE DIKES

Several north-northeast-trending dikes are concentrated in the vicinity of Granite Mountain at the head of Empire Creek. These dikes intrude Cretaceous(?) quartz monzonite and Permian and Triassic greenstone as well as some overlying flows of the Klondike Mountain Formation. Though they are not brecciated themselves, some dikes cut brecciated greenstone.

The dikes are pale yellowish-brown to brownish-gray aphanitic rock that has been classed tentatively as andesite. The rock is commonly porphyritic and some is amygdular. Phenocrysts are mostly unaltered calcic andesine as much as 5 mm wide. Minor crystals of former pyroxene have been altered to aggregates of chlorite and carbonate; the amygdules too, are mostly chlorite and carbonate. The aphanitic groundmass is composed principally of tiny laths of andesine whose arrangement gives a trachytoidal texture. Abundant carbonate and chlorite fill the interstices, and tiny subhedral crystals of magnetite are abundantly disseminated.

These dikes clearly cut some of the flows at the base of the upper part of the Klondike Mountain Formation and may represent feeders to some calcic andesite flows in the upper part of the formation or to flows that have been removed by erosion.

QUATERNARY DEPOSITS

Glaciofluvial deposits, consisting of stratified drift and till of Pleistocene age and alluvium of Recent age, cover a large part of the Curlew quadrangle. Stratified drift in the form of kame terraces, eskers(?), and outwash partly line the valleys of the Kettle River and Curlew Creek and their major tributary valleys. Alluvium partly covers the valley floors, but it is mostly reworked glacial material and, in this report, is not mapped separately.

KAME TERRACES

Probably the most striking glacial deposits in the quadrangle are the kame terraces that occur along both sides of the Curlew Creek valley and especially around Curlew Lake. A few kame terraces also remain on the valley sides in the Kettle River valley just west of Curlew and west of Danville.

The terraces commonly have almost flat tops and are pocked with numerous kettles. Where exposed by roadcuts, the terraces consist of well-stratified clay, silt, sand, and gravel in which crossbedding and abrupt lensing of beds are conspicuous.

The terraces occur over a considerable range in elevation but most are below 2,750 feet. The prominent terraces in the Curlew Creek valley have surfaces between 2,500 and 2,600 feet in elevation, though less prominent terraces occur at both higher and lower elevations. The terraces in the Kettle River valley occur at the 2,500-foot level and slightly above and below the 2,000-foot level.

According to Flint (1947, p. 146), the kame terraces formed alongside stagnant tongues of ice that lay in the Kettle River and Curlew Creek valleys. These terraces were built up by sediment deposited and sorted by marginal streams which flowed between the ice and the valley walls. The streams were fed mainly by melting ice and most sediment was derived from debris carried by the ice itself, though some no doubt came from other sources. Successive lower terraces mark stages in the wasting away of the ice. A bedrock floor (elev. 2,430 ft) in the Sanpoil Valley south of Sanpoil Lake (S. J. Muessig, written commun., 1960) may have acted as a temporary base level for a south-flowing drainage in the Curlew Creek valley and may be the reason for the extensive occurrence of terrace deposits between elevations of 2,500 and 2,600 feet.

ESKERS(?)

Narrow ridges of stratified clay, silt, sand, and gravel having the form of eskers occur on the west side of Curlew Creek just north of the mouth of Empire Creek and between Karamin and the mouth of St. Peter Creek. These features are interpreted as having been formed by the deposition of sediments in longitudinal fissures in the ice blocks by percolating glacial melt water. Certainly they are closely related to kame terraces in origin, and possibly they are only terraces that were modified shortly after their formation by streams flowing along their margins.

OUTWASH

The stratified drift filling many tributary valleys of Curlew Creek and the Kettle River has no specific topographic form. Much of it merges with kame terraces, especially in the Curlew Creek valley, and should probably be considered as merely upstream extensions of the terraces.

TILL

Till, or unstratified drift, constitutes a large part of the glacial deposits; it mantles slopes and fills gullies on some of the highest mountains in the quadrangle. It merges with outwash, kame terraces, and other glacial deposits and cannot be sharply separated except by differences in topographic form. The till ranges in thickness from a fraction of a foot to at least many tens of feet and consists of poorly sorted material ranging in grain size from clay to boulders.

ORIGIN OF GLACIAL DEPOSITS

The stratified glacial deposits are ascribed to the wasting stages of the Cordilleran ice sheet that last covered the region in the late Pleistocene. Kame terraces, eskers, and outwash deposits are sufficiently young that in many places they are almost unmodified by erosion even on the floor of the valleys.

The ice sheet was as much as 6,700 feet thick in this area according to Flint (1947, p. 208), and only the highest peaks in the Kettle Range south and east of the quadrangle projected from the ice as nunataks. The ice occupied previously established valleys, which it locally deepened and widened during its advance.

STRUCTURE

The Curlew quadrangle contains three principal structural elements, the Republic graben and the relatively raised blocks on either side. North- to northeast-trending boundary faults separate the graben from the relatively raised blocks. The blocks contain northwest-trending structures, whereas the graben, except for some parts north of Curlew, is characterized by northerly trending structures.

Another major northeast-trending fault crosses the extreme northwest corner of the quadrangle. The fault separates the metamorphic rocks of Tenas Mary Creek on the southeast from a large mass of Sanpoil(?) Volcanics that is exposed along the Kettle River for about 10 miles west of the quadrangle. Along the fault and between the volcanics and the Tenas Mary Creek rocks is a one-fourth-mile-wide zone composed of brecciated Scatter Creek Formation and Permian and Triassic greenstone. In places the breccia is sheared and has the appearance of fault breccia. According to Robert C. Pearson (oral commun., 1963) this zone of breccia thickens greatly, is not sheared, and interfingers with normal sediments in the adjoining Bodie Mountain quadrangle. Thus it possibly is not tectonic breccia, but represents debris that slumped from nearby highlands into areas depressed along the fault.

BLOCKS BORDERING GRABEN

The metamorphic rocks of Tenas Mary Creek in the western relatively raised block and the metamorphic rocks of St. Peter Creek in the eastern, relatively raised block are characterized by the low dips and broad folds that trend northwest. The folds are outlined in a general way by the trend of the foliation planes and, in the Tenas Mary Creek rocks, by the outcrop pattern of the individual units as well. Two anticlines separated by a shallow syncline are formed in the Tenas Mary Creek rocks. The most prominent fold is the anticline whose northwest-plunging axis follows a segment of the Kettle River in the western part of the quadrangle (pl. 1). Three northwest-trending anticlines are recognizable in the St. Peter Creek rocks (pl. 1). Two of them, located in the extreme southeast corner of the quadrangle, are separated by a fault. The third anticline defines the structure of the northernmost outcrop area of St. Peter Creek rocks.

Most of the minor fold axes in the Tenas Mary Creek rocks plunge northwest and correspond in direction to the major fold axes. Data on fold axes in the St. Peter Creek rocks are not sufficient to draw definite conclusions, but some axes, though not all, plunge northwest also and correspond in direction to the major fold axes. Probably the Tenas Mary Creek and St. Peter Creek rocks have had a common structural history.

Few large faults are recognized in the relatively upthrown blocks. Three miles west of Little Vulcan Mountain, a northeast-trending fault cuts some of the Tenas Mary Creek rocks. In the eastern block near the southeast corner of the quadrangle, a northwest-trending fault separates the marble unit of the St. Peter Creek rocks from the quartzite unit.

REPUBLIC GRABEN

The Republic graben, situated between the two relatively upraised blocks, is the dominant structure in the Republic quadrangle to the south. It extends southward into the Colville Indian Reservation and northward into the Curlew quadrangle and leaves this quadrangle at the northeastern corner. To the north, just beyond the international boundary, the graben loses its identity.

The generalized picture of the structure in the Republic graben is that of a downdropped block bounded by normal faults which range in trend from north to slightly east of north. The structural elements in the graben are faults, dikes, and stratification planes within remnants of the intruded country rocks. With exceptions in a few areas, these structural elements are generally parallel to the north-trending boundary faults. A large proportion of the remnants of country rocks are elongate in this same direction.

This generalized picture becomes quite complex in detail, however, owing to complicated faulting along the eastern boundary of the graben, to changes in displacement along the boundary faults, and to many north-trending faults within the graben. In addition, most of the direct stratigraphic continuity is lost because of complex intrusion, and concealment by glacial deposits limits stratigraphic data available for evaluating the structural details within the graben.

BOUNDARY FAULTS

The Bacon Creek fault is the boundary fault on the west side of the Republic graben, and the Sherman, St. Peter, and Drummer Mountain faults are the boundary faults on the east side of the graben. All the boundary faults except the St. Peter fault dip steeply, as shown by their almost straight surface traces. The St. Peter fault dips steeply in its southern part but becomes more gently dipping towards the north. The vertical component of movement along the edges of the graben is large but decreases northward. The extent of lateral movement betwen the graben and the adjacent blocks is not known but is thought to be small.

The Bacon Creek fault, named for Bacon Creek in the southwestern part of the quadrangle, trends in a north to northeast direction and can be traced for more than 30 miles. It extends the full length of the Curlew quadrangle and for at least 13 miles farther south into the Republic and Wauconda quadrangles. Northward, the fault apparently dies out only a short distance beyond the international boundary.

The Bacon Creek fault is a single fault confined to a narrow fault zone, and, in comparison to the boundary faults along the east side of the Republic graben, is remarkably uncomplicated by subsidiary branching faults. It is expressed topographically by stream valleys, gullies, and notched spurs, and physically by a breccia zone and by contrasting rocks on either side of it. Where it crosses the Kettle River, the stratigraphic throw on the fault is large, representing the entire thickness of the Tenas Mary Creek rocks (about 17,000 feet) plus an unknown thickness of Permian and Triassic and younger rocks. North of the Kettle River the displacement along the Bacon Creek fault decreases rapidly, and 1 mile beyond the international boundary no stratigraphic throw can be recognized.

The Sherman, St. Peter, and Drummer Mountain faults define most of the eastern edge of the Republic graben within the Curlew quadrangle. A fourth fault becomes the boundary fault just east of Drummer Mountain, and it increases in prominence in the adjacent Togo Mountain quadrangle.

The Sherman fault, although it is a single well-defined fault in the adjacent Republic quadrangle, dies out in the southern part of the Curlew quadrangle. The northward decrease in displacement of the Sherman fault is shown by the presence of Permian and Triassic rocks on both sides of its northern extremity (pl. 1).

Where the Sherman Fault dies out, the displacement is transferred to the St. Peter fault one-half mile to the east. The combined displacement in the overlap area is probably equal to the displacement of either fault away from the overlap area. The St. Peter fault is interpreted as joining the Sherman fault at the South Fork of St. Peter Creek, but concealment by superficial deposits prevents certainty on this point; it could be considered as a branch of the Sherman fault. The St. Peter fault extends northward for about 5 miles, then swings northwest where it probably dies out. The southern part of the St. Peter fault dips steeply to the west, as indicated by its surface trace. Northward, however, it dips more gently, measuring 40° at its northern extremity. The south half of the St. Peter fault is defined by a breccia zone of quartz monzonite. The quartz monzonite is restricted to the fault, and in one place the breccia zone is 700 feet wide. It is considered to belong to the quartz monzonite of Long Alec Creek and may represent a fault slice. Brecciated quartz monzonite is extensive also to the north in parts of sec. 9, T. 38 N., R. 34 E.

Vertical displacement along the Drummer Mountain fault reaches a maximum between West Deer Creek and Aeneas Creek and decreases to the north and south. Horizontal displacement also may have occurred, but the data are scanty and conflicting. Between Long Alec Creek and West Deer Creek, right lateral movement is suggested by an offset Tertiary dike. However, the offset segments on either side of the fault may actually be parts of different dikes. The north contact of the quartz monzonite of Long Alec Creek shows a left lateral offset of 2 miles. The south contact between Long Alec Creek and Tonasket Creek shows offset of about 4 miles in the opposite direction. If that part of the Long Alec Creek batholith west of the Drummer Mountain fault is a northwest-plunging nose, then the lateral offset of both north and south contacts can be the result of vertical movement on the fault.

The boundary faults and the general shape of the graben were established before or during the deposition of the O'Brien Creek Formation, that is, in early Tertiary time. Huge boulders of granodiorite which occur in the O'Brien Creek Formation along the edge of the graben in the Republic quadrangle (S. J. Muessig, written commun., 1960) indicate that the bordering areas were already elevated at that early date and that some crystalline rocks had already been exposed to erosion.

Movements along the boundary faults continued, probably intermittently, until well after the rocks of the Klondike Mountain Formation were deposited. Such movement is shown by the fact that Klondike Mountain rocks are faulted against the metamorphic rocks of Tenas Mary Creek along the Bacon Creek fault just north of the Kettle River.

OTHER FAULTS

Many other steep normal faults occur in the graben. Most of them are close to, and trend in the same direction as, the boundary faults. They probably represent local adjustments of individual blocks within the graben. A north-trending fault probably extends along the west side of Curlew Creek between Empire Creek and the Kettle River. The fault is concealed by glacial deposits, but its existence is indicated by a zone of steeply upturned beds in the lower part of the Klondike Mountain Formation. Only two east-west trending faults have been observed in the graben, one 2 miles west of Mount Elizabeth and the other on the south side of the South Fork of Day Creek.

FOLDS

Unequivocal folds in the Tertiary rocks are not found in the graben, with the exception of the poorly defined syncline in the Klondike Mountain Formation between Mount Elizabeth and Franson Peak. This syncline, however, is quite gentle and could be interpreted as a sag structure related to subsidence of the graben. Pairs of folds are not observed, as would be expected if the rocks in the graben had been subjected to compression. It seems likely that the tilted position of the remnants of country rock is related to movements along the graben faults and to adjustments of individual blocks during the subsidence of the graben.

Folding took place in the Permian and Triassic rocks during their metamorphism, but later faulting, subsidence of the graben, and intrusion have disrupted these structures considerably. Small folds can be seen in limestone bodies along the Kettle River north of Curlew. A broad arching structure extending from the Drummer Mountain fault to the Kettle River is outlined by isolated limestone masses in the area north of West Deer Creek.

DISTRIBUTION OF ROCKS IN THE GRABEN

Because most stratified rocks in the Republic graben are extensively intruded by Scatter Creek rocks, little detailed stratigraphic information is available to aid in the structural interpretation within the graben. Areas of extensive intrusion within the graben are found mostly along the east side of the graben south of Curlew and throughout the graben north of Curlew. Most widely intruded are the Permian and Triassic rocks and the the O'Brien Creek Formation. The Sanpoil Volcanics is intruded to a lesser degree.

As shown on the geologic map (pl. 1), the distribution of the remnants of country rocks in the graben are grouped together into areas which are made up exclusively of single formations or stratigraphic units. Along the east side of the graben these areas form north-trending belts which are also arranged in normal sequential stratigraphic order, that is, a belt of Permian and Triassic remnants is found along the eastern graben border, a belt of remnants belonging to the O'Brien Creek Formation is next to the west, and this belt is followed by the Sanpoil Volcanics, which is intruded only along its eastern margin. The trend of the elongated remnants of country rock is generally northward, parallel to the belts. The bedding planes within the remnants of the O'Brien Creek Formation strike north or northeast, for the most part, and dip steeply to the west. In addition, the tops of these beds, as determined by graded bedding, are consistently to the west.

The remnants of Permian and Triassic rocks in the graben do not show the consistent trends in bedding that are shown by the O'Brien Creek rocks. The variety of bedding attitudes reflect mostly the folds and other structures that are connected with the earlier deformation and metamorphism of the Permian and Triassic rocks and are not related to the formation of the graben.

In a general way, at least, the groupings of the various types of country rocks present a picture of the areal distribution of the stratigraphic units as they were prior to the intrusion of Scatter Creek rocks. (See pl. 2.) If intrusions were accomplished by complete replacement of the intruded country rock, that is with no expanding effects, then the present width of the stratigraphic belts would represent the true outcrop width of the stratigraphic units as they were prior to the intrusions. Aside from later faulting, this picture may be fairly accurate, because the southern continuations of these belts in the adjacent Republic quadrangle are of comparable width even though the country rocks are much less extensively intruded (Muessig and Quinlan, 1959).

As inferred from the remnants of the country rock, the Scatter Creek intrusions apparently had little effect in disrupting the preexisting structure in the graben. The remnants are regarded as roof pendants, mostly undisturbed by the intrusions, rather than as free-floating inclusions whose orientations were controlled by factors related to intrusion, such as magmatic flowage. In some places, however, this simplified picture is probably complicated by the spreading-out effect of the intrusions and by the shifting about of some free-floating inclusions.

The Permian and Triassic rocks in the Granite Mountain-Mount Elizabeth-Franson Peak area comprise one or more blocks that probably remained relatively elevated during much of the history of the graben. This area within the graben was elevated and perhaps was eroded sometime prior to the deposition of the flows in the upper part of the Klondike Mountain Formation. The absence of the normally underlying O'Brien Creek Formation, Sanpoil Volcanics, and clastic rocks of the lower part of the Klondike Mountain Formation beneath the flows and the lapping of the rocks of these formations onto the Permian and Triassic rocks are reasons for this conclusion. Relief on the unconformity is about 1,000 feet in the area on the north side of Empire Creek.

The belt occupied by remnants of the O'Brien Creek Formation between St. Peter and Art Creeks is about 13,000 feet wide. The reason for such a great breadth of outcrop is unknown, but it may be due to the combined effects of local folding, intrusion, and movement along the Drummer Mountain fault.

The Republic graben is interpreted as having resulted from block subsidence and concomitant vulcanism. Subsidence of the graben and accompanying outpouring and deposition of volcanic materials began with or preceded the Eocene(?) (O'Brien Creek Formation) and continued during or after the Oligocene (Klondike Mountain Formation). The chronologic development of the graben is described under "Geologic history," p. 83, and is similar to that outlined by Staatz (1960). During the development of the graben at least part of the Sanpoil Volcanics was introduced by the Scatter Creek Formation (considered in part an intrusive equivalent of the Sanpoil), and later the Sanpoil, Scatter Creek, and older rocks were intruded by quartz monzonite of Long Alec Creek. As the graben subsided, the rocks within it broke into blocks, and cumulative tilting and displacement among the blocks resulted in the present general structure.

In the adjoining Republic quadrangle, a different interpretation of the structure in the Republic graben has been suggested by S. J. Muessig (oral commun., 1959). He proposed that on the east side of the graben the threefold sequence of rocks, consisting of Permian rocks, the O'Brien Creek Formation, and the Sanpoil Volcanics, has been thrust southeastward about 4½ miles from its counterpart in the area around Curlew Lake.

DIKE TRENDS

The dikes in both the Republic graben and the adjacent blocks tend to outline structural directions. Some dikes are believed related to the formation of the graben; others are believed to be related to both prior and subsequent events.

The oldest dikes which probably predate the formation of the graben, are those of syenite porphyry of the alkalic rocks of Shasket Creek. These dikes trend west-northwest parallel to structural trends in the metamorphic rocks bordering the graben, but contrary to other dikes and structural trends in the graben.

The trends of dikes of the Scatter Creek Formation are not illustrated well in the graben, but in the western uplifted block in the northwest quadrant of the quadrangle, fine-grained quartz monzonite-granodiorite dikes that are believed to belong to the formation are parallel in a general way to the north-northeast trend of the graben faults. The intrusion of these dikes was clearly more recent than the metamorphism of the rocks that they cut. The dikes were probably intruded along zones of weakness set up by stresses that were responsible for the formation of the graben. Minor displacement occurs along some of the dikes.

The common north-northeast trend of quartz latite and other dikes in the area between Aeneas Creek and the international boundary is conspicuous. Most dikes in this area, both within and outside the graben, trend remarkably parallel to the trend of the graben faults. A few dikes, in the area north of Curlew, have contrary northwest trends that parallel the elongation of serpentine bodies, the orientation of roof pendants and inclusions, and the inferred contact of the Sanpoil Volcanics.

Porphyritic andesite dikes that probably are related to the Klondike Mountain Formation are also parallel to the graben border faults in the area at the head of Empire Creek.

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REGIONAL METAMORPHISM

Regional metamorphism has affected the Tenas Mary Creek rocks, the St. Peter Creek rocks, and the Permian and Triassic rocks. The present metamorphic state of all these rocks represents a period of metamorphism that occurred in post-Triassic time. The Tenas Mary Creek rocks and the Permian and Triassic rocks represent a continuous metamorphic series that ranges from almandine amphibolite facies to greenschist facies.

Randomly oriented fragments of quartzite and phyllite in the Permian and Triassic conglomerate beds may be indicative of metamorphism in this region before Triassic time. Metamorphism in the Precambrian is reported in the Coeur d'Alene district, Idaho (Eckelmann and Kulp, 1957, p. 1130; V. C. Fryklund, oral commun., 1959), and rocks related to this period of metamorphism may have served as source material for parts of the Permian and Triassic sedimentary rocks. It seems more likely, however, that these fragments represent sandstone and shale fragments derived from earlier Permian and Triassic rocks and metamorphosed after their incorporation into the conglomerate.

METAMORPHIC ROCKS OF TENAS MARY CREEK AND PERMIAN AND TRIASSIC ROCKS

The general sequence of mineralogical changes resulting from the decrease in degree of metamorphism can be traced in the Tenas Mary Creek and Permian and Triassic rocks. Most of the Tenas Mary Creek rocks lie in the almandine amphibolite facies (Turner, in Fyfe, Turner, and Verhoogen, 1958), but most of the phyllite and all the Permian and Triassic rocks belong to the greenschist facies. The observed range of metamorphic minerals and other features that illustrate the metamorphic changes from unit to unit are shown in figure 10.

Biotite occurs throughout the Tenas Mary Creek rocks. It is well formed and deep reddish brown in the lower units, green in the upper part of the quartz-plagioclase gneiss, green and greenish brown in fine flakes in the schist, and brown in fine ragged shreds in the phyllite and Permian and Triassic units. Muscovite is rare in the lower gneiss, the potassium occurring principally in orthoclase. Muscovite occurs sparingly in the marble and quartzite, but is a characterizing accessory in the quartz-plagioclase gneiss. The potassium mica, which is fine-grained muscovite and sericite in the schist, changes to fine, ragged sericite in the phyllite.

Pink garnet is an accessory constitutent in all units including the basal parts of the phyllite; none was observed above the basal parts of the phyllite.

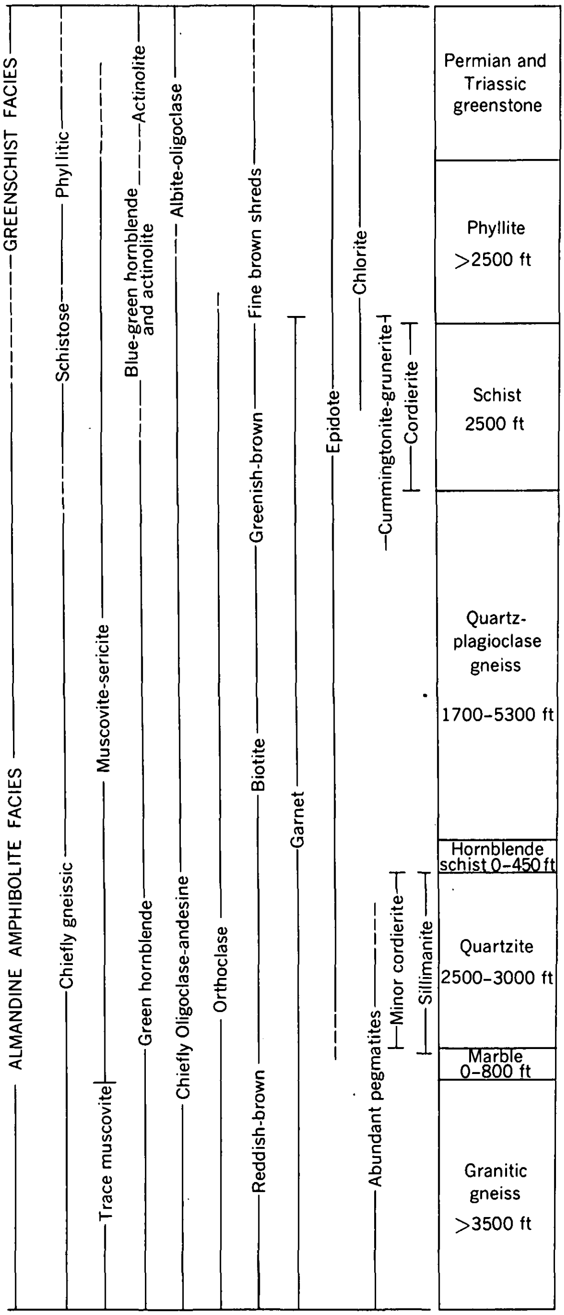

FIGURE 10.—Observed stratigraphic range of metamorphic minerals and other features of the Tenas Mary Creek and Permian and Triassic rocks.

Hornblende is characteristically green and well formed in the lower units. Bluish-green and pale-green actinolitic varieties commonly associated with epidote, chlorite, and biotite occur in the schist and overlying units, typically in diverging bladed patches, fine-grained slender prisms, and large poikilitic grains. The composition of plagioclase in the almandine amphibolite facies depends to a large extent on the composition of the parent rocks. It is typically oligoclase in the qaurtz-feldspar rocks, andesine in the hornblende schist, and calcic plagioclase in the calc-silicate rocks and basic intrusives. The dominant feldspar is oligoclase-andesine in the quartzose schists, and andesine in the amphibolites. Feldspar is not abundant in the phyllite, but albite or sodic oligoclase occurs in some rocks.

Orthoclase is the only potassium feldspar observed in the Tenas Mary Creek rocks. It is found in various proportions in most of the rock units as far as the top of the schist unit. In the feldspar-quartz schist of the schist unit, orthoclase occurs with quartz as a fine-grained mosaic in the groundmass.

Sillimanite is a conspicuous accessory in biotite-rich interbeds in the quartzite unit and the upper part of the marble unit. It was not observed above the quartzite. Cordierite is largely restricted to the schist unit but occurs sparsely in the quartzite.

The Permian and Triassic rocks that directly overlie the Tenas Mary Creek rocks are north of the quadrangle and consequently were not studied in detail, but they belong to the greenschist facies and are directly continuous with the greenstone east of the Bacon Creek fault. Typical minerals include albite or sodic oligoclase, epidote, clinozoisite, chlorite, and actinolite.

The boundary between the almandine amphibolite facies and the greenschist facies is not sharp but rather a zone of transition marked by minerals characteristic of both facies. The change from albite (greenschist facies) to oligoclase (almandine amphibolite facies) is not a useful criterion for determining the change from the greenschist facies to the almandine amphibolite facies in these rocks, because plagioclase feldspar is scarce in the phyllite unit. On the basis of the lowest observed occurrence of albitic plagioclase and the preponderance of oligoclase-andesine in the schist, the facies boundary would lie in the lower part of the phyllite. However, chlorite, typical of the greenschist facies, is found in quartz-chlorite schist several hundred feet lower in the middle of the schist. Cummingtonite, typical of the almandine amphibolite facies, occurs in garnet-cummingtonite-andesine-quartz schist about 300 feet higher in the section than the lowest chlorite. Grunerite in garnet-grunerite-epidote-quartz schist, also occurs several hundred feet above the lowest quartz-chlorite schist.

The transition from the greenschist facies to the almandine amphibolite facies apparently takes place in the stratigraphic interval between the middle of the schist unit and several hundred feet above the base of the phyllite, a zone that contains minerals characteristic of both facies.

The metamorphic grade decreases upward in the stratigraphic column. This decrease is probably more than coincidence, for the same relationship is found in the metamorphic rocks of the Aiken Lake area, British Columbia (Roots, 1954, p. 51), and in the Okanogan Valley area of southern British Columbia (Cairnes, 1940b).

The metamorphic grade decreases also away from the Cretaceous(?) granodiorite. However, the granodiorite intrudes the Tenas Mary Creek rocks, and in terms of absolute time, is therefore later than the metamorphism. Although the granodiorite probably did not cause the metamorphism at its present position, an intrusive magma that formed the granodiorite could very well have been generated at depth by processes related to the regional metamorphism. Broadly speaking, the granodiorite is considered to be a late phase in the overall period of metamorphism.

The widespread distribution of high-grade metamorphic rocks in this region suggests conditions of elevated temperature and pressure over a wide area. If this assumption is correct, then a decrease in metamorphic grade would more likely be observed in a vertical direction, that is, stratigraphically upward, than in a horizontal direction, and this relation is considered to hold for the Tenas Mary Creek and Permian and Triassic rocks.

METAMORPHIC ROCKS OF ST. PETER CREEK

The metamorphic rocks of St. Peter Creek are in general similar to parts of the Tenas Mary Creek rocks and probably have had a similar metamorphic history. The St. Peter Creek rocks were originally a series of sedimentary rocks consisting of calcitic and perhaps dolomitic limestone, calcareous and siliceous shale, and quartzose sandstone with shaly sandstone interbeds. These rocks, like those of Tenas Mary Creek, have been metamorphosed to the level of the almandine amphibolite facies. Calcareous assemblages of the St. Peter Creek rocks contain quartz, calcic plagioclase (labradorite-bytownite), diopside, calcite, and biotite, and some of these rocks also contain orthoclase. Quartzo-feldspathic and pelitic assemblages contain quartz, diopside, orthoclase, plagioclase (zoned oligoclase-labradorite), hornblende, cordierite, sillimanite, and biotite.

In the northern part of the complex, schist and quartzite grade into migmatite in which the schist is contorted and contains various amounts of foliated granitic material and pegmatite.

STRUCTURES IN METAMORPHIC ROCKS

METAMORPHIC ROCKS OF TENAS MARY CREEK

Structures in the Tenas Mary Creek rocks consist mainly of compositional layering, small-scale folds, foliation, and lineation.

Compositional layering is a highly characteristic feature of the Tenas Mary Creek rocks. Most of the units are marked by persistent layers of contrasting composition and texture which range in thickness from a fraction of an inch to 50 feet or more. Compositional layering is a reflection of the original sedimentary bedding of the parent rocks.

Minor folds range from very small scale fluting on foliation planes to folds as much as 10 feet across. In the lower units they are of small amplitude, forming gentle ripples or undulations. Minor folds are tighter in the phyllite, and in many places they produce rodding to the extent that foliation becomes obscure or is destroyed completely, and the rock breaks into cylindrical pieces rather than foliated slabs.

Foliation is produced chiefly by the parallel orientation of platy minerals such as biotite and chlorite and by elongated quartz and subparallel feldspar grains. It is well developed in most rocks and is almost parallel to the compositional layering and to the trend of the lithologic units. Foliated pegmatite bodies in the lower units, particularly in the granodiorite gneiss, tend to lie parallel to the foliation and accentuate it.

Linear structures are of two main types—minor fold axes and linear orientation of minerals. In addition, fine striations, apparently produced by the intersection of cleavage and foliation, are common in the phyllite. Easily observed mineral lineation includes oriented sillimanite crystals and streaks of muscovite along bedding planes in the quartzite, and streaks of biotite in the quartz-plagioclase gneiss and phyllite.

Fold axes and mineral lineation have the same northwest trend; most plunge from 5° to 30° NW., but a few plunge southeast. In a few places, especially in the quartzite and phyllite where minor fold crinkles and mineral streaks occur in the same outcrop, the two structures are either parallel or almost parallel. Where the mineral streaks are almost parallel, they appear to bend around the folds, and thus indicate that they are slightly earlier than the folds. In rocks, such as biotite schist, that show a planar structure only, the platy minerals likewise follow the curvature of the minor folds; however, the original bedding acted as the main control to the orientation of the platy minerals, and so the growth of the platy minerals would bear no time relationship to the folds. The platy minerals could have formed either before or after the folds, depending on when the bed itself was metamorphosed. Because the two types of lineations are parallel, or nearly so, they probably are related to the same period of metamorphism. A few small-scale recumbent folds trend N. 55° E., at variance to the main direction, but their significance is not known.

METAMORPHIC ROCKS OF ST. PETER CREEK

The metamorphic rocks of St. Peter Creek exhibit the same internal structure as the Tenas Mary Creek rocks. In most cases, minor fold axes in quartzite and schist plunge northwest and correspond to the major fold axes. This direction also corresponds to that of the major and minor folds in the Tenas Mary Creek rocks. Locally the rocks are highly deformed, a feature well illustrated by the thinly laminated calcareous and graphitic rocks beneath the marble. Here, the beds are nearly isoclinally folded and the folds are nearly recumbent. The axes of these folds plunge 5° NNE., which is at variance to the general northwest trend. The marble also has been extensively deformed and recrystallized.

PERMIAN AND TRIASSIC ROCKS

Metamorphic structures in the Permian and Triassic rocks consist mainly of foliation, though a few rocks also show lineation. Because of the low-grade regional metamorphism, bedding is much more obvious than foliation, and in most cases the two are parallel. Laminated rocks such as tuff, argillite, and chert with argillite partings commonly exhibit a marked foliation. The foliation is due to the preferred orientation of chlorite, zoisite, sericite, and other metamorphic minerals. Metamorphosed lava flows tend to retain their massive character and show neither bedding nor foliation.

Linear structures are not abundant, except in the black argillite. They consist of small-scale folds, surface crinkling, and rare stretched calcite pebbles. Within the graben, some lineations plunge to the north or northeast and some plunge to the southeast. All these linear structures are attributed to the main period of metamorphism and deformation, but the data are too scanty to justify any conclusions about significant trends. Later graben development and intrusions have probably modified the original trends of the linear elements within the graben.

West of the Bacon Creek fault 1 mile north of the international boundary, however, the greenstone rocks display linear structures parallel to those in the underlying Tenas Mary Creek rocks.

AGE OF METAMORPHISM

The available evidence indicates that the Tenas Mary Creek rocks, the St. Peter Creek rocks, and the Permian and Triassic rocks were metamorphosed after the Triassic Period but before, or during, the intrusion of the granodiorite batholith of probable Cretaceous age. An earlier period of metamorphism possibly occurred in the region, as indicated by fragments of phyllite and quartzite in the Permian and Triassic conglomerate beds, but the effects of this earlier metamorphism are masked by the post-Triassic metamorphism.

The regional metamorphism is probably related to the early stages of the Nelson composite intrusions, which were emplaced over a considerable interval of time during the Cretaceous Period (Cairnes, 1934). The intense regional metamorphism in the Sandon area as well as in the Okanogan Valley area, British Columbia, is attributed to the period of intrusion of the Nelson granitic rocks (Cairnes, 1934, p. 36; 1940b, p. 265, 269).

In other places in the northwest it appears that batholiths of probable Cretaceous age were not accompanied by regional metamorphism. In the Metaline quadrangle, Washington, the Kaniksu batholith produced only contact metamorphism in the already metamorphosed country rocks (Park and Cannon, 1943). Near Tonasket, Wash., Permian and Triassic greenstone and limestone are thought to have been deformed and metamorphosed prior to the intrusion of the Colville batholith of probable Cretaceous age (Waters and Krauskopf, 1941). Several periods of orogeny that probably took place in British Columbia are discussed in a summary article by White (1959). Those accompanied by intense metamorphism include the Cariboo orogeny (post-Ordovician to pre-Mississippian) and the Coast Range orogeny (post-Middle Jurassic to pre-Early Cretaceous), of which the Nelson intrusions are a part.

GEOLOGIC HISTORY

The geologic history of the Curlew quadrangle is recorded in rocks of pre-Permian, Permian, Triassic, Jurassic(?), Cretaceous(?), Tertiary, and Quaternary ages. The history is not complete; gaps occur in the Jurassic and Cretaceous records especially, and the age and original relations of the highly metamorphosed pre-Permian rocks are uncertain. Accurate dating of all decipherable events has not been possible, but paleontologic dating of certain rocks of Permian, Triassic, Eocene(?), and Oligocene ages form a chronologic framework into which most events can be fitted.

The earliest events, which are recorded in the Tenas Mary Creek and St. Peter Creek rocks, were (1) deposition of well-bedded limestone, sandstone, shale, and other sedimentary rocks probably under shallow marine conditions, (2) uplift, erosion, and resubmergence at two different times during accumulation as suggested by possible unconformities in the Tenas Mary Creek sequence, and (3) intrusion of felsic and mafic sills, dikes, and irregular intrusive bodies. These events occurred during an unknown interval of time prior to the Permian, probably in the late Paleozoic though possibly as early as the Precambrian.

During the Early Permian and Late Triassic at least, the region again was depressed below sea level as part of a eugeosynclinal belt along the then western continental border. Large quantities of mafic volcanic tuff and flows, black shale, chert, graywacke, conglomerate, and lenticular limestone accumulated therein. These rocks were intruded by felsic and mafic plugs and dikes and by serpentine, but the time of intrusion is not certain. All these intrusives were in place prior to the metamorphism of the Permian and Triassic rocks, but more than one intrusive epoch possibly occurred.

Sometime after Late Triassic, probably during Late Jurassic to Early Cretaceous, the deeply buried Triassic, Permian, and pre-Permian rocks were metamorphosed during early phases of batholithic intrusion related to the Nelson composite intrusions of nearby British Columbia. Deformation accompanied and intensified the metamorphism. The pre-Permian rocks, which were strongly sheared and recrystallized internally, were thrown into broad regional northwest-trending folds. Permian and Triassic rocks, being less deeply buried and more remote from the areas of intense metamorphism because of their superposition, were less strongly metamorphosed but in places were tightly folded. Later in the Cretaceous(?), younger phases of the batholith intruded the already metamorphosed rocks.

The region was uplifted in Late Cretaceous or early Tertiary time and, so far as known, remained above sea level throughout Tertiary and Quaternary time. Block faulting, the initial development of the Republic graben, was followed by deposition of the Eocene(?) O'Brien Creek Formation. Extensive erosion stripped away any Jurassic or Cretaceous sedimentary rocks that might have existed, and exposed metamorphic and granodiorite batholithic rocks. Relief along the border faults must have been considerable because of the great size of granodiorite boulders that were deposited in conglomerate of the O'Brien Creek Formation along the edge of the graben. Local volcanic activity contributed pyroclastic material that mixed with detritus derived principally from granodiorite, greenstone, and other rocks in the uplifted blocks on either side of the graben. Locally, Eocene(?) plants were deposited with mud in standing bodies of water.

As movements continued along the main boundary faults, the rocks within the graben became fragmented into subblocks by numerous north-trending faults. Continued subsidence of the graben with respect to the bordering highlands resulted in tilting of the subblocks generally toward the center of the graben and also caused adjustments of the individual subblocks to each other. Subsidence was least along the sides of the graben and north of Curlew, as indicated by the preponderance of greenstone in these areas. Greenstone areas well within the graben, especially in the Republic quadrangle, may represent subblocks which have been raised relative to their neighbors.

After much of the subsidence and block adjustments had been accomplished, the lavas of the Sanpoil Volcanics accumulated on the older tilted rocks in the graben. In places, these lavas rest upon Permian and Triassic greenstone. Some subblocks of greenstone were topographic highs at this time. As subsidence and block adjustment continued, the Sanpoil Volcanics became tilted toward the center of the graben and was cut by faults.

Probably during and following the extrusion of the Sanpoil Volcanics a series of intrusive rocks invaded the rocks both within and outside the graben. Bodies of the Scatter Creek Formation were the initial intrusives, and they were followed by the batholithic quartz monzonite of Long Alec Creek. The layered rocks in the Republic graben were mostly engulfed by these Tertiary intrusions.

In Oligocene and possibly Miocene time, pyroclastic, clastic, and glassy basaltic rocks of the Klondike Mountain Formation accumulated in depressions in the graben. They were deposited with angular unconformity on the Sanpoil Volcanics and on Permian and Triassic rocks. In post-Oligocene time, the latest movement took place along the graben faults. Erosion stripped most of the Permian and Triassic and all of the Tertiary layered rocks from the uplifted blocks, leaving exposed the pre-Permian metamorphic rocks and the Cretaceous(?) and Tertiary intrusive rocks on either side of the graben.

In the Pleistocene, glacial erosion and deposition modified the topography and drainage. The receding ice left the upland areas mantled with glacial till and laid down glacial-outwash deposits in the present valleys. These glacial features have been little modified by Recent erosion.

MINERAL DEPOSITS

Most known mineral deposits in the Curlew quadrangle are in the Danville and Curlew mining districts in the northern part of the quadrangle between Curlew and the Canadian border. The Danville district might be properly considered as a southern extension of the important Boundary district in the adjacent area in British Columbia, which has produced more than 22 million tons of copper-gold-silver ore (LeRoy, 1912; Seraphim, 1956). Deposits in the Danville district are the Comstock, Lone Star, and Morning Star. The principal deposit in the Curlew district is the Lancaster. Mineral deposits were long known in this area, but not until the north half of the Colville Indian Reservation was opened to mineral exploration on February 20, 1896, did intensive prospecting and development begin. Development on the Comstock (La Fleur), Lone Star, and other nearby claims, began in 1896 and on the Morning Star shortly thereafter. By 1910, most of the known mineral deposits around Danville and Curlew had been located.

Copper, gold, and silver have been the principal metals produced from the Lone Star, Morning Star, and Comstock mines, and a small amount of lead ore has been shipped from the Lancaster and Morning Star mines. Minor tungsten has been reported from the Morning Star mine and small pods of chromite have been discovered in the serpentine east of the mine. A small amount of gold was produced from a placer on July Creek near Danville in 1934, and an attempt was made to recover gold from Goosmus Creek in 1950. Much prospecting has been done for uranium on Mount Leona just east of the Curlew quadrangle.

No mines were producing in the Curlew quadrangle in 1959 when fieldwork was in progress, but some ore was shipped almost every year during the period 1900–43. Most of the production in the quadrangle has been from the Lone Star and Morning Star mines. More than 2,000,000 pounds copper, 6,500 ounces gold, and 20,500 ounces silver have been produced from the Danville and Curlew mining districts.

COMSTOCK MINE

The Comstock mine is in the NE¼ sec. 18, T. 40 N., R. 34 E., about 2½ miles southwest of Danville at an elevation of about 3,000 feet. The mine is mentioned by Patty (1921, p. 200), and the ore is described by McLaughlin (1919).

The property was originally located in 1896 by the Comstock Mining and Milling Co., and in 1918 it was operated under lease by the Le Fleur Mountain Copper Co. Since 1942 it has been owned by the Morning Star Mining Co.

Production from the property is unknown, but the size of the workings indicates it could not have been large.

The mine workings consist of two shallow shafts and two short adits, the longest of which is about 400 feet. Neighboring areas both east and west of the mine contain numerous prospect cuts and shallow pits.

The mine and most of the adjacent prospects are located on syenite porphyry dikes that trend about N. 80° W. These dikes are offshoots from the syenite porphyry masses in the alkalic rock complex of Shasket Creek. The dikes cut Permian and Triassic limestone and cherty greenstone, which near the contact of the Shasket Creek complex are thermally metamorphosed to marble, calc-silicate rocks, and hornfels.

The ore minerals, chalcopyrite and bornite, are local concentrations in the syenite porphyry and to a minor extent in the wallrocks. McLaughlin (1919), who studied the Comstock ore in detail, considered the ore minerals in the dikes as having formed in the period immediately following the crystallization of the silicate minerals. This conclusion was based on the facts that the ore minerals corrode orthoclase, albite, and muscovite and that, except for the presence of albite rims between ore minerals and some orthoclase, there is a notable lack of alteration. The copper mineralization in the Comstock mine area doubtless is closely related to the syenite porphyry.

LONE STAR MINE

The Lone Star mine is at the head of the North Fork of Goosmus Creek in sec. 2, T. 40 N., R. 33 E., half a mile south of the international boundary and 4½ miles west of Danville. The mine is located in what might be considered a southern extension of the Boundary district, which lies a few miles to the north in British Columbia.

HISTORY

The Lone Star mine was first developed in 1897 by the Reservation Mining and Milling Co. By 1910, underground development on the property comprised 2,155 feet of adits, shafts, and winzes. In 1910, the property came under control of the British Columbia Copper Co. which, during the period 1910–18, further explored the property with 2,220 feet of workings and 3,590 feet of diamond-drill holes. The company also constructed a 28,560-foot cable tram from the mine to the company smelter at Boundary Falls, British Columbia. When World War I ended, the mine closed, reportedly because of the decline in the price of copper; it has remained closed except for minor rehabilitation and drilling in 1952 by the present owner, the Attwood Copper Mines Ltd., and extensive drilling in 1955–56 by a lessee, the Granore Co.

MINE WORKINGS

The known underground workings of the Lone Star mine are shown on plate 3. According to company data, the property was originally opened by three adits, a shaft, and a winze, which, with one level off the shaft, totaled about 4,000 feet of workings.

GEOLOGY

The Lone Star mine was not accessible in 1959 when fieldwork was in progress. The mine geology is summarized from information obtained in 1953 in connection with a Defense Minerals Exploration

Administration application. The map (pl. 3) is modified slightly from maps supplied to DMEA by the owner, Attwood Copper Mines, Ltd.

The Lone Star property is covered by a thick overburden of glacial debris which is heavily forested; consequently only a few outcrops can be seen. Those rocks that crop out near the mine are highly sericitized and silicified, but relict phenocrysts of quartz and plagioclase preserve the original porphyritic texture. What probably originally were hornblende, augite, or biotite crystals are now aggregates of epidote, clinozoisite(?), and chlorite. The rock has been called "dacite" by mine operators but probably belongs with the Permian and Triassic rocks. The dumps of the mine contain mostly talcose or serpentinous rock.

Available data indicate a dark-gray intrusive rock locally called the "black dike," which does not crop out at the surface, is prominently exposed in the mine. Its lower contact has not been found in the mine workings or in any drill holes of which record is available. Apophyses of the dike intrude the "dacite" country rock, but in most places the contact between these two intrusive rocks is marked by a zone of strongly sheared serpentine. Both the "black dike" and the "dacite" near the contact are also sheared. Serpentine masses are common in the dike near the contact and also occur in places in the "dacite" as far as 50 feet from the contact.

The "black dike" was not seen in place by the writers, but a rock that occurs in the dump, and which is thought to be the "black dike," has characteristics suggesting an affinity to the alkalic rocks of Shasket Creek. This rock is dark gray and fine grained, and contains about 25 percent unaltered green to bluish-green hornblende, about 40 percent sodic oligoclase, about 30 percent orthoclase, and about 5 percent minor constituents—sericite, chlorite, carbonate, epidote, apatite, and magnetite. Some hornblende crystals reach lengths of 15 mm.

The ore body, containing chalcopyrite, pyrite, and a small amount of gold, occurs in the "dacite" along the sheared contact with the "black dike." Commonly, the higher grade ore occurs near the serpentinized masses. In the main part of the mine, the contact strikes roughly east-west and dips south, but on the eastern side it strikes north-south and dips east. This change in attitude of the contact forms a sharp nose comparable to an anticline plunging about 20° SE. The ore body appears to thicken along the crest of this structure, and in places it is as much as 50 feet thick. (See pl. 3.) Ore extends west and north from the nose and probably also in the direction of plunge. It is found as far west as the west end of the 3,870-foot level and is reported in a drill hole in a short adit south of the main workings. Also it was mined on the 3,955-foot level as far as 200 feet north of the point of the bend. Ore below the 3,870-foot level is reported in a drill hole about 75 feet east of the east face of this level.

MORNING STAR MINE

The Morning Star mine is in sec. 16, T. 40 N., R. 34 E., 2 miles south of Danville on the east side of the Kettle River. The mine includes also the Lucille Dreyfus, Minniehaha, Surprise, and Virginia properties.

The Morning Star is a small high-grade gold mine with a history of production from 1903 to 1943, when it closed as a result of the curtailment of gold production during World War II. Production figures are given in table 5.

The mine is served by a 3,900-foot haulage tunnel with four levels and two shafts above. Drifts, crosscuts, raises, and winzes total more than 9,000 feet in length (pl. 4). Most of the workings were inaccessible in 1959. Much of the information on the mine and its geology is based on maps and data furnished by Mr. P. E. Oscarson of the Morning Star Mining Co.

TABLE 5.—*Production of ore from the Morning Star and adjacent mines, 1903–43, Ferry County, Wash.*

[Production figures from the U.S. Bur. Mines released with permission of mine owners]

Mine	Year	Ore (short tons)	Gold (troy ounces)	Silver (troy ounces)	Copper (pounds)	Lead (pounds)
Lucille Dreyfus	1903	1,100	242	9,259	75,569	
Minniehaha	1904	689	481	434	22,548	
Lucille Dreyfus	1908	94	40	14	1,144	
	1909	152	38	102	2,600	
	1916	460	401	264		
Virginia	1916	462	398	261	394	
Lucille Dreyfus	1917	1,612	938	1,481	74,105	
Virginia	1918	499	243	242	6,620	
	1919	37	15	766		
Lucille Dreyfus	1921	53	57	53	1,213	
Minniehaha	1924	2		5		624
	1932	40	24	46	874	
Morning Star	1935	289	139	204	8,873	
	1936	679	445	352	16,036	
	1937	236	127	159	8,537	
	1938	155	65	82	4,000	
	1939	38	8	15		
	1940	201	172	145	2,770	
	1941	193	434	412		
	1942	124	275	128	1,000	
	1943	272	289	361	12,000	
Total		7,387	4,831	14,785	238,283	624

The mine is at the contact between the Permian and Triassic greenstone and a large body of serpentine. Both greenstone and serpentine have been intruded by rocks of the Scatter Creek Formation, and a small body of the Scatter Creek apparently has been intruded along the serpentine-greenstone contact in the center of sec. 16, T. 40 N.,

R. 34 E. Near the contact with the serpentine body the greenstone is cut by one or more irregular northwest-trending sheets of serpentine that in many places are strongly sheared parallel to their trend, and which, along with all other rocks, are complexly cut by younger cross faults. These sheets may represent zones of shear in the greenstone that were filled by serpentine possibly stemming from the main mass to the east. Quartz veins bearing free gold and auriferous pyrite and also those bearing pyrite and chalcopyrite have mostly north-northwest and west-northwest trends and dip steeply to the northeast. The gold-pyrite-quartz veins are almost entirely restricted to the greenstone, whereas the pyrite-chalcopyrite-quartz veins are confined mostly to the contacts of the serpentine bodies and within them. (See pl. 4.)

LANCASTER MINE

The Lancaster property is in sec. 6, T. 39 N., R. 34 E., 2 miles northeast of Curlew on the east side of the Kettle River. The workings consist of a main lower adit, 1,490 feet long at an elevation of 1,850 feet, another adit, the Panama, 225 feet in length about 700 feet southwest of the main adit, and adjacent shallow workings. Despite this extensive exploration, the only recorded production is 29 tons of hand-sorted ore which contained 1,651 lbs copper, 4,719 lbs lead, and 395 oz silver. (Production figures released with permission of mine owner, Mr. W. B. Helphrey.)

The mine is near the contact of the Scatter Creek Formation and the quartz monzonite of Long Alec Creek. Here a small body of Permian and Triassic calcareous shale, siltstone, and limestone, which was first intruded by the Scatter Creek Formation, has been intruded a second time by the quartz monzonite, and near this contact small amounts of galena, sphalerite, and chalcopyrite have been deposited. The sedimentary rocks strike N. 75° W. and dip 15° N. The lower part is coarse-grained marble. A series of northeast-trending quartz latite dikes cut all rocks in the mine area.

The main adit was driven to intersect the mineralized bodies of sedimentary rock which are exposed a short distance above the portal. Another short adit on the steep, south-facing slope of the ridge at an elevation of 2,600 feet is driven in a marble inclusion in the quartz monzonite. The dump is composed mainly of quartz monzonite and contains a small amount of calc-silicate rock, galena, pyrite, and sphalerite.

Several other prospects are concentrated along the contact between the quartz monzonite of Long Alec Creek and the Scatter Creek Formation in the area between the Lancaster mine and the Drummer Mountain fault. Most of them, like the Lancaster, are in or near remnants of Permian and Triassic rocks.

OTHER PROSPECTS

Prospecting has been widespread in the Curlew quadrangle but, except for a few mines in the Curlew and Danville districts, minable deposits have not been discovered. Much prospecting has been done along the border faults of the Republic graben and faults parallel to them. The Permian and Triassic rocks along the Drummer Mountain fault between Tonasket and Aeneas Creeks and along the Sherman and St. Peter faults are sites of many prospect pits. Commonly these prospects expose pyrite and sparse copper minerals.

Prospecting has been concentrated also on the south slope of Granite Mountain at the head of Empire Creek. Many pits in Permian and Triassic greenstone near or along north-northeast-trending dikes reveal thin quartz veins and stringers that contain galena, sphalerite, and pyrite. At least some of the dikes are younger than the Klondike Mountain flows that cap Granite Mountain.

Other sites of prospecting are widely scattered. Some are located in greenstone along quartz monzonite contacts northeast and northwest of Mount Elizabeth. Some are in pyritized Permian and Triassic rocks near the borders of serpentine bodies in the northern part of the graben. A very few prospects are in altered Klondike Mountain Formation on the south side of the Kettle River about a mile west of Curlew.

SUGGESTIONS FOR PROSPECTING

The host for nearly all the mineral deposits and the site of most prospecting in the Curlew quadrangle are the Permian and Triassic rocks. These rocks are confined to the Republic graben and are most abundant in the northern part of the graben. Places with the highest potential for the discovery of additional ore deposits are those where Permian and Triassic rocks are intruded by the alkalic rocks of Shasket Creek, by granitoid rocks such as those of Long Alec Creek, or by serpentine, and those where the Permian and Triassic rocks are cut by faults.

Rocks with less potential than Permian and Triassic rocks for containing ore deposits are the O'Brien Creek Formation, Sanpoil Volcanics, Scatter Creek Formation, and Klondike Mountain Formation. Although these rocks have not been found to be mineralized in the Curlew quadrangle, parts of the Klondike Mountain Formation are associated with the important gold-silver deposits in the Republic district in the Republic quadrangle to the south (S. J. Muessig, written commun., 1960). These Tertiary rocks in the Curlew quadrangle, therefore, should not be ruled out completely as possible hosts for similar deposits.

Rocks with the lowest potential for the discovery of ore deposits are the metamorphic and batholithic rocks bordering the graben. Possible exceptions are the metamorphic rocks of St. Peter Creek which contain pegmatites reported to contain uranium minerals, and the phyllite at the northern border of the quadrangle. The phyllite is similar in lithology to some parts of the Permian and Triassic rocks and it is strongly pyritized in places.

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