Geology of the Republic Quadrangle and a Part of the Aeneas Quadrangle Ferry County, Washington

By SIEGFRIED MUESSIG

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Geology of an area in northeastern Washington that contains important gold-silver deposits and a major structural feature, the Republic graben

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By Siegfried Muessig

ABSTRACT

The area of this report covers about 270 square miles in Ferry County, Wash., lying between long 118°30′ W. and 118°52.5′ W. and lat 48°30′ N. and 48°45′ N. Republic, the only town in the area, is within the Republic mining district, and is the site of important gold-silver production. Mining began here in 1896 and has continued to the present; production from 1902 to 1951, inclusive, was 2,217,430 tons of ore, which contained 764,546 fine ounces of gold and 4,843,430 fine ounces of silver.

The area is mountainous and lies within the Okanogan Highlands physiographic region. A central valley occupied by Curlew Lake, Sanpoil Lake, and the Sanpoil River serves as the trunk drainage for nearly all the area. Relief is nearly 5,000 feet, the highest point being Bald Mountain, which has an altitude of 6,933 feet.

The rocks of the area range in age from probable late Paleozoic to Recent. The oldest exposed rocks are schists, phyllites, and marbles. Slightly younger rocks of Permian age constitute a moderately metamorphosed eugeosynclinal suite having complex structure and a thickness of thousands of feet. Triassic, Jurassic, and Cretaceous bedded rocks are missing. These rocks are intruded and metamorphosed by a plutonic body of granodiorite of Late Cretaceous age.

Tertiary rocks are predominantly of volcanic origin and range in age from Eocene(?) to Miocene(?). At the base of the section is the O'Brien Creek Formation—mainly tuffs. It is overlain by andesitic lavas of the Sanpoil Volcanics; these formations in turn are overlain with angular unconformity by the Klondike Mountain Formation, which has three members. These members are, in ascending order, the Tom Thumb Tuff Member (fine tuffs) of Oligocene age, the middle member (coarse pyroclastics and flows), and the basalt member, of probable Miocene age. An angular unconformity separates the lower member from the upper two.

Intrusive Tertiary rocks are mostly hypabyssal and of intermediate composition. They are of Eocene(?) to Miocene(?) age and occur chiefly as dikes and small irregular bodies. Exceptions are the Scatter Creek Rhyodacite, which forms relatively large irregular bodies and dikes and is of Eocene(?) age, and large plutonic bodies of quartz monzonite, which looks much like the Upper Cretaceous intrusives but is of Eocene(?) or Oligocene(?) age.

The topography and drainage of the area have been modified by at least two periods of Pleistocene glaciation, during the last of which much of the bedrock was covered by glaciofluvial deposits and some till.

The earliest recognizable structural event was the metamorphism of the upper Paleozoic(?) and Permian rocks, which occurred during folding and the intrusion of the Upper Cretaceous batholith.

The dominant structural feature, the Republic graben, trends N. 15° E. and occupies two-thirds of the map area. Its formation began in the Eocene(?) and, by recurrent movement along its marginal faults, it remained as a structural and depositional basin for most of the time until the Miocene(?). Faults within and bounding the graben are predominantly high angled and of north trend and were formed at various times in the middle Tertiary. The Tertiary rocks were folded along north-trending lines at least twice, and during the last period, in the Oligocene, some of them as well as some of the Permian rocks were thrust eastward a maximum distance of 4.5 miles.

During Oligocene time the Sanpoil Volcanics and the Tom Thumb Tuff Member of the Klondike Mountain Formation were cut by faults along which gold- and silver-bearing quartz veins were deposited.

INTRODUCTION

LOCATION AND CULTURE

The Republic and Aeneas quadrangles are in Ferry County in northeastern Washington (fig. 1). The area geologically mapped and described in this report lies between long. 118°30′ W. and 118° 52.5′ W. and lat. 48° 30′ N. and 48°45′ N.; it includes all the Republic quadrangle, about 205 square miles in extent, and about 65 square miles of the eastern part of the Aeneas quadrangle.

Republic (population 1,000), in the west-central part of the area, is the Ferry County seat and the only town in the sparsely inhabited area. It is 24 miles south of the international boundary and 90 miles northwest of Spokane, the nearest large city. Three paved State highways join at Republic and connect the town with all the surrounding towns. The Great Northern railroad provides freight service to Republic and the surrounding area over a line that loops just north of the border through Grand Forks, British Columbia, and runs through Colville and Chewelah, Wash., to Spokane. Most points within the area are easily reached over county roads or the many logging roads in the mountainous areas.

Republic owes its founding to the nearby discovery in 1896 of gold and silver. Since then gold mining has been one of the leading industries in the area, and the gold and silver production from the Republic mining district has in most years been a significant part of the total production in the State. In 1960 only one mine within the district, operated by Knob Hill Mines, Inc., was producing; in recent years, this mine has been among the leading gold producers in the United States (see, for example, U.S. Bureau of Mines Minerals Yearbook, 1957, p. 534), and in 1956 it accounted for more than half the silver produced in the State. It has operated continuously since

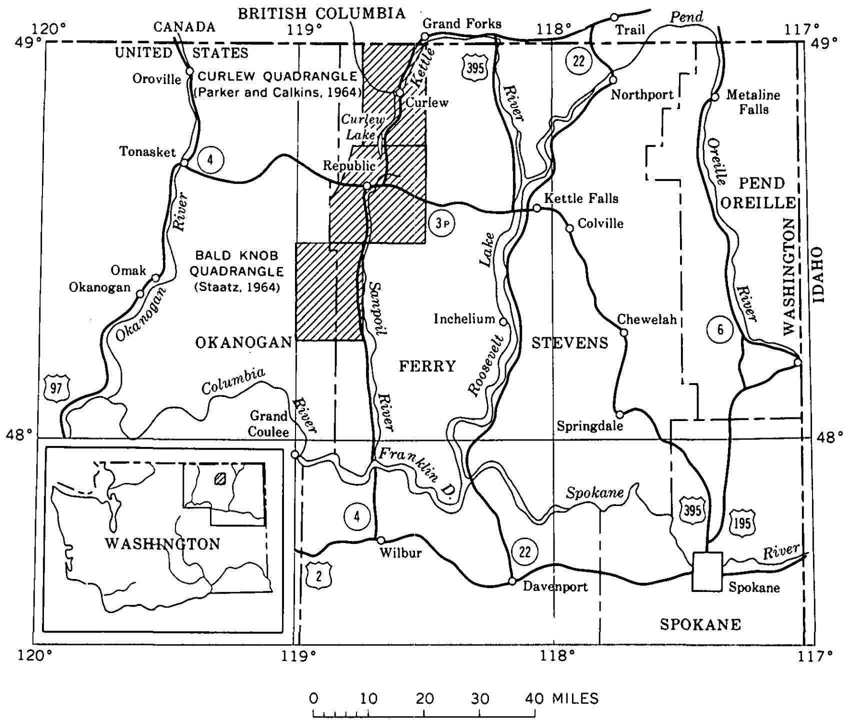

FIGURE 1.—Location of the Republic and part of the Aeneas quadrangles, Washington.

the late 1930's. Although the Republic mining district covers most of the mapped area, with one exception all the mines from which significant production is recorded are within a few miles of Republic. The exception is the Valley mine, which is just west of Curlew Lake and about a mile south of the northern border of the mapped area. The only other mining district in the area is the Belcher, which includes the Belcher and other mines in the northeastern corner of the area. This district had very little production and has been inactive for nearly 50 years.

Logging and stock raising are other important industries. More than half the area lies within the Colville National Forest, and trees are cut from the forest as well as from private land. The logs are made into various grades and types of lumber in mills at Sanpoil Lake and Pollard. In recent years many farms and ranches in valleys tributary to the main area have been abandoned; now most of the stock raised in the area is at ranches along the major valleys and roads.

The population pattern of the area follows the primary industries: most of the people live in or near Republic, which is close to the Knob Hill mine and is the trading center for the northwestern part of Ferry County. Ranches and farms are sparsely distributed; in 1958 the combined population was less than 150. Each of the lumber mills has a few permanently inhabited houses clustered near it. In addition, there are a few fishing resorts along Curlew Lake; the population at these resorts is low in winter but increases in the summer.

PHYSICAL FEATURES

The area lies within the physiographic region called the Okanogan Highlands (Pardee, 1918, p. 14). Earlier, the same region had been included in the Columbia Mountain system by Daly (1913, p. 37–40), but the name Okanogan Highlands is preferable (Fenneman, 1931, p. 202), even though the area is not considered a formal subdivision of the larger physiographic unit within which it lies—the Northern Rocky Mountain province.

The area (pl. 1) is mountainous throughout, and there is no definite separation of the mountains into distinct ranges. The mountains east of the Curlew Lake-Sanpoil Valley are locally called the Kettle Range, but in the southern part of the area all that separates this so-called range from the mountains to the west is the canyon of the Sanpoil River. Even though the area must broadly be considered one physiographic unit, it has discernible differences that reflect the lithology and structure of the underlying rocks.

Both the eastern and western margins of the area, which are underlain predominantly by massive granitic rocks, are generally higher than the central mountainous mass and are characterized by topography that is smoother and more rounded than that of the intervening mountains. The eastern granitic margin, which lies west of most of the crest of the Kettle Range and is about 2–5 miles wide along the eastern edge of the Republic quadrangle, stands distinctly higher than the mountains to the west, and near its southern end is the highest point in the area, Bald Mountain, altitude 6,933 feet.

Between the fringing granitic strips is a central block in which the mountains are generally lower but the topography is generally rougher. On the topographic map this difference is reflected by the pattern of the contours; those of the central area are much more irregular than those of the marginal areas. Structurally complex rocks of diverse lithologies underlie the central area; their diverse resistance to weathering and erosion explains the rougher topography.

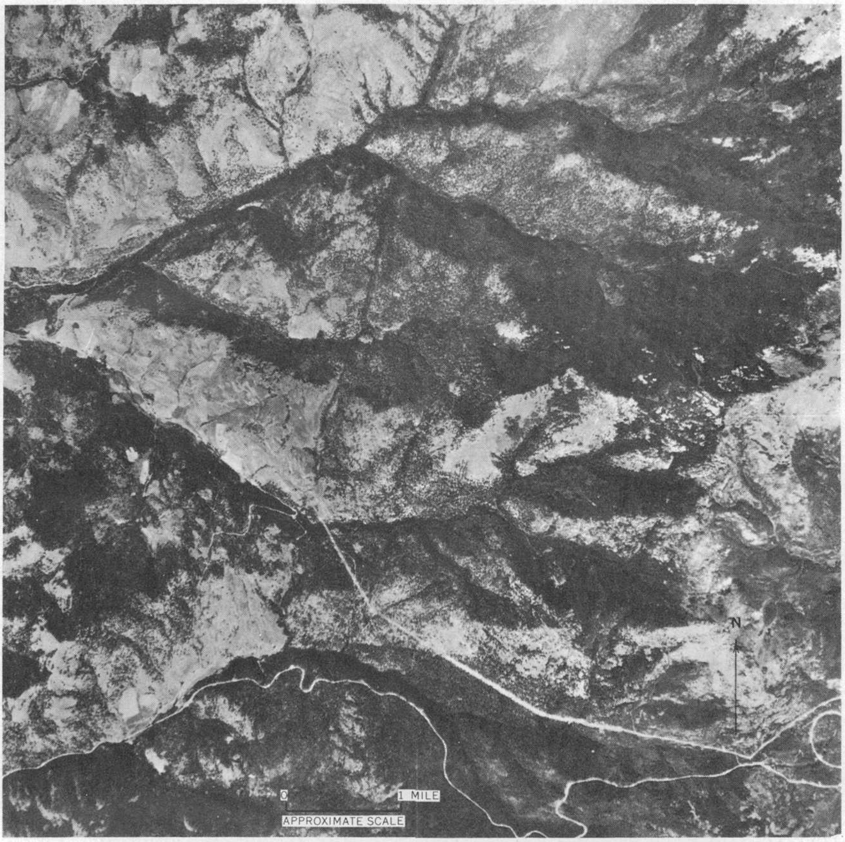

FIGURE 2.—Aerial view of area east of Republic. Narrow linear depression in center of photograph is the trace of the Sherman fault, which separates the eastern granitic block from rocks of the Republic graben to the west. The winding highway in the lower part of the photograph is along O'Brien Creek.

The central block is separated from the fringing granitic blocks by narrow linear furrows (fig. 2), which mark fault boundaries between the central and border blocks. On the east the separation is sharp, and the furrows are discontinuous depressions that cut north across the interfluves along the entire east side of the Republic quadrangle. The separation is sharp because it follows the trace of the Sherman fault—the fault which separates the eastern granitic block from the central block. On the west, the separation is sharp only along its northern end, where it follows a trench occupied by the north fork of Granite Creek and the South Fork of Trout Creek. Here, as on the east, the depression is the locus of a fault—the Bacon Creek fault. Farther south the separation between western and central blocks is less distinct. There is no straight line of depressions; rather, there are several short north-trending valleys whose positions are determined to some extent by faults or fault zones.

Throughout the area—both in the lower central block, with its more intricately sculptured topography, and in the fringing marginal blocks, with their smoother topography—the landforms show the effects of glacial abrasion. The hills are rounded and in much of the area have north-south elongation; many are separated from each other by deep and narrow valleys that, together with the hills, give a north-trending grain to the country. Undrained depressions and polished rock surfaces—other results of glaciation—abound. The only incompletely glaciated mountain in the area is Bald Mountain, in the southeast corner, whose top above about 6,750 feet is a peak that apparently was a nunatak during the Pleistocene.

Perhaps the most conspicuous feature of the area is the centrally located valley occupied by Curlew Lake, Sanpoil Lake, and the Sanpoil River. This valley serves as the trunk drainage into which most of the other streams feed. Numerous glacial terraces, some of them broad, line both sides of this valley, especially in its widest part, north of Sanpoil Lake. The major tributary streams are characterized by similar terraces. Streams in the northern quarter of the Republic quadrangle drain into Curlew Lake, whose outlet stream in the Curlew quadrangle flows north into the Kettle River and thence into the Columbia. South of Curlew Lake, at Torboy, the drainage of the master valley is split by a low alluvial fan, and nearly all the rest of the area is drained by the Sanpoil River, which flows south through a canyon into Franklin D. Roosevelt Lake—the lake formed by Columbia River water impounded behind Coulee Dam. About 15 square miles of the southeastern corner of the area is drained by the North Fork of Hall Creek, which flows southeast and empties into Franklin D. Roosevelt Lake near Inchelium.

Relief in the area is nearly 5,000 feet in the southern part of the Republic quadrangle; the highest point is Bald Mountain, altitude 6,933 feet, and the lowest point is where the Sanpoil River leaves the quadrangle, at an altitude of about 2,100 feet. Republic has an altitude of about 2,500 feet and Curlew Lake about 2,330 feet. Many of the mountains in the central area rise about 4,000 feet and hence give a local relief of several thousand feet.

CLIMATE AND VEGETATION

The climate of the area is semiarid and temperatures have ranged from a recorded maximum of 107°F in July to a recorded minimum of —32°F in January. Table 1 gives a summary of the weather data recorded at Republic between 1924 and 1952.

Forest cover is dense on nearly all the north-facing slopes (fig. 2). Many of the south-facing slopes are open and grassy, especially in the area east of Sanpoil and Curlew Lakes. Most of the tops of the hills underlain by the Sanpoil Volcanics are unforested.

Conifers are the predominant trees in the area. Douglas and alpine firs constitute about 50 percent of the conifers, the alpine being found at the higher altitudes; ponderosa and lodgepole pines constitute about 25 percent. The western larch, found mostly as second growth in burned or logged over areas, makes up about 20 percent of the coniferous cover. Hemlock, the Engelmann spruce of most creek bottoms, and the western red cedar (found only at Swan Lake) constitute a minor part of the conifer growth.

Broad-leaved trees, though a minor element in the forests, are nevertheless represented by a variety of types. Conspicuous representatives of this group are quaking aspen, cottonwoods, the mountain alder, various maples, mountain ash, and mountain laurel. Among the brushes are the snowberry, chaparral, Oregon grape, chokecherry, huckleberry, and some sumac. Sagebrush is found on some of the higher hills, whose soil retains little moisture. Pine grass and bunch grass are common on south-facing open slopes.

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork started on June 26, 1956, and continued until October 12 of that year. J. J. Quinlan was in the field with me the entire summer, mapping independently. During the next field season, June 10 to October 11, 1957, I was ably assisted for 3 months by P. M. Blacet. The last field season lasted from June 3 to October 24, 1958.

Nearly all the geologic contacts were plotted in the field on the topographic map enlarged to a scale of 1:48,000. Locations were made either by direct use of the map or by compass resection and altimeter. Because so much of the country is covered by forests and glacial drift, it is necessary to mention the "philosophy" used in mapping. Wherever there was no doubt about the bedrock unit, even though only a small part of it crops out, the unit was mapped as though there were no Quaternary cover. Areas for which there was doubt as to the underlying bedrock, or where the cover is thick and extensive, were mapped as Quaternary deposits, and the bedrock was mapped separately as islands within them.

The Curlew quadrangle to the north was also mapped by J. A. Calkins, R. L. Parker, and Alan Disbrow as a part of the same project under which the present work was done. I am indebted to these

TABLE 1.—*Weather data, Republic, Wash.*

[Furnished by E. L. Phillips, State climatologist, U.S. Weather Bur., Seattle, Wash. Data for indicated period preceding 1952]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Precipitation, 15 years [1] ..... inches	1.47	1.01	1.06	1.09	0.86	1.68	0.53	0.58	0.79	1.40	1.46	1.67	13.60
Snowfall, 13 years [1] ..... do	19.5	14.1	5.9	.2	Trace	Trace	.....	.....	.1	1.3	7.7	13.9	6.27
Mean temperature, 12 years [1] ..... °F	22.0	26.4	35.1	45.0	52.1	58.0	64.4	63.2	56.1	45.4	31.6	25.2	43.7
Maximum temperature, 13 years [1] ..... °F	30.7	36.7	46.5	59.7	68.8	74.3	84.2	83.6	74.7	59.6	40.7	32.8	.....
Minimum temperature, 12 years [1] ..... °F	15.6	15.7	23.5	30.3	35.4	41.8	44.6	42.5	37.6	31.2	22.6	17.3	.....
Lowest temperature, 28 years ..... °F	−32	−34	−5	3	16	25	29	27	14	10	−15	−26	.....
Highest temperature, 13 years ..... °F	50	58	69	86	94	97	107	101	98	87	61	60	.....

[1] Average.

colleagues, especially Calkins and Parker, for many ideas that developed, were enlarged, or sharpened during the countless field and office discussions. H. W. Little, of the Geological Survey of Canada, showed us outcrops and field relations in nearby British Columbia that furthered our understanding of the regional geology.

The work profited from the field visits of R. G. Yates of the U.S. Geological Survey. Mapping in the Republic district benefited from discussions and field conferences with Roy P. Full and David Snyder, who mapped part of the district in detail for private interests in 1958. J. Thomas Dutro, Jr., and A. R. Palmer of the Geological Survey visited the area in 1956 and helped find and collect some of the Permian fossils.

Arthur Cameron, James Davis, Sr., A. R. Patterson, Alec Ripple, and Graham McConnell rendered many services during my stay in Republic; it is a pleasure to acknowledge their many courtesies. Elmer Fine, U.S. Forest Service, Republic, supplied most of the information about the vegetation of the area.

SCOPE OF THE REPORT

Except for the knowledge resulting from work in the Republic district half a century ago (Umpleby, 1910; Lindgren and Bancroft, 1914), very little was known about the geology of the area. The chief purpose of the present work was to study the general geology and geologic history of the area in anticipation of other work in the Okanogan Highlands, some of which is now in progress. With the exception of the gold-silver deposits at Republic, there have been no economically productive mineral deposits in the area; however, there are important deposits to the north in British Columbia and to the east in Stevens and Pend Oreille Counties, Wash. It was felt, therefore, that further study of this area might make possible a more intelligent search for, or at least an appraisal of, mineral deposits not only here but also in the nearby areas.

In the time available for the work, not all areas could be studied with equal thoroughness. The area of granitic rocks and lavas received much less attention than any of the others. It was felt that the geologic history could best be unraveled by concentrating on the structure and stratigraphy of the other rocks. The report reflects this concentration and fills a gap in the geologic history of this part of the country.

GEOLOGIC SKETCH OF THE AREA

The outcrop pattern and distribution of rocks in the Republic area are in large part determined by the Republic graben. This north-trending structural feature occupies all the central part of the area. It is flanked on both sides by granitic rocks and small areas of probable upper Paleozoic rocks, and is underlain by Permian and Tertiary rocks.

The oldest rocks in the area are schist and marble of probable late Paleozoic age that crop out as roof pendants in a few areas east of the graben. Rocks considered as about the same age and having a probably thickness of more than 1,000 feet are represented by marble, schist, phyllite, and higher grade metamorphic rocks in the southeastern part of the area.

The known Permian rocks are greenstones and related eugeosynclinal rocks many thousands of feet thick; they crop out only within the graben as narrow belts along each margin and in the north-central part of the graben.

Bedded Tertiary rocks are confined to the graben and are largely of volcanic origin. They are divided into five map units that range in age from Eocene(?) to Miocene(?) and have a total thickness of more than 10,000 feet.

Intrusive rocks, exclusive of those in the Paleozoic, range in age from Late Cretaceous to Miocene(?) and are dominantly of intermediate composition. The earliest intrusive is the Upper Cretaceous granodiorite that underlies most of the area west of the graben and is a part of a much larger mass, the Colville batholith. The area east of the graben, and a small area within the graben, are underlain largely by quartz monozite that looks much like the batholith to the west and has in the past been mapped as a part of it; most of this eastern quartz monzonite is, however, of Eocene(?) or Oligocene(?) age. The most widespread intrusive within the graben, but also occurring outside it, is a hypabyssal rock of probable Eocene or Oligocene age. Other intrusive rocks occur as dikes and small irregular bodies and range in age from Eocene(?) to Miocene(?).

Structurally, the area is dominated by the Republic graben, which was probably first formed during the Eocene; because of intermittent faulting along its margins, the graben remained as a structural and depositional basin for much of the time until the Miocene. High-angle faults along the margins and within the graben are of several ages and were probably active recurrently during much of the interval from Eocene(?) until Miocene(?) time.

Folds with predominant northward trends, unconformities, metamorphic structures, and a large Tertiary thrust fault—the Lambert Creek thrust—record periods of compressive movement that occurred in Late Cretaceous, Eocene(?), and Oligocene times.

The mineralized veins of the Republic district are fracture fillings, predominantly in Tertiary flows. The veins were probably formed during a period of faulting in Oligocene time. The main mineralization probably occurred during a brief interval, but it might have continued with diminished vigor into the late Oligocene or perhaps even into the early Miocene.

The topography and drainage were modified by glaciation, and much of the area is mantled by glaciofluvial deposits and some till. The evidence at hand suggests that the glacial deposits and drainage changes are the result of at least two epochs of glaciation.

METAMORPHIC ROCKS EAST OF SHERMAN FAULT

Small inclusions and one larger mass of metamorphosed sedimentary rocks occur in the quartz monzonite east of the Sherman fault. The most extensive outcrop of metamorphic rocks is in the northeastern corner of the area (pl. 1). Here, nearly a square mile is underlain by schist and a bed of dolomite marble. These rocks extend to the north and underlie a larger area there. (See also, Parker and Calkins, 1964.)

Schist containing diopside, plagioclase, biotite, and quartz as essential constituents is the predominant rock in the northeastern corner. The schist has laminations and bands ranging in thickness from less than 1 mm up to about 1 cm and in color from light gray to dark green and almost black. The laminae and bands probably represent original sedimentary differences in lithology and bedding. The percentage of essential constituents ranges widely from one band to another. As seen in thin section, the texture is granoblastic and the grain size ranges from less than 0.1 mm to about 1 mm. The schistosity is the result of the subparallel arrangement of brown biotite and elongated quartz and diopside. A little of the biotite has altered to or been replaced by chlorite, epidote, and calcite. Minor constituents are granular sphene and apatite. The lithology and structure of the schist indicate that it was derived from calcareous to dolomitic fine-grained clastic sediments.

The contact of the schist and quartz monzonite, which is exposed only in sec. 33, T. 38 N., R. 34 E., is intrusive and is a thin cataclastic zone in places. The schist has been injected by aplite and locally contains reddish-brown garnet and some scapolite. The quartz monzonite is chloritized and has a foliation defined by hornblende and biotite lying roughly parallel to the schistosity of the intruded beds. One thin section of quartz monzonite from a cataclastic zone shows veinlets of K-feldspar that is less brecciated than the surrounding minerals. This fact and the rough parallelism of the foliation and the contact suggest that the contact zone is protoclastic.

Intercalated with the schist is a massive bed of dolomite marble. It is light gray to almost white, is fairly pure, and has a grain size as much as 1 mm. Its contacts with the enclosing schist were not seen. As inferred from the structure of the enclosing schist, the marble is about 200 feet thick; it dips northeast to north and could be in the west limb of a north-plunging syncline.

Small inclusions of metamorphic rocks crop out in the granitic area near Edds Mountain in the southeastern part of the Republic quadrangle. Most of the inclusions are micaceous quartzite and muscovite-biotite-quartz schist; some of those southwest and south of Edds Mountain contain interbeds and irregular masses of tactite. One inclusion too small to map (but whose position is shown on pl. 1 by an adit symbol just south of Edds Mountain), exposed in a short adit, contains thin discontinuous tactite bands composed principally of garnet, epidote, diopside, wollastonite, and calcite; one of the bands contains several stringers of scheelite. Tactite in the inclusion just west of the adit contains two varieties of pyroxene, salite, and what is probably acmitic hedenbergite, in addition to much magnetite, light-brown garnet, epidote, wollastonite, quartz, calcite, and a little sphene. The margins of all the inclusions have stringers and irregular masses of aplite.

The age of these rocks is not known; however, just west of the Sherman fault, at Iron Mountain, are beds of quartzite and schist, some of which resemble the rocks east of the fault. The rocks west of the fault seem to underlie the Permian limestone on Iron Mountain and are perhaps not much older. It seems likely that the rocks east of the fault are of late Paleozoic age.

PERMIAN ROCKS

The Permian rocks constitute a typical eugeosynclinal assemblage (Kay, 1951, p. 85): tuff, lava, and associated intrusives, together with graywacke, other detrital sediments, limestone, and chert. The igneous components of the assemblage probably make up more than half the exposed section. All the rocks have been regionally metamorphosed, and the igneous rocks among them are typical greenstone. For ease of description and because of the characteristic lithology, I have called this suite of rocks greenstone. Also included as part of the Permian assemblage are small serpentine bodies, which are discussed below with the greenstone of intrusive origin.

The greenstone lies almost entirely within the Republic graben and crops out from beneath the cover of Tertiary rocks in three north-trending belts—two of them along the boundary faults of the graben and the other in the north-central part of the graben. Within these belts, which are as much as 2 miles wide, outcrops are discontinuous owing to the extensive cover of regolith and forests and to the large areas of Scatter Creek Rhyodacite, which forms many dikes, sills, and irregular intrusive masses within the greenstone. The rocks within the belts, particularly the eastern two, strike generally north and dip predominantly west to northwest at steep angles. Wherever bedding could be seen, it parallels foliation; graded bedding in the graywacke indicates that the tops of the beds face west. In a few places where the detailed structure could be seen, for example in a few mine adits, the rocks are much faulted and intricately folded, and none of the discrete beds can be traced very far along the strike.

Because of the discontinuous outcrops and the complex structure, it has been feasible to determine only a gross stratigraphic succession of the rocks. In consequence, I have not tried to measure the exposed thickness, because such a measurement would be meaningless. Even with allowances for probable isoclinal folding, however, the width of outcrop, particularly in the central belt, suggests that these Permian rocks are at least 7,000 feet thick.

Except for the limestone, which crops out boldly in a few places, there is nothing distinctive about the outcrop of the Permian rocks. They are predominantly of dark color with a greenish cast and many of them exhibit more or less iron-stained weathered surfaces. Most of the limestone is dark gray but weathers to light gray.

LITHOLOGY AND PETROGRAPHY

Although the Permian rocks have been sheared, chloritized, and otherwise chemically altered, most retain enough of their primary textures and minerals to allow their origin and primary lithology to be deduced. They consist of altered basic tuff, lava, and associated intrusives, argillite, graywacke, limestone, conglomerate, quartzite, and chert, named in probable decreasing order of abundance. In the descriptive sections that follow, the lithologic names used are those of the original unmetamorphosed rocks.

MAFIC TUFF, LAVA, AND ASSOCIATED INTRUSIVES

Mafic tuff, lava, and associated intrusives make up at least half of the exposed section of Permian rocks. They have been regionally metamorphosed to massive greenstone, phyllite, and some schist, and are characterized by the development of abundant chlorite, mica, epidote (zoisite, clinozoisite), albite, actinolite, calcite, and sphene (leucoxene). A characteristic of all the igneous rocks is a high content of titanium, shown by a high content of granular sphene, made somewhat opaque in thin section by the white alteration product, leucoxene.

Tuff appears to be the most abundant of the igneous rocks. Most of the tuff is a laminated phyllite whose color is predominantly green but includes shades of dark purple. The tuff is characteristically minutely plicated, or crenulated, into chevron folds having amplitudes of a few millimeters to several inches. Intercalated among the beds of tuff are flows and dark clastic sediments, and in places it is difficult to distinguish the tuff from, say, foliated green flows or laminated argillite and phyllite. Indeed, as inferred from the megascopic features of these rocks in the field, these rocks appear to grade into each other, especially the tuff and fine-grained clastic sedimentary rock. In places, however, where the tuff contains small dark clots that in thin section are seen to be lithic fragments, recognition as tuff is certain.

The tuff exposed in the NW¼ sec. 17, T. 36 N., R. 34 E., and in the adjoining sections is representative. It is finely laminated in shades of green to purple and in many places has thin irregular calcite stringers through it. In thin section the tuff is seen to consist of thin laminae composed of very finely granoblastic sodic oligoclase and albite, alternating with laminae of chlorite crowded with granular sphene-leucoxene. Sericite and biotite occur in some of the laminae. One of the purplish tuff beds at this locality has been partly replaced by hematite but shows deformed and flattened shard structures.

Just below the stock trail on the east side of Iron Mountain and at bench mark 3091 in sec. 9, T. 36 N., R. 32 E., is a distinctive lustrous green phyllite that is everywhere intricately chevron folded (fig. 3). The phyllite is composed of laminae, 0.05–0.5 mm thick, of calcite and a little quartz, alternating with chlorite crowded with granular sphene-leucoxene.

The lava is a predominantly massive dark-green rock that probably was mostly andesite. Some lava beds contain mafic phenocrysts as much as several millimeters long and some are vesicular or amygduloidal; many, however, contain no megascopically recognizable minerals or textures. A few greenstone layers inferred to be flows are moderately to strongly sheared, and in two places the rocks are now amphibole schist.

Under the microscope nearly all the flows are seen to have retained primary flow textures. Most of the plagioclase feldspar in phenocrysts and groundmass is highly saussuritic and in some specimens is completely replaced by calcite, chlorite, sericite, and "epidote." The plagioclase could not be identified in most specimens, but in some it

FIGURE 3.—Lustrous green phyllite showing chevron folds and crenulations.

was determined to be oligoclase. Crystalloblastic, generally untwinned, clear sodic oligoclase and albite occur extensively in the groundmass of some of the rocks and as veinlets and overgrowths in the saussuritic more calcic plagioclase. Some phenocrysts that were originally mafic have been pseudomorphically replaced by chlorite, calcite, epidote, sphene, and actinolite. Chlorite, granular epidote, calcite, much granular sphene-leucoxene, some apatite, magnetite, ilmenite, and quartz are all common as secondary minerals in the original groundmass.

Typical altered lava occurs along the paved highway on the west side of Gold Hill. Most of it is aphanitic and nonporphyritic, but some flows contain phenocrysts of dark amphibole. Light-green veinlets of clinozoisite, a little zoisite, and some clear sodic oligoclase cut the rocks. The original plagioclase laths consist of a mat of clinozoisite-epidote, and the intergranular matrix is actinolite, chlorite, some calcite, and much granular sphene.

In the center of sec. 17, T. 36 N., R. 34 E., is a light-green massive porphyritic lava of silicic composition. The original plagioclase phenocrysts have been completely altered to calcite, sericite, and epidote, and those of euhedral hornblende to calcite and chlorite outlined by granular magnetite. The groundmass is granoblastic quartz and chlorite; water-clear albite veinlets cut the rock. Practically in the same outcrop is an albite-actinolite schist composed of about 70 percent nematoblastic actinolite and about 25 percent clear albite; it also contains ricelike blebs of sphene and veins of calcite and epidote.

Amygduloidal flows associated with the tuff crop out in the SW. cor. sec. 8, T. 36 N., R. 34 E., on the northwest side of Gold Hill and in other places. The amygdules of calcite, quartz, and chlorite are as much as 3 mm across. In one typical specimen, the few plagioclase phenocrysts are about 1 mm long and are now largely chlorite and clear albite or sodic oligoclase. The dense groundmass consists of chlorite, some green biotite, sphene, and a little quartz. A distinctive feature of this rock is the occurrence of a violet to blue sodic amphibole (glaucophane?) that is concentrated in small needles in the groundmass around the amygdules. This relation to the amygdules suggests that the vesicles might have once contained sodic zeolites.

Holocrystalline intrusive rocks constitute only a small part of the greenstone. So far as they were recognized in the field they are really restricted to secs. 8, 17, and 20, T. 36 N., R. 34 E., where they form irregular bodies and some dikes. Although no intrusive contacts were seen, the close association and mineralogic similarity of these intrusives with the greenstone indicate that they are probably genetically related to, and should therefore be of about the same age as, the associated rocks. The intrusive rocks are fine- to medium-grained dark-green rocks having subophitic to hypidiomorphic granular textures, and with the exception of lamprophyre and serpentine, are diabase and gabbro.

The plagioclase of the intrusives has been altered, as in the lava, and is now considerably more sodic than in the original rocks. Sodic andesine is the most calcic plagioclase found, but most of the original plagioclase is now oligoclase and albite. The secondary plagioclase, which is commonly clear and occurs as overgrowths, veins, and interstitial crystalloblastic masses, is albite and sodic oligoclase. Albite twins in the altered feldspar are commonly broad and diffuse. Alteration products of the feldspar are epidote, clinozoisite and (or zoisite, sericite, chlorite, and calcite. All the rocks are cut by white to greenish-white veins consisting primarily of epidote, clinozoisite and zoisite, calcite, clear albite, and some quartz.

In nearly all the rocks the primary mafic minerals are now blue-green actinolite or hornblende—in places clearly pseudomorphic after pyroxene—chlorite, calcite, and epidote. Skeletal crystals of rutile-leucoxene are characteristic, constituting as much as 5 percent of the rocks.

A diorite dike on Iron Mountain contains veins of the zeolite thomsonite. In the same rock, the plagioclase is saussuritic sodic andesine that has overgrowths and veinlets of clear albite or sodic oligoclase. Pyroxene still remains, but is partly altered to chlorite, apple-green amphibole, and calcite.

Serpentine is closely associated with the intrusives described above. Most of it is intensely sheared and occurs here and there along the Sherman fault and the unnamed fault just west of it, from the California mine north to the South Fork of the Sanpoil River. The best exposures are along the highway at its intersection with the Sherman fault in the south-central part of sec. 17, T. 36 N., R. 34 E., and along the north-trending road and fault in sec. 18, T. 36 N., R. 34 E. The serpentine is chiefly antigorite, but it also contains serpophite, calcite, a little olivine, same talc veinlets, and magnetite and (or) chromite. The origin of the serpentine is not known, but its present position along faults suggests that it may have been emplaced tectonically by "cold" intrusion at a time much later than the intrusion of the parent ultramafic intrusives, which are probably a part of the eugeosynclinal assemblage.

ARGILLITE AND GRAYWACKE

Argillite and graywacke are prominent constituents of the Permian rocks. They occur stratigraphically above and below the limestone units differentiated on the geologic map (pl. 1). Their largest area of outcrop is to the east and west of the discontinuous limestone outcrops in the northeastern part of the area. Although the beds here are interrupted by Tertiary intrusive bodies and are possibly duplicated by undetected structural features, they are probably more than 1,000 feet thick; on the interfluve hill, E½ sec. 5, T. 37 N., R. 34 E., the measured apparent thickness of sedimentary rocks under the limestone—assuming a straightforward section—is about 1,900 feet. To the north, in sec. 32, T. 38 N., R. 34 E., argillite and graywacke lie above limestone, but no estimate can be made of their thickness. To the south, on the west slope of Iron Mountain, the apparent thickness of these rocks above the limestone is about 1,700 feet. The clas-

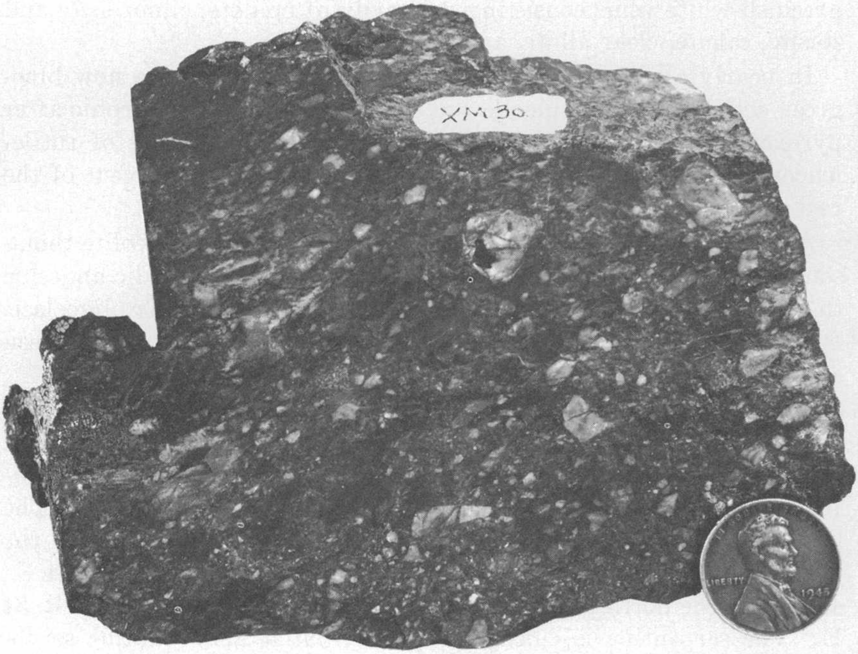

FIGURE 4.—Permian graywacke showing angular chert clasts in hard fine-grained matrix.

tics are also exposed in secs. 4 and 16, T. 37 N., R. 33 E., where they underlie limestone and overlie tuff.

The argillite and graywacke are mostly dark gray to blue gray and massive; they are hard and difficult to break along bedding—especially the graywacke—though in some places they are laminated and banded. They are commonly interbedded and grade into each other. Graded bedding occurs in several places in sec. 16, T. 37 N., R. 33 E., and sec. 5, T. 37 N., R. 34 E., and shows that the beds are right side up. The typical argillite, as seen in thin section, consists of an extremely fine grained murky lepidoblastic intergrowth of chlorite, sericite, and quartz. In one specimen, ovoidal spots about 1 mm across are developed in which sericite with reticulate fabric is surrounded by thin rims of medium-brown chlorite(?).

In mineralogic and lithologic composition the graywacke does not differ from the rocks described by Pettijohn (1949, p. 243–252). Chert is the chief component of the clasts, characteristically angular (fig. 4), followed in decreasing order of abundance by quartz, plagioclase, and fragments of phyllite, argillite, and basic igneous rocks. These lie in a paste of chlorite, sericite, carbonate, quartz, and probably feldspar. The other minerals noted are pyrite, sphene-leucoxene, apatite, epidote, biotite, and "ore."

In mechanical composition, the graywacke as discussed here ranges from sand (the graywacke of Pettijohn) to coarse conglomerate (sharp stone conglomerate), which Krumbein and Sloss (1951, p. 128) would call "graywacke conglomerate." However, "graywacke conglomerate" seems to me to be an unfortunate term because it is easily (and logically) interpreted to mean a conglomerate whose fragments are graywacke. Pettijohn (1948, p. 244) would limit use of the term "graywacke" to rocks made up of sand-size grains, but, inasmuch as the term "graywacke" has genetic connotations and because it has distinctive composition, this size limitation restricts the usefulness of the term. Because the graywacke of this area has fragments more than an inch in diameter, and yet has the same composition as the graywacke with sand-size grains, I advocate use of the term without restriction as to grain size. In this connection, see Helmbold on the Tanner Graywacke (1958).

LIMESTONE

Limestone, some of which is fossiliferous, occurs in all three outcrop belts of the Permian rocks and is especially prominent at the northern ends of the eastern and central belts. Thinner limestone crops out to the south on Iron Mountain and with some interruptions extends to the north and south for several miles. What is apparently the same limestone crops out at Copper Lakes in the western outcrop belt.

Most of the limestone is shown separately on the geologic map (pl. 1). Some beds that are too thin to show on the map and are not discussed further are interbedded with tuffs in secs. 8 and 17, T. 36 N., R. 34 E., and in sec. 27, T. 37 N., R. 33 E. A fault block of sooty marble that is also too small to show on the scale of the map crops out on the east side of Iron Mountain and probably also on the west side of the graben in sec. 22, T. 36 N., R. 32 E. It is discussed in the section that deals with the possible relations among the upper Paleozoic rocks in this area (p. 38).

The limestone in the northern outcrops occurs as podlike masses whose horizontal extent is small compared with apparent thickness. Most of the limestone is light to dark bluish gray and weathers to a light gray. It is fine grained and massive in most places but in some is in well-defined beds 2–3 feet thick. Light to dark chert occurs sporadically in the limestone as nodules and thin lenses and stringers parallel to bedding. Most of the limestone appears to be low in magnesium except in sec. 16, T. 37 N., R. 33 E., where it has intercalated beds of light-gray fine-grained and dark-gray finely crystalline dolomite, and on Cooke Mountain, where some dolomite and dolomitic limestone occur (Bancroft, 1914, p. 169). The northern limestone is clastic and contains much fossil hash, some of which shows up on weathered surfaces. In most places the clastic fragments are angular and poorly sorted, but in some, for example, in sec. 16, T. 37 N., R. 33 E., they are ovoidal to lozenge shaped and range in size from about 0.2 mm to 1 mm.

The limestone that crops out on Iron Mountain and at Copper Lakes differs from that to the north in that it is of greater horizontal extent, is in general more sheared, and has an upper member lithologically distinct from the lower. The lower member on Iron Mountain is blue-gray fine-grained limestone, much like that to the north; it is about 60 feet thick. The upper member, which is about 100 feet thick, is medium- to dark-olive-gray calcarenite that weathers to buff blocky fragments and superficially looks like argillite or graywacke. The limestone ranges in grain size from very fine to pebbly and contains abundant fossil debris. As much as 25 percent of the rock consists of fragments of phyllite, argillite, chert, altered volcanic rocks, and some grains of quartz, in a clastic calcite matrix. The foliation planes of these clasts show a random orientation.

The northern limestone masses were probably once part of a single limestone complex of unknown shape. That they now occur as isolated masses is partly due to disruption by high-angle and flat faults, folds of unknown character, and Tertiary intrusive bodies. However, much of their present podlike shape—as exemplified by the bodies east of Curlew Lake—may be a relict primary feature. This possibility is suggested by the fact that in several places the limestone sharply intertongues with, and appears to grade into, coarse conglomerate and breccia containing predominantly limestone clasts whose lithology is like that of the adjacent limestone. This relationship is well seen in the northern part of sec. 32, T. 38 N., R. 34 E., and in the west-central part of sec. 9, T. 37 N., R. 33 E., just northeast of the kettle hole east of the main highway. These relations, the shapes of the bodies, and their high content of organic debris, suggest that the presently isolated masses could have been part of a limestone reef complex. In nearby areas (Daly, 1913, p. 389–391; Pardee, 1918, p. 22; Waters and Krauskopf, 1941, p. 1360), lenses and pods of limestone having erratic distribution seem to be characteristic of rocks whose lithology and general age are about the same as that of the Permian rocks of this area. Pardee considers the shape and distribution of these features to indicate a complex structure, whereas Waters and Krauskopf state that these features are unrelated to deformation and must be original; they consider deposition in reefs as a possible origin for the limestone. Although my work does not resolve the question, I lean toward the idea that the podlike limestone masses had their origin in reef complexes.

The age of the limestone, as determined from the fossils of eight collections, is Early Permian; there seems to be little range in age among the collections. Four collections came from the northern limestone, three from the limestone of Iron Mountain, and one from an isolated block near the center of the eastern outcrop belt. The localities and collection numbers are shown on plate 1. The fusulinids were studied by R. C. Douglass, the coelenterates and bryozoans by Helen Duncan, and other megafossils by J. T. Dutro.

Miss Duncan reports (written commun., Mar. 14, 1958):

The results [of this study] are disappointing insofar as the bryozoans are concerned. In most of the collections, the material is too fragmentary and altered for positive identification. Two of the lots without fusulinids contain the same undescribed species of long-ranging bryozoan. Inasmuch as one of these collections (USGS 16451–PC) is supposedly bracketed between Permian fusulinid-bearing rocks, the other lot (USGS 16456–PC) also is inferred to be Permian.

All the rock in which the bryozoans occur appears to have been of clastic origin. The environment in which this organic debris formed was presumably turbulent, but the ultimate environment of deposition could have been quite different. Originally much of the sediment must have been calcareous sand. Some of the pieces of rock seem to be sedimentary breccia. The main problem in this case is the interpretation of the sedimentary environment rather than the paleoecology.

USGS 16451—PC. Locality: About 200 feet south of SW¼ sec. 32, T. 38 N., R. 34 E. Altitude about 4,100 feet.

Six large thin sections were made. The only identifiable fossil is the bryozoan *Leioclema*. The undescribed species is characterized by ramose growth with anastomosing branches. The same form of *Leioclema* is present in USGS 16456–PC. The matrix is comminuted organic material with some crystalline limestone (this seems to be thoroughly recrystallized).

Leioclema is a long-ranging genus—Silurian to Permian. It is common in the upper part of the Park City Formation in Wyoming and occurs rather widely in the Permian rocks of the Western States. The Permian bryozoan faunas of the region have not been described, however, so the significance of the species in the Washington collections cannot be evaluated.

USGS 16452–PC. Locality: About 450 feet southwest of 16451–PC from same limestone body. Altitude about 3,950 feet.

The rock is a crinoidal limestone with fusulinids. A little bryozoan material was noted * * *. The bryozoan debris is altered and in such small fragments that identification of genera is not possible. The fragments were derived from stenoporoid, fistuliporoid, and fenestellid forms.

USGS 16454–PC. Locality: SW¼NE¼ sec. 32, T. 38 N., R. 34 E. Altitude about 4,400 feet. From same limestone body as 16451–PC and 16452–PC.

The rock is a bioclastic limestone with fusulinids. Fragments derived from bryozoans are fairly abundant, but most of the pieces are too small or poorly oriented for identification. Fistuliporoid, fenestrate, and rhomboporoid forms are represented. *Fenestella*, *Streblotrypa*?, and *Clausotrypa*? were identified. *Clausotrypa* is diagnostic of Permian age.

USGS 16456–PC. Locality: From southernmost isolated limestone body, SE¼SW¼ sec. 18, T. 37 N., R. 34 E. Altitude about 4,750 feet.

Twelve thin sections were made. The rock is fine-grained limestone with some organic debris. No foraminifera were seen. The bryozoans are comparatively large fragments of the same species of *Leioclema* that occurs in 16451–PC. It could be inferred that both collections came from the same unit.

Some pieces of rock in this collection contain a peculiar laminate fossil that I think is probably a stromatoporoid or hydrozoan, though it might be fragments of a sponge. Spicules, however, cannot be identified.

USGS 16458–PC. Locality: SE¼ sec. 6, T. 35 N., R. 34 E. Upper member of limestone on Iron Mountain.

The material is a clastic rock containing much organic debris derived from bryozoans, brachiopods, echinoderms, and other fossils. Ten large thin sections were made. No foraminifers were found, and the bryozoan material is altered. Fenestrate, fistuliporoid, rhomboporoid, and stenoporoid forms are represented. Identification of genera would be so much guesswork. I thought some of the branching forms might be *Clausotrypa*, but I am afraid that is largely a matter of wishful thinking. Some of the fenestrate forms apparently had coarse meshworks, a feature that is generally well developed in Western Permian genera. A fragmentary solitary coral was identified as *Euryphyllum*? sp. *Euryphyllum* is a Permian genus. A few pieces exhibited molds of brachiopods, which J. T. Dutro said were not identifiable.

There is a good chance that this clastic rock is Permian, but evidence for such assignment cannot be adequately documented on the available fragmentary material.

Miss Duncan, in consultation with J. T. Dutro, Jr., had the following to say (written commun., April 16, 1959) about a collection from about the same bed as USGS 16458–PC, just described:

USGS 18370–PC. Locality: NW¼NW¼ sec. 15, T. 36 N., R. 32 E.

The rock in this collection has a considerably finer texture than most of the material in USGS 16458–PC. Two bryozoan genera—*Polypora* and *Fenestella*—can be identified. There is also a biofoliate form that may be a fistuliporoid, though one cannot be certain about a specimen preserved as a mold. A few branching types, also represented by molds, were seen. The bryozoan faunule is less diversified than the one in USGS 16458–PC, which contained a very large amount of bryozoan debris. Both the *Polypora* and the *Fenestella* are comparatively small-meshed forms not readily comparable with things in the other collection. The *Polypora-Fenestella* association occurs from the Silurian through the Permian, and forms in which the meshwork is of small size have little stratigraphic significance. Internal structure in the *Fenestella* suggests that the species is Devonian or later.

Although these bryozoans are not diagnostic, they would not be out of place in the Permian.

J. T. Dutro examined the molds of the bivalves and reports that a rhynochonellid and a spiriferoid seem to be represented. None of this material is identifiable as to genus.

Even though the faunal evidence is inconclusive, we think you might reasonably assume that this collection came from beds of about the same age as those represented at the locality of USGS 16458–PC. The texture and composition of the rock in the present collection resemble that of the slabs with brachiopod molds in USGS 16458–PC. The rock containing abundant bryozoan and echinoderm debris in 16458–PC has a much coarser texture. The original sediment was apparently a coarse sand composed largely of calcareous organic fragments; it does, however, contain pebble-sized inclusions of finer-grained material.

USGS 18116–PC. Structurally isolated limestone block in SW¼NE¼SE¼ sec. 7, T. 36 N., R. 34 E.

Miss Duncan reports (written commun., Feb. 5, 1959):

The rock is a shattered and veined dark limestone. In addition to fragments of the bryozoan *Leioclema*, there are indications of pelmatozoan debris and a possible hydrozoan. As seen in thin section the rock seems to be a bioclastic limestone that has been considerably altered. Bryozoan material is not abundant and only the one species seems to be present. So far as I can tell, there is nothing to suggest derivation from a reef.

As indicated in my previous report (3/14/58), *Leioclema* is a long-ranging genus. The species in this collection appears to be identical with the one that occurs in USGS 16451–PC and USGS 16456–PC. It is of interest to note that a laminate hydrozoan(?) also is present in the latter collection. I suspect that all three collections came from the same unit.

The following reports on the fusulinids are by R. C. Douglass (written commun., July 8 and 9, 1958):

USGS f–12390 (16452–PC). Locality given above.

Bradyina sp.

Staffella sp.

Pseudofusulinella sp.

Schwagerina or possibly *Parafusulina* sp.

The limestone of this sample is largely coquinoid being composed of tests of *Staffella* sp., crinoidal debris, and minor numbers of other fossils. No well-oriented sections of the schwagerinid form were obtained, so no definite identification is possible. This assemblage is probably of Early Permian age, possibly equivalent to the late Wolfcamp, although early Leonard cannot be ruled out.

USGS f–12391 (16453–PC). Locality: Conglomerate that underlies and interfingers with limestone of 16451–PC, 16453–PC, 16454–PC, and f20426. SW¼NE¼SW¼ sec. 32, T. 38 N., R. 34 E.

Almost no foraminifera were found although 12 large sections were prepared. A specimen of *Tetrataxis* sp. and a fragment of *Schubertella* sp. were recognized. *Schubertella* is reported from latest Pennsylvanian into Leonard equivalents in the Early Permian.

USGS f–12392 (16454–PC) Locality given above.

Staffella sp.

Pseudofusulinella sp.

Schwagerina sp. aff. *S. nelsoni* Dunbar and Skinner

This assemblage is of Early Permian age, possibly equivalent to the upper part of the Wolfcamp.

USGS f–12393 (16458–PC) Locality given above; lower member.

The limestone of this sample has been squeezed and partly recrystallized, and much of the detail in the fossils has been destroyed. Two species of *Schwagerina* appear to be represented. Neither can be identified with any certainty.

One looks as though it may have resembled *S. linearis*, the other may have resembled *S. fax* of Thompson and Hazzard. An age close to that of f12392 is suggested, but any age from late Wolfcamp into Leonard is possible.

USGS f20425. Locality: Probably same limestone as on Iron Mountain. W½W½ sec. 29, T. 36 N., R. 34 E.

Climacammina sp.

Bradyina sp.

Pseudofusulinella sp.

Schwagerina sp.

The species of *Schwagerina* in this sample represents a very large form. The specimens are recrystallized and distorted and are not assignable to any species with which I am presently acquainted. The age of the sample is uncertain but is probably Early Permian, either late Wolfcamp or Leonard.

USGS f20426. Locality: Same limestone as 16452–PC, probably about 100 feet stratigraphically below 16452–PC, and about 400 feet south. NW¼NW¼SE¼ sec. 32, T. 38 N., R. 34 E.

Staffella sp.

Schubertella sp.

Schwagerina sp.

This sample consists of a rounded calcarenite with scattered abraded specimens of forams. The schwagerinids are all small immature specimens and do not show sufficient character to be identified specifically, but the evolutionary stage suggests Early Permian, probably middle Wolfcamp to Leonard age.

CONGLOMERATE

Beds of conglomerate, none of which can be traced very far, occur chiefly in association with limestone. In most places the conglomerate is more than 100 feet thick. Where it grades into limestone, the conglomerate contains unsorted angular to rounded fragments of limestone, chert, argillite, and phyllite, and fine-grained greenstone, loosely packed in a quartzose calcarenite matrix. The limestone clasts contain much crinoid hash, some bryozoans, a fusulinid, and brachiopod fragments. All the fragments are of rock types that occur in the enclosing Permian rocks—a feature that suggests that they are of about the same age.

A different kind of conglomerate crops out near the Sherman fault in SE¼ sec. 5 and NE¼ sec. 8, T. 37 N., R. 34 E., and along the fault in the north-central part of sec. 4, T. 37 N., R. 33 E. This conglomerate has a murky green aphanitic matrix in which are set angular to rounded pieces of limestone, altered holocrystalline igneous rocks, and greenstone. Some of the fragments are as much as 1 foot in diameter. The limestone clasts are of calcarenites, and some of them contain fossil hash. The whole aspect of this rock suggests that it is a volcanic conglomerate.

Another bed of conglomerate, exposed in pits east of the fault on the west edge of sec. 32, T. 38 N., R. 34 E., contains abundant large unsorted fragments of dark phyllite, mica schist, limestone, green phyllitic tuff, and smaller fragments of aplite and pegmatite, in a greenstone matrix. Except for the aplite and pegmatite, all the clasts are represented by similar lithologies in the enclosing rocks.

In all the conglomerate, most of the limestone clasts have been partly removed by solution, leaving cavities in surfaces that are otherwise relatively smooth.

QUARTZITE AND CHERT

Quartzite in beds at least a few feet thick but not traceable very far, occurs in only a few places among the greenstone. Massive vitreous white to light-tan quartzite that could be several hundred feet thick crops out on the steep heavily wooded east slope of Iron Mountain west of bench mark 3903. The quartzite appears to be overlain by green tuff and the sooty marble referred to above. But inasmuch as contacts on this east slope are probably faults, the stratigraphic position of the quartzite is unknown. Beds of comparable thickness and lithology crop out high on the southwest slope of Gold Hill, but they cannot be traced along the strike to the northern slope, which is underlain by greenstone. A white vitreous quartzite, about 15 feet thick, crops out for short distances in NE¼SW¼ sec. 17, T. 36 N., R. 34 E., and in secs. 16 and 21, T. 37 N., R. 33 E. In all three places the quartzite occurs among laminated tuff and albite-actinolite schist. The three outcrops are probably of the same bed, but it has too restricted a distribution to be of much value in unraveling the complex structure and stratigraphy of the Permian rocks.

Chert is characteristically associated with the green tuff and the green laminated tuffaceous sediment and is rather widespread although minor in amount. Most of it is light-colored ribbon chert occurring in long interleaved or separated lenses whose thicknesses are measurable in millimeters. Laminated and banded chert in thicker beds crops out just east of Torboy but is absent a short distance along strike to the north.

MARBLE

White calcite marble crops out northeast of Iron Mountain and is shown separately on plate 1. It is thin bedded to massive and has intercalated orthoclase-quartz-mica schist that looks like some of that in the white marble north of Sheep Mountain. Near the top of the outcrop a little tremolite occurs in the rock. The calcite of the marble has complex lamellar twins and is biaxial with a maximum 2V of about 10°. The marble has an apparent thickness of about 200 feet and at the top of the outcrop grades into quartz-mica schist.

About 2 miles south, on the east side of the isolated Permian outcrop just south of Rabbit Creek, is a marble band too thin to show on the map. It is outlined by alluvium on the east and by graywacke on the west. Diopside, orange-brown garnet, orthoclase, labradorite, quartz, and sphene occur in the rock.

The occurrence of orthoclase and brown biotite in the schist and of diopside in marble indicates that these rocks have been more highly metamorphosed than the contiguous greenstone. The cause of the higher grade of metamorphism is not known.

ORIGIN

The origin of the Permian rocks cannot be inferred from the limited exposures in this area. The presence of massive limestone-bearing marine fossils shows, however, that at least part of the rocks are marine. Although associated greenstone and clastic rocks have no diagnostic features showing them to be marine, the association of greenstone and graywacke with the limestone strongly suggests marine origin (Pettijohn, 1949, p. 254). Further, the association is typical of that found in eugeosynclines and probably formed in the western trough of the Cordilleran geosyncline under conditions such as those lucidly described by Eardley (1947): An orogenically active volcanic archipelago lay to the west and from it came volcanic debris and associated sediments. Eardley pictures (1947, fig. 2) the archipelago as lying several hundred miles west of the Republic area during the Permian. The presence of conglomerate, relatively pure quartzite, and clastic limestone suggests, however, that shoal waters, and perhaps land, must have existed in the Republic area during that time. Islands, outliers of the archipelago, may well have existed ephemerally in the volcanic trough.

Although most of the conglomerate is probably intraformational, the presence of granitic pebbles strongly suggests an orogenic source in nearby areas. Acidic intrusives of almost certain pre-Permian age occur to the northwest near Vernon, British Columbia, where rocks identical to the Cache Creek (Pennsylvanian and Permian) unconformably overlie the granite and pegmatite that intrude the Mount Ida Group (Precambrian or Paleozoic, according to Rice and Jones, 1948).

AGE AND CORRELATION

The age of the greenstone is inferred to be Early Permian on the basis of the fossils found in the associated limestone. Admittedly, the greenstone is not bracketed between limestone beds of known age, and some of the rocks here included with the Permian could range in age from Pennsylvanian to Triassic. As noted previously, the northern limestone is inferred to be near the top of the exposed section, so its age sets an upper age limit for the unit. The limestone of Iron Mountain probably lies below the northern limestone. At any rate, possibly several thousand feet of rocks lie below the Iron Mountain bed, and these could extend into the Pennsylvanian.

In rocks so heterogeneous and bearing so few fossil horizons, precise correlation with rocks in nearby areas is impossible. However, rocks of comparable diverse lithology and of approximately the same age are widespread in adjacent areas.

To the south, the Covada Group, which has limestone in "lenses and podlike masses" (Pardee, 1918) greenstone, and other rocks like those in the Republic area, is probably in part correlative with rocks of this area. Rocks of comparable age and lithology in the Okanogan Valley have been correlated by Waters and Krauskopf (1941, p. 1358–1364) with the Anarchist Series (Daly, 1913, p. 389–341). The Permian rocks of the Republic area probably are represented to the north within the Mount Roberts Formation of Pennsylvanian and (or) Permian age and the Anarchist Group of Permian(?) age (Little, 1957). Around Kettle Falls (see fig. 1), middle Permian fossils (McLaughlin and Simons, 1951) occur in lenticular limestone intercalated with graywacke and greenstone. North of Kettle Falls, a limestone and graywacke sequence has been mapped as the Churchill Formation (Bowman, 1950); it is of probable middle Permian age (Lloyd Henbest in Bowman, 1950) and lies unconformably above a thick phyllite assumed to be of Ordovician(?) age.

Farther afield, rocks of late Paleozoic age characterized by limestone of erratic distribution, greenstone, and graywacke are found in the Fraser eugeosynclinal belt (Kay, 1947) extending from Alaska south to California. The occurrences have been partly summarized by Wheeler (1940) and extensively by Kay (1951, p. 40–44). Eardley (1947) considers the sediment of the Fraser belt—his western trough of the Cordilleran geosyncline—as being a volcanic archipelago assemblage. Most recently, White (1959) has discussed the upper Paleozoic rocks of this belt in British Columbia; he considers them to be a "negative tectonic unit," which he calls the "Cache Creek sequence."

GRADE OF METAMORPHISM

The Permian rocks have been regionally metamorphosed and are characterized by the presence of chlorite, epidote minerals, actinolite, muscovite-sericite, albite and sodic oligoclase, green and some brown biotite, and sphene. This mineral association is typical of the greenschist facies as described by Turner (1958, p. 217–224). That the grade of metamorphism is not uniform over the entire area is shown by the presence in some rocks and absence in others of brown biotite, zeolite, original pyroxene, and calcic plagioclase. It seems probable that metamorphism locally reached conditions that obtain in the glaucophane schist facies (summarized by Turner, 1958, p. 224–228); as noted, glaucophane(?) occurs in some of the greenstone.

UPPER PALEOZOIC(?) ROCKS NEAR SHEEP MOUNTAIN

Moderately to strongly metamorphosed unfossiliferous sedimentary rocks and a small amphibolite body, all probably of late Paleozoic age, crop out in the southwestern part of the area west of the Republic graben. The outcrops extend over a wooded area of several square miles and are bounded on the east by a linear intrusive body of Scatter Creek Rhyodacite, which lies along the western marginal fault zone of the graben. On the north and west the outcrops are bounded by the large intrusive body of granodiorite that lies west of the graben. The sedimentary rocks extend to the south and form more extensive outcrops in the Bald Knob quadrangle (Staatz, 1964).

The rocks are divided into four mapped units. A light-colored marble, whose base is an intrusive contact, is the oldest unit. It is overlain conformably by a dark-gray siliceous marble. Above the dark marble unit lie schist and some phyllite; the top of this unit is not exposed in the area. The fourth mapped unit is a small amphibolite body that intrudes the schist and phyllite; it crops out at the southern edge of the Aeneas quadrangle and extends into the adjoining Bald Knob quadrangle. The three layered units lie in fairly open folds that plunge gently south, but in detail the beds are tightly folded. Because the structure is complex and the outcrops poor—especially those of the phyllite—the total thickness of the units is not known. It is probable, however, that the exposed section is more than 1,000 feet thick. Because of the fairly open folds and the predictable correlation of stratigraphic succession and structure on Sheep Mountain, the beds are assumed to be right side up. Further indication that they are right side up and that the schist-phyllite unit is the youngest comes from the area north of Golden Harvest Creek. Here, rocks inferred to be the high-grade metamorphic equivalents of the schist-phyllite unit seem to be overlain conformably by the Permian rocks.

MARBLE

The most extensive outcrops of the light-colored marble unit are in the low wooded terrain of sec. 4, T. 35 N., R. 32 E. Here, all the exposures are surrounded by younger intrusive rocks or by Quaternary deposits. The marble occurs as north-trending low drumlinoid ribs as much as several hundred feet wide interspersed with swales in which there are few outcrops. To the south, the marble crops out in several narrow bands below the overlying dark marble unit that caps Sheep Mountain.

Most of the exposed marble is massive and is gray to rusty on the weathered surface. The fresh rock, however, is nearly white, and most of it is a fairly pure calcite marble. Calcite grains are as much as 5 mm across, although the average grain size is probably a little more than 1 mm. Interbeds originally clastic and probably dolomitic now occur as discontinuous thin layers and lenses of apple-green to gray silicate minerals. The interbeds form many thin stripes separated by thin intervals of marble. Two types of silicate bands were observed. The most common type consists of poikiloblastic diopside that encloses crystalloblastic andesine, K-feldspar, a little biotite, and some granular sphene. The other type, as seen in one thin section, is made up of crystalloblastic intergrowths of about 50 percent andesine, 30 percent K-feldspar, 15 percent biotite—replaced by calcite, sphene, and chlorite—apatite, zoisite, and a little epidote and tourmaline. There are also several beds, as much as 20 feet thick, of medium-grayish-brown thinly foliated schist. One thin section shows this rock to consist predominantly of quartz and K-feldspar; brown biotite and small porphyroblasts of blue-green hornblende make up about 30 percent of the rock, together with a little chlorite and sphene. This schist probably represents original calcareous argillaceous sandstone.

Many thin fine-grained pegmatite and alaskite dikes cut the marble in sec. 4, and at several places along them calc-silicate minerals have been formed. In one place much idocrase, reddish-brown garnet, epidote, and some tremolite were found. At another, a skarn of epidote, garnet, and diopside is cut by thin veins of scapolite. Near a dike of Scatter Creek Rhyodacite, a few very small euhedrons of diopside occur in the marble.

Calc-silicate minerals were also observed at all exposed contacts with the granodiorite body to the north and west. They are in general the same minerals that occur near the dikes except in sec. 8, T. 35 N., R. 32 E., where the contact is defined by a thin band of calc-schist consisting predominantly of diopside and wollastonite, together with sillimanite, calcite, and a little staurolite. The wollastonite and sillimanite crystals have their long axes parallel to the lineation of the area. There are pink garnets in the granitic rock.

The thickness of the marble in sec. 4 is not known. On the flanks of Sheep Mountain to the south, it crops out on the limbs of folds beneath the dark marble. Its exposed thickness in the westernmost fold is about 300 feet. Because the folds plunge south, it is probable that some of the marble in sec. 4 lies stratigraphically below that to the south; a greater thickness may therefore be exposed to the north.

DARK SILICEOUS MARBLE

Lying stratigraphically above the light-colored marble is a finer grained dark siliceous marble unit. It is best exposed on Sheep Mountain and south of there west of Ferry Lake; the other relatively large area of outcrop is on Swan Butte.

Most of the marble is predominantly medium to dark gray and fine to medium grained. It is mostly thin bedded to laminated, the individual beds being distinguished by differences in color, grain size, and composition. The lighter beds contain a high percentage of calcite, whereas the darker ones contain less calcite or almost none. On the weathered surface the darker bands and laminae stand in relief; they are punky and sooty and do not fizz with acid. On a fresh surface some of the darker layers can be seen to contain dark tremolite. In most places, quartz grains, which are the major constituent, cannot be recognized with a hand lens.

The marble crops out in slabs and in some places in pencillike fragments. Locally, it forms a soil that is very dark and almost sooty.

The basal layers of the dark marble unit, which seem to be conformable with the light-colored marble below, were originally dolomitic siltstone that is now metamorphosed to a thin-bedded dark-gray rusty weathering rock. A thin section of a specimen from just above the light-colored marble on the west side of Sheep Mountain is seen to contain mostly poikiloblastic diopside as much as several millimeters long enclosing granoblastic quartz and andesine in addition to grains of sphene and clinozoisite. Much granular "ore" and graphite(?) give the rock its dark color. A little higher in the section, what looks like the same rock contains about 80 percent quartz, in grains 0.02 mm to about 0.2 mm in diameter, about 10 percent tremolite and a little diopside, 10 percent hematite and graphite(?), and a few wisps of biotite.

The basal quartz-rich beds probably aggregate about 50 feet in thickness. Overlying these beds is the dark marble, thin sections of which contain mostly calcite, some tremolite, quartz grains in bands, and as much as 5 percent "ore" and graphite(?). Small reddish-brown garnets were seen in one place. The original lithology of the dark marble, as shown by the metamorphic minerals, was probably a dolomitic limestone that contained ferruginous and carbonaceous material and interbeds of quartz grains, probably of silt to clay size.

East of Swan Butte, the marble has been metamorphosed to a skarn containing brownish-red garnet, much epidote, fluorite, idocrase, scapolite, diopside, plagioclase, quartz, and calcite.

The internal structure of the marble, especially on Sheep Mountain, is contorted. On the western and southern slopes of the mountain, for example, the apparent dip of the beds is predominantly to the east, and the strike is north. Most of the rocks, however, show prominent lineation and some crop out in pencillike fashion; these are the clues to the structure. In a few places, especially at the lookout, the rocks, which here also appear to dip steeply east, actually are anticlinal in gross structure, but in detail are tightly folded along axial planes that dip steeply east. The lineation is evidently due mostly to wrinkling along bedding planes because the rocks show very little cleavage, even in thin section. What few cleavages were detected in thin section are at high angles to the bedding and are poorly developed; although no oriented sections were made, the cleavage probably represents axial-plane cleavage.

An estimate of the thickness of the marble must take into account the complicated structure. On Sheep Mountain, the only place an estimate can be made, the marble appears to be about 200 feet thick as measured along the axis of the eastern anticline and more than 350 feet measured along the axis of the western anticline. Obviously, one or both of these estimates are in error; however, it can safely be said that the marble is several hundred feet thick.

SCHIST AND PHYLLITE

Overlying the dark siliceous marble is a thick monotonous sequence of beds composed mostly of very fine grained thinly foliated schist and phyllite. The largest area underlain by these rocks is along the south margin of the Aeneas quadrangle; smaller outcrops are found just south of Ferry Lake and on Sheep Mountain. Exposures are poor in most places, the best being along the ridgeline that trends southeast from Swan Butte and then along the south border of the map. The contact of this unit with the underlying marble is not exposed, but the parallel attitudes of the two units and the presence of sooty silty marble in the upper unit suggests that there is no stratigraphic break between them.

The most common rock type, one found in nearly all exposures, is a dark-gray to nearly black laminated to thinly bedded mica-quartz schist. Foliation, which is parallel to bedding, is imparted by biotite and muscovite. In many places the schist contains thin intercalated layers of calcite that commonly weather out as irregular linear solution cavities along the bedding. Most of the schist weathers to a rusty brown. In thin section, the quartz, which forms as much as 90 percent of some of the rocks, is seen to be crystalloblastic, and some of it is streaked out along the foliation; the micas—brown biotite and muscovite—are lepidoblastic and are concentrated between more quartz-rich layers. In all thin sections, granular "ore" and some sphene are concentrated along bedding planes.

Most of the phyllite, which occurs sporadically, is virtually a finer grained equivalent of the schist. Some phyllite has much chlorite—a mineral not found in the schist—and these rocks are commonly greenish. Just east of the amphibolite shown along the south border of the map is black lustrous calcareous phyllite that is probably graphitic. Black phyllite is also exposed, albeit poorly, south of Ferry Lake. On the west slope and near the top of the hill in sec. 30, T. 35 N., R. 32 E., phyllite contains ellipsoidal clots of granoblastic cordierite.

At the base of the section the rocks contain very little mica and are thus best called quartzite. They are thinly laminated but nonfissile and as dark as the rocks above. Beds of comparable lithology occur in the schist and phyllite above.

Several other rock types occur as interbeds in the schist-phyllite unit. Thinly bedded sooty tremolitic marble, much like that of the unit below, occurs with black phyllite in several places. It also occurs with phyllite and schist in the isolated outcrop along the Ferry-Okanogan County line. In the same outcrop, some of the marble, in addition to crystalloblastic calcite and quartz, contains much granoblastic and some poikiloblastic diopside(?) enclosing calcite, a little plagioclase poikiloblastically enclosing calcite, and some granoblastic K-feldspar. The diopside(?), some of the plagioclase, and much of the quartz are crowded with grains of magnetite and hematite. Calcareous coarse green amphibole schist and coarse thinly laminated quartz-biotite schist crop out at the top of the hill in sec. 30, T. 35 N., R. 32 E., and extend into the Bald Knob quadrangle.

In a few favorable exposures, penciled and finely lineated schist shows a detailed structure much like that of the marble below (fig. 5). Because of this structure, the paucity of good outcrops,

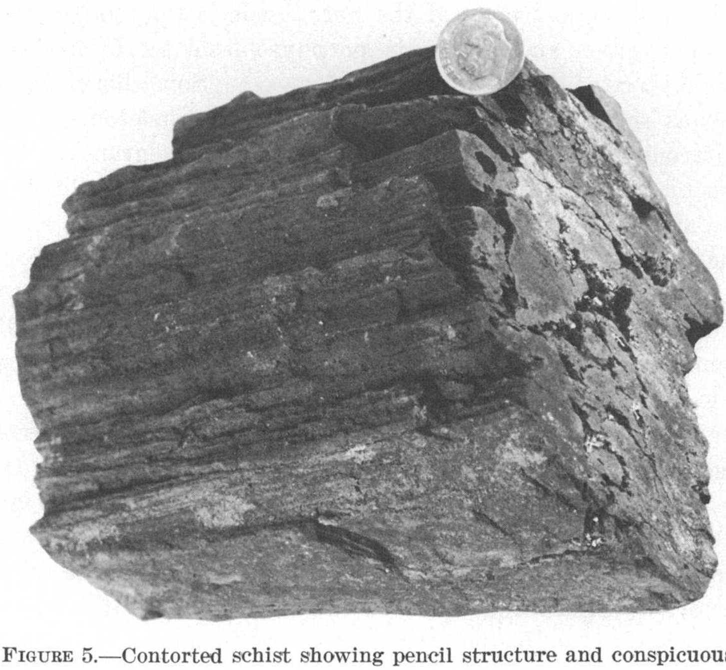

FIGURE 5.—Contorted schist showing pencil structure and conspicuous lineation.

and the lack of stratigraphic markers, the stratigraphy of the unit has not been worked out. However, its lithology shows that it was a finely clastic unit deposited in thin layers, some of which were rich in quartz and some rich in argillaceous material, with intercalated dolomitic beds. The sedimentary conditions were not drastically different from those inferred for the underlying dark marble; only less carbonate was deposited. The thickness of the unit is not known because its top is not exposed and the structure is obscured. Although it crops out over a wide area, there is probably much complex folding and repetition of beds; therefore, the thickness may not be more than 1,000 feet.

AMPHIBOLITE

A small body of amphibolite crops out along the southern border of the Aeneas quadrangle in sec. 29, T. 35 N., R. 32 E., and extends into the adjacent quadrangle. Although no intrusive contacts were seen, the body transects the bedding of the schist and phyllite and must therefore be intrusive into them. Most of the rock is massive and has unoriented fresh dark-green hornblende porphyroblasts as much as 5 mm long set in a light-olive-gray fine-grained matrix of plagioclase. The hornblende forms 50–60 percent of the rock. As seen in thin section, most of the hornblende is light olive green to light blue green and occurs as porphyroblasts set in a crystalloblastic matrix of clear plagioclase (An_{20-35}). Some hornblende also occurs as small crystals in the groundmass. Skeleton crystals of titaniferous magnetite or ilmenite surrounded by granular sphene, brown biotite altered to chlorite, calcite, apatite, and a little clinozoisite are other constituents of the amphibolite.

The western part of the body has lineation and foliation, defined by the hornblende prisms, virtually parallel to that of the intruded rocks. In other respects this part of the amphibolite is the same as the massive part, and the change in structure from one part to the other seems to be gradational.

The age of the amphibolite is not known. It intrudes rocks thought to be of late Paleozoic age and is thus younger. It was probably originally a diorite and may be a part of the basic igneous suite of rocks represented by the Permian greenstone to the north and east. On the other hand, the amphibolite could be an early phase of the Cretaceous batholith that was subsequently regionally metamorphosed, with the surrounding sedimentary rocks, during the period of orogenesis and batholithic intrusion.

AGE AND CORRELATION OF THE LAYERED ROCKS

The age of the layered rocks cannot be independently determined because of the lack of fossils. As previously noted, these rocks extend to the south, and they have been mapped there as the Covada Group (Pardee, 1918, p. 20–27), a poorly defined stratigraphic unit, much of which may be of late Paleozoic age.

A black sooty limestone, like the unit described above, crops out in a small fault block on the east side of Iron Mountain in the Republic quadrange. Just north of it is a white marble unit that could be the same as the marble described here. Both these carbonate rocks appear to lie below the mapped limestone on Iron Mountain from which Permian fossils have been collected. Assuming a valid correlation between the lower carbonate rocks there and those in Sheep Mountain, and a more or less valid age designation for the Covada Group, it seems reasonable to believe that the rocks here are of late Paleozoic age and are only a little older than the Permian rocks described above (p. 12).

The rocks around Sheep Mountain are similar in gross lithology to rocks of the middle part of the Anarchist Formation (Waters and Krauskopf, 1941, p. 1361) in the Okanogan area, which are thought to be of late Paleozoic age.

METAMORPHIC ROCKS NEAR GOLDEN HARVEST CREEK

Schistose sedimentary rocks that are more highly metamorphosed than the Permian rocks crop out in a small area along the west side of the Republic graben near Golden Harvest Creek. The outcrop area is a little more than 1 square mile in extent and is bounded on all sides by faults, intrusive bodies, or Quaternary unconsolidated deposits. The rocks are in general tightly folded and wrinkled and in some places have a finely spaced lineation that makes a small angle with the fold axes. The lineation shows as fine lines on foliation surfaces and probably represents the intersection of an incipient cleavage with foliation. The rocks form small scattered outcrops surrounded by much larger areas in which bedrock is covered by unconsolidated material and forest. Hence, individual lithologic units cannot be traced very far, and the thickness of the metamorphic rocks cannot be estimated.

LITHOLOGY AND PETROGRAPHY

The exposed rocks are predominantly thin-bedded quartz-rich schist, amphibolite schist, calc-silicate marble, and some quartzite. Where bedding could be determined, it is parallel to the foliation of the rocks. Staurolite and garnet are common constituents of some of the rocks and many of them contain much carbonaceous material. Banded amphibolite schist, staurolite-garnet-quartz schist, and granulose laminated and banded plagioclase-quartz schist containing hornblende and diopside are assumed to be the major rock types represented.

Banded and laminated amphibolite schist forms the largest area of outcrop; it is nearly the sole rock type along the east flank of the hill in sec. 16, T. 36 N., R. 32 E., from the bench at about 3,700 feet north to the section line. It also forms the outcrop south of Golden Harvest Creek. The typical rock is dark green and is layered in bands that range from ½ mm to more than 10 mm in thickness, the thicker bands being mostly hornblende and the thinner ones being rich in biotite, or in quartz and plagioclase. In one place, staurolite-garnet-biotite-muscovite-quartz schist is interbedded. As seen in thin section, the hornblende is light blue green. It forms as much as 75 percent of some layers and occurs in nematoblastic aggregates together with clear granoblastic andesine and granoblastic quartz. Some layers are rich in brown biotite. One specimen contains a thin layer rich in olive-green tourmaline. Another has thin layers rich in rounded sphene interspersed with layers containing hornblende, biotite, quartz, and calcite. Several specimens contain as much as 10 percent carbonaceous material. In some places the layers of lepidoblastic biotite are minutely crinkled.

Coarse-grained lustrous staurolite-garnet-biotite-muscovite-quartz schist underlies most of the south-trending spur from near the top of the hill in W½ sec. 16, T. 36 N., R. 32 E., south to the intrusive contact in the next section. The rock is coarsely foliated with tightly interleaved biotite and muscovite. The flakes are as much as several millimeters across and define the foliation. Quartz, which is the predominant constituent, is fine grained and is not prominent megascopically. Euhedrons of brownish-red garnet as much as 3½ mm across and of very dark brown staurolite as much as 10 mm long occur with no recognizable pattern or distribution within the rock. Microscopic examination adds little to the description of the schist, but it does show that the garnet and staurolite formed while the rock was under stress, because the garnet and staurolite porphyroblasts contain abundant rounded quartz inclusions whose swirled patterns indicate that the porphyroblasts were rotated during growth. Moreover, some of the garnets are broken, and nearly all the quartz has strain shadows.

Next in importance is orthoclase-biotite-diopside-hornblende-plagioclase-quartz schist, which crops out east of the long dike of

Scatter Creek Rhyodacite and also west of the dike in discontinuous outcrops about 1,000 feet wide in NE¼ sec. 21, T. 36 N., R. 32 E. The schist is formed of well-defined alternating light- and dark-greenish-gray layers about ½–10 mm thick. The light-colored layers are composed of granoblastic quartz and sodic labradorite, lepidoblastic brown biotite, and some light-brownish-green hornblende. The dark layers are formed predominantly by acicular hornblende and some diopside, both of which poikiloblastically enclose quartz and plagioclase and occur in optically continuous masses as much as 1 cm long. The little orthoclase that occurs is clear and poikiloblastic. Rounded xenoblasts of sphene and some carbonaceous material and a little chlorite are minor constituents. The quartz and plagioclase, which together form more than half the volume of the rocks, range in grain size from band to band from 0.01 mm to about 2 mm, but most of the grains are less than 0.2 mm across.

On the very top of the hill in sec. 16, T. 36 N., R. 32 E., is some sooty marble that looks much like that on Sheep Mountain. The marble is composed of calcite, diopside, much carbonaceous material, and a little orthoclase. Down the hill due east at an altitude of about 3,600 feet is a small outcrop of dark-green chlorite-forsterite-talc schist. The rock contains porphyroblasts of forsterite (about Fo_{80}) as much as 6.5 mm long lying mostly in the plane of the foliation and set in a matt of finely fibrous interleaved talc, clinochlore, and a little penninite. At high angles to the foliation is coarser talc in sheaves of tabular masses, some of which are bent and are as much as 2 mm long. Carbonate and magnetite are present in minor amounts.

Very dark gray to light-gray banded vitreous quartzite crops out sporadically in the northern part of the metamorphic area. In most places, brownish biotite-muscovite-quartz schist is associated with it, and these two rock types probably underlie much of the heavily forested north-facing slope.

There is no noticeable change in the metamorphic rocks as their contact with the Cretaceous and Tertiary intrusive bodies is approached except in the NW¼ sec. 21, T. 36 N., R. 32 E. Here is found a white marble much like that exposed to the south. Near its contact with the granodiorite, the marble is a coarse skarn of diopside, garnet, idocrase, zoisite, carbonate, and strained quartz.

ORIGIN

The sedimentary rocks near Golden Harvest Creek have been more highly metamorphosed than most of the other older rocks in the area. Their metamorphism and that of the rocks near Sheep Mountain are discussed in a separate section below (p. 84). The original rocks, as inferred from their mineralogical and structural makeup, were predominantly fine-grained quartz and were laid down in thin beds. Some of the beds were rich in argillaceous material and probably most were somewhat calcareous. It is not known if the rocks are marine or nonmarine.

AGE AND CORRELATION

The age of these rocks cannot be directly determined because they contain no fossils. Although separated from the known Permian rocks to the north and east by faults, they appear to be more or less structurally—and perhaps stratigraphically—conformable with the underlying Permian rocks. If they are, they are probably only slightly older and may therefore be of Late Pennsylvanian or Early Permian age.

Except that they are more highly metamorphosed, these rocks are lithologically the same as the schist and phyllite unit in the area around Sheep Mountain to the south, and I suspect that the two units are correlative. The presence of the distinctive sooty marble in both units seems to me to point strongly toward this conclusion.

RELATIONS AMONG UPPER PALEOZOIC ROCKS IN THIS AREA

The whole problem of correlation among the upper Paleozoic rocks in this area has already been alluded to. In this section, I will summarize what I believe the relations to be.

As mentioned in the description of the Permian rocks (p. 14), there is a plicated very thin bedded green phyllite on the steep east side of Iron Mountain. In fault contact with the phyllite is a small block of well-bedded sooty marble. Just north of these two occurrences white marble is exposed (pl. 1). The relation of these three units to each other is not known because of the apparently complex structure, which has not been unraveled. Nor are their relations to the fossiliferous limestone of Iron Mountain known. However, their west dips are more or less conformable with those of the fossiliferous limestone. It seems reasonable that the units lie conformably below the limestone and are probably not much older.

What appears to be the same phyllite as that on Iron Mountain crops out at bench mark 3091 west of Copper Lakes. Here the phyllite lies conformably below a limestone bed that is almost certainly the same as the one of Iron Mountain. The phyllite also crops out in sec. 22, T. 36 N., R. 32 E., and associated with it is a sooty marble that may be the same as the one on Iron Mountain. To the west, and separated from the Permian rocks mainly by faults and younger deposits, are the metamorphic rocks just discussed. These rocks appear to be structurally conformable with the dated Permian rocks in NW¼ sec. 27, T. 36 N., R. 32 E. and are only a little older. And, as has been pointed out in the last section, the metamorphic rocks are probably correlative with the schist and phyllite unit to the south around Sheep Mountain.

Admitting that the relations among the upper Paleozoic rocks are largely inferred, they can be summarized as follows: The oldest exposed unit is the white marble of Sheep Mountain; it may be represented by the marble on the northeast side of Iron Mountain. Lying above the white marble is the dark siliceous marble, overlain by the schist and phyllite containing sooty marble. The metamorphic rocks of Golden Harvest Creek are probably correlative with the schist-phyllite unit and probably conformably underlie the sooty marble and green phyllite, the green phyllite being known to lie conformably just below fossiliferous Permian limestone at Copper Lakes.

To the north, in the Curlew quadrangle (Parker and Calkins, 1964), the metamorphic rocks of Tenas Mary Creek may be correlative with the rocks near Golden Harvest Creek and Sheep Mountain. The upper unit of the Tenas Mary rocks is a phyllite that appears to lie under greenstone probably of Permian and Triassic age. The phyllite of Tenas Mary Creek may be correlative with the phyllite near Sheep Mountain.

CRETACEOUS BATHOLITH

NAME AND DISTRIBUTION

Most of the area lying west of the Republic graben is underlain by a plutonic body of intermediate composition. It is part of the so-called Colville granite batholith (Pardee, 1918, p. 30–34), whose areal extent is shown by Waters and Krauskopf (1941, fig. 1). The plutonic rocks in and east of the graben have also been shown as Colville.

The plutonic rocks west of the graben are of diverse lithology, but most of them have the composition of granodiorite and are so shown on plate 1. The granodiorite extends north into the Bodie Mountain and Curlew quadrangles and south into the Bald Knob quadrangle (Staatz, 1964). It extends westward into the west half of the Aeneas quadrangle and crops out intermittently between there and the Okanogan Valley, where what is probably the westernmost part of the same batholith has been studied by Waters and Krauskopf (1941).

RELATIONS TO OTHER ROCKS

Along the northern half of its outcrop in the area, the batholith is separated from younger and older rocks to the east by the Bacon Creek fault. In the southern half of the area the batholith intrudes the upper Paleozoic metamorphosed sedimentary rock and is in turn intruded by the Scatter Creek Rhyodacite, which separates it from the younger rocks of the Republic graben to the east. Near the intrusive contact with the older rocks in T. 35 N., R. 32 E., the rocks of the batholith are in general finer grained, lighter colored, and of quartz monzonite composition. Dikes of aplite and leucocratic quartz monzonite intrude the white marble in sec. 4. In most places the contact with the intruded rocks is sharp, but in a few, especially due west of Sheep Mountain where quartz-rich sedimentary rocks occur in the marble near the intrusive contact, it is difficult to determine where highly metamorphosed sediments end and the intrusive begins.

The structural and metamorphic relations of the batholith to the upper Paleozoic rocks is a subject of special interest and is treated separately in this report (p. 84). Suffice it to say here that in the southern part of the area the structure in the batholith and that in the layered rocks are parallel and related in origin.

Here and there the batholith is intruded by Tertiary dikes, the oldest of which is of Scatter Creek Rhyodacite, of Eocene(?) age. In the north, andesite and trachyte dikes lie along the Bacon Creek fault. Farther south the batholith is intruded by a few dikes of the Scatter Creek Rhyodacite and one of monzonite.

GENERAL CHARACTER AND LITHOLOGY

The granodiorite generally forms rounded outcrops that in the higher parts form bald hills. The prevailing color is gray to reddish brown, and the rocks are generally quite fresh.

The lithology of the intrusive body differs from place to place but no effort was made to map the diverse rock types. In general, however, three broad types occur. The most extensive type is nonfoliated granodiorite, which is the predominant rock type north of Golden Harvest Creek. South of it the body is also mostly granodiorite but is foliated and lineated in most places. Near the intrusive contacts in T. 35 N., R. 32 E., it is lighter colored than elsewhere.

The massive granodiorite is fine to coarse grained, predominantly inequigranular, and porphyritic in some places. Plagioclase (andesine) is the dominant mineral, greatly exceeding orthoclase, quartz, and biotite. Some rocks have a little muscovite; all have accessory zircon, magnetite, apatite, and sphene. Near the northwest corner of the area the rock contains more hornblende and biotite than elsewhere and about 5 percent each of orthoclase and quartz; it thus has the composition of quartz diorite. On the northeast, east, and southeast slopes of Storm King Mountain the granodiorite is of uneven grain, has feldspar phenocrysts more than 1 inch in length, and contains partly uralitized augite (Lindgren and Bancroft, 1914, p. 140). Between Golden Harvest Creek and State Highway 4 the granodiorite is in general light gray, medium grained, and inequigranular. The quartz is slightly smoky, and black splendent biotite is the only mafic mineral. The rock is hypidiomorphic granular. Orthoclase, some of which is microperthitic, is interstitial and poikilitically encloses all other major minerals; it occurs as masses as much as 8 mm across. Plagioclase (andesine) is in generally clear idiomorphic crystals having an average size of 2.5 mm. Chemical analysis, mode, and norm of a specimen collected in a roadcut in the south part of sec. 17, T. 36 N., R. 32 E., are given in table 2.

South of Golden Harvest Creek the intrusive body in most places is shades of pink to brown; it is coarser grained than to the north and is characterized by more or less pronounced foliation and lineation. In many places it is largely inequigranular and porphyritic.

TABLE 2.—*Chemical analysis, mode, and norm of granodiorite, in percent*

[Rapid-rock analysis by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack]

Chemical analysis		*Mode*		*Norm (CIPW)*	
SiO_2	68.1	Orthoclase	20	Apatite	0.3
Al_2O_3	17.5	Plagioclase	52	Ilmenite	.7
Fe_2O_3	1.1	Quartz	20	Magnetite	1.6
FeO	1.4	Biotite	8	Orthoclase	12.8
MgO	.52			Albite	42.4
CaO	3.4			Anorthite	16.1
Na_2O	5.0			Calcite	1.0
K_2O	2.2			Hypersthene	2.2
H_2O	.34			Quartz	22.7
TiO_2	.36			Total	99.8
P_2O_5	.11				
MnO	.04				
CO_2	.05				
Total	100				

Some orthoclase phenocrysts, which tend to be rounded, are more than 1 inch in length although most are smaller. Foliation and lineation are imparted to the rock by the alinement of somewhat smoky quartz and biotite, which occur as streaks in the rock. As seen in thin section, the texture is hypidiomorphic to allotriomorphic granular and most specimens show incipient to well-defined cataclastic structures inferred to be protoclastic. Grain size ranges widely. Orthoclase is interstitial, poikilitic, and, in some places, microperthitic. Zoned plagioclase (An_{25-45}) shows fractures and bent twin lamellae, and near interfaces with orthoclase is commonly myrmekitic. Intergrown mosaics of strained quartz occur in streaks as much as several centimeters long and several millimeters wide. Biotite is dark brown and in a few places is altered to chlorite; hornblende is absent. A small amount of muscovite occurs here and there. Apatite, magnetite, zircon, and sphene are common accessories. In most places the rocks are granodiorite having a plagioclase-orthoclase ratio greater than 65:35; in some, however, the ratio is as low as 60:40, and the rocks are quartz monzonite. The compositional range of the essential minerals as determined from thin sections, is as follows: plagioclase, 25–45 percent; orthoclase, 20–40 percent; quartz, 25–40 percent; biotite, 3–10 percent.

South of Golden Harvest Creek a marginal phase of the batholith is typically finer grained than the foliated variety, is mostly equigranular, has much less biotite, and has pink garnets as much as 1 mm across. The quartz is characteristically smoky. The texture is allotriomorphic granular. The marginal phase is mostly quartz monzonite, having as much as 50 percent orthoclase. Some of the marginal phase is foliated and lineated. Aplite and pegmatite dikes of quartz monzonite composition are confined to this marginal zone, and some of them cut the white marble.

The batholith is relatively free of inclusions of older rocks; only small inclusions of schist have been seen. In the northernmost area there are a few mica schist inclusions, and west of Copper Lakes, two inclusions, one of mica schist and one of amphibole schist, were seen.

AGE AND CORRELATION

The age of the granodiorite can only be determined within rather wide limits. The intrusive cuts rocks of probable late Paleozoic age and is in turn cut by the Scatter Creek Rhyodacite of Eocene(?) age. The presence of granitic boulders in the oldest Tertiary sedimentary formation in the Republic graben, the O'Brien Creek Formation (Eocene?), whose source must have been the granodiorite, indicates that the granodiorite was being eroded during Eocene time; its emplacement, therefore, must have been somewhat earlier.

To arrive at a closer age estimate of the batholith, we must rely on correlation with other nearby granitic intrusive bodies whose ages are more precisely known. Zircons in rocks from two places near the western edge of the Colville batholith (Waters and Krauskopf, 1941) near Tonasket, have lead-alpha ages of 95 and 92 million years (Larsen and others, 1958, p. 56). The western margin would thus be of early Late Cretaceous age. The intrusive rocks near Tonasket probably extend into the Republic area; if so, we may take the early Late Cretaceous age as the best estimate for the age of the intrusive body of this area.

To the north, the Nelson batholith has a lead-alpha age of 105 m.y. (million years) in one place (Gottfried in Beveridge and Folinsbee, 1956) and may thus be broadly correlative with the Colville as dated near Tonasket. The ages of and relations among other more or less synchronous batholiths have been summarized by Larsen and others (1958) and Smith and Stevenson (1955).

Zircon age determinations on samples from batholithic rocks on both sides of the graben were made by T. W. Stern of the Geological Survey; there was such a small amount of lead in the samples, however, that the calculated ages are inconsistent with themselves and with geologic evidence.

UNCONFORMITY AT THE BASE OF THE TERTIARY ROCKS

The basal Tertiary rocks that make up the O'Brien Creek Formation (Eocene?) are in what could be depositional contact with older rocks (Permian) in only two places, in SE¼ sec. 13, T. 37 N., R. 33 E., and just east of sec. 24, T. 35 N., R. 33 E. In both localities the relations are obscure and shed no light on the nature of the unconformity. Regardless of its nature, however, the apparent time span represented by the unconformity is from the Permian to the Eocene(?). From evidence in nearby areas it seems likely that this time span is actually much shorter.

In the Curlew quadrangle to the north (Parker and Calkins, 1964), Tertiary rocks lie on Upper Triassic limestone. In the Salmo area, British Columbia (Little, 1950; McAllister, 1951), about 65 miles to the northeast, Triassic, Jurassic, and possibly Cretaceous marine and nonmarine sedimentary and volcanic rocks are found. West of the Salmo area is conglomerate, probably of Late Cretaceous age, that lies unconformably on older rocks (Little, 1950, p. 29–30). In the Princeton area, British Columbia (Rice, 1947), about 70 miles northwest of Republic, are Upper Triassic, Upper Jurassic(?), and Lower Cretaceous rocks.

The Triassic rocks at one time probably extended south from the Curlew quadrangle, because Triassic limestone also crops out to the west in the Okanogan Valley (Waters and Krauskopf, 1941). Probably Jurassic rocks also once covered the Republic area (Imlay in McKee and others, 1956, pl. 8), but there is no evidence that rocks younger than the Jurassic ever extended into the Republic area. Hence, on the basis of limiting beds, the orogeny now recorded by the unconformity cannot be dated more closely than as post-Jurassic and pre-Eocene(?). However, evidence of a different sort may serve to tie down the unconformity.

In the section of this report on structure (p. 84), evidence is presented suggesting that the folding of the upper Paleozoic rocks occurred at about the same time as the intrusion of the Cretaceous batholith. If it did, the unconformity probably represents the interval from some time in the Cretaceous to the Eocene(?). There is support for this view from evidence in the Salmo area (Little, 1950), where the Nelson batholith was probably emplaced during the orogeny that preceded the Late Cretaceous. The most significant evidence, however, is the presence of granitic boulders in the O'Brien Creek Formation. These boulders could only have come from the Cretaceous batholith and so date the unconformity as being later than Cretaceous. Whether there was any sedimentation in the Republic area during the interval from Cretaceous to Eocene(?) is not known.

TERTIARY ROCKS

In this area the Tertiary rocks are predominantly igneous and include intrusives of various kinds, bedded volcanic rocks, and sediments. The layered Tertiary rocks are found only in the Republic graben, where they form the major part of the outcrop. The oldest bedded unit, of probable Eocene age, is the O'Brien Creek Formation, chiefly a sedimentary tuff. Lying above it more or less conformably are the Sanpoil volcanic rocks—chiefly lava flows of andesitic composition. This formation is separated by a pronounced angular unconformity from the overlying Klondike Mountain Formation—a composite unit, which has at its base the well-known Republic lake beds, of Oligocene age. The youngest member of the Klondike Mountain Formation, and the youngest layered rock in the area, is basalt, which caps Klondike Mountain.

The Tertiary intrusive rocks consist of dikes, sills, and irregular bodies of predominantly hypabyssal rocks as well as two bodies of granitic rock that are probably part of a batholith; the largest granitic body underlies nearly all the area east of the graben. In the descriptions that follow, the intrusive rocks are discussed together with the layered rocks as nearly as possible in their correct stratigraphic order.

DIORITE

A few small bodies of diorite intrude the Permian greenstone in the east-central part of the area. The rock is nonfoliated, medium grained, and mostly equigranular; its color ranges from dark green to light gray speckled with dark-green hornblende. As determined from thin sections, the texture is hypidiomorphic granular. Greenish-brown hornblende is the dominant mineral, forming 20–50 percent of the rock; it is poikilitic in places, replaces pyroxene, and some of it is altered to epidote, biotite, and chlorite. Plagioclase is present in amounts as much as 35 percent; it is clouded by sericite and clinozoisite and is mostly calcic oligoclase (An_{25}); some clear albite is also present. Quartz and K-feldspar are interstitial and together make up less than 10 percent of the rock in most places, but locally are abundant enough to make the rock a granodiorite. Brown biotite has altered to chlorite, epidote, and granular sphene; some of the biotite contains fine sagenitic rutile. Apatite and "ores" are accessory.

The age of the diorite is not known with certainty. In one place the Scatter Creek Rhyodacite (Eocene(?)) intrudes it. It is provisionally considered to be of Tertiary age because it is less highly altered than the Permian rocks and nowhere appears to be foliated. It could be correlative with the amphibolite in the southwestern part of the area, which it somewhat resembles, but there is no stratigraphic or structural evidence for this correlation.

O'BRIEN CREEK FORMATION

DEFINITION

The basal Tertiary formation in the Republic area is a thick sequence of sedimentary tuff and some conglomerate, named the O'Brien Creek Formation after easily accessible and typical exposures along the North Fork of O'Brien Creek (Muessig, 1962, p. D56). A thicker and more complete section crops out southwest of Cooke Mountain, to the north, but the name "Cooke Mountain" has been preempted and so cannot be used. The exposed base of the unit is a fault or intrusive contact in most places. What may be the base is poorly exposed in SE¼ sec. 13, T. 37 N., R. 33 E., the lowest exposed part of the formation is coarse conglomerate. The top of the formation is taken as the base of the lowest flow in the overlying Sanpoil volcanic rocks.

The O'Brien Creek Formation is the dacite flow conglomerate of Umpleby (1910) and the breccia-conglomerate of Lindgren and Bancroft (1914).

DISTRIBUTION AND THICKNESS

The O'Brien Creek Formation underlies most of the graben but crops out only along the edges of the graben and in the north-central part. Its outcrop pattern virtually follows that of the Permian rocks, which it overlies. Along the east margin of the graben it lies in a discontinuous belt, west of the Permian rocks. In the north-central part of the graben, it is present on both edges of the Curlew-Sanpoil Valley, west of the belt of Permian rocks. To the west, the formation crops out along the west edge of the graben along its central part, and, where its dip is more gentle than elsewhere, the outcrops swing to the east and form the lower sides of Granite Creek west of Republic. Several small isolated outcrops serve to bridge the gap between the eastern and central belts. In addition, two small outcrops of what looks like the O'Brien Creek Formation lie among the Permian greenstone in sec. 6, T. 36 N., R. 34 E., and sec. 25, T. 37 N., R. 33 E. Their position is probably due to a more gentle westward dip, or perhaps even a reversal in dip of the formation, which preserved them as outliers east of the other exposures.

The eastern outcrop belt extends into the Curlew quadrangle to the north (Parker and Calkins, 1964) and into the Colville Indian Reservation to the south, where it probably forms part of the unit mapped as Tertiary porphyry (Pardee, 1918).

Because both the base and top of the unit are not exposed at any one place, it is impossible to determine the true thickness. Such a thickness probably would not be of great moment anyway, because almost certainly the thickness varies greatly from place to place. The thickest exposed part of the formation is in the west part of sec. 24 and the northeast part of sec. 23, T. 37 N., R. 33 E.; here, although neither base nor top is exposed, about 4,200 feet of the unit crops out. At the southern end of the eastern outcrop belt, in sec. 25, T. 35 N., R. 33 E., the upper 2,300 feet of the formation is exposed, and along the west side of the graben, at the bend in Scatter Creek, about 1,350 feet. The north part of the belt underlying the Curlew-Sanpoil Valley may contain the thickest section of O'Brien Creek in the area. Here, the apparent thickness is more than 6,000 feet, and because dips along both sides of the valley are at high angles, steep faults would have no marked effect in changing this value.

LITHOLOGY

The greater part of the O'Brien Creek Formation is made up of beds of white to greenish-white coarse sedimentary crystal tuff (Wentworth and Williams, 1932) that characteristically contain dark phyllite and argillite chips lying parallel to the bedding (fig. 6). Most of the essential mineral grains—feldspar and quartz—are megascopically visible and have an average size of less than 1 mm, although some are more than 4 mm. The clasts also include a few greenstone, quartzite, granitic types and other older rocks. Nearly all are rounded and range in size from fractions of an inch to several inches. In most outcrops the clasts make up only a few percent of the total rock, but in rare occurrences they make up almost 30 percent. The tuff beds range in thickness from a few inches to many feet; most of them are several feet thick. The thick beds are commonly massive, but their attitude is shown in most places by the alined dark chips.

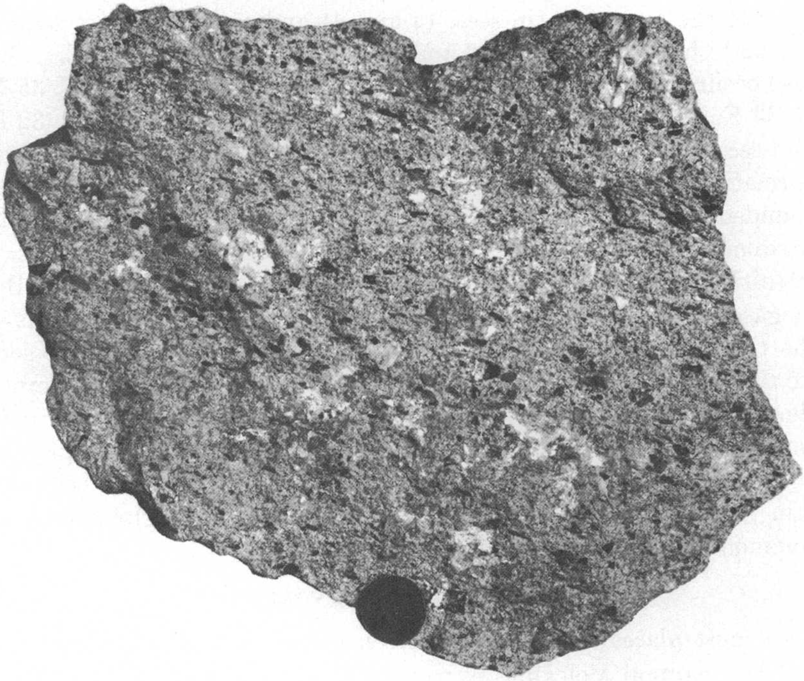

FIGURE 6.—Sedimentary crystal tuff of the O'Brien Creek Formation showing the characteristic phyllite and argillite chips lying parallel to bedding.

A subordinate though typical part of the formation is made up of dark fine-grained sedimentary tuff that looks like shale. It occurs as clearly defined beds, some of which are laminated, whose thickness is commonly several inches but in places is 5–6 feet. Some of these dark beds contain carbonized plant trash, and one contains several thin beds of lignite.

Microscopically, the texture of the tuff is typically pyroclastic. In order of decreasing abundance, plagioclase (An_{20-40}), quartz, and orthoclase make up most of the crystals of the tuff. Except for a few rounded quartz grains, the crystals are nearly all broken, and therefore angular, and lie in a matrix that ranges from glassy but feebly anisotropic through cryptocrystalline to felsophyric. Crystals commonly make up more than 70 percent of the light-colored tuff, but much less of the dark tuff, whose groundmass is murky and difficult to resolve under the microscope. Biotite, sericite, sphene, apatite, calcite, magnetite, and pyrite are present in minor amounts. A few glassy volcanic rock fragments were seen in thin section, but no shards were identified.

Beds of boulder conglomerate occur locally; they are a significant but not a widespread part of the formation. They occur in the lower part of the formation in secs. 13 and 24 and along and just west of the main highway in secs. 16 and 20—all in T. 37 N., R. 33 E. They also occur in the uppermost part of the formation in sec. 24, T. 35 N., R. 33 E., secs. 13 and 27, T. 36 N., R. 33 E., sec. 27, T. 36 N., R. 32 E., and sec. 33, T. 37 N., R. 32 E. The boulders in the lower part of the formation are as much as 6 feet across, mostly angular to subrounded, unsorted, and in a sandy matrix. In some places they are predominantly of argillite, phyllite, and schist, but in others of granitic types, mostly pink quartz monzonite and granodiorite that megascopically and in thin section look like some of the rocks of the Cretaceous batholith. However, they also closely resemble some of the granitic rocks east of the Sherman fault. The boulders in the upper part of the formation are representative of all the older rock types and are characteristically well rounded; some porphyritic volcanic boulders are included. None of the conglomerate beds contain limestone boulders. Both upper and lower conglomerates are commonly several hundred feet thick.

RELATION TO SANPOIL VOLCANICS

In most places the contact between the O'Brien Creek Formation and the Sanpoil Volcanics is parallel to the bedding of the O'Brien Creek—a feature that indicates that the formations are roughly conformable. In the southeast part of the outcrop there seem to be local disconformities probably representing channels in the tuff that were filled by lava. The contact appears to be gradational in the western outcrop area. This relation was inferred from exposures in sec. 27, T. 36 N., R. 32 E., and sec. 33, T. 37 N., R. 32 E. Here there seems to be no sharp break between conglomeratic tuff containing dark argillite-phyllite chips and overlying flow breccia containing similar chips.

CONDITIONS OF SEDIMENTATION

Conditions of sedimentation of the O'Brien Creek are difficult to infer without knowing how far, if at all, the unit extended outside the graben. Its thickness and the presence of boulder conglomerate suggest that it was deposited in a basin whose surrounding hills were fairly high and steep. These hills were underlain by older phyllite, argillite, and granitic rocks. The basin was probably the ancestral Republic graben. The lower conglomerate was probably laid down in alluvial fans. At the onset of explosive volcanism, tuff probably blanketed the hills as well as the basin. Intermittent rains carried the tuff off the hills, together with the underlying slabby phyllite and argillite, into the basin in anastomosing streams and mudflows. The thin-bedded metamorphic rocks, as well as the more massive older rocks, were rounded in transport. Some of the dark finer grained interbeds were probably deposited in standing water in the basin. Marshy conditions existed in places, resulting in the accumulation of plant trash.

AGE AND CORRELATION

Plant fossils probably of Eocene age were collected along the road in NW¼ sec. 9, T. 37 N., R. 33 E., from dark tuff with associated thin lignite beds (the lower part of the formation). R. W. Brown, of the Geological Survey, studied the collection and reported the following species:

Equisetum sp.
Metasequoia occidentalis (Newberry) Chaney
?*Pinus* sp.
?*Glyptostrobus* sp.
A monocotyledon, probably a grass or sedge
?*Alnus corylina* Knowlton and Cockerell
?*Malapoenna magnifica* (Saporta) Hollick

Brown wrote:

> This material is not well preserved, and consequently, question marks occur with the tentative identifications. The aspect of the collection as a whole is like that of the Eocene of Alaska and of the Puget Group of Washington.

The O'Brien Creek Formation is probably roughly correlative with the Kettle River Formation (Daly, 1913), which crops out just to the north in British Columbia. (The type Kettle River is actually a shale and tuff member in Daly's Midway Volcanic Series, according to H. W. Little, written commun., Nov. 15, 1956.)

The Kettle River occupies the same stratigraphic position as the O'Brien Creek. As described by Daly (1913, p. 396), some of the Kettle River is "characterized by sliverlike, subangular fragments of black argillite, from one-half to one inch in length." Daly thought these beds were sandstone and arkose, as did Seraphim (1956), but where I have seen them they look like the tuff of the O'Brien Creek; Little (1957) reports them to be rhyolite and dacite tuff. Penhallow (in Daly, 1913) considered the Kettle River to be of Eocene age, but Daly reports him as designating Oligocene. A recent potassium-argon age determination of 49 m.y. for an ash bed in rocks just overlying the Kettle River (Mathews, 1964, p. 465) indicates that the Kettle River is no younger than Eocene.

North of Grand Forks in the Franklin mining camp (Drysdale, 1915a, p. 62–68), the Kettle River consists of conglomerate, arkosic grit, acidic tuff, and rhyolite flows; it contains some plant remains. The formation was probably deposited in a large valley having steep slopes and an erratic drainage pattern. Some material may have been added from alpine glaciers in the mountains.

Rocks mapped as Kettle River in various places in southern British Columbia are probably all of about the same age, and it seems probable that they accumulated in separate or ephemerally connected basins.

SANPOIL VOLCANICS

The name Sanpoil Volcanics is given to the volcanic rocks, and some included sedimentary rocks, that are structurally conformable with the underlying O'Brien Creek Formation. An angular unconformity separates the Sanpoil Volcanics from the overlying pyroclastic rocks of the Klondike Mountain Formation (Muessig, 1962). The formation is named after the Sanpoil River valley, whose towering walls are carved in the lavas for many miles south of Republic.

The Sanpoil Volcanics includes all the rocks previously described as "earlier andesitic flow breccia" (Umpleby, 1910, p. 23–24) except those around the Republic mine. These are considered to be a part of the Klondike Mountain Formation; it also includes nearly all the rocks previously mapped and described by Umpleby (1910, p. 25–26) as "later andesite flows" and considered by him to overlie conformably the basal member of what is now called the Klondike Mountain Formation. The formation also is represented in the lower part of the so-called "andesites," previously mapped in the same area by Lindgren and Bancroft (1914).

Flows of the Sanpoil Volcanics are the host for nearly all the gold-silver deposits in the Republic district.

DISTRIBUTION AND THICKNESS

Outcrops of the Sanpoil Volcanics cover the greatest extent of any rock unit in the area. South of Republic its exposures are nearly continuous from one side of the graben to the other. A relatively narrow belt extends to the north along the west side of the Curlew-Sanpoil valley into the adjacent Curlew quadrangle (Parker and Calkins, 1964). The formation also crops out east of the valley in a small area shown along the northern edge of the map and in a narrow continuation of the larger area to the south. South of the area the formation extends into the Colville Indian Reservation (Staatz, 1964).

Because the stratigraphy of the Sanpoil was not worked out, no really good estimate of the thickness can be made. However, along the southern part of the Sanpoil valley the formation seems to form a syncline whose trough roughly coincides with the valley bottom. As measured between the top of Brown Mountain and the valley bottom, assuming a dip of 35°, about 2,600 feet of the formation is represented, with neither base nor top exposed. The entire formation is certainly much thicker. As measured east from Klondike Mountain between the base of the Klondike Mountain Formation and the top of the underlying O'Brien Creek Formation, assuming a west dip of 65°, the formation is about 4,000 feet thick.

LITHOLOGY AND PETROGRAPHY

The Sanpoil Volcanics consists of primarily andesitic lava flows whose outcrops at higher altitudes are normally on bare slopes. The flows are massive to fragmental and in many places are conspicuously banded. Individual flow bands range from fractions of an inch to several inches in thickness and crop out in sheeted masses. Attitudes of the bands were mapped on the field sheets, but because they show no consistency, they were left off the final map. From a distance, the flows, few of which are separately distinguishable, look dirty brown, but at outcrops the colors range from light pinkish gray through light olive drab, various shades of brown, purplish, greenish gray, to dark gray and black. The dominant colors appear to be purplish brown, olive drab, and greenish gray.

The multitude of colors superficially hides the fact that most of the flows are petrographically and chemically similar. They are nearly all porphyritic; dark hornblende prisms are the most conspicuous phenocrysts, but in the darker rocks equant to tabular plagioclase phenocrysts are common; biotite is visible megascopically in some of the rocks. The feldspar phenocrysts have an average size of about 1 mm, but many are as much as 4 mm across. Size of the average hornblende phenocryst is about the same but has a wider size range, 5-mm phenocrysts being not uncommon. The groundmass, which in most flows forms more than 50 percent of the rock, is mostly aphanitic and stony looking but in some places is glassy.

On the basis of their phenocrysts, as seen in about 25 thin sections, the flows are classed as andesite and basalt. The groundmass is mostly light-brown to straw-yellow dusty glass in various stages of devitrification; here and there it contains crystallites, and some is perlitic. Felty textures are rare, and none are pilotaxitic. Plagioclase, hornblende, and biotite are the predominant phenocrysts; a small amount of augite is present in less than half the specimens studied, hypersthene is present in a few, and pigeonite is present in two. The plagioclase crystals are zoned in normal-oscillatory fashion, and the extreme range of composition of all crystals is An_{15-75}; most range from An_{35} to An_{65}

Nearly all the rocks have hornblende and most have biotite. Together, these minerals constitute as much as 60 percent of the phenocrysts in a few rocks, and probably average about 30 percent. Both minerals are dark reddish brown in most rocks and are characteristically, but not everywhere, rimmed or completely replaced by dusty and granular magnetite and other "ores." (In places, the flows are magnetic enough to deflect a compass needle.) The hornblende is commonly basaltic. Augite and (or) hypersthene phenocrysts form a maximum of 10 percent of the rocks in which they occur; they are commonly less than 1 mm across. Apatite, magnetite, zircon, and calcite are present in lesser amounts; sphene and leucoxene are rarely found. Some of the rocks have as much as 5 percent tufted, finely fibrous olive-green biotite. It occurs as blebs and along cracks in plagioclase, as replacements of hornblende or, more rarely, pyroxene and as microcrystalline aggregates in the groundmass.

In some thin sections the groundmass is more devitrified than in others, and quartz and K-feldspar can be identified as distinct grains. In sections in which individual grains cannot be identified, the presence of K-feldspar is suggested by the areas of yellow stain that result from treating with sodium cobaltinitrite; when thus treated, the K-feldspar is selectively stained, whereas quartz and

TABLE 3.—*Chemical analysis and norm of a flow from the Sanpoil Volcanics, in percent*

[Rapid-rock analysis by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack]

Chemical analysis		*Norm (CIPW)*	
SiO_2	61.8	Quartz	16.1
Al_2O_3	15.9	Orthoclase	16.1
Fe_2O_3	3.3	Albite	33
FeO	2.4	Anorthite	17.8
MgO	2.7	Diopside	2.6
CaO	4.4	Hypersthene	5.9
Na_2O	3.9	Magnetite	4.9
K_2O	2.7	Ilmenite	1.4
H_2O	1.5	Apatite	.3
CO_2	.26		
TiO_2	.71	Total	98.1
P_2O_5	.24		
MnO	.09		
Total	99.9		

plagioclase remain uncolored. That quartz and K-feldspar are indeed present, or would have crystallized from the groundmass if conditions had been favorable, is shown by the following chemical analysis and norm (table 3) of a porphyritic flow from along the road in the SW¼NW¼ sec. 24, T. 35 N., R. 33 E. This flow, a widespread type in the Sanpoil Volcanics, has a slightly devitrified groundmass and is 30 percent phenocrysts. Plagioclase, which forms 70 percent of the phenocrysts, has a compositional range of An_{25-55}. Nearly all the rest of the phenocrysts are basaltic hornblende, conspicuously rimmed by magnetite dust. There are a few biotite crystals. The analysis and normative minerals show that this rock should be classed as a rhyodacite. Because most of the flows are petrographically so similar, it is reasonable to suppose that they are rhyodacite also; a few, however, may be trachyandesite.

Flow breccias are exposed south of McMann Creek along the Sanpoil River and extend into the Colville Indian Reservation to the south. They form the high cliffs on both sides of the river, toward which they dip, forming a syncline. Fine-grained light-yellowish-brown tuff is interbedded with flows. The tuff is several hundred feet thick but does not extend very far along strike. Here and there it contains poorly preserved plant fragments.

About 2 miles west of Republic, I have mapped a small area of dark-bluish-gray porphyritic rock that is evidently an intrusive phase of the Sanpoil flows; it crosscuts the underlying O'Brien Creek Formation and appears to grade into the surrounding flows. Andesine phenocrysts about 1 mm across lie in a pilotaxitic groundmass that contains much granular sphene-leucoxene and magnetite. All the hornblende and most of the biotite are completely altered to dusty magnetite, and some calcite and chlorite. One resorbed quartz grain was seen. There are probably other intrusive masses within the volcanics.

AGE AND CORRELATION

The Sanpoil Volcanics overlies the O'Brien Creek Formation of Eocene (?) age and is unconformably overlain by the Tom Thumb Tuff Member of the Klondike Mountain Formation of Oliogocene age. On the bases of lithology and stratigraphy, the Sanpoil Volcanics is correlated with the Midway Volcanic Group of Daly, which appears to lie conformably on the Kettle River Formation (Daly, 1913, p. 398) in most places, but in some lies with angular unconformity above the Kettle River (Drysdale, 1915a, b). Little (1957) has called the Midway of previous authors the Phoenix Volcanic Group, and he states that it overlies the Kettle River Formation unconformably. West of Midway in the Kettle River valley, the Phoenix and Midway contain plants of Paleocene or Eocene age. An ash bed from the Midway has recently been dated as 49 m.y. old or middle Eocene (Mathews, 1964). This age and its position below beds of Oligocene age support the conclusion that the Sanpoil is also of Eocene age.

SCATTER CREEK RHYODACITE

DEFINITION

The name Scatter Creek Rhyodacite is given to the widespread predominantly porphyritic hypabyssal intrusive rocks that are younger than the O'Brien Creek Formation but older than the Klondike Mountain Formation (Muessig, 1962). Excluded from the formation are the quartz latite porphyry bodies that occur in the northeast part of the area. Scatter Creek, in the southwest part of the area, is designated as the type locality; typical rhyodacite crops out along the Scatter Creek road. The intrusive rocks of the formation include types other than rhyodacite; however, the rhyodacite is the typical rock type in so much of the area that I feel the advantages of using the petrographic term outweigh those of using the word "formation." The Scatter Creek Rhyodacite was previously mapped in the Republic district as latite porphyry (Umpleby, 1910) and as quartz latite porphyry (Lindgren and Bancroft, 1914).

DISTRIBUTION

The Scatter Creek Rhyodacite occurs as dikes, sills, and irregularly shaped intrusive bodies, distributed sparsely in the Sanpoil Volcanics, and more widely in the older rocks, especially in the O'Brien Creek Formation and the Permian rocks. There are just a few intrusives in the Sanpoil Volcanics, and these are largely limited to the edges of the Sanpoil outcrop. The intrusives are at least in part feeders to the Sanpoil Volcanics and accordingly are probably less abundant and certainly harder to identify in the uppermost part of the Sanpoil section, which forms the center of the graben. At the type locality, the Scatter Creek occurs as a thick linear body that has apparently been emplaced along a fault. To the west, only a few dikes occur in the Paleozoic rocks and the Cretaceous batholith.

Along the east and north-central part of the graben the intrusives are largely confined to the outcrop bands of the Permian and O'Brien Creek Formation. At the southern end of the eastern band, the intrusives are not numerous and are mostly dikes. Northward they become much more abundant and assume a variety of irregular shapes. There is only one dike of Scatter Creek east of the Sherman fault in the granodiorite; this is at the south end of the area, just east of the fault.

LITHOLOGY AND PETROGRAPHY

The typical rhyodacite (fig. 7) is a massive rock that crops out boldly in most places It is light gray to dark greenish gray and is mostly porphyritic. Predominantly equant plagioclase pheno-

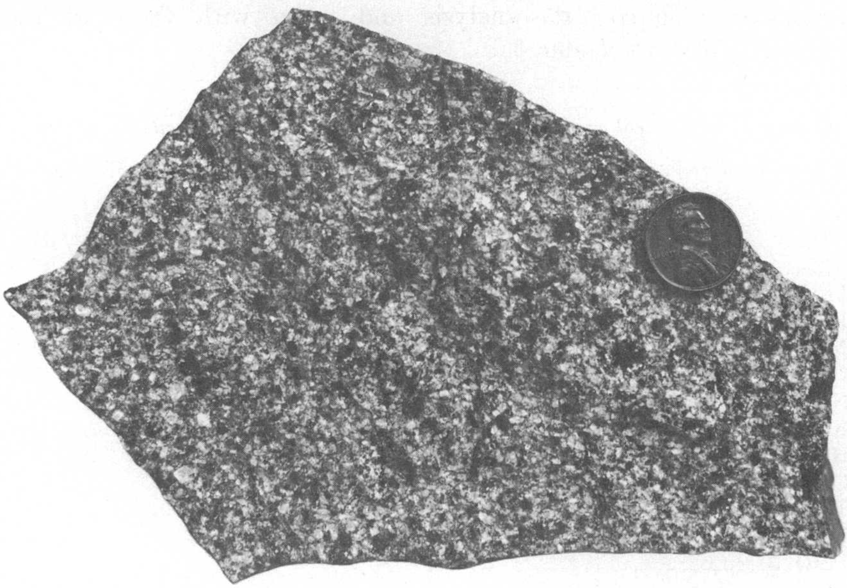

FIGURE 7.—Typical Scatter Creek Rhyodacite.

crysts, whose average size is near 1 mm, lie in a murky green chloritic aphanitic groundmass that is flecked in places by splendent biotite crystals and (or) by hornblende prisms as much as 5 mm long; in some of the rocks the hornblende phenocrysts are altered to chlorite. In a few places the intrusives have a little visible quartz. Pyrite is usually present.

The zoned plagioclase phenocrysts range in composition from oligoclase (An_{20}) to labradorite (An_{55}) but most are andesine (An_{30-45}). They lie in a very fine grained holocrystalline groundmass of allotriomorphic-granular texture that consists of quartz, K-feldspar, and plagioclase of more albitic composition than the phenocrysts. The phenocrystic quartz, where present, is commonly partly resorbed. Biotite and hornblende are altered to spindle-shaped and granular sphene, chlorite, calcite, and less commonly to epidote. A few rocks contain augite, or pseudomorphs of secondary minerals after augite. Here and there sanidine phenocrysts are sparsely distributed in the rocks. Apatite and zircon are accessory, and magnetite is present in every specimen.

The groundmass of the typical Scatter Creek intrusive is so fine grained that a mode cannot be determined, but I have estimated the mineral composition of six specimens; four are typical rhyodacite and two may be quartz latite, inasmuch as they have a little more K-feldspar than the others. A chemical analysis and norm of the typical intrusive (table 4) confirm the results of the petrographic estimates. Compare the analysis and norm with those of the Sanpoil Volcanics (table 3).

TABLE 4.—*Chemical analysis and norm of Scatter Creek Rhyodacite, in percent*

[Rapid-rock analysis by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack. Collected from railroad cut in sec. 32, T. 36 N., R. 33 E.]

Chemical analysis		*Norm (CIPW)*	
SiO_2	61.6	Quartz	17
Al_2O_3	15.6	Orthoclase	17.8
Fe_2O_3	1.7	Albite	30.4
FeO	3.8	Anorthite	13.9
MgO	2.6	Corundum	1.3
CaO	4.3	Hypersthene	10.9
Na_2O	3.6	Magnetite	2.5
K_2O	3.0	Ilmenite	1.4
H_2O	2.0	Calcite	2.7
CO_2	.69	Total	98
TiO_2	.20		
P_2O_5	.04		
MnO	1.2		
Total	100		

In the northeastern part of the area, north of Torboy, some of the Scatter Creek is dark and holocrystalline and looks like diorite. Most of the rocks, however, have enough orthoclase to be classed as syenodiorite. In a few places the rocks are coarse grained and light colored and contain more orthoclase; these are augite syenite and biotite monzonite. In a few other places a dark diorite occurs that contains as much as 80 percent dark hornblende in euhedral crystals as much as 2 cm long. West of the Republic mine, on top of the north flank of the hill in the west-central part of sec. 12, T. 36 N., R. 32 E., typical Scatter Creek grades into a small dike of very coarse grained pink quartz monzonite. All these atypical varieties have the same mode of occurrence as the normal Scatter Creek and in places grade into it imperceptibly.

RELATIONS TO SANPOIL VOLCANICS AND O'BRIEN CREEK FORMATION

The Scatter Creek intrusives are apparently related to the Sanpoil Volcanics even though they intrude them. In some places the intrusive relations are clear cut, but in many they are obscure and the two rocks grade into each other. The dike at the bend in Scatter Creek illustrates both types of relations. In most places the intrusives seem to cut only the lower part of the Sanpoil Volcanics; for example, there are no intrusives in the south-central part of the graben, which is apparently underlain by the upper flows of the Sanpoil. I do not know if they cut the upper part of the volcanics.

The chemical analyses and norms of the flows and intrusives are nearly identical. This similarity and the relations discussed above indicate that the Scatter Creek intrusives are the hypabyssal equivalents of the Sanpoil Volcanics, though some of the intrusives may never have reached the surface and may be later than any of the flows.

In the northeastern part of the area and in the contiguous Curlew quadrangle (Parker and Calkins, 1964), it seems certain that the O'Brien Creek beds had their present steep dips before they were intruded by the Scatter Creek. If they did, and because the Sanpoil flows appear to be conformable with the O'Brien Creek, it seems probable that at least some of the intrusives are later than the Sanpoil and are not the source of flows; if they were, there should be an angular unconformity between some of the flows and some of the O'Brien Creek beds.

AGE AND CORRELATION

The Scatter Creek Rhyodacite cuts the O'Brien Creek Formation of Eocene(?) age and is overlain by the Klondike Mountain Formation, Tom Thumb Tuff Member, of Oligocene age. The formation is about the same age as the Sanpoil Volcanics, although part of it at least is younger than the older part of the Sanpoil. It is assigned an Eocene(?) age.

The Scatter Creek is probably of about the same age as the shonkinite, monzonite, and pulaskite intrusives described by Daly (1913) in British Columbia and recently cited as middle Eocene (Mathews, 1964). To the south the Scatter Creek is probably represented by the porphyry of Pardee (1918).

QUARTZ MONZONITE OF HERRON CREEK

OUTCROP AREA AND RELATION TO OTHER ROCKS

An intrusive body of fine- and medium-grained quartz monzonite crops out over an area of about 5 square miles in the northeastern part of the Republic graben. Herron Creek drains the southern part of this area. Along its western margin the fine-grained facies of the intrusive cuts the Permian rocks and the Scatter Creek Rhyodacite, of Eocene(?) age. Except at one place where a little garnet is developed in greenstone, the intrusive has had no observable effect on the invaded rocks.

LITHOLOGY AND PETROGRAPHY

As noted above, the Herron Creek body is composed of two rock types—fine- and medium-grained quartz monzonite. The fine-grained rock is predominant in the western half of the body. The relations of the two rock types to each other are not known; they were seen in contact only in the west-central part of sec. 12, T. 37 N., R. 33 E.

In many places, especially in its eastern half, the body is highly sheared. In the NW. cor. sec. 13, T. 37 N., R. 33 E., and adjacent sections, for example, the rocks are brecciated and complexly sheared along what appear to be north-trending lines. Here and there the rock has been bleached and the mafic minerals altered to limonite; a few quartz stringers are exposed in pits. To the north, especially in sec. 1, T. 37 N., R. 33 E., nearly all the rocks are intimately and complexly sheared, brecciated, and chloritized, but I could not detect a predominant structural trend. Brecciated rock is well exposed on the Lambert Creek road. The cause of the shearing, where not related to high-angle fault zones, is probably related to an overlying thrust fault (see p. 109). The bleaching and limonitic alteration are probably not related to the thrust.

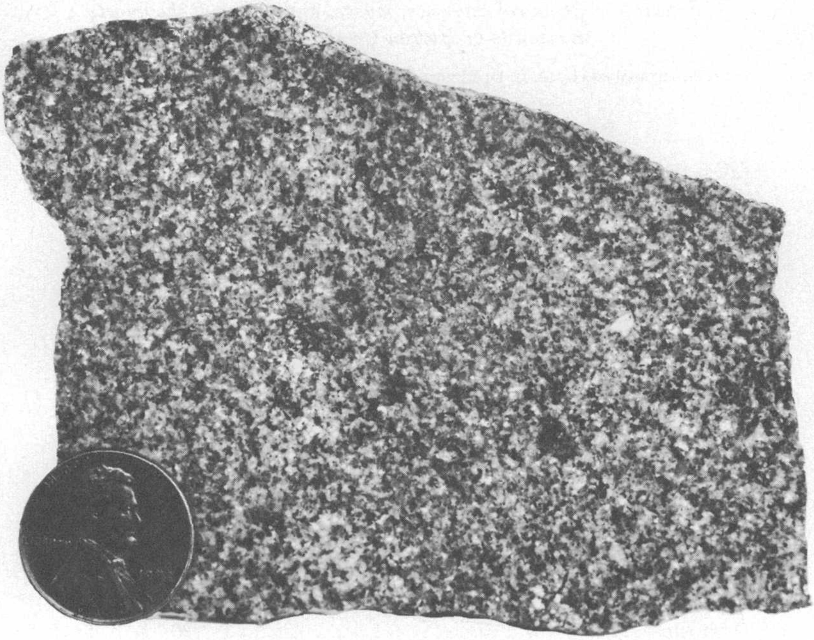

FIGURE 8.—Fine-grained quartz monzonite of Herron Creek.

The fine-grained quartz monzonite (fig. 8) is light gray and speckled with black biotite; the constituent grains are all about 0.6 mm across, but rare equant phenocrysts of plagioclase are as much as 5 mm. The texture is hypidiomorphic-granular; the orthoclase is cloudy and the plagioclase (An_{15-35}) is somewhat altered to sericite and calcite. Quartz is strained and biotite is altered in a few places to chlorite and iron oxides. Apatite needles and minor sphene are the only accessories. A chemical analysis, mode, and norm of this rock are given in table 5.

The medium-grained quartz monzonite is mineralogically not much different from the fine grained. It is generally pink, and the grain size is about 3 mm. The texture is also similar except that the mafic minerals occur in clusters of crystals. Former hornblende has altered completely to chlorite, calcite, and magnetite. Zircon, apatite, and sphene are the accessories. The mode of this rock (table 5) is not completely satisfactory because it is based on only one average-sized thin section. Nonetheless, it and the chemical analysis show that the medium-grained rock contains less free quartz and more orthoclase than the fine grained.

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TABLE 5.—*Chemical analyses, modes, and norms of the quartz monzonite of Herron Creek, in percent*

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

Chemical analyses

	1	2
SiO_2	70.2	65.8
Al_2O_3	15.9	14.7
Fe_2O_3	.4	1.5
FeO	1.7	2.2
MgO	.89	1.4
CaO	1.8	2.6
Na_2O	4.3	3.2
K_2O	4.1	5.4
H_2O	.62	1.3
TiO_2	.33	.51
P_2O_5	.07	.22
MnO	.03	.06
CO_2	.28	1.5
Total	100	100

Modes

	1	2
Orthoclase	29	43
Plagioclase	40	26
Quartz	24	20
Biotite and other	7	11

Norms (CIPW)

	1	2
Ilmenite	0.6	0.9
Magnetite	.7	2.3
Orthoclase	24.5	31.7
Albite	36.2	27.2
Anorthite	8.9	9.8
Hypersthene	4.4	5.4
Diopside		1.8
Quartz	23.3	18.5
Total	100	100

1. Fine-grained quartz monzonite, SW¼ sec. 14, T. 37 N., R. 33 E.
2. Medium-grained quartz monzonite, from creek bottom, NE¼ sec. 1, T. 37 N., R. 33 E.

AGE AND CORRELATION

The quartz monzonite intrudes the Scatter Creek Rhyodacite (the relations are clearly shown in the center of sec. 15, T. 37 N., R. 33 E.) and hence can be no older than Eocene(?). It is also older than the Lambert Creek thrust, which I tentatively correlate with the folding that preceded the period of erosion now represented by the unconformity at the top of the Tom Thumb Tuff Member. The folding is probably older than the upper members of the

Klondike Mountain Formation (see p. 109). Therefore, the age of the intrusive probably is between that of the Scatter Creek Rhyodacite (Eocene?) and of the Tom Thumb Tuff Member (Oligocene).

The granitic intrusive in the eastern part of the Curlew quadrangle to the north (quartz monzonite of Long Alec Creek) and most of the intrusive east of the Sherman fault are probably part of the same body as the Herron Creek. The Herron Creek intrusive (and its two associates) is one of the many granitic intrusive bodies of the region around Republic that belong to a plutonic period clearly later than the period during which the great Mesozoic batholiths were intruded (Larsen and others, 1958). In southern British Columbia the best known of these Tertiary intrusives are the Coryell batholith and the Sheppard Granite (Daly, 1913, p. 354–365). The Sheppard Granite is thought to be earlier than the Coryell (Daly, 1913; Drysdale, 1915b) and is considered to be Tertiary(?) because it intrudes conglomerates of Cretaceous and (or) Tertiary age (Daly, 1913; Little, 1950). The Coryell intrusives are more widespread than the Sheppard but are no more reliably dated. However, in a 1958 field conference with H. W. Little of the Canadian Geological Survey (on Bunch Grass Hill, about 25 miles north of Grand Forks), Coryell intrusives were found cutting probable Midway lavas. It would seem then that the Coryell is at least as young as Eocene and could be younger.

The Coryell and Sheppard intrusives in general have less quartz than the Herron Creek and allied intrusives, but their dikes are typically granophyric, as are those of this area. Indeed, this seems to be one of the characteristics of these Tertiary granitic rocks and also of those in central Idaho (Ross, 1928). In other respects the Idaho intrusives are like the ones discussed here, but they are probably a little younger.

The Snoqualmie Granodiorite (Smith and Calkins, 1906), a batholith in the Cascades, can probably be correlated (broadly) with the other Tertiary granitic plutons in the region. The Snoqualmie intrudes Miocene volcanic rocks and so is a little younger than comparable bodies in this area and in British Columbia.

QUARTZ LATITE PORPHYRY

Quartz latite porphyry is probably the hypabyssal phase of the quartz monzonite of Herron Creek. It crops out in several small irregular bodies and in a dike in the northeastern corner of the area. Two small bodies also occur just east of Curlew Lake. Most of the intrusives are poorly exposed; only those in sec. 32, T. 38 N., R. 34 E., can be easily seen.

The porphyry is a light-pinkish-brown aphanitic rock characterized by slender tabular salmon-colored orthoclase phenocrysts as much as several centimeters long together with chalky andesine crystals that are generally somewhat smaller than the orthoclase; phenocrysts of lustrous black biotite in euhedrons about 1.5 mm across and chloritized mafic clots several millimeters across also are present. The phenocrysts lie in a holocrystalline orthophyric groundmass consisting of about 60 percent orthoclase in equant crystals about 0.02 mm across and optically continuous patches of quartz. Anhedral to euhedral biotite and hornblende, more or less altered to chlorite, calcite, and sphene, together with apatite and many magnetite cubes are also present in the groundmass. Mafic clots of hornblende and augite are mostly altered to chlorite and calcite.

The quartz latite intrudes the Scatter Creek Rhyodacite and is thus younger. It crops out in the Curlew quadrangle (Parker and Calkins, 1964) where dikes of it grade into the quartz monzonite of Long Alec Creek, of which it is clearly a hypabyssal phase. Its relation to the quartz monzonite is probably the same as in the Curlew quadrangle.

QUARTZ MONZONITE EAST OF SHERMAN FAULT

Granitic rocks that are mostly quartz monzonite underlie nearly all the area of the Republic quadrangle outside the Republic graben east of the Sherman fault. The quartz monzonite is part of a large granitic terrane that extends almost without interruption east and south to the Columbia River (Franklin D. Roosevelt Lake) and west to the Okanogan River (Pardee, 1918; Waters and Krauskopf, 1941); this is the Colville batholith of late Mesozoic and Tertiary age.

The quartz monzonite was not studied in detail, and probable pendants of metamorphic rocks are included in the unit as shown on plate 1, particularly between Edds Mountain and Belcher Mountain, where three traverses were made across the outcrop. In the intervening area, the rocks were studied at widely separated places along the Sherman fault. The granitic area is heavily covered by forest, a considerable part of the cover being dense second growth, which impedes all traverse through it.

GENERAL FEATURES AND PETROGRAPHY

Because of the massive nature of the quartz monzonite, its topographic expression is generally smoother than that of other rocks. This difference is obvious on the topographic map. Except in the area south of Edds Mountain, the rocks east of the fault are not strongly jointed, and only south of Rabbit Creek and on the south shoulder of Edds Mountain are joints strong enough to be seen on aerial photographs. Four directions of jointing are conspicuous on the photographs, and from ground observations I know that several others exist. In addition, the quartz monzonite is sheeted in many places.

The intrusive relation of the quartz monzonite to the schist east of the Sherman fault has already been described. In addition, at the northernmost end of the fault, aplite—apparently related to the quartz monzonite—intrudes massive greenstone. At the same place is what seems to be a linear mass of Scatter Creek Rhyodacite and, in several isolated outcrops, quartz latite porphyry; a small amount of fine-grained quartz monzonite much like that intruded along the Sherman fault also occurs in association with the rhyodacite and quartz latite. The quartz latite and quartz monzonite are fresh, but some of the rhyodacite is well chloritized and could be sheared. Outcrops are so sparse and so poor, however, that the relations among the rocks other than between the greenstone and aplite are not known.

Near the southern border of the area, a short dike of what looks like Scatter Creek Rhyodacite apparently intrudes the quartz monzonite. No other dikes, except the aplites, were seen cutting the quartz monzonite.

As might be expected, the rocks east of the fault differ greatly in general lithology. In composition, however, the differences are less. Most of the mass is quartz monzonite; locally the composition ranges to granodiorite and even to diorite. The rocks are fine to medium grained and are shades of gray and pink. The finer grained rocks, which are in the minority, are medium gray and mostly equigranular; they have a grain size of about 0.5 mm and in places have a few plagioclase phenocrysts as much as 2 mm long. The fine-grained rocks look like those of the Herron Creek body, and biotite is the only mafic mineral.

The medium-grained rocks are gray and pink and are inequigranular. The grain size ranges from about 1 mm to 1 cm, the larger size being almost exclusively orthoclase. Orthoclase, plagioclase, quartz, biotite, and hornblende are the essential minerals of the medium-grained rock. As determined from estimates and modes, the combined feldspar makes up more than 60 percent of the rock, and the orthoclase-plagioclase ratio mostly ranges from 35:65 to 65:35; quartz ranges from 10 to 20 percent, and combined biotite and hornblende range from about 10 percent to about 30 percent. The gray medium-grained rocks are found largely in the southern and central part of the outcrop, and pink rocks are the only ones seen in the northern part of the area.

As seen in thin section, the textures and minerals of the gray and pink varieties of quartz monzonite are about the same. The texture is characteristically hypidiomorphic-granular. Orthoclase, some of which is microperthitic, is turbid and occurs interstitially, in allotriomorphic patches, and as phenocrysts. Plagioclase is nearly all oligoclase but has a range of An_{15-35}; some of it is sericitized and in one place it was partly altered to epidote and clinozoisite. Some of the quartz is strained. Biotite is brown and typically has ragged ends and is in various stages of alteration to chlorite and sphene. Green hornblende occurs in euhedrons and in crystal aggregates, and in

TABLE 6.—*Chemical analyses, modes, and norms of quartz monzonite, in percent*

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

Chemical analyses	1	2	3
SiO_2	61.7	66.0	65.8
Al_2O_3	15.7	15.1	14.7
Fe_2O_3	1.7	1.2	1.5
FeO	3.4	2.6	2.2
MgO	3.2	1.9	1.4
CaO	5.3	2.9	2.6
Na_2O	3.6	3.5	3.2
K_2O	3.7	4.8	5.4
H_2O	0.73	1.0	1.3
TiO_2	0.79	0.57	0.51
P_2O_5	0.42	0.22	0.22
MnO	0.09	0.06	0.06
CO_2	0.06	0.16	1.5
Total	100.4	100.0	100.4
Modes			
Orthoclase	20	34	43
Plagioclase	36	38	26
Quartz	14	15	20
Biotite	15	6.5	11
Hornblende	15	6.5	11
Norms (C.I.P.W.)			
Apatite	1.0	0.7	
Ilmenite	1.5	1.2	0.9
Magnetite	2.6	1.9	2.3
Orthoclase	21.7	28.4	31.7
Albite	28.8	29.3	27.2
Anorthite	15.8	11.4	9.8
Diopside	6.2	.9	1.8
Hypersthene	8.7	7.0	5.4
Quartz	11.8	19.6	18.5

1. Medium-grained gray quartz monzonite from near center of T. 35 N., R. 34 E., about ½ mile south of bench mark 4324 along road.
2. Medium-grained pink quartz monzonite from near top of hill in SW¼ sec. 33, T. 38 N., R. 34 E.
3. Medium-grained pink quartz monzonite from the Herron Creek body (table 5).

some places has replaced augite. Sphene, apatite, and zircon are common accessories.

Chemical analyses, modes, and norms of two of the common rock types in the quartz monzonite are given in table 6. Figure 9 shows the analyzed pink variety from the northern end of the outcrop, and figure 10 shows a specimen of the gray variety, much like the one from the southern end of the outcrop whose analysis appears above. Analysis 3 is of the medium-grained pink quartz monzonite in the Herron Creek body; it is given here for comparison with what looks like the same rock type east of the Sherman fault. Note that the chemical analyses are nearly identical, and the photograph of the rock from east of the fault (fig. 10) could very well be that of the rock from west of the fault.

COMPARISON WITH ROCKS OF CRETACEOUS BATHOLITH

As judged from individual hand specimens, the plutonic rocks east of the graben are not distinguishable from those of the Cretaceous batholith west of the graben. Petrographically and chemically, however, there are general differences between the two plutonic masses

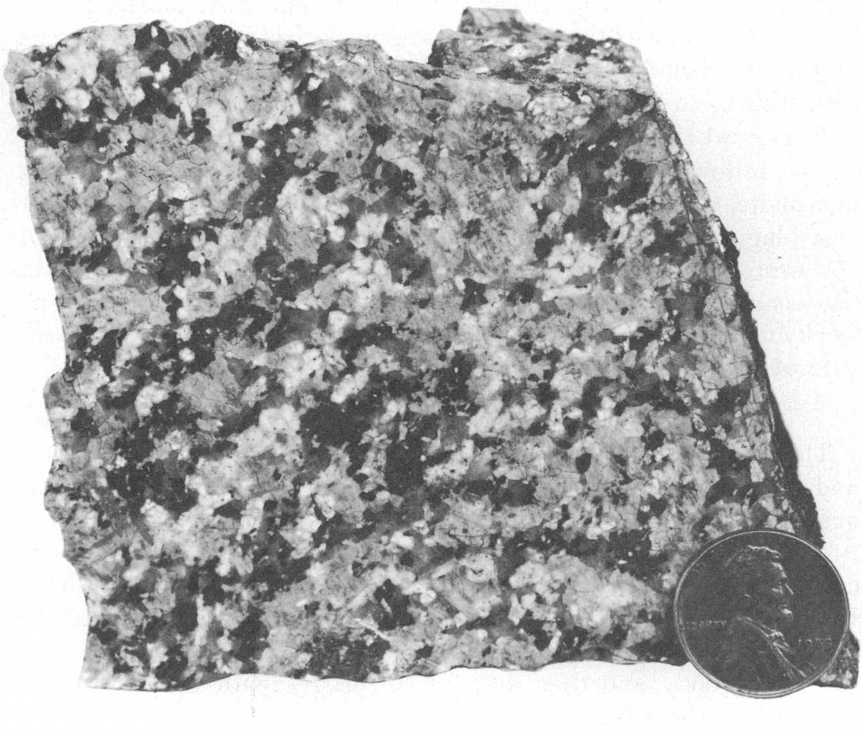


FIGURE 9.—Medium-grained pink quartz monzonite from east of the Sherman fault from near its northern end in sec. 33, T. 38 N., R. 34 E.

FIGURE 10.—Medium-grained gray quartz monzonite from east of the Sherman fault in sec. 16, T. 36 N., R. 34 E.

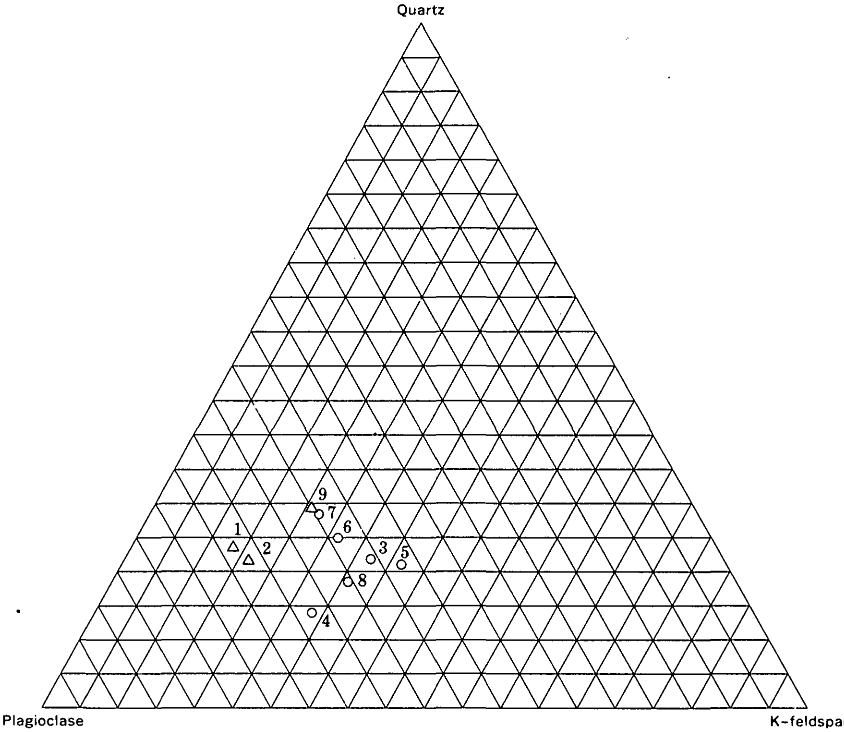
(fig. 11). Let me stress that these differences are neither exclusively nor invariably those of either intrusive mass. This means that a boulder from one of the two masses—now enclosed in a conglomerate of the O'Brien Creek formation, for example—cannot certainly be identified as to source.

In general the eastern plutonic rocks differ from those to the west in the following aspects: (1) The eastern ones are mostly quartz monzonite, whereas the western ones are generally granodiorite. (2) The plagioclase of the eastern rocks is typically oligoclase; that of the western is typically andesine. (3) Myrmekite is uncommon in the eastern rocks, common in the western ones. (4) I have seen no smoky quartz in the eastern mass, whereas the quartz of the southern part of the western mass is commonly smoky.

AGE AND CORRELATION

The age of the quartz monzonite cannot be determined directly and must be inferred. Most of it seems to be the same age as the quartz monzonite of Herron Creek (Eocene(?) or Oligocene(?)) and is part of the same intrusive body, but at the south end of its outcrop, the granitic body is intruded by a short dike of Scatter Creek Rhyodacite(?). This relationship suggests that at least a part of the quartz monzonite east of the fault is considerably older than the Herron Creek body and thus may be correlative with the Cretaceous batholith to the west.

The idea that most of the quartz monzonite east of the Sherman fault is correlative with the Herron Creek intrusive, and is therefore



EXPLANATION

1. Cretaceous granodiorite. Sec. 17, T. 36 N., R. 32 E., Aeneas quadrangle
2. Cretaceous granodiorite. Curlew quadrangle
3. Quartz monzonite east of Sherman fault. SW¼, sec. 33, T. 38 N., R. 34 E., Republic quadrangle
4. Quartz monzonite east of Sherman fault. T. 35 N., R. 34 E., one-half mile south of bench mark 4320, Republic quadrangle
5. Herron Creek intrusive, medium-grained. NE¼, sec. 1, T. 37 N., R. 33 E., Republic quadrangle
6. Herron Creek intrusive, fine-grained. SW¼, sec. 14, T. 37 N., R. 33 E., Republic quadrangle
7. Quartz monzonite of Long Alec Creek, fine-grained. SE¼, sec. 4, T. 39 N., R. 34 E., Curlew quadrangle
8. Quartz monzonite of Long Alec Creek, porphyritic. SE¼, sec. 4, T. 39 N., R. 34 E., Curlew quadrangle
9. Cretaceous quartz monzonite west of graben. Sec. 16, T. 34 N., R. 31 E., Bald Knob quadrangle

FIGURE 11.—Relative amounts of normative quartz, K-feldspar, and plagioclase in plutonic rocks of Republic graben area.

Tertiary rather than Cretaceous, is based on the following lines of evidence: (1) The medium-grained pink quartz monzonite that makes up most of the northern half of the outcrop area east of the fault is indistinguishable from the medium-grained facies of the Herron Creek intrusive. As noted above, the two rocks are chemically identical. (2) The quartz monzonite extends into the Curlew quadrangle, where, except for some short interruptions, it can be traced into the quartz monzonite of Long Alec Creek (Parker and

Calkins, 1964). Quartz latite dikes of the Long Alec Creek body intrude the Scatter Creek Rhyodacite; hence, it seems assured that the Long Alec body is of the same age as the Herron Creek, and therefore the quartz monzonite east of the fault also is the same age as the Herron Creek. (3) Except for one dike, the quartz monzonite is nowhere intruded by the Scatter Creek Rhyodacite. This suggests that the quartz monzonite is younger, especially since the rhyodacite is so widespread directly west of the Sherman fault. If it is younger than the Scatter Creek, it is probably the same age as the quartz monzonite of Herron Creek.

At the southern end of the area the Scatter Creek Rhyodacite(?) crops out in a short band just east of the Sherman fault in quartz monzonite. No intrusive contacts were seen, but the dikelike shape of the porphyritic intrusive and the occurrence of quartz monzonite on either side of it lead me to believe that the intrusive is a dike and that here some of the quartz monzonite is probably Cretaceous. If this postulation is correct, some of the granitic boulders in the O'Brien Creek Formation to the west could have come from what is now the eastern side of the graben, rather than from the batholith to the west.

UNCONFORMITY AT THE BASE OF AND WITHIN THE KLONDIKE MOUNTAIN FORMATION

In the west-central and northern parts of the area, the Sanpoil Volcanics and Scatter Creek Rhyodacite are overlain unconformably by the Klondike Mountain Formation, of Oligocene and Miocene(?) ages. Inasmuch as there is also an angular unconformity between the two lower members of the Klondike Mountain and the lowermost member is missing in some areas, the surface at the base of the formation may represent several periods of crustal disturbance and erosion.

The Tom Thumb Tuff Member of the Klondike Mountain Formation, which contains an Oligocene flora (see below), overlies the Sanpoil Volcanics along Barrett Creek and along the belt north and south of Republic. The contact, although nowhere well exposed, is best seen along the south wall of the Knob Hill mine tailings pond, where silicified plant-bearing tuff overlies silicified and sheared flows. That the contact is an angular unconformity cannot be determined at the outcrops but must be inferred from the presence of coarse volcanic conglomerate and breccia at the base of the Tom Thumb and from the fact that the Tom Thumb seems to have a much simpler structure than the underlying flows. The unconformity at the base of the Tom Thumb may represent much of Oligocene time, the remainder being represented by the Tom Thumb Tuff Member. As noted previously, the quartz monzonite of Herron Creek was probably emplaced during this time.

The upper members of the Klondike Mountain unconformably overlie the Sanpoil flows on Klondike Mountain north of Republic. The unconformity is well exposed in secs. 25 and 36, T. 37 N., R. 32 E., and secs. 19 and 30, T. 37 N., R. 33 E., where it has a relief of about 1,000 feet as measured from a point just west of the Republic cemetery to near the top of Klondike Mountain. Although the relations cannot actually be seen in the field, there seems to be no question that the unconformity is angular because the upper part of the Klondike Mountain in the northern half of its outcrop area lies almost flat, and overlies Sanpoil flows that seem to dip steeply and have complex structure. This unconformity is probably the same age as that between the Tom Thumb Member and the middle member.

The intraformational unconformity is angular, a definite discordance in attitudes existing between the two members. A further indication of the nature of the unconformity is given by an isolated block—too small to map—of the middle member that lies directly on the O'Brien Creek Formation and the Scatter Creek Rhyodacite at the portal of the Flag Hill mine (sec. 1, T. 36 N., R. 32 E.). Less than half a mile to the east, virtually the full thickness of the Tom Thumb Tuff Member is present below the middle member. It must have been present at the Flag Hill mine before the middle member was deposited. Therefore, the absence of the Tom Thumb at the Flag Hill mine can only be explained by movement along the fault (Republic fault, see p. 104) in the gulch east of the mine after deposition of the Tom Thumb and before that of the middle member. This exposure, therefore, dates a period of movement on the fault—a point to be considered later in the discussion of the structural control of the ore bodies in the Republic district.

I do not know whether this later angular unconformity is more pronounced than that below the Tom Thumb Tuff Member, but I suspect it is not, because the angularity between the Tom Thumb and the middle member is not great. The age of the unconformity is either late Oligocene or early Miocene.

The regional extent of the unconformity below the Klondike Mountain Formation is not known either because not enough detailed mapping has been done in nearby regions, or because the plant fossils that have been discovered do not allow precise correlation. However, the unconformity extends into the Curlew quadrangle (Parker and Calkins, 1964), where the Tom Thumb Member is missing (it was probably not deposited), and the upper members lie directly on the Sanpoil Volcanics. West of the mapped area, along State Highway 4 in the northwestern part of the Aeneas quadrangle, glassy gently dipping basalt (upper member, Klondike Mountain) directly overlies coarse conglomerate and breccia that are probably correlative with the O'Brien Creek Formation; the lower members of the Klondike Mountain and the Sanpoil Volcanics were probably never deposited here. North of the highway a few miles, the basalt seems to overlie Sanpoil Volcanics.

KLONDIKE MOUNTAIN FORMATION

DEFINITION

The name Klondike Mountain Formation is given to the volcanic rocks that unconformably overlie the Sanpoil Volcanics and the Scatter Creek Rhyodacite (Muessig, 1962). The formation is named for the mountain north of Republic, whose top and western slopes are underlain by pyroclastics and lavas. The formation is divided into three members, but only the lowest one, the Tom Thumb Tuff Member, is here given a formal designation. Stratified tuff—the well-known Republic "lake beds" of earlier literature (Umpleby, 1910; Lindgren and Bancroft, 1914)—constitute the Tom Thumb Member. An angular unconformity separates the lower member from the overlying rocks. The middle member consists of coarse pyroclastic rocks, and the upper of glassy basalt flows.

Because of the importance of these units in the exploration for new ore bodies in the Republic district, let me correlate the stratigraphic subdivisions of the earlier reports with this report. The earlier workers considered the "lake beds" (essentially the present Tom Thumb Tuff Member) to be a sedimentary lens within the andesite (essentially the Sanpoil Volcanics of this report) and the present middle member of the Klondike Mountain was considered to be upper andesite. The basalt, the present upper member, was considered to be a cap lying unconformably on all older rocks. Hence, the earlier workers considered all the Tertiary rocks below the basalt to be more or less conformable. There seems to be no question, however, about the existence of pronounced unconformities above and below the Tom Thumb Tuff Member. Moreover, these unconformities give testimony of events related to the mineralization in the Republic district. For this reason, and because of the differences in lithology across the unconformities, the Klondike Mountain Formation is here recognized as a stratigraphic unit distinct from the volcanic rocks below.

DISTRIBUTION AND THICKNESS

Most of the formation crops out in a fairly narrow band in a syncline (the Sanpoil syncline) whose trough extends from the Sanpoil Valley south of Republic, through Republic, and several miles north. The major outcrop is about 8 miles long and occupies an area of about 10 square miles. North of it are two other small areas of outcrop—one north of Barrett Creek and the other north of Trout Creek as shown on the northern edge of the map. The rocks of the northernmost outcrop extend into the adjacent Curlew quadrangle.

As might be expected in a unit of volcanic origin deposited on a highly irregular surface, the thickness of the formation varies. The maximum apparent thickness of the Tom Thumb Tuff Member, measured along a line trending about northeast from the Knob Hill mine, is about 1,900 feet, but the member thins sharply eastward and is absent a little more than a mile to the east. The middle member—flat lying under the northern slopes of Klondike Mountain—is about 800 feet thick. The basalt flows of the upper member attain a maximum thickness of a little more than 200 feet. In the Curlew quadrangle and about 10 miles west of Klondike Mountain, in the Aeneas quadrangle, the flows are much thicker.

TOM THUMB TUFF MEMBER

The Tom Thumb Tuff Member, as exposed along the road south of the Tom Thumb mine, consists of thin-bedded fine tuff; this is the "lake beds" of the earlier reports. At its base is a variable thickness of volcanic breccia, volcanic conglomerate, and tuff. At the top of the unit is an unconformity above which are the more coarse grained pyroclastic rocks that make up the middle member.

As noted, fine tuff constitutes most of the Tom Thumb. This tuff, which contains abundant plant remains in and around Republic is best seen just north of the road intersection at the south end of town and along the road south of the Tom Thumb mine. In these places the tuff is predominantly light tan to orange. Some sedimentary tuff and some coarse tuff are interbedded with the other types of tuff; plant trash commonly occurs along parting planes in the beds. In thin section the rocks are seen to be typical tuff. They have pyroclastic texture and consist of both crystals and volcanic rock fragments in a mostly devitrified microcrystalline groundmass.

At the base of the Tom Thumb are volcanic breccia and conglomerate, tuff breccia, and various other kinds of tuffaceous rocks. These coarse pyroclastic rocks were mapped with the andesite (the Sanpoil Volcanics of this report) in one of the earlier works in the area (Lindgren and Bancroft, 1914), but they seem definitely to belong with the pyroclastic rocks above rather than with the flows below. This basal unit is well exposed in the roadcut along State Highway 4 west of Republic and at the portal of the No. 3 adit of the old Republic mine. It also occurs in the hanging wall along the Republic vein in the caved stopes that are now exposed on the top of the hill above the adits of the Republic mine. In depth, the unit occurs in the hanging wall nearly up to the Republic vein (Umpleby, 1910, p. 45; Lindgren and Bancroft, 1914, p. 156). These basal rocks in the Republic mine area (sec. 12, T. 36 N., R. 32 E.) and to the south are included in the undivided Klondike Mountain Formation on the geologic map (pl. 1). What are probably the basal beds are exposed in the Knob Hill mine (Patty, 1921, p. 179) and also in the Quilp (Umpleby, 1910, p. 54) about a mile south of the Knob Hill along the valley locally known as Eureka Gulch.

Much of the basal unit is quite coarse, having volcanic fragments as much as several feet across, both rounded and angular, in a fine to coarse tuffaceous and tuff matrix. Interbedded with this coarse material are beds of fine to coarse crystal and crystallithic tuff.

The basal coarse pyroclastics, and, where they are thin or absent, the "lake beds," are highly altered along the Republic district vein system over distances of hundreds to several thousands of feet east of their contact with the underlying Sanpoil Volcanics or other rocks. The area of altered rock is shown by stippling on plate 1. The alteration, which was not studied in detail, is manifested by rocks that are moderately to intensely bleached, and in places the rocks are iron stained yet retain most of their primary textures. The altered rocks are white to cream colored and consist of light-colored silica in fine networks and chalky clay that has selectively replaced feldspar and some rock fragments. As seen in thin section, the silica is mostly cryptocrystalline, but some is finely crystalline quartz; iron oxides indicate the former presence of mafic minerals; a little biotite occurs here and there, and in a few places, some partly devitrified glass remains. X-ray analyses of the clay by R. L. Parker show it to be largely kaolinite, a little quartz being the only recognizable impurity. Intensely altered pyroclastics are well exposed along the highway on the west side of Republic.

In addition to the pyroclastic rocks, the Tom Thumb Tuff Member contains several greenish-gray porphyritic latitic flows that have not been separately mapped. The most prominent flow crops out in Republic just northwest of the high school and can be traced to the north, east of the road that goes to the Knob Hill mine. A small elliptical body of olive-drab finely porphyritic rhyodacite(?) intrudes thin-bedded tuff just below the junction of the road going to the Tom Thumb mine with that going to the North Fork of Granite Creek.

MIDDLE MEMBER

Lying unconformably above the Tom Thumb Tuff Member, or in its absence, the Sanpoil Volcanics, is the middle member, which consists predominantly of coarse pyroclastic rocks. The unconformity between the two members is not observable at their contact because the middle member, although fairly well bedded when considered in general, is poorly bedded in detail; hence, the unconformity must be inferred.

The middle member is characterized by its coarse pyroclastic nature and buff color. It is a heterogeneous unit, containing volcanic conglomerate and breccia (some of which are undoubtedly tuff breccia), some coarse tuff, and finer tuff and tuffaceous sandstone; here and there a few olive-gray to buff latitic flows make up a small part of the member. The predominant conglomerate and breccia contain porphyritic flow rocks of light gray to purplish hues; the fragments are round to angular, are as much as several feet across, and lie in a buff matrix of coarse crystallithic tuff.

BASALT MEMBER

The basalt member seems to lie conformably on the middle member, on and near the top of Klondike Mountain. Small bodies of basalt, probably both intrusive and extrusive, occur within the middle member; for convenience, these are treated as a part of the basalt member. The basalt dikes and the large basalt body in Republic are considered to be intrusive equivalents of the basalt flows and are mapped separately. Although they are not a part of the basalt member, they most logically belong with it and are discussed below.

The typical extrusive basalt occurs as thin flows, many of which show columnar joints. The rock is characteristically dark brownish black and glassy to aphanitic. Microscopic study shows the rock to be pilotaxitic; it contains labradorite phenocrysts as much as 1.5 mm long and smaller phenocrysts of augite, hypersthene, and some olivine. In the groundmass are magnetite, andesine microlites, and augite. At the base of the northernmost outcrop of the member is a light-olive-gray vesicular flow that has much augite in glomeroporphyritic masses and andesine microlites as the only feldspar; the rock contains some phenocrystic quartz and is probably an andesite.

The most prominent mass of intrusive basalt is a sill-like body in Republic. In addition, there are thin sills in the Tom Thumb Tuff Member, the thickest one being exposed near the northeastern end of the Republic grammar school building. The rock of this sill is greenish black and weathers in a crumbly fashion. The texture is intergranular, and the interstices between the labradorite laths are occupied by augite and iddingsite(?) after olivine. Some of the veins in the Republic district are cut by basalt dikes (Patty, 1921, p. 175); therefore they are later than the mineralization.

UNDIVIDED KLONDIKE MOUNTAIN FORMATION

The rocks of the Klondike Mountain Formation south of Republic and west of the Sanpoil River are undivided on the geologic map. In the Republic mine area most of the rocks are altered coarse pyroclastics of the Tom Thumb Tuff Member, but to the south, though there is no marked lithologic break there is a decrease in the amount of alteration, and the rocks become indistinguishable from many of those in the middle member. Glassy flow breccia, volcanic breccia, and volcanic conglomerate, all containing gray, blue-gray, and buff porphyritic lava, are common, and pinkish rhyodacite flows also occur in the area. Near the southwestern part of the outcrop, some of these rocks are difficult to distinguish from some of the underlying rocks of the Sanpoil Volcanics. At the head of the landslide in sec. 13, T. 36 N., R. 32 E., thin- to thick-bedded tuffaceous sandstone crops out along south-facing cliffs. The sandstone is about 100 feet thick and seems to underlie coarse pyroclastics and some flows. The sandstone may be correlative with the Tom Thumb Tuff Member; if it is, the pyroclastics are probably correlative with those in the middle member. On the other hand, the sandstone may belong with the rocks in the middle member. It is because of such difficulties of correlation that the rocks discussed here have been undivided.

AGE

Thin-bedded tuff of the Tom Thumb Member in Republic has yielded a fossil flora that R. W. Brown of the Geological Survey considered to be of Oligocene age. He reported the following forms from a collection I made in 1956 from the excavation for the hospital in Republic:

Ginkgo adiantoides (Unger) Heer
Metasequoia occidentalis (Newberry) Chaney
Pinus spp.
Pseudolarix americana Brown
Thuites or *Chamaecyparis* sp.
Alnus sp.
Cercidiphyllum crenatum (Unger) Brown
Aralia republicensis Brown
Quercus sp.
Porana speiri Lesquereux
Fragments of insect wings

Brown commented: "This is an Oligocene assemblage. Its environmental conditions were warm temperate to temperate, somewhat similar to those in Hupseh and Szechuan provinces, in western China, today."

The Republic beds had been reported to be of early Miocene age (Brown, 1937, p. 163–164), but it is now known (Brown, 1959, p. 128–129) that the morning-glory-like flower *Holmskioldia*, formerly called *Porana speiri*, which occurs at Republic, does not occur in beds known to be younger than Oligocene. This occurrence, then, dates the Tom Thumb Tuff Member as Oligocene. Further, the climatic conditions inferred from the Republic flora suggest that the flora is of late Oligocene age, for Brown (1959, p. 129) said: "The upper Eocene and the lower Oligocene floras contain a higher percentage of species with tropical or subtropical affinities, but the upper Oligocene flora is notably temperate, showing a strong trend toward cooler conditions."

If the Tom Thumb Tuff Member is indeed of late Oligocene age, it seems likely that the upper members are Miocene. If they are, the basalt may be roughly correlative with some of the Columbia River Group and with Miocene basalt in British Columbia (Geological Survey of Canada, 1947, p. 241–242; Little, 1957).

INTRUSIVE ROCKS OF UNCERTAIN RELATIVE AGES

Dikes, a few sills, and some irregular bodies of trachyandesite, quartz monzonite, and aphanitic rocks intrude Tertiary rocks in the northern half of the area and are among the youngest rocks in the area. Because their relative ages are uncertain, they are grouped under one heading for convenience.

GRANOPHYRIC QUARTZ MONZONITE

Fine-grained granophyric quartz monzonite dikes and small irregular bodies lie in and along the Sherman fault. Elsewhere, these bodies cut the Scatter Creek Rhyodacite, the Sanpoil Volcanics, and all the older rocks. Especially prominent is the long dike that cuts the Cretaceous batholith and the Scatter Creek Rhyodacite west of the Republic graben.

The dike along the Sherman fault in T. 37 N., R. 34 E., cuts sheared Scatter Creek Rhyodacite and is itself sheared in places. Its contact with the medium-grained quartz monzonite east of the fault could not be seen, but the dike obviously cuts the quartz monzonite east of the fault. The relations at this place indicate that the dike came in along an existing fault between the Scatter Creek and the medium-grained quartz monzonite; some movement along the fault continued after the emplacement of the dike. How much movement and when it took place are problematical.

The granophyric quartz monzonite is light gray, fiue grained, and equigranular. In most places it contains brown biotite in small flakes and tends to be somewhat porphyritic. Small white plagioclase phenocrysts are just a little larger than the average grain size of the rock, which is a little less than 1 mm. A few isolated phenocrysts are as much as about 1 cm across. Quartz is megascopically abundant only in the dike along the Sherman fault; in all the other quartz monzonite occurrences most of the quartz is too fine grained to be seen even with a hand lens. Under the microscope, the rock is seen to have a microporphyritic to hypidiomorphic-granular texture. The phenocrysts are andesine; both quartz and K-feldspar are interstitial and occur principally as micrographic intergrowths. Some K-feldspar is microperthitic, and some plagioclase is antiperthitic. Much of the biotite is altered to chlorite and sphene, and there is a little altered hornblende. The mineral composition ranges about as follows: plagioclase (An_{25-45}), 30–50 percent; K-feldspar, 30–35 percent; quartz, 15–25 percent; biotite and hornblende, about 10 percent.

The quartz monzonite is younger than the Scatter Creek Rhyodacite of Eocene(?) age. It was intruded after early movement on the Sherman fault, but earlier than the latest movement on the fault. It could well be a very late phase of the quartz monzonite of Herron Creek, whose fine-grained phase some of it closely resembles.

TRACHYANDESITE DIKES AND SILLS

Trachyandesite dikes and sills, many of which are vesicular and amygduloidal—some of them strikingly so—are particularly abundant along the outcrop belt of the Tom Thumb Tuff Member north of Republic, but isolated exposures also occur near the mouth of Barrett Creek. Two of these dikes and sills were previously mapped as trachyte flows (Umpleby, 1910, p. 25; pl. 8A is an excellent photograph showing the vesicular nature of this rock). The most accessible exposures of the rock are along the road between Mud Lake and the Tom Thumb mine and at the road junction north of the Tom Thumb mine. Along the road north of Mud Lake, the trachyandesite can be seen to be intrusive into the Tom Thumb Tuff Member.

The trachyandesite crops out in the Bacon Creek fault zone and most of it is sheared and altered; however, at the road junction mentioned above, an unsheared vesicular trachyandesite dike lies in the fault zone and dips steeply east. At this point at least the dike is clearly later than the fault. In the pit of the Mountain Lion mine (NW¼ sec. 27, T. 37 N., R. 32 E.) north of Mud Lake, unaltered trachyandesite dikes cut the Sanpoil Volcanics, which are here intensely bleached and mineralized. A virtually unsheared trachyandesite dike occurs along the Republic fault (see p. 103) in SW¼ sec. 35, T. 37 N., R. 32 E.

The unaltered trachyandesite is predominantly olive drab and microcrystalline, and has long drawn-out vesicles and amygdules. Most of the amygdules are calcite, quartz, and chalcedony, but some contain combinations of these minerals in a zoned arrangement. In thin section the texture appears trachytic and intergranular, the angular interstices between the andesine microlites being filled with fine brown fibrous biotite and a little granular augite. One glomeroporphyritic mass of augite 5 mm across and a few grains of quartz were noted. The slide is crowded with tiny magnetite cubes. The altered rock has much the same texture and mineralogy as the fresh rock, but the color is pinkish brown owing to the alteration of the magnetite and biotite(?) to ochre-colored iron oxides.

The trachyandesite is later than the main period of mineralization in the Republic district and is younger than at least the lower part of the middle member of the Klondike Mountain Formation. It could, of course, be much younger than all the Klondike Mountain, but at the base of the basalt member is an olive-gray vesicular flow (p. 73) that megascopically and mineralogically looks very much like the trachyandesite; the flow is probably the extrusive equivalent of the dikes. At any rate, the intrusives are probably of Miocene age.

APHANITE DIKES

Thin aphanite dikes and a few small irregular intrusive bodies, some too small to be shown on the map, crop out in and along the Bacon Creek fault in secs. 2 and 10, T. 37 N., R. 32 E. The aphanitic rocks intrude sheared granodiorite; some are likewise sheared, but some are not, and thus postdate at least some of the movement along the fault. Another aphanite dike crops out in sec. 9, T. 36 N., R. 32 E., where it probably cuts the Scatter Creek Rhyodacite.

The aphanitic rocks range in color from nearly black to brownish cream. In a few places they have a few ragged plagioclase phenocrysts that are less than 1 mm across. As seen in thin section, one of the rocks has a few small andesine phenocrysts in flow lines lying in a microcrystalline groundmass of plagioclase and K-feldspar(?) and some fine biotite; there are a few grains of quartz. Another specimen has a somewhat devitrified groundmass in which are many tiny magnetite cubes, a small amount of fine biotite, and about 10 percent of ragged quartz microphenocrysts about 0.1 mm across.

All that can be said about the age of the aphanite dikes is that they are younger than the Scatter Creek Rhyodacite and that they postdate some of the movement on the Bacon Creek fault.

QUATERNARY DEPOSITS

Unconsolidated deposits, most of which are of glacial origin and thus of Pleistocene age, cover a large part of the area. Little time was spent in mapping these deposits, and, even though they include materials of diverse origin, they have all been shown as one unit on plate 1. They include predominantly glaciofluvial deposits, but also some morainic deposits, alluvium, and—especially on the north-facing slopes of hills—slope wash and soil cover so thick that the bedrock below is completely hidden. The unconsolidated deposits are described under the headings of "Glaciofluvial deposits" (p. 81) and "Morainic deposits" and "Alluvium" (p. 83). Not discussed are the regolith and a landslide, mostly of thin-bedded rocks of the Tom Thumb Tuff Member south of Republic, which has slid into the Sanpoil Valley along bedding planes.

Because most of these deposits are of glaciofluvial origin, I feel that some notes on the drainage development in the area would be helpful before the deposits themselves are described. These notes should perhaps properly go in a separate section on geomorphology, but not enough work was done on the drainage problem—nor is the area of study large enough to have yielded many answers—to warrant separate detailed treatment.

NOTES ON DRAINAGE DEVELOPMENT

The presence of outwash along most valley sides and of glacial grooves on the bedrock of valley bottoms and sides, together with other less obvious evidence, shows that the present valley pattern—but not all the present drainage directions—was established before the area was last glaciated. I say "last glaciated" because even though there is no direct evidence for multiple glaciation in this part of Washington, there is much evidence in neighboring regions (for example, see Alden, 1953, p. 65–67, 142–146), and thus an earlier glaciation in this area may perhaps be inferred (Flint, 1937, p. 226).

Nearly all the streams now flow into the Sanpoil-Curlew Valley, which contains the master drainage system in the area. The drainage of the valley is split on a low alluvial-fan divide (altitude about 2,360 ft) south of Curlew Lake at Torboy at one of the wide parts of the valley (fig. 12). Consequently, Curlew Lake (altitude 2,333 ft) now drains north and joins the Kettle River at an altitude of about 1,760 feet; the Sanpoil River now heads southeast of Curlew Lake, flows through a bedrock notch at about 2,350 feet just south of Sanpoil Lake, and leaves the quadrangle principally on bedrock at an altitude of a little less than 2,150 feet.

Earlier, the valley must have contained a through-going stream of which the upper Kettle River was but a tributary (Willis, 1887). The evidence for this seems clear; the valley contains many terraces, most of which do not seem to match across it, but several prominent ones at around 2,500 feet do appear to match, and, as far as I could determine with a hand level, they slope south.

It likewise seems clear that the drainage reversal of Curlew Creek and the Kettle River northeast (downstream) of its junction with Curlew Creek must have taken place before the last glaciation. Not only does the present valley pattern antedate the last glaciation, but the valleys—especially those of east-west trend—were probably not much deepened by the ice. The chief evidence for this statement is that most of the previously existing valleys are still integrated and are more or less accordant; there are few hanging valleys; there would be many more if the ice had been a more effective erosive agent. If, then, the valleys were not much deepened during the last glaciation, the loop of the Kettle River (fig. 1) must have been established before this last glaciation because the altitude of the river along the loop, which is about 1,850 and 1,750 feet, is at least 500 feet lower than the bedrock notch at 2,350 feet along the Sanpoil River. Therefore, the Kettle River could not have flowed south through the Curlew-Sanpoil Valley just prior to the last glaciation.

The Kettle River loop is an odd one, and, as already noted, the upper river—that part forming the loop into the United States—must have been tributary to the ancestral Curlew-Sanpoil drainage. Thus the original drainage reversal, which is most logically ascribed to glaciation, was not a result of the latest glaciation but must be ascribed to an earlier glaciation, other traces of which are absent or obscure.

Let me summarize the glacial drainage history and add to the postglacial history as I have been able to interpret it. The earliest decipherable event is that the Curlew-Sanpoil Valley contained a south-flowing master stream whose largest tributaries were the arms of the loop of the present Kettle River. An early glaciation resulted in drainage reversal of at least the eastern area of the Kettle

River loop so that instead of flowing south it flowed north. A glacial lake was probably the reversing agent; the dam, probably of ice, must have been between the town of Curlew and the present Curlew Lake, and the lake probably spilled over the divide east of Grand Forks, British Columbia. The lake must have occupied all the wide valley around Grand Forks, much of the loop of the Kettle River, and most of the Curlew Valley north of the present Curlew Lake. The lake beds that must have formed in such a lake were probably mostly removed during the last period of glaciation. No physical evidence for the dam remains, and the area of the inferred spillway has not been closely studied. The reversed stream cut its valley deeply and the present Sanpoil Valley was virtually abandoned. After the reversal and valley incisement, the area was again glaciated to such a depth that all but the highest peaks were covered by ice. During the last stage of this glaciation, the Curlew and upper Sanpoil Valleys were occupied by residual ice whose melting resulted in kame terraces along the valley. At about this time the Curlew Valley drained south, as is shown by the south-sloping terraces along Curlew Lake. Therefore, the Kettle River, which also had some stagnant ice along it (shown by kettle holes in terraces) probably also drained south. But this southward drainage was short-lived, and, as soon as most of the ice had melted, the earlier reversed drainage reestablished itself in its present direction.

Curlew Lake, which is little more than a large kettle hole, drains north because a north gradient had been established prior to the last glaciation. The Sanpoil alluvial-fan divide at Torboy is probably a postglacial feature.

Of more than passing interest in the drainage history are gorges cut into bedrock and waterfalls along many of the streams tributary to the Sanpoil-Curlew drainage. One of the gorges, near the mouth of O'Brien Creek, can be seen from State Highway 3P. Another is along the Sanpoil River just east of Torboy and a third is along Granite Creek just west of Republic. The gorges are about 100 feet deep and may have been formed when the last of the wasting ice in the main valley melted and thereby lowered the base level to which the streams had been adjusted. Such gorges are common in other areas nearby (Drysdale, 1915a, p. 27).

Just west of bench mark 2439 south of Sanpoil Lake, the Sanpoil River flows through a gorge about 70 feet deep. The gorge is cut into water- and ice-worn bedrock whose average altitude is about 2,430 feet. On the face of it, it looks as if this gorge might have been formed at the same time as the others, but it could not have been because on the upstream side is Sanpoil Lake; in other words, this gorge could not have been cut by headward erosion. Evidently the gorge cuts through a bedrock dam, behind which a small lake formed. The lake probably was fed by and ponded against wasting ice not far to the north, possibly at the south end of the present Curlew lake. The gorge was cut when the lake spilled over the bedrock divide. The lake was probably of such short duration that only a negligible amount of sediment was deposited in it. At any rate, no lake sediments have been discovered along the valley sides; the bottom of the valley north of Sanpoil Lake, however, is flat and fertile and may well be formed of lake beds.

Freeman (1934) states that during the glacial recession a lake developed in front of the ice near the present Curlew lake and that the outlet channel was to the south. Because he gives no further information, I do not know if he was referring to the lake and outlet channel discussed above.

GLACIOFLUVIAL DEPOSITS

The Cordilleran ice sheet evidently covered all the area except the top of Bald Mountain. Assuming that the ice had a more or less level top, it must have been a little more than 4,500 feet thick in the Republic area. It was not until the waning stages—when the ice was melting faster than it was building up—that much glacial debris was deposited. Although the ice was in the form of sheet, its waning stages were not characterized by the retreat of a single front along which moraine and outwash were deposited. Rather, as the ice got thinner, more and more islands of bedrock were exposed and more and more melt water deposited fluvial material against the ice and the adjoining bedrock. When the upland areas were cleared of ice, most of the valleys were still filled with stagnant ice and outwash, although here and there local ice tongues advanced and dammed up outwash in tributary valleys. There was probably not much regularity in the disappearance of the ice except that the wider and deeper valleys contained ice longer than the smaller ones.

In a few places, local mountain glaciers may have remained longer than the stagnant ice in the valleys, but these glaciers did not deposit much debris. During the waning stages of glaciation they probably did not project much beyond their cirques. An inferred cirque and two tarns, the site of one such glacier, occur just east of the road in the center of T. 35 N., R. 34 E.

It is not difficult to imagine the kind and distribution of deposits laid down in such an environment. All the valleys tributary to the Sanpoil-Curlew drainage have outwash terraces along them. For example, along the South Fork of O'Brien Creek in the south parts of secs. 32 and 33, T. 36 N., R. 34 E., there are gravel terraces at altitudes of 3,910, 3,940, 3,990, 4,170, and 4,250 feet. Most of the terraces cannot be traced very far and many cannot be matched with others across the valley. Some, with knolls and kettles, are obviously kame terraces; others are just outwash terraces. Many valleys contain bedrock trenches that represent glacial stream channels, one side of which was ice. The great number of terraces, their random distribution, and their generally short extent indicate a complex history whose unraveling has not been attempted.

The glaciofluvial deposits in the Sanpoil-Curlew valley are not much different from those in the tributaries, except that they are more extensive and, being better exposed, are more striking (fig. 12). As in the tributaries, there are multiple outwash terraces. The most prominent ones are along Curlew Lake at altitudes between 2,470 and 2,540 feet. What appears to be the most extensive terrace has an altitude of about 2,520 feet. It may be seen at the mouth of Herron Creek and seems to be the same as the terrace at 2,510 feet northwest of Sanpoil Lake and the one about 2,530 feet west of the highway in sec. 9, T. 37 N., R. 33 E. There are other large terraces along Curlew Lake and many along the Sanpoil River. Few can be traced very far with any assurance and fewer still can be matched

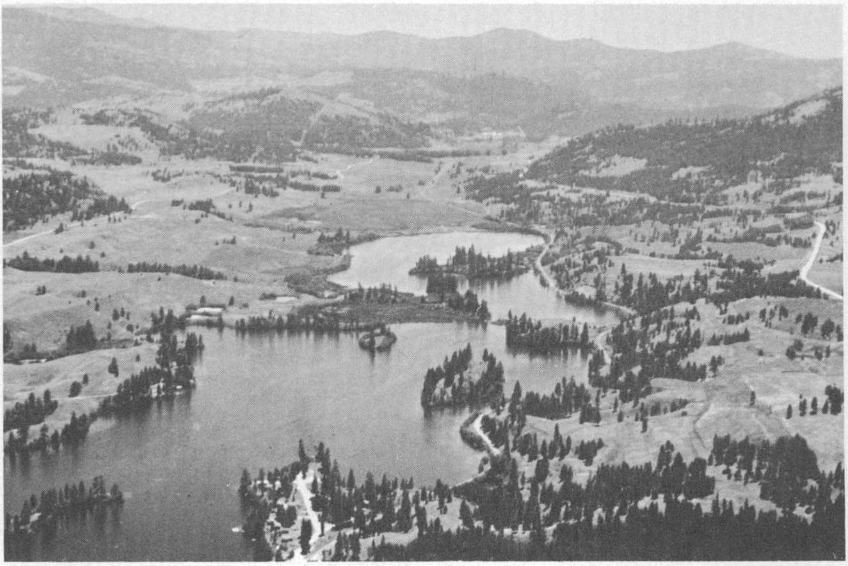


FIGURE 12.—Aerial view looking south over Curlew Lake. Note prominent kame terraces, kames, and kettle holes. Divide of the Sanpoil-Curlew drainage is in the valley at the bifurcating tree lines in the upper center of the picture.

across the valley—at least with a hand level. Many of the terraces, especially the 2,520-foot terrace along Curlew Lake, are kame terraces deposited against stagnant ice. The outward slopes of many of the terraces along Curlew Lake are mainly constructional ice-contact forms that have been little modified since glaciation. And, as noted before, Curlew Lake is itself a large kettle hole.

The terraces are composed of a heterogeneous accumulation of outwash material ranging in size from gravel to silt and locally to clay. Most of it is poorly sorted and does not reflect the lithologies of the nearby rocks. Thicknesses depend on the configuration of the underlying bedrock. Along Curlew Lake, for example, the 2,520-foot terrace may be underlain in places by gravel that extends under the bottom of the lake, which is 130 feet deep at the deepest point (Spokesman-Review, Spokane, Wash., June 14, 1959); the gravel here would be more than 300 feet thick.

MORAINIC DEPOSITS

Few morainic deposits were identified in the area. What appears to be ground moraine is exposed in gullies on the south slope of Gold Hill and around Mud Lake. A questionable lateral moraine is exposed along the highway in the west-central part of sec. 15, T. 36 N., R. 33 E. The moraines noted seem fresh, and there is no evidence of any age difference among them. The material of the moraines is till having no unique characteristics.

ALLUVIUM

Some of the flat alluvial bottoms of both the wide and narrow valleys are probably underlain by postglacial water-laid material. This material was not mapped, so no criteria were formulated to distinguish it from material deposited by glacial waters. The only deposits that are certainly postglacial are those of the Recent flood plains.

STRUCTURE

The dominant structural feature of the area is the centrally located north-trending graben, here named the Republic graben. The graben extends northward into the Curlew quadrangle where it becomes narrower and finally indistinct near the international boundary. In less well defined form it extends southward into the Colville Indian Reservation (Staatz, 1964). Within the mapped area, the layered Tertiary rocks are confined to the graben and lie within it in a syncline, here called the Sanpoil syncline because most of its trough lies along or in the Sanpoil River valley. The rocks of the graben are cut by Tertiary north-trending high-angle faults of several stages and, in the northeastern part of the graben, by a thrust with a displacement of a few miles. The thrust is called the Lambert Creek thrust because the thrust plane crops out above the south side of Lambert Creek.

The events that shaped the structure of the area began in the Cretaceous and continued until late in the Tertiary. Relations among most of these events are complex and have not all been unraveled; however, the presence in this area of many Tertiary rock units, the relative ages of which are known, allows the Tertiary history to be more completely read in this area than in adjacent ones.

The structural history began during the early Late Cretaceous, when the upper Paleozoic rocks were intruded by a batholith, folded, and metamorphosed. The area was eroded until the Eocene(?), when Tertiary volcanic rocks began to be deposited in a structural trough whose margins probably coincided closely with those of the Republic graben. The most important Tertiary structural events are recorded—at least in part—by the unconformities above the Sanpoil Volcanics and above the Tom Thumb Tuff Member of the Klondike Mountain Formation. The unconformities are probably of Eocene and late Oligocene or early Miocene ages. Faulting continued intermittently until some time in the Miocene.

In the pages that follow, the structures are described as units—whether a group of faults, stratigraphic units with common structure, or separate areas—rather than as events in a structural chronology. There is much to be said for the chronologic presentation, but it does not seem to lend itself to the present study; I present the structural evolution in "Geologic history" (p. 123). The brief outline of the preceding paragraphs is intended only to give some continuity to the more-or-less unrelated discussions that follow.

DEFORMATION AND METAMORPHISM OF THE UPPER PALEOZOIC(?) ROCKS ON THE SOUTHWEST SIDE OF THE REPUBLIC GRABEN

The fold axes of the metamorphosed rocks at Sheep Mountain and southward, and, less strikingly, of the ones north of Golden Harvest Creek, are parallel to the lineation and strike of the foliation of the granodiorite that intrudes them. The structures obviously are synchronous. Several lines of evidence show that the deformation was not superimposed on both rocks later, but rather must have taken place during the final intrusive stages of the granodiorite. The synchroneity is most clearly shown by the fact that most of the quartz monzonite aplite dikes intruding the folded marble (p. 42) have no directional structures and are themselves unfolded, thus placing them later than the folding; but one of them is lineated parallel to the fold axes of the layered rocks, thus placing it earlier than the folding. Because the aplite dikes are a marginal, and probably late, phase of the granodiorite and are dilation dikes, the deformation must have exited during a late stage of the intrusion. A second line of evidence involves the structures of the granodiorite. West of Sheep Mountain the structures trend N. 20°–25° W., whereas to the north, where the granodiorite embays the metamorphic rocks, they trend slightly south of east. If these were superimposed, rather than primary structures, I would expect them to be parallel over a larger area. Thin-section study of the granodiorite (p. 42) shows it to have cataclastic textures; I infer that these and the resulting lineation are protoclastic, and I relate their trend to that of the intrusive border.

The third line of evidence shows that the emplacement of some of the granodiorite was later than the folding and thus that the structure cannot have been superimposed on granodiorite and metamorphic rocks. The reference here, of course, is to the granodiorite embayment having east-trending lineation. This body cuts across the folded marble in sec. 4, T. 35 N., R. 32 E., and was therefore emplaced slightly later than the granodiorite west of Sheep Mountain. In line with this evidence, the deformation of the rocks north of Golden Harvest Creek is probably synchonous with the intrusion of the embaying body and is thus slightly later than the deformation of the rocks to the south. In saying "slightly later" I do not mean to imply that the intrusion of the mass on the embayment and the concomitant deformation were an isolated episode in the structural evolution of the area; rather, they were probably only a short episode in the sequence of events constituting batholithic intrusion.

The upper Paleozoic(?) rocks, whose mineralogy has been described in earlier sections of this report, were metamorphosed at about the same time as they were intruded (and deformed). This synchroneity of the processes is shown by the fact that the metamorphic grade of the rocks increases toward the intrusive. As described on page 31, tremolite and, in one place, garnet are the only metamorphic minerals above the basal part of the siliceous marble unit at Sheep Mountain; farther west toward the base of the unit, and also toward the intrusive, diopside appears and tremolite drops out. Still farther west, at its intrusive contact, the light-colored marble contains diopside, wollastonite, sillimanite, staurolite, and calcite; here the wollastonite and sillimanite have their long directions parallel to the prevailing structures. The progressive increase in metamorphic grade, which is here traced in rocks of limited compositional range (calcareous), is indicated by the appearance of tremolite, then diopside, and finally wollastonite, the order in which these minerals should appear in calcareous rocks having free silica (Bowen, 1940). Wollastonite, found only at the contact, indicates one of the highest grades of metamorphism possible at a granitic contact (Bowen, 1940, p. 263), and sillimanite and staurolite, found most commonly in the almandine amphibolite facies (Turner, in Fyfe, Turner, and Verhoogen, 1958, p. 228–231), are indicative of the highest grade of regional metamorphism.

In the metamorphic rocks north of Golden Harvest Creek, the increase in grade of metamorphism toward the intrusive contact is not so clear-cut because the rocks differ in composition, but it is nonetheless unmistakable and forms a contact aureole. On the north-facing slope the highest grade rocks are biotite-muscovite-quartz schist; farther south on the northeast flank of the hill is amphibolite schist, and in one place a chlorite-olivine-talc schist; most of the south slope right up to the intrusive contact is underlain by coarse-grained staurolite-garnet-biotite-muscovite-quartz schist, whose staurolite and garnet porphyroblasts were rotated during growth. The skarn at the intrusive contact consists of diopside, garnet, idocrase, zoisite, carbonate, and quartz.

The increase in grade of metamorphism toward the intrusive contacts can be largely attributed to the increase in temperature that must have obtained during metamorphism. The inference I draw from the relations of the minerals is that the upper Paleozoic(?) and Permian rocks were regionally metamorphosed to a low grade (greenschist facies) during the time of batholithic intrusion, and, because of the higher temperatures around the intrusive bodies, the grade of the metamorphism became progressively higher nearer to these bodies. A similar situation has been described by Billings (1937, p. 557–559). It follows that the age of the metamorphism and deformation is the same as that of the intrusion, that is, Cretaceous.

The possibility that these beds were regionally metamorphosed long before the Cretaceous batholithic intrusion must be considered because earlier metamorphic episodes are reported from areas not too far distant. A probable Early Jurassic metamorphism is noted in the Ashcroft area, British Columbia (Duffell and McTaggart, 1952), where unmetamorphosed Middle and Upper Jurassic rocks unconformably overlie metamorphosed Upper Triassic rocks of the Nicola Group; and the Guichon Creek batholith of that area is of about the same age as the metamorphism. Park and Cannon (1943, p. 39–40) report that in the Metaline quadrangle the sedimentary and volcanic rocks of the region were regionally metamorphosed before the intrusion of the Cretaceous(?) Kaniksu batholith; a superimposed thermal aureole later than their "main period of regional deformation" surrounds the batholith. The age of the metamorphism cannot be definitely stated because the youngest affected beds are Devonian. However, in view of the apparently close temporal relations between the Mesozoic intrusions and the regional metamorphism in this general area, as inferred from data over a large area (Smith and Stevenson, 1955; White, 1959), it seems probable that the deformation is but an early phase of the Cretaceous orogenesis that was climaxed in the Metaline area by batholithic intrusion. Waters and Krauskopf (1941) believe that in the Okanogan area the regional metamorphism of upper Paleozoic rocks preceded the deposition of an Upper Triassic carbonate sequence, which lies unconformably above the Paleozoic rocks. In more recent work, mainly west of the area just mentioned, Peter Misch has found (written commun., Feb. 9, 1959) that the carbonate sequence is overlain by a formation of tremolite-actinolite schist and granulite and this in turn by thick pelitic schist. Moreover, a large ammonite from the carbonate sequence that was previously reported to be Triassic or Early Jurassic (Waters and Krauskopf, 1941, p. 1366) is now definitely thought to be of Early Jurassic age (Ralph Imlay, oral commun., June 9, 1959). These findings, then, indicate that the metamorphism must be at least Late Jurassic (see also Misch, 1949, p. 686) and could be younger. Finally, White has concluded (1959, p. 72) that the late Paleozoic deposition was terminated in British Columbia by a major deformation, the Cassiar orogeny, although the evidence of the orogeny is masked in many parts of the province by later deformations.

There is no evidence in the Republic area that the Paleozoic rocks have been metamorphosed more than once. However, it is true the presence of poikiloblastic minerals indicates that recrystallization continued after deformation stopped, but this recrystallization is not inferred to manifest a distinctly later thermal metamorphism superimposed on the already thermodynamically metamorphosed rocks; rather, the two processes graded into each other and were part of the same orogeny. In the Curlew quadrangle (Parker and Calkins, 1964), Upper Triassic rocks are metamorphosed to the same degree as the Permian rocks; there is no record of a pre-Triassic metamorphism. Much evidence from less than 100 miles to the northeast in British Columbia indicates that the metamorphism and deformation are virtually synchronous with the emplacement of the Cretaceous(?) Nelson batholith. In the Ymir area there is "no evidence of structural unconformity of strata" from later Precambrian to Jurassic (Little, 1950, p. 32); the Nelson batholith was probably emplaced during the orogeny that preceded Upper Cretaceous sedimentation (Little, 1950). Farther north in the Slocan area the regional metamorphism is presumably connected with the period of orogeny of which the Nelson batholith was a part (Cairnes, 1934, p. 36, 48, 59, 67).

In summary, from the evidence in this area, only one period of regional metamorphism—of Cretaceous age and synchronous with batholithic intrusion—is inferred. Several workers in nearby areas suggest earlier periods, but in one area (Okanogan) the data are in conflict and in another (Metaline) the data are inconclusive. Most workers in the area to the northeast, around Nelson, British Columbia, seem to agree that the metamorphism there is of the same general age as the Nelson batholith. Therefore, the evidence for an earlier metamorphic period (for example, the Cassiar orogeny of White) is not very strong in the Republic and contiguous areas. If such evidence was ever present around Republic, it has been erased. In nearby areas where intrusives believed to be late Mesozoic cut already deformed rocks, it seems reasonable to suspect that a discordant intrusive was emplaced later in the same orogenic cycle in which the rocks were deformed. Moreover, when one considers the evidence from the whole of northeastern Washington and adjacent British Columbia, it seems reasonable to infer that the orogeny and metamorphism extended over quite a long period of time, but that at any one spot in this area, only a part of this time is represented.

STRUCTURE OF THE UPPER PALEOZOIC(?) ROCKS NEAR SHEEP MOUNTAIN

The internal and small-scale structural features of the three metamorphosed sedimentary units near Sheep Mountain were discussed earlier (p. 28–34). Suffice it to recall here that where the third dimension can be seen, the units have complex tight folds with amplitudes ranging from inches to several feet (fig. 5). The larger structures appeared to be simpler.

Most of the fold axes of the smaller folds bear about N. 20° W. and plunge gently to the south. The larger structural features, also folds, are parallel to the smaller ones and likewise plunge south. Thus, because the overall structure is anticlinal, successively younger beds crop out from north to south.

At Sheep Mountain the structural features are shown by the outcrop pattern of the basal marble unit to be several fairly broad folds (pl. 1, section *E–E′*). The structure of the massive marble to the north is undecipherable, but presumably the marble forms the core of a plicated anticline whose faulted east limb is defined by the inliers of siliceous marble north and a little east of Sheep Mountain.

Between Sheep Mountain and the east-trending fault at Swan Butte, the gross structure is less clearly defined because of the intervening mass of granodiorite. Nevertheless, the distribution of the three stratigraphic units shows that they lie in a south-plunging broad plicated anticline whose north-trending crest lies between Ferry and Swan Lakes. The basal marble is exposed only in the northern part of the crest; to the south are pendants of the next younger unit—the siliceous marble. Swan Butte is on the west limb of the anticline, and the area just south of Ferry Lake is on the east limb. On the limbs of the anticline are the outlying schist and phyllite units.

Although no broad structural features can be recognized in the schist and phyllite south of the east-trending fault at Swan Butte, it seems reasonable to infer that the rocks south of the fault represent a slightly higher part of the same anticline. This inference is strengthened by the fact that the rocks west of Swan Butte are lithologically indistinguishable from those south of the fault and apparently extend without interruption into the area south of the westward projection of the fault.

STRUCTURE OF THE PERMIAN ROCKS

Very little is known about the gross structures in the Permian rocks. In most places in the central and eastern parts of the graben, the rocks dip moderately to steeply west and the structure would appear to be quite simple. In a few mine adits, however, where the structural details can be seen, the rocks are complexly faulted and folded. It seems logical to assume that this detailed structural complexity reflects at least some complexity on a larger scale. Indeed, in the southeastern part of the area at least, the rocks are probably closely or isoclinally folded. Although large isoclinal folds were not seen in the field, the fact that in places some lithologic units have such short strike length can perhaps be attributed to such folds or perhaps to faults.

In the northern part of the area, the graywacke in some places is associated with the limestone in graded beds. The west-dipping beds under the limestone at the head of Lambert Creek and those under the limestone at bench mark 2482 along the highway east of Curlew Lake are right side up.

If the Permian rocks are considered as a unit, a simplified structural picture results, but one that reflects the Tertiary rather than an older deformation. The rocks in the southern part of the eastern outcrop belt are deflected westward at about the latitude of Gold Hill, and from there northward they crop out in the central outcrop belt. The westward deflection took place through a combination of movements along north- and east-trending faults (see p. 105). The deflection is shown by the stratigraphic offset of phyllitic tuff containing amygduloidal flows from south of the south fork of Sanpoil River to the west side of Gold Hill. The rocks in the eastern outcrop belt north of about the latitude of Gold Hill are in the upper plate of the Lambert Creek thrust; they have been moved several miles to the east from the central outcrop belt.

The Permian rocks in the western outcrop belt are folded along axes parallel to those in the metamorphic rocks near Golden Harvest Creek.

THE REPUBLIC GRABEN AND ITS MARGINAL FAULTS

The Republic graben is the dominant structural feature of the area and one of the prominent features of northeastern Washington (pl. 1, inset map). Its eastern border is straight and is defined by a single fault, the Sherman fault, which trends N. 12° E. Its western border is not straight but is defined by two faults that meet at an acute angle at about the middle of the western graben border. The northern one is the Bacon Creek fault, which has the same trend as the Sherman fault and apparently dies out to the southwest. The fault that forms the southwestern border of the graben trends about north and is really a zone of faults that extends from the North Fork of Granite Creek to the southern border of the area. This zone is called the Scatter Creek fault zone, even though much of the zone lies north of Scatter Creek. Although these faults are all bounding faults of the graben and all show several periods of movement, they are distinctive enough to warrant separate descriptions.

SHERMAN FAULT

The Sherman fault, which bounds the graben on the east, is the longest high-angle fault in the area. The name is taken from Sherman Pass, a well-known landmark a few miles east of the area. It trends N. 12° E. from the north to the south edge of the area; it extends into the Curlew quadrangle to the north and into the Colville Indian Reservation to the south. The fault is not shown on the geologic map of the reservation (Pardee, 1918, pl. 1), but the straight contact of the Tertiary "porphyry" (O'Brien Creek and Scatter Creek Formations of this report) with the Colville batholith suggests a fault. The fault is expressed as a line of furrows incised on the west-trending interfluves along the entire east side of the area; this line of furrows—one of the striking topographic features of the area—is easily seen on both the topographic map and a high-altitude aerial photograph of the area (fig. 2). The linear depressions no doubt result largely from differential glacial erosion of the fault zone. The straight trace of the fault shows that it dips steeply.

Even though the fault is a well-expressed topographic and structural feature, the actual fault zone is exposed in only two places in prospect pits along the southernmost outcrop of the fault. At the northernmost pit, the fault zone is nearly vertical and contains fragments of both layered rocks and quartz monzonite in a zone of gouge and breccia about 100 feet wide. Farther north, along a roadcut of the main highway in sec. 17, T. 36 N., R. 34 E., sheared serpentine and Permian rocks are probably part of or adjacent to the fault zone.

On the west slope of Belcher Mountain, 3 miles from the northern border of the area, a Tertiary granophyric quartz monzonite dike occurs in the fault zone and intrudes both the Scatter Creek Rhyodacite on the west and the quartz monzonite on the east. As described previously (p. 75), two periods of movement along the fault are indicated here, the second being later than the dike.

The amount of displacement along the fault is not known, but it must be thousands of feet, judging by the difference in metamorphic grade of the rocks on either side of the fault and by the complete absence of Permian rocks and the paucity of other upper Paleozoic rocks east of the fault. The displacement is assumed to be dip-slip because there is no evidence for strike-slip movement.

BACON CREEK FAULT

The Bacon Creek fault, named (Parker and Calkins, 1964) after Bacon Creek in the Curlew quadrangle, is the border fault along the northwestern part of the Republic graben It trends slightly more eastward than the Sherman fault and extends through about two-thirds of the Republic area and northward through the Curlew quadrangle, where it seems to die out a few miles north of the international boundary. Along its northern half in the mapped area (pl. 1), the fault is strikingly expressed by a deep narrow valley occupied by the North Fork of Granite Creek and the South Fork of Trout Creek. South of Granite Creek the trace of the fault follows shallower depressions.

Along the road up the North Fork of Granite Creek the fault follows a zone of intensely sheared granodiorite in many places and sheared greenstone at the southern end. In several places the fault trace is expressed as a narrow straight furrow along the valley wall; one such furrow can be seen just southwest of the Tom Thumb mine at the lowest bend in the road that joins the north-trending road in the valley. Slickensides on granodiorite are exposed along the road in the NE¼ sec. 28 and in sec. 15, T. 37 N., R. 32 E.; in sec. 28 the fault plane dips 60° E., and in sec. 15 about the same although it was not measured. It is difficult to say whether the dip along most of the fault is steeper than this because its trace does not cross very steep topography. In sec. 22, T. 37 N., R. 32 E., and along its southern end, the fault appears to be vertical.

The Bacon Creek fault is a normal fault along which the graben block must be downthrown at least 19,000 feet. To arrive at this figure, I assume thicknesses of 8,000 feet for the Permian rocks, 5,000 feet for the O'Brien Creek, and 4,000 feet for the Sanpoil Volcanics, and add a topographic relief of 2,000 feet. I am assuming that the upper contact of the granodiorite is and was at the same stratigraphic level east and west of the fault. On a cross section, Wright (1947) shows the Bacon Creek fault as a reverse fault dipping about 50° E. in the North Fork of Granite Creek, but he discusses it as a thrust fault. The concept of this fault as being a thrust, however, is not based on any observational data; it is, rather, part of a structural scheme that is largely hypothetical.

Trachyandesite dikes crop out in and along the fault zone. Most of them have been involved in the faulting, but the one at the road junction in sec. 15, T. 37 N., R. 32 E., and the one in the NE¼ sec. 4, T. 36 N., R. 32 E., show no shearing. Farther north, aphanite dikes also occur in or along the fault zone; some are sheared and some are not. The inference can be drawn that movement on the fault was intermittent and that major movement was completed before the last trachyandesite and aphanite dikes were intruded. Because the trachyandesite may be the hypabyssal phase of the flows at the base of the basalt in the Klondike Mountain Formation (p. 73), the last major fault movement probably took place in the Miocene.

Much earlier movement along the Bacon Creek fault is suggested by the fact that west of Copper Mountain, and outside the graben, long dikes of Scatter Creek Rhyodacite and granophyric quartz monzonite trend more or less parallel to the Bacon Creek fault. The supposition is that the fractures along which the dikes were intruded were formed at the same time as movement occurred on the fault. If this supposition is correct, Eocene movement can be inferred.

In "Faults within the Republic graben" (p. 101), it is suggested that initial movement on the Bacon Creek fault probably was slightly later than that on the Scatter Creek zone to the south.

A possible relation of movements on the Bacon Creek fault to mineralization in the Republic district is shown in two places. In the middle of sec. 22, T. 37 N., R. 32 E. (at the adit symbol shown at the right "2" of "22", pl. 1), the dump of a caved adit driven east from the east edge of the fault zone contains mostly brecciated tuff and flow breccia of the basal Klondike Mountain Formation. Just east of the adit, the Klondike Mountain Formation is brecciated and has brecciated banded vein quartz in stringers through it. I infer from these relations that vein quartz was deposited during faulting and that the faulting was along the Bacon Creek fault. At the Mountain Lion mine (about one-fourth inch north of the "M" of Mud Lake, pl. 1), three veins that trend north are reported (Joseph, 1900). I suspect this trend was established sympathetically to movement on the Bacon Creek fault.

SCATTER CREEK FAULT ZONE

As the displacement along the Bacon Creek fault becomes progressively less to the south, progressively more and more movement along the graben border occurs on faults of the Scatter Creek fault zone. The zone begins at about the latitude of Mud Lake with a single high-angle fault that branches obliquely from the Bacon Creek fault and brings the O'Brien Creek Formation into juxtaposition with Permian greenstone. The fault is exposed along an old logging road in the NW¼ sec. 33, T. 37 N., R. 32 E., and in a pit in the NE¼ sec. 3, T. 36 N., R. 32 E.; in each place the fault dips steeply. From this last outcrop, the fault trends a short distance southeastward, then bends southwestward. It is not again exposed to the south except for what I believe may be the same fault in an adit on the steep west flank of Copper Mountain. In shallow pits just north of this adit, O'Brien Creek tuff overlies greenstone, and I infer that the covered contact is a fault. At the adit portal, which is caved, is a flat shear zone about 8 feet thick in which the upper part is light colored and appears to be brecciated O'Brien Creek and the lower part is dark and appears to be sheared argillite or graywacke. Rocks in the shear zone are so brecciated that they are completely friable. All the dump material is fine and appears to be comminuted; one of the latest rocks on the dump is some O'Brien Creek tuff having plant fragments. I think that the flat shear zone represents a late period of reverse movement on an otherwise steep fault, such movement being related to the last folding of the Sanpoil syncline. (See pl. 1, section *D–D′*.)

South of the adit, the fault, which is the main graben fault south of about Golden Harvest Creek, is not again exposed in the quadrangle, but the fault, or a branch of it, is exposed just south of the quadrangle in the Scatter Creek dike south of Fish Lake; here brecciated phyllite surrounded by Scatter Creek Rhyodacite is in fault contact with the phyllite along one side (M. H. Staatz, written commun., Nov. 26, 1958). Between Golden Harvest Creek and the south end of the map, the fault zone is occupied by the thick Scatter Creek Rhyodacite dike, which must have been intruded along the fault. The existence of the fault is shown by the stratigraphic discontinuity across the dike. Movement along the fault prior to the intrusion of the dike is inferred from the shape of the dike, the absence of a topographic depression, and the relations south of the area reported by Staatz. Some movement later than the intrusion of the Scatter Creek Rhyodacite is shown by the fact that the formation is cut south of the area and also at the extreme north end of the fault.

About a mile south of Copper Lake, a subsidiary fault of the Scatter Creek zone trends south and separates Permian phyllite from granodiorite in sec. 22, T. 36 N., R. 32 E. It either joins the main fault to the south in the large dike or dies out. This subsidiary fault can only be seen in one place, just west of the farmhouse in the NW¼ sec. 34, T. 36 N., R. 32 E., though it occupies a straight mile-long trench just north of the exposed fault. Movement along the fault is probably not very great. At its southern end, the stratigraphic displacement is only between the two marble units, which normally lie next to each other anyway, and farther north the displacement is all within one unit of the metamorphic rocks.

The displacement along the Scatter Creek zone cannot be measured, but I presume it to be of about the same magnitude as that along the Bacon Creek fault to the north. To the south, the zone becomes wider and more complex (Staatz, 1964) and extends through the entire length of the Bald Knob quadrangle.

Faulting began along the zone before the emplacement of the Scatter Creek Rhyodacite and continued or was renewed during or after emplacement.

GRABEN DEVELOPMENT AND TERTIARY DEPOSITION

Movements along the faults on either side of the graben probably kept pace with each other, because the faults are of about the same age, both had repeated movement along them, and both are part of a common structure. The evidence is clear that faulting, and therefore graben development, began before the intrusion of the Scatter Creek Rhyodacite. How much earlier is problematical, but there is evidence that the Tertiary deposits were laid down in local basins or valleys. It seems to be quite generally accepted that the Tertiary deposits were laid down in local basins elsewhere (Drysdale, 1915a, p. 241–242; Pardee, 1950, p. 366; Daly, 1913, p. 420). Because in the Republic area at least the depositional basin is structural, rather than erosional as previously thought (Umpleby, 1910, p. 20), I would argue that the faulting began just before the O'Brien Creek Formation was deposited rather than later.

In the Republic area the evidence that the O'Brien Creek Formation was largely confined to the ancestral Republic graben, although compelling, is largely inferential. The great thickness of the O'Brien Creek and the lack of O'Brien Creek fragments in later formations strongly suggest this conclusion. The presence of coarse granitic conglomerate in the O'Brien Creek indicates that there must have been steep local relief of the kind expectable along fault scarps.

Just a few miles west of the mapped area in what looks like another graben, the basal unit, which is probably correlative with the O'Brien Creek, is a coarse conglomerate and breccia. The unit apparently directly overlies granitic rock and contains a high percentage of granitic fragments. The conglomerate is much thinner than the O'Brien Creek, and its lithology, which reflects that of the local bedrock, is different from that of the typical O'Brien Creek but much like that of the conglomerate in the O'Brien Creek east of Curlew Lake. Above the conglomerate is glassy basalt of the upper part of the Klondike Mountain Formation, the Sanpoil Volcanics and lower part of the Klondike Mountain being missing. I infer that the different lithology, thickness, and relations of the basal Tertiary rocks argue strongly for local deposition rather than for deposition over a large area and then down faulting after deposition. Moreover, the relations here suggest that the history of this basin must have been somewhat different from that of the Republic graben. However, if the conglomerate is indeed correlative with the O'Brien Creek, then this basin must have had its inception by faulting at about the same time as the Republic graben.

The evidence for later and probably periodic movements along the marginal faults, as outlined, indicates that the major movement on the Bacon Creek fault probably had terminated before the deposition of the basalt member of the Klondike Mountain Formation. There is no limiting upper date for movement along the Sherman fault, but it seems logical to suppose that the history of movement was not very different from that of the other graben faults. If the synchroneity of later faulting along both sides of the graben is accepted, it then follows that the post-O'Brien Creek formations were also largely confined to the graben. The arguments advanced for the deposition of the O'Brien Creek in the ancestral graben likewise apply to the later Tertiary units and fortify the conclusion of basin deposition that was based on the evidence of late faulting.

In summary, then, the structural and sedimentary record indicates a long-lived intermittently subsiding graben, in which volcanic rocks accumulated. As indicated by Tertiary angular unconformities and a major thrust fault, subsidence and deposition were interrupted several times by compressive movements, whose extent and genesis will be unknown until more mapping has been completed in the region, particularly to the west. The mechanism of graben subsidence whereby magma is withdrawn from below and extruded onto the surface is a hypothesis that can neither be confirmed nor refuted by the local evidence. The age of the latest faulting along the marginal faults cannot be determined because the youngest preglacial beds in the area have been faulted. Recourse to geomorphology has been of no help because I have not found any erosion surfaces, which, if shown to be offset, might have helped date possible post-Miocene faulting.

The question of erosion surfaces, raised in connection with the structural development of the area (Umpleby, 1910, p. 11–14; Pardee, 1918, p. 44–45), may well be discussed here. Umpleby proposed an Eocene peneplane in the Republic area and stated that the Tertiary deposits lie in a valley cut into that peneplane; I can find no evidence for its existence. The "Sanpoil surface," a post-Miocene surface according to Pardee (1918, p. 44–45), supposedly is cut on the granitic and older rocks, although in the southern extension of the Republic graben in the Colville Indian Reservation the surface is cut on tilted Sanpoil Volcanics. Pardee believed the surface to be deformed and older than the Columbia River basalt. It is true that from certain vantage points in the Republic area, as, for example, at Lion Mountain, there are summits within the graben which appear to be accordant. However, a series of east-west projected profiles drawn at 1-mile intervals across the graben revealed no features that suggest an erosion surface. (See for example, pl. 1, section *E–E′*.)

FAULTS WITHIN THE REPUBLIC GRABEN

Most of the faults within the Republic graben are straight and dip steeply. They are most numerous in the eastern part of the graben, where they impart a structural linearity to the terrane. North of the latitude of Gold Hill, most of the high-angle faults in the eastern part of the graben trend slightly east of north, virtually parallel to the marginal faults of the graben north of that latitude. To the south of this latitude the faults trend north, parallel only to the Scatter Creek fault zone. In other words, the high-angle faults in the eastern part of the graben have a trend parallel to the western border faults.

Besides the high-angle faults, there is a thrust fault of large displacement, the Lambert Creek thrust, in the northeastern part of the graben.

The faults of the graben are not readily classified according to age, genesis, or relations to other structural features because no single classification fits them all. Therefore, I have made ease and clarity of presentation the criteria by which I arbitrarily classified the faults. Figure 13 shows the major faults in the area.

HIGH-ANGLE FAULTS OF NORTH TREND

Most high-angle faults in the area are poorly exposed and hence are not obvious features. The most easily discerned are those that mark recognizable stratigraphic discontinuities; most contacts between O'Brien Creek and Permian rocks are fairly easily recognized as faults once the overall relationship is established. The faults within single stratigraphic units or within intrusive rocks, as, for example, the two parallel faults several miles east of Curlew Lake, are in places extremely difficult to recognize. The existence of these faults was first suspected from their expression on aerial photographs as lines of trees, depressions, and other linear features. On the ground they appear in places as lines of depressions or gullies on hillsides; they are exposed here and there in prospect pits that have commonly been dug along them. A few faults within single geologic units, mapped as "photogeologic" faults, are discussed briefly below.

FAULTS OLDER THAN THE LAMBERT CREEK THRUST

East of the Herron Creek intrusive body a high-angle fault, the Cooke Mountain fault, separates the O'Brien Creek and Scatter

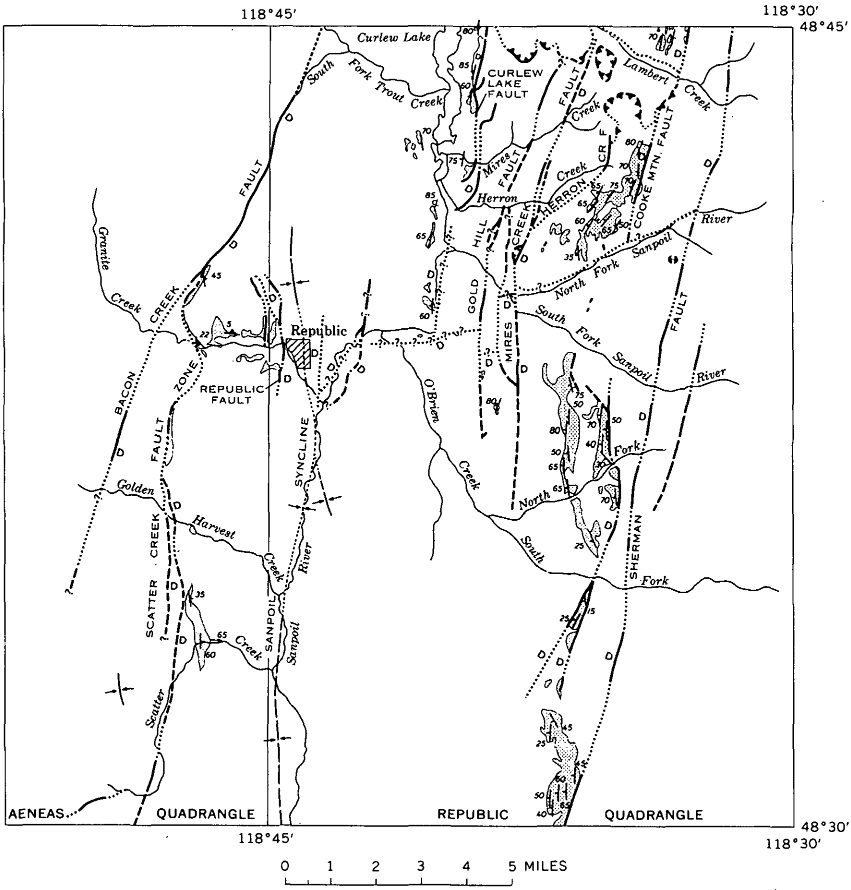


FIGURE 13.—Structure of the Republic graben as reflected by distribution of O'Brien Creek Formation.

Creek Formations from the Permian greenstone. The fault is traced with certainty from the north edge of the area southward for about 4 miles. Near its southern end the fault is wholly within Tertiary intrusive rocks and thus is not the contact between them and the Permian rocks as it is to the north. The Cooke Mountain fault extends into the adjoining Curlew quadrangle (Parker and Calkins, 1964) for a short distance. At the northern edge of the area the fault is well exposed in a series of pits where it dips steeply east. The hanging wall is formed of silicified and brecciated Permian rocks, whereas the footwall for about 4 feet from the fault is of Scatter Creek Rhyodacite(?) that has been replaced by hematite and magnetite. Farther south the fault follows a dike of Scatter Creek, which, along the line between secs. 13 and 18, is silicified in places and lies against brecciated Permian clastic rocks. The fault is apparently vertical here.

The amount of displacement on the Cooke Mountain fault is not known because both the O'Brien Creek and the Permian rocks dip steeply along the fault and have no horizon markers. The fault does not appear to cut the Lambert Creek thrust in secs. 6 and 7, T. 37 N., R. 34 E., and is thus older than the thrust. The presence of the Scatter Creek dike along the fault suggests that movement began before the emplacement of the dike; silicification along the dike suggests that movement continued or was repeated after the emplacement.

The Curlew Lake fault separates the O'Brien Creek from the Permian rocks along the east side of Curlew Lake; this fault is in the lower plate of the Lambert Creek thrust, and I interpret it to be the offset downward extension of the Cooke Mountain fault.

In the northern 2 miles of its extent, the Curlew Lake fault is marked by brecciated zones, prospect pits, a pronounced linear depression, and a dike in sec. 4, T. 37 N., R. 33 E. In the southwestern part of this section, the fault forms a scarp. The fault is exposed in an adit in the NW¼ sec. 16, T. 37 N., R. 33 E. A short distance south it extends under alluvium and is not seen again; it apparently extends into the O'Brien Creek Formation, as does its upper plate counterpart to the east. Its southward continuation may be the high-angle fault inferred to be present under Sanpoil Lake, because the O'Brien Creek Formation appears to be abnormally thin in that area.

FAULTS YOUNGER THAN THE LAMBERT CREEK THRUST

Of the faults that are younger than the thrust, the two most prominent, the Gold Hill and the Mires Creek, have a trend parallel to the western border of the graben; they are about a mile apart and extend for nearly half the length of the quadrangle. Only the eastern of these two faults, the Mires Creek, cuts the thrust and is thus obviously younger; for lack of other evidence, I assume its parallel companion, the Gold Hill fault, is of about the same age. East of the Mires Creek fault, and apparently branching from it, is a northeast-trending one, the Herron Creek, that also cuts the thrust. Other faults that cut the O'Brien Creek Formation along the southeastern margin of the graben are also inferred to be younger than the thrust, even though they do not cut the thrust, because they are exposed only in the lower plate.

The Mires Creek fault cuts the thrust in sec. 27, T. 37 N., R. 33 E. From there it trends about due south and cuts the Sanpoil Volcanics; to the north it changes trend to about N. 20° E. and is entirely within the quartz monzonite of Herron Creek. Its position in the quartz monzonite is marked by chloritized and iron-stained shear zones and in places by narrow topographic furrows; in the volcanics it is most easily detected by topographic features on the aerial photographs. In sec. 27, T. 37 N., R. 33 E., the volcanics in the upper plate of the thrust are dropped down on the east at least 500 feet because the base of the thrust plate does not crop out again east of the fault. South of where it cuts the thrust, the fault appears to die out in the Sanpoil Volcanics. To the north the offset on the fault also decreases, and just south of Lambert Creek the west side rather than the east side appears to be downthrown. Farther north in the Curlew quadrangle (Parker and Calkins, 1964) the offset increases.

The Gold Hill fault apparently begins near the northern edge of the quadrangle and parallels the Mires Creek for a little more than 8 miles. I do not know the direction of displacement or its amount, but I think the west side is dropped down, because the east-trending fault in the Sanpoil Valley appears to be offset to the south across the fault. In making this statement I assume that the east-trending fault is indeed offset and that it dips south, but there is no evidence for either of these assumptions (see p. 105). The Gold Hill fault is marked by prospect pits along most of its outcrop. From east of Gold Hill southward, pits are numerous and the fault passes through country rock that is in places highly bleached, iron-stained, and silicified; these conditions are especially well marked in the southern 1.5 miles of the fault and can be observed along the road between secs. 2 and 3 and 10 and 11, T. 36 N., R. 33 E. Between Gold Hill and Herron Creek are many more prospect pits. Just north of Herron Creek, brecciated and sheared country rock indicates the presence of the fault. In secs. 3 and 10, T. 37 N., R. 33 E., the fact that the fault follows a Scatter Creek dike suggests that the fault helped localize the dike and is perhaps an old one; later movement then brecciated the dike. North of the dike, quartz monzonite is sheared and somewhat bleached along the fault zone, and there are prospect pits in the greenstone. The fault apparently dies out just south of Lambert Creek.

The fact that the Gold Hill and Mires Creek faults have trends parallel to the western border faults of the graben suggests that all the faults were formed under the same physical conditions and therefore were formed at about the same time. Because the two parallel faults are younger than the Curlew Lake fault, which trends nearly due north, I infer that the N. 20° E. trend is younger than the due-north trend. If it is, then the initial movement on the Bacon Creek fault (which established the N. 20° E. trend) must have been somewhat later than that on the Scatter Creek fault zone, which has a north trend. The Cooke Mountain fault, which is in the thrust plate, originally had a north trend, as does its downdip extension in the lower plate, the Curlew Lake fault; the present N. 20° E. trend of the Cooke Mountain fault is a result of eastward movement of the thrust plate, which was greater in the northern part of the plate than in the southern, resulting in eastward rotation.

Branching from the Mires Creek fault is a hypothetical northeast-trending fault, the Herron Creek, that cuts the Lambert Creek thrust and drops the upper plate down on the southeast side. The Herron Creek fault is marked by a pronounced north-trending shear zone in sec. 13, T. 37 N., R. 33 E., where the Scatter Creek Rhyodacite of the thrust plate is faulted against quartz monzonite below the thrust; elsewhere the fault is covered by glacial debris.

The faults that cut the O'Brien Creek Formation along the southeastern margin of the graben are recognized chiefly because a marked stratigraphic break occurs there. The faults are exposed in only a few places, as for example just west of Iron Mountain. West of the California mine and along the road in sec. 18, T. 36 N., R. 34 E., sheared serpentine marks the presence of the fault.

CURVED FAULTS EAST OF CURLEW LAKE

Three curved faults cut the Permian rocks east of Curlew Lake in secs. 4, 9, and 21, T. 37 N., R. 33 E. The northernmost, which is the only one that is well exposed, crops out in several pits and can be walked out along the entire curve. The fault dips 75° NW. and bounds Permian limestone and clastic rocks. The direction and amount of displacement on the fault cannot be determined. Just south of it, another curved fault seems to have a similar origin. The fault is poorly exposed, but it accounts for the disappearance of about 400 feet of graywacke between the two limestone beds in SE¼ sec. 4, T. 37 N., R. 33 E., along the strike, and finally for the lower thinner limestone also. Its steep dip and probably downthrown west side indicate that this is a normal fault. The southernmost fault cuts out beds below a massive limestone. The fault dips steeply, and the amount of displacement is not known.

The origin of the curved faults is obscure. Each one is between limestone and clastic rocks; this position may suggest a genetic connection between the structure of the limestone lenses and the trend of the faults. Whether the limestone was folded and faulted at the same time, whether the faults followed a pre-existing trend, or whether they were initially straight and later folded are alternatives that cannot be satisfactorily evaluated with the evidence at hand. Inasmuch as I did not find curved faults in the thrust plate, they probably are younger than the thrust, though their curvature may be related to the waning stages of thrusting.

SHORT FAULTS WEST OF THE REPUBLIC DISTRICT VEIN SYSTEM

West of the Republic district vein system (see below) are many relatively short north-trending faults that cut the O'Brien Creek Formation, the Sanpoil Volcanics, and the Scatter Creek Rhyodacite. Because most of the faults are confined to one formation, their presence is generally not indicated by stratigraphic offset; rather, most of these faults lie along narrow topographic furrows that are noticeable on aerial photographs. On the ground some of the faults cannot be recognized except by their topographic expression. Others are exposed in prospect pits or are shown by altered shear zones although displacement is probably not great. Some of the faults have thin barren quartz stringers along them. The faults are probably of about the same age as those along the vein system because the general type of mineralization is about the same.

FAULTS JUST EAST OF REPUBLIC

Three apparently normal faults occur just east of Republic. They are given special mention because they collectively probably account for the widening and bending of the Sanpoil Valley here and because the westernmost one appears to be overlain by the middle member of the Klondike Mountain Formation and is thus older than this member. The easternmost fault is exposed along Gibralter Mountain and in the railroad cut to the north; north of the cut, it is located by the alinement of several springs. The amount of displacement along this fault is not known. The middle fault only crops out along the railroad. The westernmost fault cuts out much of the Tom Thumb Member against the Sanpoil Volcanics. It is expressed by a scarp and some seeps along it. The displacement, as judged by the thickness of the Tom Thumb Member, is probably more than 1,000 feet. So far as I can tell, the fault is overlapped in the northeastern corner of Republic by the middle member of the Klondike Mountain Formation.

FAULTS RECOGNIZED ONLY ON AERIAL PHOTOGRAPHS

Faults recognized only on aerial photographs occur just west of Curlew Lake—one southeast of Gibralter Mountain and one east of the Sherman fault. The presence of these faults is indicated by linear depressions, some of which have lines of trees in them.

The faults in the graben are shown only by sharp and narrow depressions; however, the one east of the Sherman fault, in the granitic rocks, has several wide but deep valleys along it (fig. 2).

FAULT ZONE ALONG THE REPUBLIC DISTRICT VEIN SYSTEM

For purposes of discussion, the Republic district vein system is defined as the series of veins starting at an elevation of about 3,000 feet in the center of sec. 12, T. 36 N, R. 32 E., at the Southern Republic or Princess Maud mine (Lindgren and Bancroft, 1914, p. 153), that trend north along either side of the steep-sided valley, locally known as Eureka Gulch, which lies between Republic and the Knob Hill mine. The vein system, as I am using the term here, includes the Knob Hill veins but specifically excludes the short veins to the southwest and west.

The fault zone along the main vein system begins at the south end of the system along the veins of the Southern Republic and Republic mines in sec. 12, T. 36 N., R. 32 E. At the Republic mine (W½, NE¼, sec. 12, T. 36 N., R. 32 E.) the vein follows a fault zone; for purposes of discussion, I am assuming that there is only one fault here and that it lies along the vein. The fault vein exposed in the caved workings at the top of the hill at the Republic mine, hereafter referred to as the Republic fault, separates the coarse lower part of the Tom Thumb Tuff Member of the Klondike Mountain Formation on the east from Sanpoil Volcanics on the west. The stratigraphic displacement across the vein is not known. Slickensides, seams of claylike gouge, and brecciated vein material show that some of the faulting is later than the vein.

To the north, the Republic fault separates the Tom Thumb Member from the Sanpoil Volcanics. It is exposed at the north edge of sec. 1, T. 36 N., R. 32 E., in a prospect pit. Just to the north, at the Republic town boundary, a trachyandesite dike that does not seem to be sheared lies in the fault. The fault is also exposed in the NE. cor sec. 34, T. 37 N., R. 32 E., at the portal of several adits. What appears to be a slickensided surface here dips 65° NE. What I infer to be the same fault was exposed underground in the Insurgent claim (Lindgren and Bancroft, 1914, p. 162) at about the end of the road in NW¼ sec. 35, T. 37 N., R. 32 E. Here the vein that was mined continues a few feet into the fault gouge; thus, some of the faulting, at least here, was earlier than the mineralization. The fault was also exposed underground in the Black Tail claim where a vein in andesite is cut off and "lake beds" lie east of the fault (Patty, 1921, p. 186). To the north the Republic fault extends under alluvium in SE¼ sec. 27, T. 37 N., R. 32 E., and may extend into the Knob Hill mine.

In the NW¼ sec. 35, T. 37 N., R. 32 E., the Tom Thumb Tuff Member has an apparent exposed thickness of about 700 feet, whereas northeast of the Knob Hill mine the thickness appears to be about 1,900 feet. This difference in thickness suggests a stratigraphic throw along the fault of about 1,200 feet, or a net throw of about 1,400 feet if the fault is assumed to be vertical. The displacement could be less if some of the decrease in exposed thickness of the Tom Thumb were due to stratigraphic thinning. In any event the fault is apparently a major one.

Branching from the Republic fault in the SW¼ sec. 35, T. 37 N., R. 32 E., is another fault that I believe lies along Eureka Gulch and drops the Sanpoil Volcanics down on the east side of the gulch. I have not seen this fault but it must exist, because otherwise the O'Brien Creek Formation that crops out just to the south and has only gentle dips would crop out northeast of the fault or at least be exposed in some of the deeper mine workings along the gulch. Some of these workings extend 800 feet below the surface (Patty, 1921, p. 181); those at the Knob Hill mine are much deeper and have not found the O'Brien Creek—an indication that the fault extends south of the Knob Hill and strikes under Mud Lake.

Another fault just east of the Flag Hill mine separates the O'Brien Creek Formation from the Scatter Creek Rhyodacite. To the north the fault is covered, but I infer that it extends along the vein shown in the NE¼ sec. 34, T. 37 N., R. 32 E. At the southernmost end of this vein the dump of an old shaft of unknown depth has many fragments of flow breccia containing slate and argillite chips that belong at the base of the Sanpoil Volcanics.

The faults along the vein system are younger than the Tom Thumb Tuff Member but older than the trachyandesite dikes. Some of the movement was probably earlier than the mineralization, and there is good evidence that movement on the Republic fault took place after the deposition of the Tom Thumb Tuff Member but before deposition of the middle member of the Klondike Mountain Formation. This movement may have been the main period of movement along the fault. I suggest too that some of the faulting began before the intrusion of the Scatter Creek Rhyodacite, as in other parts of the area, and therefore the Scatter Creek dike along Eureka Gulch was probably emplaced along a fault or fault zone. The inference, then, is that movement along the fault zone was probably intermittent over a period extending from just prior to intrusion of the Scatter Creek until sometime before the intrusion of the trachyandesite dikes.

HIGH-ANGLE FAULTS OF EAST TREND

The only high-angle faults in the area that trend east are three inferred faults south of Gold Hill, the westernmost of which lies in Sanpoil Valley. These three faults may be offset segments of a single continuous fault. Except for a northeast-trending shear zone at the bend of State Highway 4A, there is no direct evidence for the three faults; the indirect evidence, however, leaves no doubt that these faults exist.

The first line of indirect evidence involves the cutting out of the O'Brien Creek Formation between the Permian rocks and the Sanpoil Volcanics. Northeast of Gold Hill the O'Brien Creek is more than 4,000 feet thick. To the north along Curlew Lake, isolated outcrops of structurally parallel, steeply dipping O'Brien Creek indicate comparable thickness. Thicknesses to the southeast are also comparable. The indicated thicknesses of the formation, the apparent stratigraphic uniformity over a large area, and the lack of evidence of pinching out by onlap on bedrock highs of older rocks, all indicate that the O'Brien Creek was deposited on the Permian rocks near Gold Hill and that it was not eroded after deposition. Directly south of Gold Hill, there is no room for more than about 1,000 feet of the O'Brien Creek Formation between the Sanpoil Volcanics and the greenstone. Therefore, even though no fault could be detected in the northern part of sec. 3, T. 36 N., R. 33 E., a fault dropping the O'Brien Creek down on the south side is confidently inferred here.

The presence of the middle fault, in the next section east, is inferred on the assumption that the O'Brien Creek Formation south of the fault strikes north and therefore would abut into the greenstone. The assumption that the O'Brien Creek strikes north here, even though it is engulfed by the Scatter Creek intrusive, is based on the north strike of the beds in the large inclusion of O'Brien Creek in sec. 11, T. 36 N., R. 33 E., and on the evidence in the northeasternmost part of the area that the Scatter Creek has apparently not structurally disturbed the beds it has intruded.

No doubt exists as to the presence of the easternmost fault: There is room for very little of the O'Brien Creek between the volcanics to the south and the greenstone to the north.

Any extension of the faults east of the Mires Creek fault in sec. 34, T. 37 N., R. 33 E., is evidently under the Lambert Creek thrust.

Another line of evidence suggesting the presence of these faults indicates that they are parts of a fault that was originally single. Beds in the southeastern O'Brien Creek outcrops have been displaced west to the Curlew-Sanpoil Valley; that is, the east limb of the Sanpoil syncline (see below), north of Gold Hill, has been sharply narrowed. Because the O'Brien Creek beds generally have steep dips, their westward shift is difficult to explain solely by offset along the apparently vertical Gold Hill and Mires Creek faults. The displacement of the O'Brien Creek could be accomplished by a sudden westward swing in strike alone, or by a decrease in dip and a westward swing in strike together with some offset on the Gold Hill and Mires Creek faults. There is no evidence of a decrease in dip between the North Fork of Sanpoil River and the Curlew-Sanpoil Valley. Therefore, it seems plausible that the three faults were once part of a single fault that cut the west-dipping O'Brien Creek Formation and that, in some combination with the younger north-trending faults and possible changes of dip and strike of the formation, was chiefly responsible for the displacement of the O'Brien Creek westward from the North Fork.

The attitude of the three faults is not known, but if they are assumed to be offset members of a single fault, then the horizontal displacements of their traces across the north-trending faults suggest that they dip south. Moreover, the amount of displacement suggests that either the dip is not too steep or that there might be some horizontal component of movement along the Gold Hill and Mires Creek faults. Neither of these possibilities can be explored further with the data at hand.

From this outline, the following simplified sequence of events is indicated: The west-dipping, north-striking O'Brien Creek Formation was offset on an east-trending fault from near the North Fork of Sanpoil River west to the Curlew-Sanpoil Valley. Later the O'Brien Creek of the Curlew Valley was thrust east several miles and the thrust sheet and the east-trending fault below the thrust were cut by the north-trending Gold Hill and Mires Creek faults.

The possibility that the three faults were never part of a single fault must also be considered. If these three were discrete faults, the presently assumed large horizontal displacement of their surface traces along the Gold Hill and Mires Creek faults would be apparent, rather than real. However, the concept of three faults does not rule out the necessity of a pre-thrust fault displacement of the O'Brien Creek from the North Fork of Sanpoil River west to the Curlew-Sanpoil Valley. Because the north-trending faults are clearly later than the thrust and therefore must be later than any east-trending faults, it seems to me that the idea of three discrete faults is automatically ruled out.

LAMBERT CREEK THRUST

The Lambert Creek thrust is the dominant structural feature in the northeastern part of the area. Its trace can be followed along the south side of Lambert Creek, and it is covered by unconsolidated deposits along the north side of Lambert Creek. The upper plate of the thrust includes all the rocks north of the North Fork of Sanpoil River lying between the Sherman fault and the long north-trending Mires Creek fault that cuts the quartz monzonite of Herron Creek, below the thrust. Northwest of the quartz monzonite, the upper plate comprises the beds of the Sanpoil Volcanics, which lie on the quartz monzonite, Permian, and Tertiary rocks. South of the North Fork of Sanpoil River is a small klippe consisting of Scatter Creek Rhyodacite and Permian rocks. Along the northeast edge of the graben the upper plate of the thrust is downfaulted against the quartz monzonite along the Sherman fault. To the west it is also downfaulted along the Herron Creek and Mires Creek faults. A small remnant of the thrust plate still remains on the west side of the Mires Creek fault about a mile northeast of Gold Hill (sec. 27, T. 37 N., R. 33 E.). The thrust extends into the Curlew quadrangle to the north, but most of its trace there is covered by younger deposits.

The geometry and geologic relations of the thrust are fairly simple (fig. 14). The normal stratigraphic order of the rock column below the thrust as exposed along the east and west sides of Curlew Lake, is, from oldest to youngest—Permian rocks, O'Brien Creek Formation, and Sanpoil Volcanics. Because the rocks dip west, the Permian rocks are the easternmost ones, followed successively to the west by the O'Brien Creek and the Sanpoil. The Curlew Lake fault separates the Permian from the younger rocks. This rock column has merely been repeated along the northeast edge of the graben by eastward movement of the upper plate along the thrust.

The displacement of the upper plate is greater along the north part than the south. The contact between the Sanpoil Volcanics and the O'Brien Creek Formation below the thrust east of Curlew Lake and above the thrust north of Lambert Creek (as measured along the township line between T. 37 N., and T. 38 N.) is displaced about 4.5 miles, the maximum eastward displacement of the upper plate in the northern part of the area. Near the south edge of the thrust, the approximate 2.5 miles of displacement of the Sanpoil-O'Brien Creek contact below and above the thrust, as

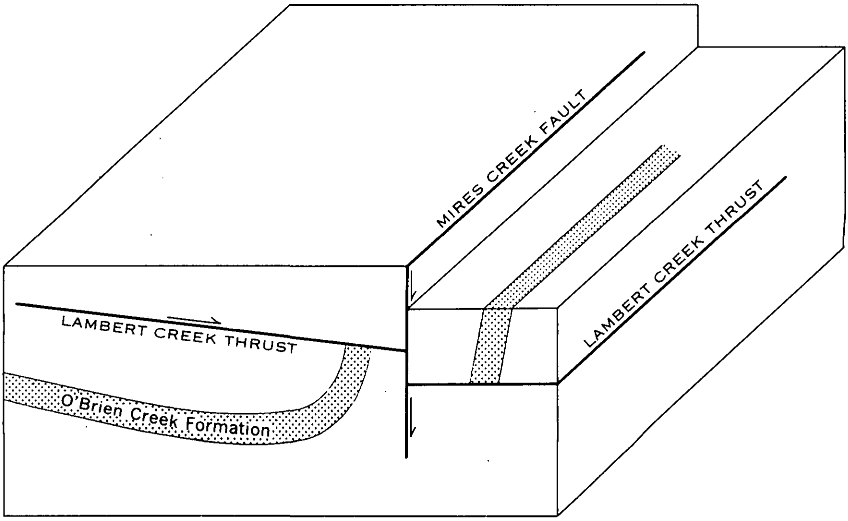


FIGURE 14.—Diagram of Lambert Creek thrust.

measured along the east-west line through Torboy, indicates this much eastward movement of the upper plate. The displacement here may actually be a little greater, because the Sanpoil-O'Brien Creek contact in the upper plate seems to be offset a little to the west by folding that is independent of the thrust. An eastward differential movement of 1.5–2 miles more along the north than along the south of the thrust over a north-south distance of about 5 miles shows that the thrust plate has been rotated clockwise about 20° (tan 20°=1.75/5). This rotation, as determined by measuring differential displacement, is also reflected in the rotation of the displaced fault between the Permian rocks and the O'Brien Creek Formation; below the thrust east of Curlew Lake the fault strikes nearly north (N. 4° E.); above the thrust to the east its displaced extension strikes about N. 16° E.

Along the south side of the Lambert Creek valley, the thrust dips gently to the north; the dip measured on the base of the Sanpoil Volcanics klippe in sec. 1, T. 37 N., R. 33 E., is 8° N. Just a little farther south the thrust is virtually horizontal. South of Herron Creek the plate is downfaulted, but the thrust is inferred to reemerge along the North Fork of Sanpoil River under the unconsolidated deposits. At its southeastern end, between the inferred klippe on hill 4588 and the valley of the North Fork, the thrust has a dip of a little less than 20° more or less north. Almost due north, in secs. 6 and 7, T. 37 N., R. 34 E., the dip is to the east.

I do not know if the dips on the thrust are original or are the result of later broad folding and (or) tilting.

The fault zone itself is a mylonite in most places. Along the south side of the klippe in sec. 3, T. 37 N., R. 33 E., the mylonite is 20–40 feet thick and has prospect pits in it. The zone consists of extremely dense, hard fine-grained rock of predominantly brownish colors. It is iron stained and has horizontal streaks and shears as well as some rock and mineral fragments embedded in the dense matrix; a few calcite veins are strung through it. Thin sections of specimens from six places along the fault zone just south of Lambert Creek and from one place in sec. 27, T. 37 N., R. 33 E., all show extreme granulation of rock and mineral fragments. In most places where the thrust plate overlies the quartz monzonite of Herron Creek the thrust zone is a mylonite and the adjacent quartz monzonite is highly brecciated, sheared, and chloritized.

Although the southern end of the thrust is nowhere seen, it is inferred to lie along the North Fork of Sanpoil River. Even though it appears that stratigraphic boundaries can be projected across the North and South Forks of Sanpoil River, as reflected by outcrop patterns, there is a difference in the gross structure to the south, as compared with that to the north of the valley. Moreover, there is a zone of intensely brecciated Scatter Creek Rhyodacite along the south slope of the top of hill 4588 in sec. 30, T. 37 N., R. 34 E., which I believe to be the base of an outlying klippe. In the northernmost part of sec. 34, T. 37 N., R. 33 E., is a small isolated outcrop of Scatter Creek Rhyodacite that is highly sheared; its shearing is thought to be the result of movement along the thrust.

The youngest formation cut by the thrust is the quartz monzonite of Herron Creek, which it therefore postdates. The latest sharp folding in the area involves the Tom Thumb Tuff Member but not the overlying members of the Klondike Mountain Formation. I would therefore correlate this folding with the thrusting. If this correlation is correct, the thrusting is older than the middle member of the Klondike Mountain and is thus of late Oligocene or early Miocene age.

The thrusting took place before the latest movement on the graben faults and therefore before the deposition of the middle member of the Klondike Mountain, because, as previously noted, the latest movements on the Bacon Creek fault are probably synchronous with the deposition of flows in the upper part of the middle member.

The mechanics of thrusting and its regional extent will have to be resolved outside this area—in areas having other outcrops. The thrust must have extended beyond the graben border, for there is no evidence—nor does there seem to be a logical scheme—for explaining the observed relations by local landsliding.

The coincidence of compressive and tensional effects in the graben during its development poses interesting problems in mechanics that are beyond the scope of this report. Because of the relative completeness of the stratigraphic record preserved in the graben, dates can be assigned to Tertiary structural events, but further explanation of the structure requires much more regional knowledge than we now have.

THE SANPOIL SYNCLINE

The Sanpoil syncline is the dominant structural feature in the southern half of the Republic graben and to a large extent determines the outcrop pattern of the formations within the graben. The trough of the syncline begins about 2.5 miles north of Republic and extends south about coincident with the Sanpoil River valley. Inasmuch as the trough appears to be considerably closer to the western edge of the syncline than to the eastern, the eastern limb—especially south of the North Fork of O'Brien Creek—has probably been widened by faults or by some reversals in dip of the Tertiary formations. Actually, the structure within the syncline is not well known because most of the outcrops are flows in the Sanpoil Volcanics, whose sole planar structure, flow banding, has no consistent pattern and does not at all reflect the synclinal structure which is seen only along the trough, where pyroclastic rocks have sedimentary bedding planes. The inferred structure of the southern part of the syncline is shown in structure section *E–E′* on plate 1.

Between the North Fork of O'Brien Creek and the east-trending faults to the north, the width of the east limb is maintained by the high-angle north-trending faults, because the west-dipping beds are dropped down on the east. To the north, the syncline is narrowed considerably because the northern part of the fold has been moved up along the east-trending faults (see p. 105).

From a point about 3 miles south of Republic to the north end of the syncline, the axial region is occupied by the Klondike Mountain Formation. (See sections *C–C′* and *D–D′* on pl. 1.) South of Republic the Tom Thumb Tuff Member in the east limb locally dips steeply and is overturned to the west, whereas the west limb dips gently east everywhere. A little farther north the Tom Thumb Tuff Member of the west limb dips moderately east and that of the east limb is faulted down out of view. The syncline as expressed in the middle member of the Klondike Mountain Formation has much gentler dips and loses its identity about 2.5 miles north of Republic.

The syncline probably developed as a result of several deformations. The earliest deformation may have resulted in a syncline with a trend not much different from the present one; in it the O'Brien Creek Formation and Sanpoil Volcanics were folded. After the Tom Thumb Tuff Member was deposited, at least the central part of the syncline around Republic was again folded—this time sharply. The highly incompetent Tom Thumb beds may have been folded much more sharply than the underlying Sanpoil flows, because on Gibraltar Mountain the flows seem to dip west, whereas the Tom Thumb is overturned to the east in places. Furthermore, some of the folding of the Tom Thumb may be due to sagging along the faults that lie in the axial region under the Sanpoil Valley just south of Republic. The syncline expressed in the middle member of the Klondike Mountain north of Republic probably represents a repeated but subdued compression; however, the dips outlining the syncline could be fortuitously placed initial dips inasmuch as the material of the middle member is coarse.

The compression that resulted in the initial formation of the syncline probably was not confined to the graben and thus not generated by downdropping of the graben block because most of the graben boundary faults dip steeply. Therefore, the block moving down between them probably did not act as a wedge. As previously noted, the folding that came after the deposition of the Tom Thumb Tuff Member must have been more or less synchronous with the formation of the Lambert Creek thrust. This later folding may have been a side effect of the compression that led to the thrust.

MINERAL DEPOSITS

The mineral deposits of the Republic and Aeneas quadrangles were not specifically studied because nearly all are inaccessible. With the exception of those in the Republic district, which are discussed below, most of the deposits have lain inactive since the 1930's.

The main emphasis of this discussion on mineral deposits is on the structural setting of the gold-silver deposits along the Republic district vein system.

For purposes of discussion, the deposits are divided into two groups—the gold-silver deposits in Tertiary rocks, which are currently of economic importance, and the metallic oxide and sulfide deposits in upper Paleozoic rocks, which are of only little economic importance. Nearly all the gold-silver deposits are along the Republic district vein system. The Valley mine, although lying outside the heart of the Republic district, is on a vein of the same type as those near Republic and is therefore discussed briefly.

DEPOSITS IN UPPER PALEOZOIC ROCKS

With the exception of the scheelite that occurs south of Edds Mountain in pendants within the intrusive east of the Sherman fault (see p. 12), the upper Paleozoic deposits occur in the Permian rocks within the Republic graben. Prospect pits, short adits, and shafts are generally located along shear zones and in areas where pyrite, other sulfides, and iron oxides occur. At Iron Mountain (Bancroft, 1914, p. 201) and in sec. 10, T. 36 N., R. 32 E. (Lindgren and Bancroft, 1914, p. 145–146) shafts were sunk to exploit sulfide ores carrying silver and some gold. The limestone lens in the SE¼ sec. 4 and N½ sec. 9, T. 37 N., R. 33 E., contains several replacement bodies of iron sulfides and oxides. One of the bodies has been explored by a 90-foot shaft and an adit as well as by diamond-drill holes; the adit showed 90 feet of ore where it cut the ore at the 150-foot depth (Huntting, 1956, p. 195). The only production recorded from the deposits in Permian rocks came from the California mine and from the mines in the Belcher district.

CALIFORNIA MINE

The California mine is in the eastern belt of Permian greenstone and argillite within the Republic graben in SW¼ sec. 20, T. 36 N., R. 34 E. The mine follows a quartz vein that contained gold and some silver, which had a value of about $60 per ton. The vein strikes about northeast and dips northwest and is developed through an inclined shaft and four levels. The position of the vein next to the fault that separates the Tertiary and Permian rocks suggests that this fault may have been partly responsible for localizing it. If so, the vein is of Tertiary age.

Most of the production from the mine came in the years 1901–02, when more than $100,000 worth of ore was produced (M. T. Huntting, written commun., 1956). Several hundred tons was mined in subsequent years, the last production having been in 1939 (Huntting, 1956, p. 119).

BELCHER GROUP OF MINES

East and northeast of Cooke Mountain in the northeast corner of the area, the Belcher group, which includes the Oversight, Copper Key, and Belcher mines, lies in a belt a little more than a mile long that trends slightly east of north. The deposits were mostly inaccessible at the time of the present study but were studied and rather fully described earlier (Bancroft, 1914, p. 166–179) during the period when they were being developed and exploited.

The deposits consist of irregular masses of magnetite and pyrite containing a little gold and silver, together with pyrrhotite and some chalcopyrite; they occur in limestone, dolomitic limestone, argillite, and graywacke. So far as could be determined by the present study and those of Bancroft (1914), the ore bodies lie next to a network of dikes, sills, and irregular intrusive bodies of the Scatter Creek Rhyodacite. As inferred from the distribution of mine adits, the ore bodies evidently occur as small isolated masses. In one short adit, garnet and other calc-silicates were found in the limestone at an intrusive contact, but, as noted by Bancroft, contact-metamorphic minerals are not abundant in the intruded rocks. At one place near the upper adit of the Belcher mine (Bancroft, 1914, p. 177), limestone adjacent to an intrusive has been almost completely replaced by hematite and magnetite—minerals that appear to retain the primary structure of the calcareous rock. The percentage of iron minerals decreases rather uniformly away from the intrusive contact over a width of about 20 feet. This occurrence suggests that the deposits are contact replacements related to the intrusion of the Scatter Creek Rhyodacite.

The Oversight mine consists of several short adits and a shaft in the NE¼ sec. 18, T. 37 N., R. 34 E. The only production recorded is from 1933 and 1934, when several tons of gold and silver ore was mined.

The Copper Key mine is just to the northeast at the common corner of secs. 7, 8, 18, and 19, T. 37 N., R. 34 E. As shown by Bancroft (1914, fig. 19), the workings are developed from adits at three levels. The ores represent irregular replacements, generally along bedding, and in their unoxidized state carry from 0.08 to 0.25 ounce of gold and 0.14 to 0.46 ounce of silver to the ton and less than 1 percent copper. All the recorded production came in 1904, 1905, and 1910.

The Belcher mine is in unsurveyed sec. 8, T. 37 N., R. 34 E. The ore bodies, which are mostly replacements of limestone, are developed by three main adits whose portals are near the contact of the limestone either with clastic rocks or with the Scatter Creek Rhyodacite. The mine is by far the largest of the group described here; production began in 1904 and is recorded for each year of the interval 1909–1918 inclusive. The ore was hauled from the lowest adit, sent by gravity tramway to the camp in Lambert Creek, and transferred to a narrow-gage railway that ran along Lambert Creek west to the Curlew Valley; from there, it was shipped on the Great Northern Railway to the Granby and Trail smelters in British Columbia.

Production from the Belcher group of mines, as recorded in the files of the U.S. Bureau of Mines, is as follows: 2,243 fine ounces of gold, 22,023 fine ounces of silver, 305,999 pounds of copper, all from 63,791 short tons of ore. At the Trail and Granby smelters, the ores were important chiefly as a flux for the smelting of other ores.

GOLD-SILVER DEPOSITS IN TERTIARY ROCKS

VALLEY MINE

The Valley mine (see Huntting, 1955, p. 61) is just west of Curlew Lake in NE¼ sec. 6, T. 37 N., R. 33 E. The deposit is in a milky white quartz vein that probably lies along a shear zone in Scatter Creek Rhyodacite. At the surface the vein is about 1,000 feet long and as much as 8 feet wide, strikes north, and dips east 40°–45°. In places the vein is vuggy and banded and is considerably broken up. The volcanic rocks near the vein do not appear to be bleached or otherwise altered. The vein is developed through a 900-foot incline and workings on three levels that total 2,500 feet in length. Aurous selenide, pyrite, and tetrahedrite are reported to occur in a gangue of quartz and calcite. A typical assay shows 0.28 ounce of gold and 1.0 ounce of silver per ton, and analyses show 0.0027–0.0061 percent selenium. Production is recorded by the U.S. Bureau of Mines for the years 1939 through 1944 and in 1950. The production figures, which are published by permission of Thomas Consolidated Mines, Inc., are 20,933 tons of ore that contained 6,113 fine ounces of gold and 21,911 fine ounces of silver.

REPUBLIC DISTRICT VEIN SYSTEM

The Republic mining district, as formally constituted, covers an area of about 440 square miles and includes the Belcher mining district. However, the Republic district proper, characterized by quartz veins that have yielded abundant amounts of gold and silver, lies next to the town of Republic in a north-trending belt that is as much as a mile wide and about 6 miles long. It is this area, beginning at the Republic mine (sec. 12, T. 36 N., R. 32 E.), extending northward along Eureka Gulch (the valley between the Knob Hill mine and Republic) to the Knob Hill mine, and ending on the north at the Tom Thumb mine, to which most attention will be given in the discussion that follows.

Because none of the mines could be studied underground, attention in the fieldwork was directed largely to the structure. The general nature of the veins and their mineralogy, together with the characteristics of individual mines, were studied by earlier workers, whose reports (Umpleby, 1910; Lindgren and Bancroft, 1914; Patty, 1921, p. 165–188; Wright, 1947) treat these features much more comprehensively than I am able to. Indeed, most of my brief discussion of the general features of the veins is taken from the earlier work. The present work adds a new geologic history for the district, which may have an important bearing on the search for new ore bodies.

SUMMARY OF HISTORY AND PRODUCTION

The early history of the Republic district is given in some detail by Umpleby (1910, p. 32–34), whose account serves as a record of the discoveries and developments to about 1909. The later history, summarized below, comes chiefly from the annual production figures, which cover the years 1902–1951, made available to me by the U.S. Bureau of Mines. Production prior to 1902, records for which are not available, is based on an estimate quoted by Lindgren and Bancroft (1914, p. 135).

The first locations in the district were made shortly after the north half of the Colville Indian Reservation was thrown open to mineral entry on February 21, 1896. The occurrence of gold quartz vein outcrops had been well known, and in the first few weeks following the opening, the locations made covered nearly all the ground in which the important mines of the district are found. These include the Knob Hill, Ben Hur, Lone Pine, Mountain Lion, Quilp, Republic, San Poil, Surprise, and Tom Thumb. The earliest samples showed low values in gold and silver, but in the summer of 1896, ore having a value of more than $100 per ton was discovered on the Republic and Lone Pine Claims. Within a few years, three mills had been built, which treated "rather unsuccessfully" much of the ore from the camp (Lindgren and Bancroft, 1914, p. 135). According to Umpleby, "active mining continued up to the spring of 1901, when the large custom mill and also the Republic mine," the leading early producer, were closed down. By 1903 the camp was served by two railroads, and mining increased to a production of 35,284 tons of ore having a value of $348,841 (Lindgren and Bancroft, 1914, p. 136), but production decreased again drastically, reaching an alltime low for the district in 1907, when the total value of ore produced was about $9,000. Production increased a little in 1908 and continued to increase in the following years, reaching an alltime high in 1911 (for the period to 1951, inclusive) of a little more than 38,000 ounces of gold and having a total value of $868,108.

In this early period, the Republic mine was the largest producer. Other substantial producers were the Ben Hur, Insurgent, Lone Pine, Mountain Lion, Quilp, San Poil, and Surprise. In 1911, the peak production year, the Lone Pine was by far the leading mine, having a production of about 17,400 ounces of gold. This same year is also marked by the first substantial production from the Knob Hill mine, which has since become the leading mine in the district.

As recorded only by the output of ounces of gold (and disregarding the silver output, which, though substantial, follows virtually the same pattern as that of gold), the district underwent a rather steady decline to 1922, when about 4,000 ounces was produced. From then to 1927 there was a resurgence of activity and moderate, rather steady production, as indicated by the output of 15,600 ounces of gold during 1927. The years 1929 and 1930 mark another low in production, only about 900 ounces being recorded for both these years, and only one mine, the Republic, showing production in 1929. From 1930 to 1936 there was a small but gradual increase in production. In 1934 there were at least 12 active mines, which, even though most of the mines produced less than a few hundred ounces, is a large number for the district. Production increased sharply in 1937 and again in 1938 and reached a peak in 1941 of about 33,400 ounces, from six producers. During the war, output declined steadily to 1945, when four reporting units recorded a production of about 17,600 ounces of gold; production in 1945 was probably lower than any year since.

During the post-1911 period, the number of producing mines was generally no more than 10, and the major production was shared among a few, all of which had produced during the earlier period. From 1912 to 1916 the leading mine was the Lone Pine. The Quilp was the leading producer in 1919, 1920, 1927, and 1928. From 1935 to 1950, the Aurum Mining Co., owned by Day Mines, Inc., which operated intermittently the Little Cove, San Poil, Tom Thumb, Surprise, Lone Pine, Pease, and Blacktail mines, had a continuous moderate production.

The Knob Hill mine, located early in the history of the camp, has been the only active mine since 1950 and is by far the leading producer in the district. Early recorded production was small and intermittent, but since 1910 the mine has been inactive in only 4 years, 1927, 1928, 1929, and 1936. In all but a few years it has been the leading producer in the district since 1921. In recent years some of the ore produced by the Knob Hill mine has come from the adjacent Gold Dollar claim, owned by Day Mines, Inc., and leased by Knob Hill Mines, Inc. Ore discovered in 1957 on the Gold Dollar claim was of substantially higher grade than that mined previously. The Knob Hill mine presumably has an assured future, because in 1958 the shaft was deepened from the 10th to the 14th level, and in 1959 new office and shop buildings were constructed.

Production from the Republic district vein system for the years 1902–51, inclusive, as supplied by the U.S. Bureau of Mines, was 2,217,430 tons of ore, which contained 764,546 fine ounces of gold and 4,843,430 fine ounces of silver. The average silver:gold ratio was 6.3:1, and ores contained an average of 0.345 ounce of gold and 2.2 ounces of silver per ton. Production figures for the period subsequent to 1951 are not available.

Total value of the production for the period prior to 1902 can be roughly estimated by using data from Lindgren and Bancroft (1914, p. 135–136). The value of the total production of the Republic camp was estimated by M. H. Joseph in August 1909 to be $3,051,000. Adding to this the value of the production for 1910 and 1911 results in a total value to 1911, inclusive, of $4,732,800. The recorded value of production for 1903–11, inclusive, was $2,604,792. Subtracting this figure from that of total value to 1911, inclusive, and rounding the last three digits, results in a figure of $2,128,000, which represents the value of total production, 1897–1902, inclusive. Value of production in 1902 was about $90,000; therefore, the estimated value of total production, 1897–1901, inclusive, was about $2 million.

GENERAL FEATURES OF THE VEINS

In the discussion that follows, the features ascribed to the Republic vein system pertain chiefly to the veins lying in the narrow belt that extends from the Republic mine at the south, along Eureka Gulch to the Knob Hill mine, and from there northward to the Tom Thumb mine. The discussion excludes the short, generally nonproductive veins that lie west of this belt. It includes a description of the disseminated mineralized areas that occur at the Knob Hill mine and at the Mountain Lion mine, about 2,000 feet north of the west end of Mud Lake.

The veins of the Republic system are fissure fillings of predominantly fine-grained to chalcedonic quartz that make bold outcrops. They are from one to four in number and trend from slightly east of north to about N. 30° W. at their northern end at the Knob Hill mine. At their southern end (in sec. 12, T. 36 N., R. 32 E.) there are two veins, ending in a single vein at the Republic mine. Farther north, along Eureka Gulch, there are as many as four, but only two of the veins—one on either side of the gulch—are more than 200 feet long. The vein system at the Knob Hill mine is not well known because of the lack of outcrops. The veins of this north-trending system are the most continuous in the district and the most productive. They dip east at moderate to steep angles. Their thickness is extremely variable, but the average is probably not more than 4 feet, although in some areas the veins are more than 30 feet wide. The veins lie entirely within the flows of the Sanpoil Volcanics except at the Republic mine, where the hanging wall is the basal zone of the Klondike Mountain Formation.

Subsidiary to the long north-trending veins are a few relatively short northeast-trending veins that lie along the line between secs. 34 and 35, T. 37 N., R. 32 E. These veins, about five in number, lie on the Lone Pine and Blacktail claims. They range in thickness from several feet to 13 feet and dip steeply south. So far as known, none join the long north-trending vein lying to the west on the east side of Eureka Gulch; on the east, one vein extends into the Republic fault. (See p. 103; Lindgren and Bancroft, 1914, p. 162.) All the veins lie in somewhat brecciated and altered flows of the Sanpoil Volcanics.

To the north of the Knob Hill mine, the veins of the mineralized belt are shorter and discontinuous and are localized in two places, at the Mountain Lion mine north of Mud Lake and at the Tom Thumb mine, the northernmost producer in the camp. At the Mountain Lion (Lindgren and Bancroft, 1914, p. 164), the principal vein is more than 800 feet long, trends east of north, and dips to the west; the thickness was 10–12 feet in open cuts. At the Tom Thumb, several veins, in a complex system, strike northeast. The veins dip southeast, according to Umpleby (1910, p. 65), and have an average thickness of no more than 8 feet according to Lindgren and Bancroft. The veins are entirely within the Sanpoil Volcanics.

The veins are composed of fine white quartz containing thin dendritic black stringers of finely distributed ore minerals. These stringers are parallel to the vein walls and are in delicate white to bluish-gray bands formed by alternating layers of coarser and finer quartz and calcite. Plate 18 of Lindgren and Bancroft clearly shows the characteristics of the veins. Less common than the massive banded veins are those that have been brecciated and again cemented by quartz containing irregular thin black seams of ore minerals. In places, according to Lindgren and Bancroft (1914, p. 146), large vugs coated with rich black crusts of ore minerals are common; some are filled with coarse calcite. Near the surface some of the veins have a reddish-brown appearance, probably caused by iron stain.

Most of the veins have sharply defined walls. At the Republic mine the footwall is a fault, marked by a claylike gouge. At several other places one or the other of the vein walls is a slickensided surface having gouge along it.

At the Knob Hill and Mountain Lion mines the rocks of the Tom Thumb Tuff Member of the Klondike Mountain Formation are bleached white and silicified. The flows below the sediments are bleached and consist predominantly of a porous chalky, somewhat crumbly mass of silica. This material constituted low-grade ore at the two mines; probably the fine-grained rocks of the Tom Thumb acted as a trap below which the silica-bearing solutions spread out in the lava; the solutions mineralized the lava and, to a lesser degree, the Tom Thumb rocks above.

According to Lindgren and Bancroft (1910, p. 146) the ore shoots commonly occupy the full width of the veins and are irregular in form.

The ore minerals, which occur in thin irregular black bands and crusts, are extremely fine grained. Pyrite and chalcopyrite are locally large enough in grain size to be easily identified. Native gold occurs in a few places.

The precise mineralogical composition of the ore minerals has been a subject of much interest, especially inasmuch as selenium has been reported from the ore (Umpleby, 1910, p. 39; Lindgren and Bancroft, 1914, p. 149). Lindgren and Bancroft considered the black bands to consist predominantly of tetrahedrite, an unidentified dark-gray mineral containing sulfur, antimony, copper, iron, and silver, and possibly the gold selenide, Au_2Se_3.

Specimens from the Knob Hill mine were examined by Charles Milton, of the Geological Survey, who reports (written commun., Dec. 7, 1957):

The "good sized-black crystals" * * * are stephanite, Ag_5SbS_4. It is a late-stage vein mineral found in many silver deposits. Our identification rests on similarity of the X-ray pattern (film 12795) with stephanite from Pachuca, Mexico (film 6167), and a spectrographic analysis:

Sb, Ag	Over 10%
—	5–10%
—	1–5%
Cu, Fe, Si	0. 5–1%
—	0. 1–0. 5%
Mg, Bi	0. 05–0. 1%

The mineral is therefore essentially silver antimony sulfide. The streak is black.

These crystals occur on a white calcareous rock with large calcite crystals. Black ore minerals, fine grained, are abundant. A polished section (1216) showed the major ore mineral to be naumannite, Ag_2Se. Some of this is intergrown with native silver; electrum, or native gold-silver, is also coarsely crystallized. The naumannite is intergrown (or partly replaced?) with an unidentified yellowish mineral, possibly aguilarite, silver sulfoselenide. The naumannite was identified by its optical characters and X-ray pattern (film 12863), similar to that of naumannite from Bolivia (U.S. Natl. Mus. R7752, X-ray film 6583, Gun Factory). Pyrite and chalcopyrite are also present. Presumably it is naumannite which Lindgren and Bancroft refer to as tetrahedrite.

Among gangue minerals, adularia is not uncommon (Lindgren and Bancroft, 1914, p. 147). Laumontite, marcasite, and fluorite also occur but are not common.

ALTERATION OF THE COUNTRY ROCKS

The alteration of the Sanpoil Volcanics and Scatter Creek Rhyodacite adjacent to the Republic veins has been discussed by Lindgren and Bancroft (1914, p. 152). This alteration, which has affected the rocks more than half a mile from the veins, is typically prophylitic, has changed the color of the rocks to a dull green, and in many places has made them indistinguishable from each other. Small crystals of pyrite are common in the rocks. Secondary calcite, epidote, chlorite, and sphene resulted from the alteration. Some feldspars have been partly replaced by sericite. Alteration of the groundmass is least pronounced, calcite being the predominant secondary mineral. This prophylitic rock commonly lies next to the veins; but in some places, as for example, at the Republic mine, the rocks have been silicified and more or less bleached.

Rocks of the Tom Thumb Tuff Member, adjacent to the veins or the Republic fault, are in places highly altered for distances as much as several thousand feet from their contact with the underlying rocks. They are moderately to intensely bleached and in places iron stained. As discussed on page 72, the altered rocks are now mostly cryptocrystalline quartz and kaolinite.

The propylitic alteration probably took place during the period of vein formation. The time of the silicification and bleaching of the Tom Thumb Tuff Member is not definitely known, but it seems reasonable to relate this alteration to one of the later stages of vein formation. The relationship of the two types of alteration is not known; detailed work at and in the Knob Hill mine would perhaps clarify it.

AGE OF MINERALIZATION

The age of the mineralization is known, because the mineralized rocks are intruded by unmineralized rocks that are not much younger than those that are mineralized. The youngest mineralized rocks are those of the Tom Thumb Tuff Member of the Klondike

Mountain Formation. At the Mountain Lion mine these are cut by unmineralized trachyandesite dikes and in other places veins are cut by basalt dikes. As previously noted, the trachyandesite dikes are probably correlative with a flow in the lower part of the basalt member of the Klondike Mountain Formation. This flow lies only a short distance below the basalt that is correlative with the basalt dikes of the area (see p. 73). Therefore, the mineralization occurred after the deposition of the Tom Thumb Tuff Member but before the emplacement of the trachyandesite dikes.

Stated in another way, mineralization must have been during the interval represented by the unconformity between the Tom Thumb and middle members of the Klondike Mountain Formation and the deposition of the basalt member.

A closer dating may be possible by considering the relations between some of the veins and the Republic fault. At the Republic mine the vein lies within the fault zone and some of the movement on the fault clearly postdates the vein, but the upper age limit of movement is defined by the presence within the fault zone of an unaltered trachyandesite dike. However, the main period of movement along the fault probably occurred after the deposition of the Tom Thumb Tuff Member but before the deposition of the middle member of the Klondike Mountain. Further, the brecciated nature of some of the veins indicates repeated movement during their formation. Hence the mineralization could have been synchronous with the main period of movement on the fault, and, if so, broadly correlative with the unconformity at the top of the Tom Thumb Tuff Member.

The mineralization cannot be related to any intrusive in the area. Earlier workers had suggested that the ore deposits were genetically connected with the Scatter Creek Rhyodacite, but the present work shows that the Scatter Creek was intruded long before the veins were formed.

STRUCTURAL SETTING AND CONTROL OF THE VEINS

The most obvious feature of the distribution of the veins is that they lie in a narrow belt next to and parallel to the contact of the Klondike Mountain Formation with older rocks, at most places the Sanpoil Volcanics. In the central part of the principal vein system, from the Republic mine to south of the Knob Hill mine, this contact is the Republic fault; to the north and south, the contact is an unconformity. Another but less obvious feature is that the veins from the Republic mine north to the Knob Hill mine—the really productive part of the district—lie in a fault zone along which there has been intermittent movement. This coincidence of veins with a fault zone and the unconformity could be fortuitous, but I think not; indeed, I think the features are interrelated and I believe the sequence of events described below will explain the vein distribution. Admittedly, some of the events, and their timing, may be speculative, but speculation is almost inherent in geologic synthesis, based as it is on evidence that may be no more than suggestive and rarely susceptible of certain proof.

Movement along the fault zone probably began shortly before the intrusion of the Scatter Creek Rhyodacite, initiating a structurally weak zone along which later movement and mineralization could take place. Intermittent movement along the zone probably resulted in a highland, and along its east front the coarse debris of the lower part of the Tom Thumb was deposited. As deposition proceeded, the fault zone was probably covered in some places by coarse debris and in others by the finer grained rocks of the Tom Thumb. During a later period of movement, which may have been the main one, the major displacement probably took place along the Republic fault, displacements along the other faults of the zone being mainly of a sympathetic nature. It was during this period that mineralizing solutions probably came up along the fault zone and formed veins within the Sanpoil Volcanics. Where the solutions intersected the overlying Tom Thumb pyroclastics and sediments, they were ponded and spread out to form relatively low grade disseminated deposits within the volcanics. Movement along the mineralized faults north of the Republic mine was small compared with that along the Republic fault; the Tom Thumb rocks were not much broken up and therefore ponded the solutions at the Knob Hill and Mountain Lion mines.

The veins at the Mountain Lion and Tom Thumb mines are probably along fractures that are sympathetic to the Bacon Creek fault rather than to the Republic fault and were evidently formed at about the same time as the other veins of the district.

Erosion of some of the Tom Thumb Tuff Member from areas west of the fault zone probably occurred during and after the faulting. The erosion in turn was followed by the deposition of the middle member of the Klondike Mountain Formation; west of the fault zone this member must have been deposited directly on the Sanpoil Volcanics, as it was at the Flag Hill mine (see p. 69).

There may well have been some intermittent movements along the fault zone during the deposition of the middle member of the Klondike Mountain and there may have been some further mineralization during this period, but all mineralization stopped before the deposition of the uppermost part of the middle member.

The sequence of events outlined above indicates that the veins were formed under the cover of the Tom Thumb Tuff Member, which was probably several thousand feet thick. At the Knob Hill mine, the upper part of the veins is now at the surface and the bottom has apparently not yet been reached at more than 1,000 feet below the outcrop. Elsewhere the tops of the veins of the main system have been eroded away, and there is little indication that the bottom has been reached at the maximum mine depth of about 800 feet. It seems likely, therefore, that most of the mineralization occurred at a minimum depth of about 2,000 feet and may have extended much more than 3,000 feet below the outcrops at the time of mineralization.

OUTLOOK FOR EXPLORATION

The exploration for mineral deposits is nearly always risky, and the odds against finding an economic deposit are generally high. Within this framework of risk, however, the chances of finding other blind ore bodies along the main vein system are, in my opinion, good.

The area south of the Knob Hill mine to about the northern boundary of the town of Republic and between the Republic fault and the westernmost vein fault of the fault zone seem to offer a prime exploration target for other veins at depth. The chief target in this area would be veins along fractures parallel to the main vein system and lying within the fault zone.

The area to the east of the Republic fault, under the Tom Thumb Tuff Member, may also have fractures sympathetic to the fault, and these fractures could be mineralized. The fact that the Tom Thumb Tuff Member is highly altered east of the Republic fault may indicate veins at depth in the Sanpoil Volcanics. This area east of the fault, from the Republic mine north to the Knob Hill, is probably nearly as good an exploration target as the one to the west, but any existing ore bodies would lie at greater depth.

GEOLOGIC HISTORY

The following summary of the geologic history, as deciphered from the rocks and structures of the Republic area, is expressed in rather categorical fashion. I have done this in order to present as clear and smooth a sequence of events as possible; the evidence for the conclusions here expressed without qualification is given in previous sections of the report.

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The decipherable history of the area begins in late Paleozoic and Permian time with the deposition of sedimentary and volcanic rocks in the western trough of the Cordilleran geosyncline. Fine and coarse clastics, together with pyroclastic rocks and lavas, accumulated in a marine environment; volcanic islands and limestone reefs had a transitory existence here and there in the sea. The trough was probably parallel to the eastern fringe of a volcanic archipelago that was tectonically active.

These eugeosynclinal conditions existed throughout the Triassic Period and may have extended into the Jurassic. It seems probable that the area was above sea level during much of Jurassic and Cretaceous time and was being denuded by streams; coarse clastic rocks, however, may have accumulated in local terrestrial basins. Such deposits, if formed, were removed by erosion before Eocene time.

During middle and Late Cretaceous time, large bodies of magma of intermediate composition were intruded at depth. The intrusives were part of a large batholith (the Colville batholith), and were probably emplaced over a long period of time. The intrusions occurred during the late phases of regional folding and compression. The upper Paleozoic rocks of the area were subjected to higher temperatures and differential pressures than normal and were thus metamorphosed to greenstone, schist, phyllite, argillite, and marble. Near the intrusives, where higher temperatures prevailed and the preexisting rocks were more thoroughly recrystallized, rocks of higher metamorphic grade were formed. In places the partly crystallized magma was deformed during emplacement, and linear structures were developed in the granitic rocks parallel to the fold axes and mineral alinements in the intruded rocks; west of Copper Mountain, garnet and staurolite were rotated as they were being formed. One body of magma north of Sheep Mountain was intruded slightly later than others and cuts across previously deformed and metamorphosed sedimentary rocks. During the waning stages of intrusion and deformation, aplite dikes were injected into the margin of the intrusives and the surrounding now-metamorphosed rocks. There is no evidence that any of the magmas ever reached the surface.

It seems certain that the Republic area was part of a large land mass from Cretaceous time on. During Eocene time the area was riven by long north-trending faults, and a linear structural valley—the ancestral Republic graben that spanned the entire length of the area—came into being. The later Tertiary bedded rocks were largely confined to this valley. The upland areas along the valley were underlain by granitic and metamorphic rocks, which were eroded and deposited as alluvial fans in the valley. After the initial faulting, a volcanic episode was initiated, and pyroclastic rocks were deposited in the hills and basin as tuff. Some of the volcanic rocks from the hills, together with the older rocks, were carried into the basin by streams and mudflows. Fine-grained rocks and plant trash were deposited in shallow lakes and marshes. The resulting assemblage of rocks is the O'Brien Creek Formation. Faulting along the margins of the basin probably continued intermittently during this period of deposition.

Following the deposition of the O'Brien Creek Formation, volcanism became more intense. Andesitic lavas and pyroclastic deposits of the Sanpoil Volcanics accumulated in the graben in much greater thicknesses than in the surrounding uplands. Toward the end of the volcanic period, the O'Brien Creek and Sanpoil were further downfaulted within the graben and folded into a north-trending syncline. Some of the intrusive equivalents of the Sanpoil Volcanics (the Scatter Creek Rhyodacite) rose nearer to the surface and intruded the folded rocks within and outside the graben. In places the intrusives followed faults, some of which were still active.

At some time after the folding of the O'Brien Creek and Sanpoil and after the intrusion of the Scatter Creek but before deposition of the Tom Thumb Tuff Member of the Klondike Mountain Formation, more deep-seated magmatic bodies—the quartz monzonite of Herron Creek and most of the quartz monzonite east of the Sherman fault—invaded rocks in the eastern and northeastern parts of the area. These Tertiary granitic rocks were probably emplaced at a shallower depth than their Cretaceous counterparts and had little effect on the surrounding rocks. Quartz latite porphyry dikes were injected as a hypabyssal phase of the intrusion. Dikes and irregular small bodies of fine-grained granophyric quartz monzonite may also be related to the larger intrusive but were injected considerably later.

Erosion probably took place during much of Oligocene time. There was some high-angle faulting within the graben and probably also along its boundaries. It seems likely, however, that there was no pronounced valley and that faulting along the margins was less intense than during the time when a sedimentary basin existed. In consequence, the debris from the earlier Tertiary formations and the flanking older rocks was carried out of the area.

In the later part of the Oligocene, renewed faulting created a shallower basin having greater internal relief. Erosion continued nearly everywhere except near the present site of Republic. Here coarse pyroclastic rocks were deposited along the western edge of a local basin—a feature that was probably initially defined by early movement on the Republic fault. The basin was the site of a lake, which gradually encroached upon the coarse sediments and in which the fine-grained tuff and some flows of the Tom Thumb Tuff Member were deposited.

Renewed compression, probably on a regional scale, produced the Lambert Creek thrust in the northern part of the area; the Permian rocks, the O'Brien Creek Formation, and the Sanpoil Volcanics were thrust eastward a maximum distance of 4.5 miles. Near Republic, along the axis of the syncline previously formed, the Tom Thumb Tuff Member was locally intensely folded.

After thrusting and the local folding, there was a relaxation of horizontally oriented forces and renewed high-angle faulting. During this time the main movements probably took place along the Republic district vein system, and most of the mineralized veins were emplaced in open fractures. Other high-angle faults cut the thrust, and there was renewed movement along the graben boundary faults.

Erosion that probably continued during the times of thrusting, folding, and high-angle faulting removed a part of the Tom Thumb Tuff Member and may have somewhat deepened the intragraben basin in which the coarse pyroclastic rocks and lava flows of the middle member of the Klondike Mountain Formation were deposited. Near the end of this time, trachyandesite dikes were intruded along the still-active western graben fault and the Republic fault and also cut some of the mineralized rocks of the Republic district. Following the deposition of the middle member on a surface of some relief, there was probably little further movement along the faults. Basalt dikes were intruded, and extensive basalt flows covered the northern part of the area in Miocene time.

No deposits record the history of the area between the extrusion of the basalt flows and the advent of the latest continental glaciers in Pleistocene time. All the area was above sea level, and relief was about the same amount as at present. Just prior to glaciation, the present pattern of valleys, but not the present pattern of drainage, was established. The Curlew-Sanpoil Valley was the site of a south-flowing master stream whose main tributaries were the two parts of the loop of the Kettle River just to the north. In an early glacial period, a lake formed as the result of an ice dam somewhere north of Republic, and the drainage north of the present Curlew Lake was reversed. During the last glaciation much glaciofluvial material was deposited in the valleys, and for a time the Curlew-Sanpoil was again the site of a through-going south-flowing master stream. After the ice melted, however, the reversed drainage was reestablished. The ice stayed longest in the valleys, and on melting left many kame terraces along their sides, and in the main valley left Curlew Lake as a large kettle hole. Some tributary streams, which had been graded to the main ice-filled debris-choked valley, cut their valleys rapidly as the base level was lowered by the melting ice. The topography imposed on the area by glaciation has been virtually unmodified in postglacial time.

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