Eocene Rocks in Northeast Washington — Radiometric Ages and Correlation

GEOLOGICAL SURVEY BULLETIN 1433

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By R. C. PEARSON *and* J. D. OBRADOVICH

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The genetic relations among numerous patches of volcanic rocks

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EOCENE ROCKS IN NORTHEAST WASHINGTON — RADIOMETRIC AGES AND CORRELATION

By R. C. PEARSON and J. D. OBRADOVICH

ABSTRACT

Potassium-argon ages, stratigraphic succession, and lithologic and chemical compositions form the basis for proposed correlation of Eocene volcanic rocks in northeast Washington and southern British Columbia that are preserved only in separated remnants, mostly fault blocks. The formations in the Republic graben have now been recognized in many areas outside the Republic graben. The basal Tertiary unit at many places in northeast Washington is the O'Brien Creek Formation which is mainly pyroclastic and which was partly formed by explosive quartz latitic volcanism. The resulting tuffs (53.1±1.5 million years on biotite from one sample) of the O'Brien Creek and the partly correlative Kettle River and Springbrook Formations in British Columbia are known in an area about 80 by 260 kilometers. Probable vent areas have been recognized in British Columbia, and others are possible near the Republic graben in Washington. The overlying Sanpoil Volcanics, rhyodacitic lavas and breccias, erupted from innumerable vents. Coalescing volcanic rocks probably covered most of northeast Washington in Sanpoil time, 51 million years ago (average of 13 potassium-argon determinations). The Sanpoil and partly correlative Marron Formation in British Columbia have almost the same known areal distribution as the O'Brien Creek Formation in the U.S. and Kettle River and Springbrook Formations in British Columbia. The Klondike Mountain Formation, which unconformably overlies the Sanpoil, covers a much smaller area. It is present in the Republic graben and in one area east and one area west of the graben. The Klondike Mountain consists mainly of flows, breccias, and domes of intermediate composition, but at or near the base, it contains bedded tuffaceous deposits and large masses of slide breccia. The Republic flora from the basal deposits of the Klondike Mountain is inferred to be about 46 million years old (latest Bridgerian) on the basis of eight potassium-argon determinations on hornblende and biotite from three samples that range from 41.3 to 49.1 million years. The Klondike Mountain is partly correlative with the White Lake and Skaha Formations in British Columbia.

INTRODUCTION

Volcanic rocks north of the Columbia Plateau in the northeast part of Washington have, with minor exceptions, been regarded as of Tertiary age; they are not metamorphosed or strongly deformed, as are the Mesozoic volcanics, and they contain plant fossils which indicate a Tertiary age. In a few studies, confusion with the much younger Columbia River Basalt to the south has also resulted. Plant fossils have suggested ages ranging from Paleocene to Miocene, but no vertebrate fossils have been found. Patches of these rocks are separated from one another by as much as several tens of kilometers, and consequently their mutual age, stratigraphic, and petrologic relations were not recognized. The absence of detailed studies and of diagnostic fossils has also hindered correlation.

In the 1950's detailed geologic mapping in the Republic area provided a firm local stratigraphic framework that has since proven useful in interpreting the broader relationships of these isolated patches of rocks. Each of these patches was known and had been studied prior to the present investigation in degrees of detail that ranged from gross reconnaissance to high-quality detailed mapping. Most of the maps are published, whereas others are available as student theses. This report will summarize the earlier work and will repeat only enough of the rock descriptions and other descriptive material to show the similarity of rocks in question. The reader will be referred to the original sources at appropriate places. This report is an outgrowth of geologic mapping of the Bodie Mountain quadrangle (Pearson, 1967) and is based also on geologic reconnaissance done mainly in 1967 and on potassium-argon age determinations made from 1967 to 1969.

Our studies show that distinctive volcanic rock units have remarkably wide distribution, the limits of which are probably not yet known, that these rocks accumulated within a few million years in the early and middle Eocene, and that they are part of a major volcanic field that may have been 1,500 km long.

The area of principal consideration is approximately the northeast fifth of the State of Washington — the part that lies north of the Columbia River Plateau between 117° and 119° W. long — an area of about 11,000 km^2 (fig. 1). The erosional remnants of these Eocene rocks are exposed or inferred beneath Quaternary deposits in only 5 percent of this area, although their former extent must have been considerably greater. Rocks that are probably correlative are known farther west along the Okanogan River, and rocks of the same age are widespread even farther west in the Cascade Range. East of the area, dikes of the same age are present near Pend Oreille Lake, Idaho. Comparable volcanic and intrusive rocks are present in a vast area in British Columbia.

In one of the earliest geologic studies of these rocks, Daly (1912) recognized a succession of continental sedimentary and pyroclastic rocks overlain by lavas in southern British Columbia, and he separated them into the Kettle River Formation and the Midway Volcanic Group. On the basis of plant fossils identified by Penhallow, he concluded that they were Oligocene and Miocene. (Although some authors have questioned Penhallow's dating of the fossils as Eocene and Daly's quoting Penhallow as saying they are Oligocene, the confusion is removed when it is realized that Penhallow used "upper Eocene" when he meant Oligocene.) In the United States, early geologic studies were mainly concerned with mining districts, such as the Republic district (Umpleby, 1910; Lindgren and Bancroft, 1914), but these studies did not cover enough area outside the mineralized and structurally complex parts of the districts to determine the stratigraphic succession. An important early study is one by Weaver (1920), who defined several stratigraphic units the names of which have continued in use until recently. The names originated by Weaver — the Gerome Andesite, the Phalen Lake Volcanics, and the Palmer Volcanics — can now be replaced by other formational names that are regionally significant.

During mapping of the Republic quadrangle, Muessig (1962) restudied the Tertiary sequence which had been investigated previously by Umpleby (1910) and Lindgren and Bancroft (1914). Muessig named three formations which were, from oldest to youngest, the O'Brien Creek Formation, the Sanpoil Volcanics, and the Klondike Mountain Formation. He also named the Scatter Creek Rhyodacite, a hypabyssal intrusive rock, equivalent in age and similar in chemical composition to the Sanpoil Volcanics. In the Republic area these units are confined to the Republic graben for a length of over 80 km (Staatz, 1964; Parker and Calkins, 1964; Muessig, 1967). Granitoid rocks, principally epizonal quartz monzonite, intrude the Sanpoil Volcanics and the hypabyssal equivalents in the graben; similar quartz monzonite also occurs outside the graben.

O'BRIEN CREEK FORMATION

The O'Brien Creek Formation consists mainly of tuff, tuffaceous sandstone, and conglomerate. At the few places in the Republic graben where the base of the formation is exposed, it lies unconformably on low-grade metamorphic rocks of Permian or Triassic age. It is overlain, apparently conformably, by flows of the Sanpoil Volcanics. As expected from its fluviatile origin and deposition in local basins, the thickness of the unit is highly varied, and it is absent locally. The thickest exposed section in the graben is about 1,300 m as reported by Muessig (1967, p. 46); this section is near Cooke Mountain about 13 km east of Republic, Washington.

Conglomerate occurs at many places in the formation, but is most common at the base and near the top. The conglomerate is composed mainly of nonvolcanic pebbles of metamorphic and intrusive rocks, including some that may be as young as Cretaceous. Commonly, the conglomerate beds contain cobbles, and locally boulders as much as 2

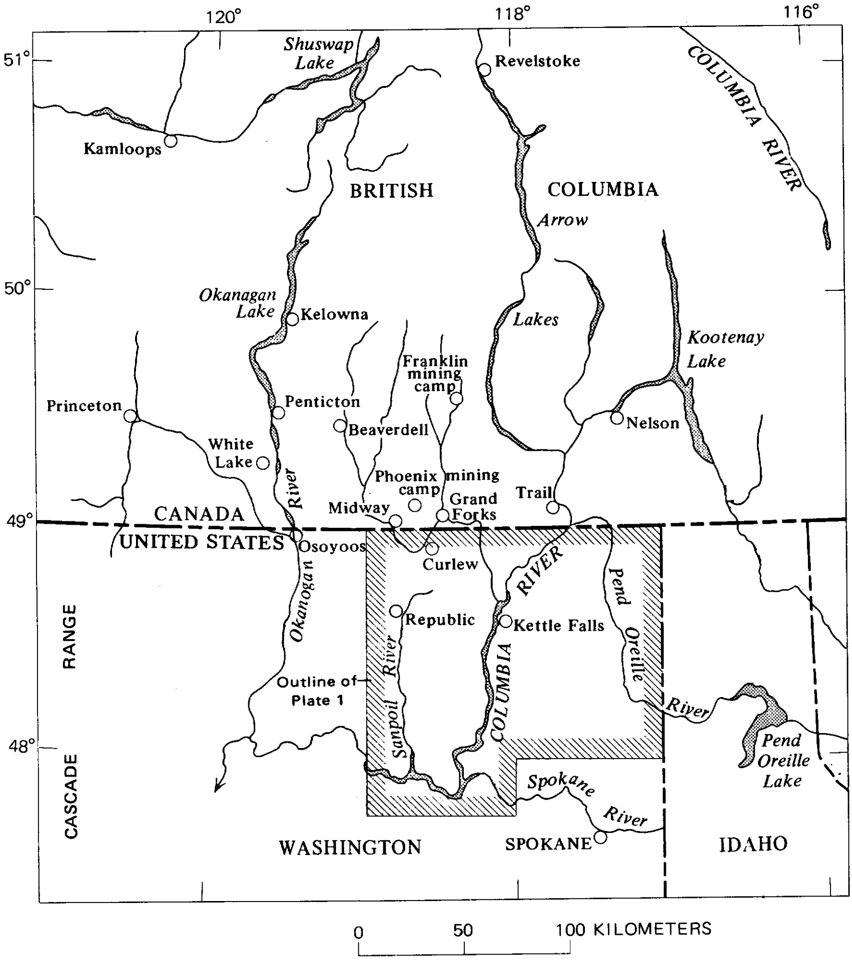


FIGURE 1.— Index map showing parts of Washington, Idaho, and British Columbia.

meters long. Although clasts of volcanic rock are rather rare, the matrix of the conglomerate contains pyroclastic mineral grains. The tuffaceous rocks that form the bulk of the O'Brien Creek are mostly well bedded sandstones that formed by reworking of air-fall tuff. Many outcrops are creamy white, pale green, and pale shades of brown. The sandstones consist mainly of plagioclase and quartz grains set in varying amounts of clayey matrix. Chips of gray slate or phyllite are so characteristic of these tuffaceous sandstones that they may also have had a pyroclastic origin. The presence of pyroclastic quartz, recognized by occasional crystal faces and resorbed embayments, serves to distinguish O'Brien Creek rocks from tuffaceous rocks in the younger Sanpoil and Klondike Mountain Formations. Interbedded gray carbonaceous shale and mudstone constitute a minor part of the formation. The rocks are fairly well indurated, though they erode more readily than most adjacent rocks and hence crop out poorly.

DISTRIBUTION AND CORRELATION

The distribution of the O'Brien Creek Formation is shown on plate 1. The most extensive exposures are in the Republic graben. The unit has been recognized in five additional areas in northeast Washington: (1) Toroda Creek graben, (2) lower Sanpoil River valley, (3) Orient area, (4) Williams Lake area, and (5) Pend Oreille River area. It probably also occurs in the Okanogan River valley (fig. 1) about 55 km west of the Republic graben. Additional possible occurrences within the area of plate 1 are in the Kettle Falls and Enterprise Valley areas.

In the Republic graben, the formation crops out along both margins of the graben and generally dips toward the center, where it is largely covered by younger rocks. In places, however, the formation has been raised along longitudinal faults and is exposed in the central portion of the graben as well. The type locality is 11 km southeast of Republic along the North Fork O'Brien Creek. Both northeast and southwest from the vicinity of its type locality, the formation evidently thins; it seems to be discontinuous, although faulting, intrusion, and poor exposure make this uncertain. It is discontinuously exposed along the graben for a distance of 70 km.

The southernmost exposures of typical O'Brien Creek Formation in the Republic graben are about 35 km south-southwest of Republic (pl. 1). From descriptions and analyses given by Staatz (1964, table 3, spec. 3; table 6, specs. 2 and 3), dikes and lava flows 10 km farther to the south-southwest seem to resemble O'Brien Creek more closely than Scatter Creek Rhyodacite and Sanpoil Volcanics as mapped. Staatz recognized that these quartz latites were atypical of the assigned units. The dikes contain large phenocrysts of quartz and orthoclase. The lava flows, east of the dikes and at the base of the Sanpoil Volcanics, also contain quartz phenocrysts. Scatter Creek and Sanpoil rocks elsewhere do not contain quartz or orthoclase phenocrysts.

The O'Brien Creek Formation crops out, albeit poorly, along the west side of the Toroda Creek graben (Pearson, 1967). At a few localities the formation seems to lie in depositional contact with pre-Tertiary rocks, but generally its base is not exposed and its western edge is probably bounded by faults. The beds dip mainly to the east and the unit is overlain, seemingly conformably, by the Sanpoil

Volcanics. It is more than 400 m thick along Beaver Creek but thins both to the south and north.

In the lower Sanpoil River valley, the O'Brien Creek Formation crops out along Bridge Creek, an east tributary of Sanpoil River, and along Empire Creek, a tributary from the west (pl. 1). The geology shown in these areas is from reconnaissance by Pearson, and as a result the extent of the unit and its thickness and relationships to other rocks are not fully known. This brief examination suggested that along Empire Creek, 30 m or more of O'Brien Creek beds lie on pre-Tertiary diorite and are overlain by Sanpoil Volcanics. Near the base, pebbles of the diorite are present; a few meters above the base, cobbles of O'Brien Creek seem to be weathering out of the unit; above that, typical pale-gray crystal tuffs are present that contain quartz phenocrysts as much as 4 mm long. Along Bridge Creek, 100 m or more of well-bedded light-brown tuffaceous sandstone probably of O'Brien Creek seems to be in fault contact with quartz-feldspar porphyry and intrusive Sanpoil Volcanics on the east and appears to be overlain by volcanic rocks, tentatively assigned to Sanpoil Volcanics.

In the Orient area, about 60–90 m of O'Brien Creek beds lie on pre-Tertiary metamorphic rocks and are overlain by Sanpoil Volcanics (fig. 2). These beds were included in the lower member of the formation at First Thought Mountain of Bowman (1950). On Toulou Mountain, the O'Brien Creek dips north about 25°, and on the south side of Sand Creek, 8 km to the north, it dips south about 45°. These dips thus define a syncline that is cut off on the west by the north-trending Kettle River fault, and on the east by other faults.

In the Williams Lake area about 16 km southeast of the Orient area, the O'Brien Creek Formation is at least one hundred meters thick and occupies an area about 8 by 16 km (Yates and Engels, 1968; Yates, 1971). Poor exposure and many faults obscure relations to older rocks, but dikes of shonkinite and rhyodacite intrude O'Brien Creek, and lava flows of the Sanpoil Volcanics overlie it. Together these Tertiary rocks constitute the Phalen Lake Volcanics of Weaver (1920). The name Phalen Lake Volcanics should not be adopted, however, because most of these rocks belong to O'Brien Creek Formation and Sanpoil Volcanics, as pointed out by Yates and Engels (1968) and Yates (1971).

Within the area of Tertiary volcanic and sedimentary rocks east of the Pend Oreille River, tuffaceous beds covering a limited area are believed to be O'Brien Creek Formation. These beds are exposed in cuts along a logging road on the east side of the ridge between Skookum Creek and Pend Oreille River. The locality is near the saddle between Moon Hill and the 1,100-m hill 1.6 km to the south (Browns Lake 7½-minute topographic quadrangle). Tuff and tuffaceous shale

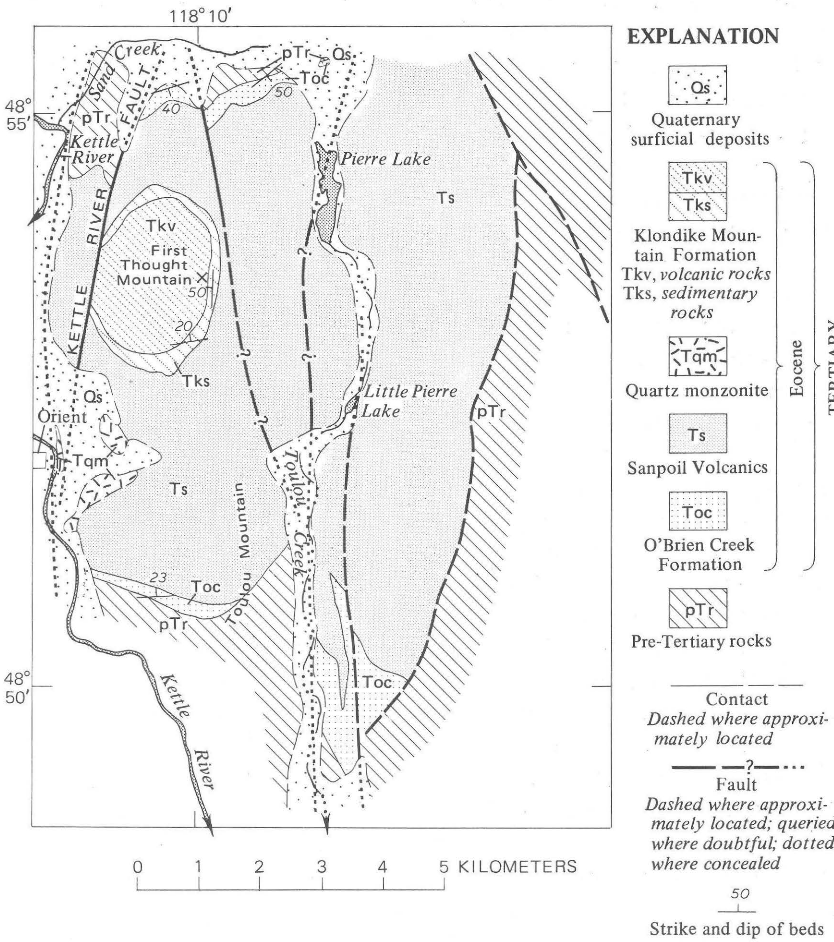


FIGURE 2.—Geologic map of the Orient, Washington, area. Modified from Bowman (1950).

beds with gentle westerly dip are exposed for about 100 m along the road. A stratigraphic thickness of only 8 m of beds is visible, and neither the top or base of the unit is exposed. The tuff may lie unconformably on Precambrian and Cambrian strata such as those exposed north of the saddle on the south side of Moon Hill (Miller, 1974a). The tuff contains euhedral biotite and quartz and, except for its finer grain size, resembles the O'Brien Creek Formation in the Williams Lake area, 65 km to the northwest. It is here assigned to the O'Brien Creek because of its lithology and its probable stratigraphic position below Sanpoil Volcanics. The 1,100-m hill that rises above the exposures of the O'Brien Creek tuff is capped by conglomerate of the Tiger Formation. On the intervening slope, float of rhyodacite lava of the Sanpoil

Volcanics may indicate that the flows of Sanpoil extend this far to the north and overlie the O'Brien Creek tuff. The Sanpoil Volcanics are thicker and crop out more extensively farther south, and F. K. Miller suggested (oral commun., 1971) that the float may be weathered out of conglomerate beds of the Tiger that contain volcanic detritus.

In the Okanogan River valley more than 150 km west of the Pend Oreille River, tuffaceous beds described by Rinehart and Fox (1972) closely resemble the O'Brien Creek Formation. They call the unit volcanic graywacke and state (p. 61) "*** the unit contains, in places, a conspicuous zone of pale-green to grayish-green crystal lithic tuff at or near the base. The tuff contains broken to euhedral delicately zoned oligoclase-andesine crystals, quartz crystals, intergrowths of calcite-chlorite pseudomorphous after hornblende(?), and clasts of devitrified glass in a matrix of weakly birefringent fine-grained chlorite."

The O'Brien Creek Formation in the United States seems to be equivalent to most of the Kettle River and Springbrook Formations in Canada as shown in figure 3. The O'Brien Creek and Kettle River are continuous across the international boundary near the west edge of the Toroda Creek graben several kilometers southwest of the type locality of the Kettle River Formation (Daly, 1912). Le Roy (1912) extended the name Kettle River Formation to the Phoenix mining camp about 20 km northeast of the type locality, and Drysdale (1915) extended it 65 km in the same general direction to the Franklin mining camp. The Franklin camp is on the trend of the Republic graben and adjacent to faults that are continuous with the east side of the Republic graben (Little, 1957).

Deposits of similar lithology and analogous stratigraphic position to the Kettle River Formation are found in British Columbia at many other places to the north, northwest, and west of the Kettle River's type locality. Reinecke (1915) used the term Curry Creek Series in the Beaverdell area (fig. 1) for tuffaceous strata that are undoubtedly Kettle River Formation (Little, 1961). Bostock (1940, 1941a, b) called similar beds Springbrook Formation west of the Okanagan River; Little (1961) has mapped the same unit farther north in the Okanagan valley near Kelowna (fig. 1). In the White Lake area, where it has been studied in most detail by Church (1973), the Springbrook Formation is mainly conglomerate and breccia without contemporaneous volcanic material. A few miles to the north, however, the Springbrook contains tuff and agglomerate that are intruded by the lithologically similar Shingle Creek Porphyry of Bostock (1966), which he regarded as as a volcanic neck and associated dikes. The rock in the intrusive body is a distinctive granite porphyry containing large pink sanidine and bipyramidal quartz phenocrysts in fine-grained matrix. The associated agglomerate and tuffs contain fragments of similar rocks and pieces of the large sanidine and quartz phenocrysts. Church (1973) speculated, as did Drysdale (1915), that the "Coldwater beds" of Dawson (1895) may also be correlative. The "Coldwater beds," however, have not been described as containing tuffaceous beds which are the single distinctive feature of the Kettle River and O'Brien Creek Formations. The Princeton Group of Rice (1947), crops out about 60 km west of the White Lake area (fig. 1) and is made up of intermediate to mafic lavas of Eocene age (Hills and Baadsgaard, 1967). It lacks bedded deposits beneath the lavas and thus includes no likely correlatives of Springbrook or Kettle River Formations. Although the Springbrook and Kettle River are probably correlative, it might be useful to restrict the name Springbrook Formation to rocks that do not contain the silicic tuffs characteristic of the Kettle River Formation.

The largest area occupied by the Kettle River Formation is west and northwest of Midway, British Columbia, just north of the Toroda Creek graben. Monger (1968) has subdivided the formation in that area, which includes Daly's type locality of the Kettle River, into two members, a lower feldspathic volcanic sandstone and an upper lithic volcanic sandstone; both of these members contain conglomerate and breccia beds. Part of the lithic volcanic sandstone member contains detritus derived from the Marron Formation, and hence, as mapped by Monger, the Kettle River and Marron interfinger and overlap in time. Only very locally does there seem to be a similar gradation between the O'Brien Creek and Sanpoil Formations (Muessig, 1967, p. 49).

Our mapping and correlations place the O'Brien Creek, Kettle River, and Springbrook Formations in an oval-shaped northwesterly trending area about 80 km wide and 260 km long.

CHEMICAL ANALYSES

Chemical analyses of two samples of O'Brien Creek tuff (analyses 1 and 2) and one of the quartz latite porphyry(analysis 3) in the lower Sanpoil River area (pl. 1) are listed in table 1 and compared graphically on figure 4 with other volcanic rocks from the area. The analyses provide an indication of a wider range in composition, particularly in SiO_2 and Al_2O_3, than can be characterized by just three analyses. The problems of winnowing, alteration, and contamination are also apparent. Contamination by fragments of argillite is clearly evident in analysis 2, where the Al_2O_3 is 18.3 percent. The two analyzed samples of tuff were collected about 75 km apart, but they are more nearly alike chemically than are the quartz latite porphyry and the tuff collected only a few kilometers apart. The porphyry and tuff compositions have common features such as low contents of iron and magnesium and high contents of sodium; at the least, these do not

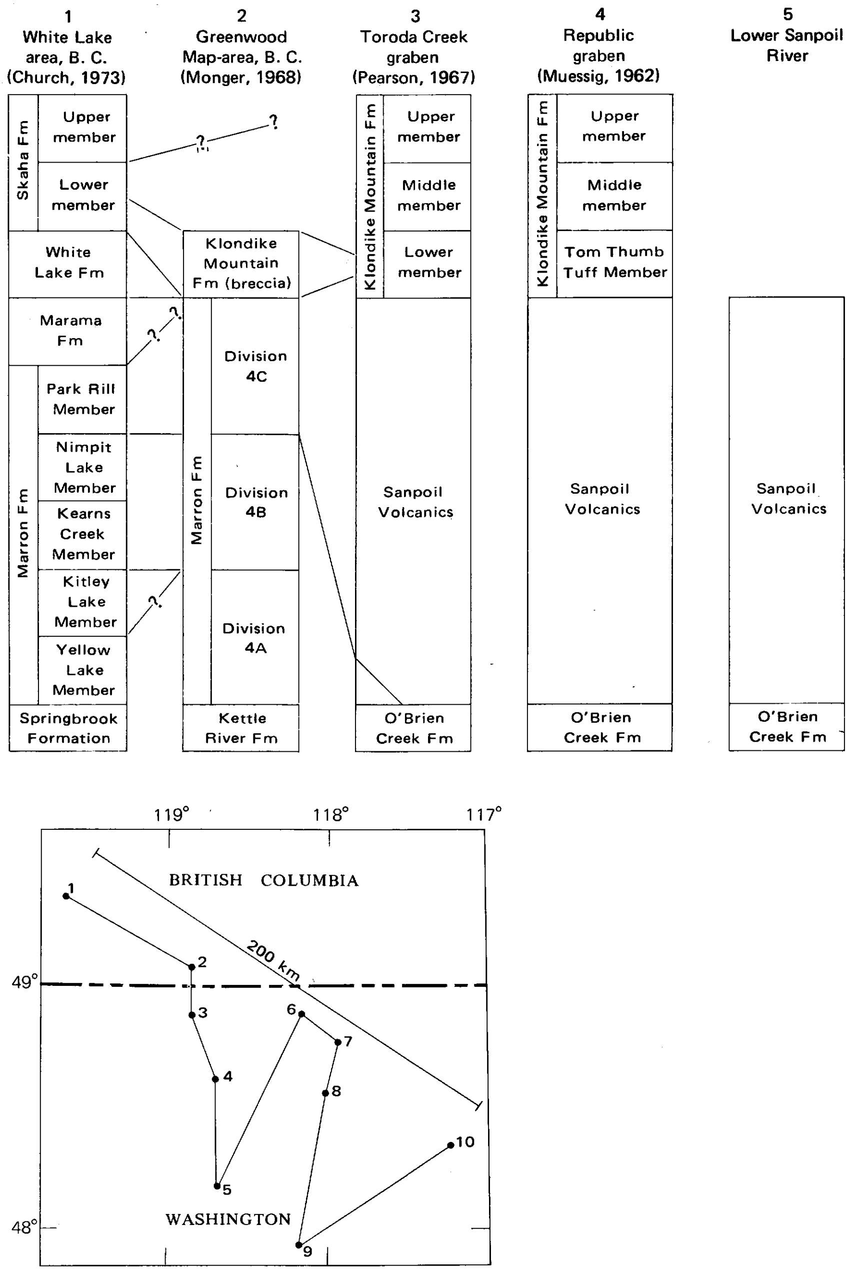
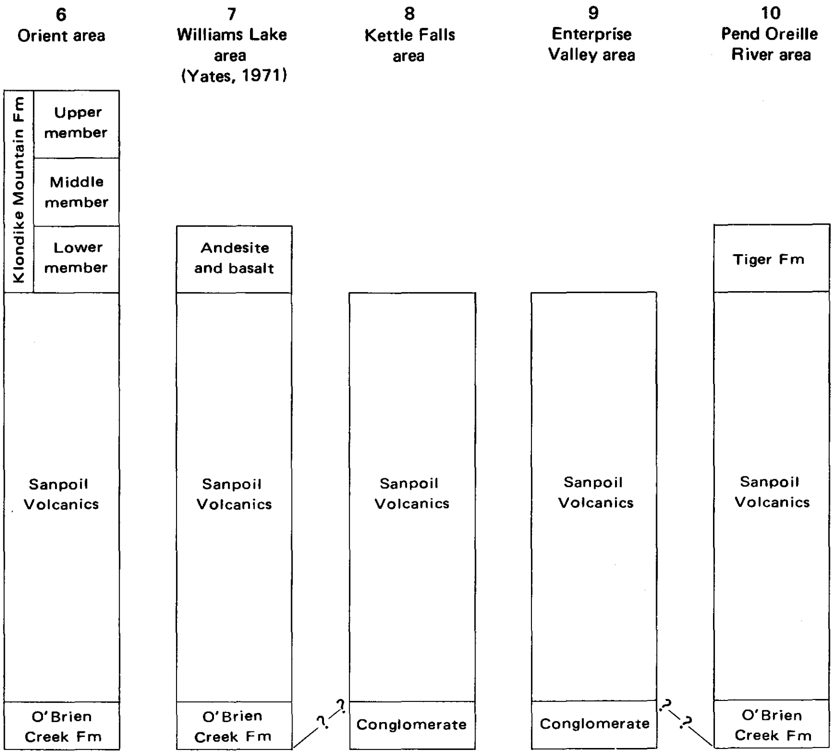


FIGURE 3.— (Above and right.) Correlation chart of Eocene volcanic rocks in northeast Washington and southern British Columbia. Correlation lines queried where uncertain.



preclude a genetic connection between the tuffs and the porphyry. The O'Brien Creek rocks seem to be significantly more silicic than the Sanpoil Volcanics, except for two samples of lavas and two of dikes (fig. 4, samples 17, 18, 22, and 23) that differ from Sanpoil and may be O'Brien Creek as discussed on page 5. In the O'Brien Creek the content of P_2O_5 is only one-third to one-half as much as in the Sanpoil.

AGE

The ages of the O'Brien Creek and Kettle River Formations cannot be assigned from paleontologic evidence. Plant fossils have not provided a definitive age, and no vertebrate fossils have been found. The plant fossils have been interpreted at various times as being Paleocene, Eocene, or Oligocene (Penhallow, *in* Daly, 1912; Drysdale, 1915; Little, 1957; Muessig, 1967). Stratigraphically the formations can be bracketed crudely as Cretaceous to Eocene. Monger (1968) states that the Kettle River Formation grades into and interfingers with parts of the generally overlying and conformable Marron Formation of Eocene age, indicating partial equivalence in age. Sedimenta-

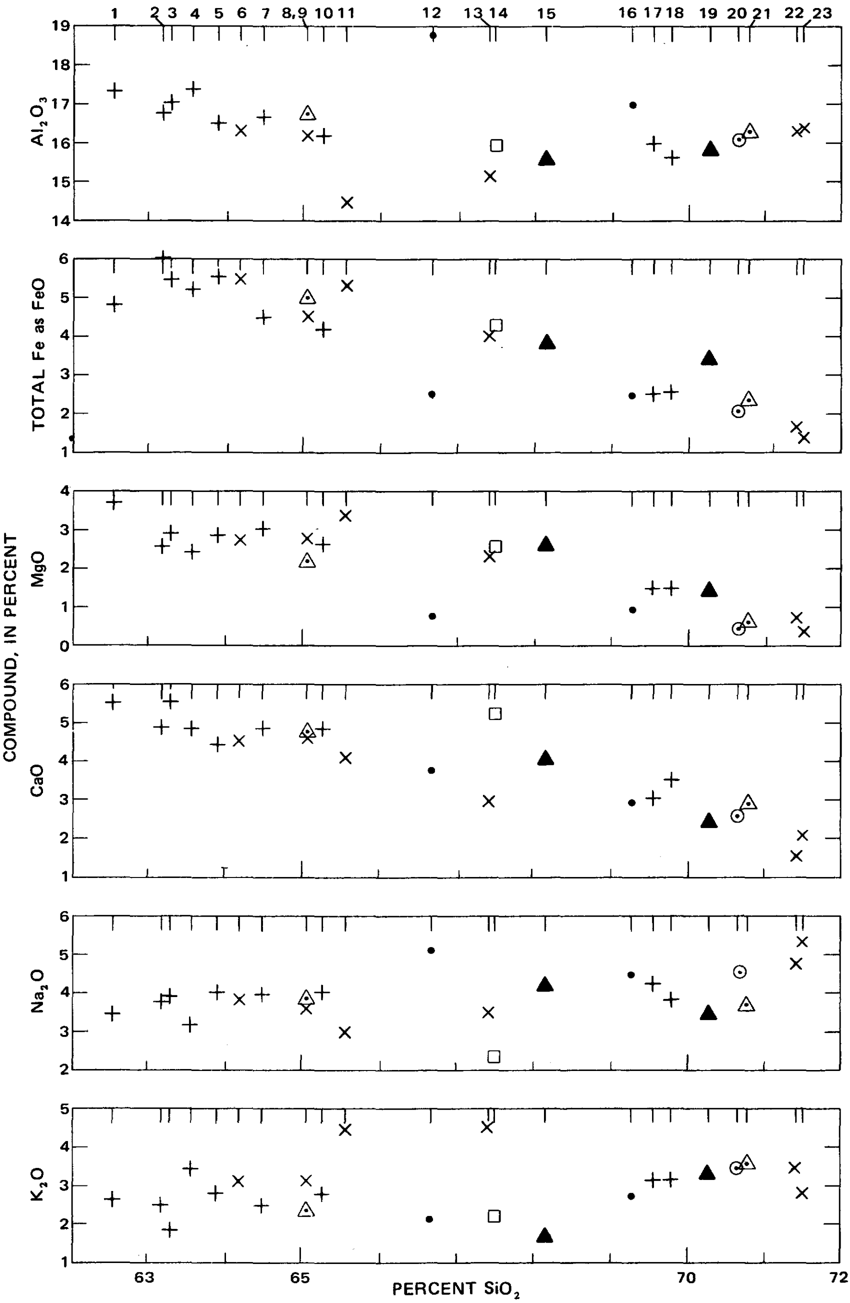


FIGURE 4.— (Above and right.) Silica-variation diagram of Eocene volcanic rocks from northeast Washington. Analyses were recast by eliminating minor components and recalculating the remaining major components to 100 percent.

EXPLANATION

Sanpoil Volcanics

+ Lava

× Intrusive

□ Tuff

O'Brien Creek Formation

⊙ Intrusive

• Tuff

Klondike Mountain Formation

△ Lava

▲ Intrusive

SOURCE OF ANALYSES

NO. ON DIAGRAM	REFERENCE	TABLE	SAMPLE NO.
1	This report	1	4
2	----do----	1	5
3	Becraft and Weis (1963)	3	6W-502A
4	----do----	3	6W-502B
5	Muessig (1967)	3	None
6	----do----	4	None
7	This report	1	6
8	Staatz (1964)	6	1
9	This report	1	13
10	Staatz (1964)	5	1
11	Becraft and Weis (1963)	3	7B-259
12	This report	1	2
13	Becraft and Weis (1963)	3	6B-500
14	----do----	3	7W-120
15	This report	1	12
16	----do----	1	1
17	Staatz (1964)	5	3
18	----do----	5	2
19	This report	1	11
20	----do----	1	3
21	----do----	1	10
22	Staatz (1964)	6	2
23	----do----	6	3

tion seems to be continuous locally, which tends to substantiate their closeness in time.

Previous attempts to date the O'Brien Creek and Kettle River Formations by K-Ar techniques have not been very successful. Biotite from dacite, which was considered by Little (1961) to be part of the Kettle River Formation, gives an age of 46 m.y. (million years) (Mathews, 1964). However, K-Ar ages on the younger Marron Formation are generally older by three or four million years, an amount which is equal to or slightly greater than that which can be attributed to analytical error. Biotite from O'Brien Creek tuff from the Williams Lake area gives age of about 41 m.y. (Yates and Engels, 1968) that are distinctly too young, because the tuff is intruded and overlain by Sanpoil Volcanics and other rocks that are about 50 m.y. old.

We determined a K-Ar age of 53.1±1.5 m.y. on euhedral biotite crystals from bedded tuff from the Pend Oreille River area (table 2). This age is reasonable in view of all known evidence for the age of the O'Brien Creek Formation and may be very close to the true age, despite the problems commonly encountered in dating biotite from tuffs. The exact age of the O'Brien Creek and Kettle River Formations eventually will be determined by dating intrusive and fluidal extrusive equivalents. Some of the rocks discussed in the following paragraphs doubtless will prove to be synchronous with the O'Brien Creek.

SOURCE

No source for the large quantity of tuff in the O'Brien Creek Formation has been found in the United States. In Canada, a volcanic neck, a lava flow, and several intrusive bodies of similar lithology and appropriate chemical composition point to numerous widely separated vents that contributed to the Kettle River and Springbrook Formations and thus to the correlative O'Brien Creek.

In northeast Washington there seems to be a gradual decrease in size of pyroclastic fragments in the formation from northwest to southeast, suggesting that the source was to the northwest. Lithic volcanic fragments as large as 5 cm across are present in the O'Brien Creek Formation on the west side of the Toroda Creek graben and in the northern part of the Republic graben (Parker and Calkins, 1964, p. 47), but no fragments as coarse as lapilli (4 mm) have yet been found east of the Kettle River Range (pl. 1), where, in the Orient and Williams Lake areas, the deposits are largely crystal tuff, and in the Pend Oreille River area, the tuffaceous beds have a grain size of fine sand and silt. The coarsest lapilli in the Toroda Creek graben are in massive beds that have a pronounced planar fabric parallel to bedding and that contain only minor non-volcanic clasts. These lapilli do not appear to be water worn. Although the origin of these beds is in doubt, they may be the product of mudflows. Regardless of the origin of the massive beds, however, they give little information on the distance to the vent. Airborne, lithic lapilli as much as 5 cm long probably travelled no more than a few tens of kilometers; in mudflows they may have travelled a few kilometers more. If the coarsely porphyritic dikes in the southwestern part of the Republic graben are O'Brien Creek intrusives and hence deeply eroded vents, no evidence has been found in the grain size distribution of the tuffs.

In the lower Sanpoil River area south of Republic, light-colored quartz latite porphyry dikes and intrusive bodies of unknown shape are over 150 m wide; they cut the Pennsylvanian (?) Covada Group and are intruded by dark hornblende-plagioclase porphyry dikes of Sanpoil Volcanics along the Bridge Creek road and on the north side of Thirtymile Creek (pl. 1). Tuffaceous sediments of the O'Brien Creek that crop out west of the exposures of the quartz latite are probably separated from this porphyry by a fault. The porphyry has a superficial resemblance to O'Brien Creek tuff, and the two have petrographic features in common, such as zoned phenocrysts of partly albitized and zeolitized plagioclase that have about the same ranges in composition. Calcic oligoclase phenocrysts have $n_{X'}$ (measured on cleavage fragments by the focal masking technique) averaging about 1.540 in samples of tuff from several localities, some from along Bridge Creek and others from the Toroda Creek graben; $n_{X'}$ of the plagioclase phenocrysts from the porphyry averages about 1.542. Resorbed quartz phenocrysts are common to both rocks, and euhedral crystals of biotite are present in both, although mostly chloritized in the tuffs. Zircon, apatite, and sphene are also present in both. The groundmass of the porphyry is a very fine grained aggregate of alkali feldspar and quartz. In contrast, tuffs in undoubted Sanpoil Volcanics are much darker, their plagioclase is andesine and labradorite, and they contain no volcanic quartz crystals but do contain abundant biotite, hornblende, and (or) pyroxene.

In British Columbia the best defined vent area for volcanic ejecta in the Springbrook and Kettle River Formations is the Shingle Creek Porphyry of Bostock (1966) near Penticton (fig. 1). Bostock interprets this coarse granite porphyry to be in part a volcanic neck that has intruded agglomerate and tuff derived from the same rock. In the Franklin mining camp, Drysdale (1915) recognized the closely similar chemical and mineralogic composition of "rhyolite" lava in the Kettle River Formation and the associated tuffs. Little (1957), Mathews (1964), Monger (1968), and Preto (1970, p. 38) mentioned other quartz-fedspar porphyry bodies that are probably intrusive or near-source extrusive phases of the Kettle River Formation and that could be sites of volcanic vents. Near-source volcanic breccias of quartz-feldspar porphyry occur in the same general area as the intrusives discussed by Monger (1968).

Drysdale (1915) speculated that the Valhalla Granite, which crops out over an area of 1,000–2,000 km² (Little, 1957, 1961) and occurs only 3 km east and west of the "rhyolite" lava at Franklin camp, could be an intrusive equivalent of the volcanic component of the Kettle River Formation. Near Beaverdell certain intrusives mapped as Valhalla by Little (1961) seem to be identical to the Shingle Creek Porphyry according to the description of Reinecke (1915). Although some rock mapped as Valhalla Granite, particularly east of occurrences of Kettle River Formation and east of the Granby River fault (Preto, 1970), is evidently pre-Tertiary (Little, 1960) and hence too old to be correlative with Kettle River; other parts of the Valhalla may be Tertiary. The Sheppard Granite (Daly, 1912; Yates, 1964) is also a possible intrusive equivalent of O'Brien Creek Formation volcanics; it has appropriate composition and is the oldest Tertiary intrusive rock in the area where it occurs (Yates, 1964, 1971).

SANPOIL VOLCANICS

The Sanpoil Volcanics is a thick widespread unit of rhyodacitic lava flows, volcanic breccias, and tuffs that overlies the O'Brien Creek Formation with apparent conformity. At localities where the O'Brien Creek is absent, the Sanpoil lies on pre-Tertiary rocks. The Sanpoil

Volcanics was defined by Muessig (1962) to include rocks exposed along the Sanpoil River south of Republic, Washington. He estimates that 1,200 m are present in the Republic quadrangle, although poor knowledge of internal structure and stratigraphy prevents a close measurement of the thickness. Individual lava flows or masses of volcanic breccia range from about 3 m to over 30 m in thickness. In general, the unit crops out boldly and forms cliffs 30 m or higher along the Sanpoil River and some tributaries. Air-fall tuff and water-laid beds are only rarely exposed, but because they crop out so poorly they are probably more common than they seem. They are more abundant in the southern part of the Republic graben (Staatz, 1964) than elsewhere. This unit is overlain locally by the Klondike Mountain Formation or the Tiger Formation, but in most places it is the youngest bedrock unit preserved.

The rocks making up the Sanpoil Volcanics are mainly porphyritic rhyodacite, but compositions may range from andesite to quartz latite. They are somber hued, in shades of gray and brown; locally deuteric alteration has produced purple and green shades. Most of the rocks are very strongly porphyritic, and commonly the phenocryst content is between 25 and 50 percent. The phenocrysts consist mostly of plagioclase (andesine and labradorite) and lesser amounts of either biotite, hornblende, or augite, or combinations of the three mafic minerals. Conspicuous gray rocks in a few flows contain prominent hornblende phenocrysts, but these rocks lack appreciable plagioclase phenocrysts. The groundmass in almost all of the Sanpoil flow rocks is dull and stony and consists of microlites of the phenocryst minerals embedded in a microgranular matrix of quartz and alkali feldspar.

The Scatter Creek Rhyodacite was defined by Muessig (1962) as a hypabyssal intrusive rock that resembles rocks of the Sanpoil Volcanics in lithology. It is similar in age to the Sanpoil, as it intruded parts of the Sanpoil Volcanics, as well as older formations, but does not cut the immediately succeeding Klondike Mountain Formation. Muessig (1967), Staatz (1964), and Parker and Calkins (1964) found that in some areas the intrusive phase was intimately mixed with the extrusive phase making mapping of these phases difficult or impossible. They also recognized phases of intrusive Sanpoil that differed somewhat from typical Scatter Creek. The Scatter Creek Rhyodacite unit thus has limited usefulness; in areas where a relationship to Sanpoil Volcanics can be inferred, we have chosen to refer to these bodies of rock as intrusive Sanpoil.

DISTRIBUTION AND CORRELATION

In the Republic graben, the Sanpoil Volcanics is the most extensive rock unit exposed. The formation occupies about 1,000 km^2, although partly concealed by overlying Klondike Mountain Formation and glacial deposits, and removed or displaced by many faults and intrusive rocks. To the south, Columbia River Basalt lies unconformably on Sanpoil, which in that area was mapped by Pardee (1918) as porphyry and andesite. Near the international boundary the Sanpoil has been removed by erosion except for small hypabyssal bodies, but correlative lavas are exposed farther north along the trend of the graben (Little, 1957; Preto, 1970).

Outside the Republic graben, as well as within it, Sanpoil Volcanics are almost coextensive with O'Brien Creek Formation probably because the areas of deposition were similar, and the O'Brien Creek remains chiefly where preserved from erosion by the more resistant rocks of the Sanpoil. In addition to the areas where the O'Brien Creek is known, as described previously, Sanpoil Volcanics are present near Kettle Falls, Washington, and in the Enterprise Valley area near the mouth of the Spokane River (pl. 1).

In the Toroda Creek graben, the Sanpoil Volcanics may be over 1,000 m thick at the international boundary. The true thickness is uncertain because of faulting and lack of internal stratigraphic control. To the south the formation overlaps the O'Brien Creek Formation, gradually thins, and is finally absent 40 km south of the boundary (pl. 1). Nearly all of the Sanpoil rocks in the Toroda Creek graben are similar lithologically and chemically to the highly porphyritic lavas and breccias of the type locality on the Sanpoil River in the Republic graben. At the base of the formation near the international boundary, however, some flows are andesitic and others are alkalic. These extend only a few kilometers south of the boundary and have been included for convenience in the Sanpoil, even though these rock types have not been recognized elsewhere in this unit. Further work might indicate that a separate unit should be distinguished. Alkalic intrusive rocks in many small bodies were not included in the Sanpoil by Pearson (1967). These bodies intrude O'Brien Creek Formation but not Sanpoil Volcanics along the west side of the Toroda Creek graben for at least 21 km south of the boundary. They are similar in composition to the alkalic lavas farther north, perhaps indicating that those lavas were once more extensive but were eroded before the rhyodacitic lavas erupted.

In the lower Sanpoil River valley (pl. 1) typical porphyritic Sanpoil lavas lie on O'Brien Creek Formation, and Sanpoil intrusives cut O'Brien Creek and its inferred intrusive equivalent. More mafic lavas (pyroxene andesite (?)) in the same area are tentatively included in the Sanpoil.

Some of the 600 m or so of volcanic rocks in the Orient area (fig. 2) that are included here in the Sanpoil Volcanics are also probably pyroxene andesite, but they seem to be subordinate in volume to more typical biotite- and hornblende-bearing rhyodacite. Some of these rocks have been described in detail by Bowman (1950) who included them in the lower member of his formation at First Thought Mountain; this name should not be considered formal, as these rocks belong to the Sanpoil. On Toulou Mountain, stratigraphically above the main section of O'Brien Creek Formation, blocks of O'Brien Creek–like tuffs seem to be included within the Sanpoil Volcanics. Although these masses, which are as much as many tens of meters across, could be rafted blocks that were picked up by lava flows, it is more likely that most of Toulou Mountain is composed of intrusive Sanpoil rocks and the blocks of O'Brien Creek are inclusions. Around Pierre Lake, lava flows, flow breccias, and bedded tuffs in the Sanpoil unit are clearly surface deposits. On First Thought Mountain, flows of Sanpoil Volcanics are overlain by bedded tuffs of the Klondike Mountain Formation.

Thirty-five kilometers south of the Orient area, volcanic and sedimentary rocks crop out in an area of about 24 km^2 southeast of Kettle Falls, Washington (fig. 5). These rocks were named Palmer Volcanics (Weaver, 1920, p. 103) and have since been mapped in more detail by Bradshaw (1964), who also called them Palmer Volcanics. The Palmer Volcanics are, however, petrographically indistinguishable from the Sanpoil Volcanics, have identical K-Ar ages, and should be correlated with them. The name Palmer Volcanics is preempted and should not be adopted, as the rocks belong to the Sanpoil Volcanics.

Lava flows, volcanic breccias, and volcanic conglomerates are the main rocks in the Kettle Falls area. They form a shallow syncline that plunges about 20 degrees southwesterly. The syncline is cut off on the south by a west-northwest-trending fault that separates the Tertiary deposits from Paleozoic sedimentary rocks in the higher parts of the Huckleberry Range. Alluvium in the Colville River valley to the north covers the lower contact of the Tertiary rocks.

The oldest Tertiary rocks exposed in the Kettle Falls area are beds of conglomerate that total 190 m thick (Bradshaw, 1964, p. 22), composed of rounded pebbles and cobbles of rocks that could have been derived from nearby outcropping Paleozoic formations. Near the top of the conglomerate section there is a single tuff bed 1.5 m thick. Volcanic sandstone beds 150 m thick and a tuff bed 2.5 m thick overlie the conglomerate; above this tuff, lava flows and volcanic breccias total at least 900 m thick. These are overlain by hundreds of meters of conglomerate and sandstone beds composed of volcanic and nonvolcanic detritus. All the recognizable volcanic rocks in these deposits have the lithologic characteristics of Sanpoil Volcanics.

In the Kettle Falls area the older nonvolcanic conglomerate may be in part a time equivalent of the O'Brien Creek Formation, and some of the youngest sandstone and conglomerate beds may be equivalent to Klondike Mountain Formation. As none of the volcanic rocks characteristic of these formations are known in the Kettle Falls area, all but the lower prevolcanic conglomerate is considered a part of the Sanpoil Volcanics. The lower conglomerate cannot be assigned to any regionally recognized formation.

Tertiary volcanic and sedimentary rocks, that Weaver (1920) named the Gerome Andesite and Becraft and Weis (1963) called the Gerome Volcanics, crop out in the Enterprise Valley area near the mouth of the Spokane River (pl. 1). Though covered extensively by Pleistocene deposits and locally by Columbia River Basalt, these rocks form a belt about 1.5–6 km wide and 50 km long that occupies the Enterprise Valley and colinear segments of the valleys of the Columbia and Spokane Rivers (Becraft and Weis, 1963; Campbell and Raup, 1964). These Tertiary deposits unconformably overlie granitic rocks of Cretaceous age and other older rocks. They consist of rhyodacite lava flows and volcanic breccias, tuffs, sandstone, conglomerate, and carbonaceous shale. The rocks constituting the lava flows and breccias are dark gray and contain prominent phenocrysts of hornblende and

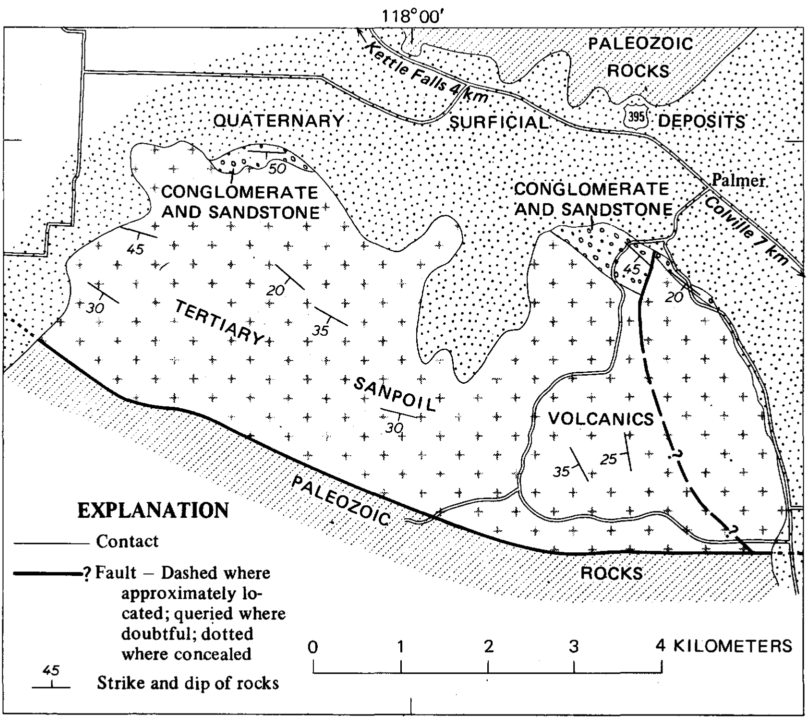


FIGURE 5.—Geologic map of Kettle Falls area, Washington. Geology modified from Bradshaw (1964).

locally of plagioclase; clinopyroxene phenocrysts are also common. These rocks contain fewer plagioclase phenocrysts and are generally darker gray than the principal rock types of the Sanpoil Volcanics in other areas. They are, however, lithologically identical to some of the hornblende-bearing flows of the Sanpoil in the Republic and Toroda Creek grabens, and thus are correlated here with the Sanpoil Volcanics. We propose, therefore, that the name Gerome Volcanics be abandoned.

Miller (1969) stated that a small body of volcanic rock south of Chewelah, Washington (pl. 1) is similar to Gerome Volcanics. This body is here referred to Sanpoil Volcanics on the strength of Miller's description.

In the Williams Lake area, Yates and Engels (1968) assigned the extrusive rhyodacite that lies on the O'Brien Creek Formation to the Sanpoil Volcanics. Shonkinite that intrudes the O'Brien Creek and biotite andesite and basalt lava flows that lie above the identified Sanpoil Volcanics were not included in Sanpoil unit by Yates and Engels (1968) or by Yates (1971). Similarly, the andesitic and basaltic rocks on Belshazzar and Grouse Mountains, north of the Williams Lake area (pl. 1), were not included in the Sanpoil by Yates presumably because they are somewhat more mafic than the typical Sanpoil rhyodacite.

Along the east side of the Pend Oreille River valley, volcanic rocks extend south for 13 km beyond the O'Brien Creek (?) Formation exposed near Moon Hill. These dark-gray porphyritic lava flows, probably rhyodacite, were called Pend Oreille Andesite by Schroeder (1952); Miller (1974a) established a type locality in sec. 18, T. 32 N., R. 45 E. in the valley of the Pend Oreille River. The rocks resemble the Sanpoil lavas in the Enterprise Valley area described previously, in that they contain conspicuous hornblende and sparse plagioclase phenocrysts; they contain conspicuous biotite and pyroxene phenocrysts as well. The flows are overlain by gently west-dipping ill-defined beds of poorly sorted conglomerate and conglomeratic sandstone of the Tiger Formation. Except where they lie on provisionally identified O'Brien Creek tuff, the lava flows seem to lie on sedimentary rocks of the Precambrian Y Belt Supergroup. They dip westerly toward the Pend Oreille River, but the amount of dip is uncertain. At least 150 m of volcanic rocks are present locally. Schroeder (1952, p. 25) reported a dike of rock similar to the flows that may be one of the feeders. Because of their similar compositions and ages (table 2, A7), these lavas are here correlated with Sanpoil Volcanics. We propose here that the name Pend Oreille Andesite be abandoned.

Along the Okanogan River in north-central Washington, some of the volcanic rocks are believed to correlate with Sanpoil Volcanics. These include two plugs of porphyritic hornblende dacite 2 km southwest of Osoyoos that resemble typical Sanpoil in lithology and have K-Ar ages that are indistinguishable from Sanpoil (Rinehart and Fox, 1972, p. 62–63).

The Sanpoil Volcanics in the Toroda Creek graben are continuous with the Midway Volcanic Group of British Columbia, in which Daly (1912) included the volcanic rocks overlying the Kettle River Formation and occurring near the town of Midway (fig. 1). Little (1957) recognized the need to rename the Midway Group because even when defined in 1912, the name had precedence elsewhere. Monger (1968) proposed that Midway Group be replaced by Marron Formation, a unit of comparable stratigraphic position, composition, and K-Ar age about 65 km to the west (Bostock, 1940, 1941a, 1941b). As described by Monger (1968), the Marron Formation in the Greenwood map-area (a 15-minute area immediately north of Toroda Creek graben) is divisible into three units. To judge by the chemical analyses given by Monger (1968, table 3) using the Rittman classification, the lowest unit (division 4A) is tephrite and phonolite, the middle unit (division 4B) is mostly latite, and the upper unit (division 4C) is mostly rhyodacite. Monger's chemical analyses and rock descriptions suggest to us, as they did to Monger (1968, p. 26–27), that Sanpoil Volcanics correlate principally with division 4C of the Marron Formation in the Greenwood area. Some of the lavas of Monger's divisions 4A and 4B extend south of the international boundary for a few kilometers. Certain intrusive rocks in Washington including the alkalic rocks of Shasket Creek in the Curlew quadrangle (Parker and Calkins, 1964), the shonkinite in the Williams Lake area (Yates and Engles, 1968; Yates, 1971), and the alkalic intrusives on the west side of the Toroda Creek graben have compositions that suggest that they may correlate with Monger's division 4A. Monger (1968) and Church (1973) described the close similarity between the Marron Formation in its type locality west of the Okanagan River and in the Greenwood map-area, and suggest that at least some members are correlative. In addition, Church (1973) suggested that similar rocks farther north, near Kelowna are correlative with part of the Marron Formation. More detailed work may demonstrate that parts of the Princeton and Kamloops Groups (Rice, 1947; Dawson, 1895) will also be correlative with the Marron, as suggested by K-Ar ages (Hills and Baadsgaard, 1967). As shown by Campbell (1966, fig. 4–9), the lower Tertiary volcanic rocks in south-central British Columbia occupy a northwest-trending belt that extends more than 650 km north from the international boundary. In this volcanic field, the northwest limits of the Marron Formation are not known.

CHEMICAL ANALYSES

Chemical analyses of Sanpoil Volcanics, 2 samples from lava flows and one from an intrusive, are listed in table 1. According to Rittmann's classification, these rocks are rhyodacite. Silica variation plots of these analyses, together with published analyses of Sanpoil from the Republic graben (Muessig, 1967; Staatz, 1964) and from the Enterprise Valley area (Becraft and Weis, 1963) show (fig. 4) that most of the rocks contain between 62.5 and 65.5 percent silica. The few that are more silicic, less calcic, and less femic than the main cluster are mostly from the southern part of the Republic graben (Staatz, 1964); as discussed in a previous section, they may be O'Brien Creek rather than Sanpoil. Two analyses of Marron Formation, division 4C, which seems most nearly correlative with Sanpoil (Monger, 1968, table 3), are slightly more calcic and femic than the main cluster of Sanpoil analyses. Monger's observation that Sanpoil rocks become more silicic toward the south may be valid, but if the rocks tentatively identified by us as O'Brien Creek (fig. 4, Staatz (1964) analyses 17, 18, 22, and 23) are omitted from consideration, this trend is very slight. Analyses of Sanpoil lavas from as far east as the Enterprise Valley area (fig. 4, analyses 3 and 4) are typical of the bulk of the Sanpoil.

AGE

The Sanpoil Volcanics were judged to be Eocene(?) by Muessig (1967) because, on the basis of plant fossils, the underlying O'Brien Creek was considered Eocene(?) and the overlying Klondike Mountain Formation was considered Oligocene. Staatz (1964) interpreted the evidence as indicating an age of Eocene or Oligocene for the Sanpoil. Plant fossils from tuffaceous sandstones interbedded with lavas in the Enterprise Valley area (Becraft and Weis, 1963) were interpreted as Oligocene. Our isotopic ages indicate that the unit is 50–51 m.y. old and, therefore, middle Eocene.

Rouse and Mathews (1961) and Mathews (1964) dated some rocks now known to be of the Marron Formation by the K-Ar technique; they first showed that the widespread volcanics in south-central British Columbia were for the most part about 46–50 m.y. old. They obtained no ages that substantiated the Oligocene age as suggested previously by plant fossils collected from various localities in British Columbia and Washington. Church (1973) reported a K-Ar age of 51.61.8 m.y. obtained on biotite from trachyte in the Kitley Lake Member of the Marron Formation. The Kitley Lake Member is the fourth oldest of the five members he defined and is probably slightly older than the

Sanpoil. Yates and Engles (1968) obtained a 49.81.5 m.y. K-Ar age on an intrusive rock from the Williams Lake area that they correlated with the Sanpoil Volcanics. Two plugs that resemble Sanpoil in the Okanogan River valley near Osoyoos gave K-Ar ages of 52.1 m.y. and 51.4 m.y. (Rinehart and Fox, 1972).

We have determined K-Ar ages on minerals from seven samples of Sanpoil lavas and intrusives from the Toroda Creek graben, Republic graben, Enterprise Valley area, Kettle Falls area, and Pend Oreille River area (table 2). The ages determined on biotite and hornblende are almost all between 50 and 51 m.y. and the two plagioclase ages from sample A5 average 49.4 m.y. The biotite age from sample A2 of intrusive Sanpoil is 53.4 m.y. and the hornblende age from the same sample is 52.6 m.y. Although these ages from the intrusive rocks are slightly older than those of the lavas, the ages overlap when assigned errors are considered. The ages of the intrusive rocks probably do not represent a significant difference from the 50–51 m.y. age of the lavas.

These ages agree, within the assigned errors, with those obtained on Sanpoil Volcanics from the Williams Lake area by Yates and Engels (1968) and with those obtained from the Marron Formation and its equivalents in British Columbia by Mathews (1964). K-Ar ages on dikes of granodiorite porphyry from Pend Oreille Lake, Idaho, are indistinguishable from Sanpoil ages, that is, 50–51 m.y. (Harrison, Kleinkopf, and Obradovich, 1972).

SOURCE

Dikes and irregular discordant intrusive bodies of Sanpoil and plutons of quartz monzonite, interpreted as comagmatic with Sanpoil, are abundant and widespread, suggesting that the Sanpoil was extruded from a large number of vents rather than from a few large volcanoes. Criteria used by Smedes and Prostka (1972) to locate vents in the Absaroka volcanic field in Wyoming and Montana included facies relations (near-vent breccias and flows grade outward to epiclastic, reworked, and air-fall deposits), radial dike swarms, and plugs and stocks. Of these features, only intrusive bodies have been recognized in association with the Sanpoil and Marron Formations. Many of the intrusive bodies are too large and eroded too deeply to be of use in identifying a single vent area. Virtually all the Sanpoil, and evidently the Marron as well, are vent facies. Only Kettle Falls and Enterprise Valley areas have an appreciable accumulation of alluvial-facies deposits. Even in these areas, intrusives, near-vent breccias, and lava flows are abundant and indicate local sources. If large quantities of alluvial-facies deposits ever existed in the Sanpoil-Marron volcanic field, they have been eroded away. It is evident that the Sanpoil-Marron field has been eroded to a much greater depth than the Absaroka field.

QUARTZ MONZONITE

Plutons of generally intermediate composition occupy large areas in northeast Washington. Geologic relations and radiometric ages show that they range widely in age. Many are definitely pre-Tertiary, but an increasing number of Eocene age are being recognized. Some of these Eocene plutons are shown on plate 1. Although the granitoid rocks are not the main subject of this report, they nonetheless bear on the volcanic history, for many are epizonal and some of them certainly must have fed superjacent volcanoes.

In the north-central and northwestern parts of the area (pl. 1), rocks similar to the Coryell plutonic rocks of southern British Columbia are evidently the youngest plutonic rocks. The Coryell plutons (Daly, 1912, p. 358; Little, 1957; Little, 1960, p. 90) include several small batholiths and many stocks and dikes generally of monzonitic to syenitic composition. In addition to a low quartz content, the Coryell rocks characteristically contain biotite and hornblende, and some contain clinopyroxene. Older plutons in southern British Columbia and adjacent parts of Washington have a higher quartz content, are mostly biotite granodiorite (although hornblende is present in some), and are more deformed. In the north-central part of the area of plate 1, apophyses from a Coryell pluton in British Columbia extend south into Washington and correlative dikes extend at least 10 km south of the boundary (Yates, 1971). Similar dikes and stocks are present in the Orient area (Bowman, 1950), and in the adjacent Kettle River Range and Republic graben (pl. 1).

Along the east side of the Republic graben, biotite, biotite-hornblende, and biotite-hornblende-pyroxene monzonite cut the Sanpoil Volcanics and its hypabyssal intrusive equivalents. The quartz monzonite of Long Alec Creek (Parker and Calkins, 1964) extends east across the graben faults with little offset and into the higher parts of the Kettle River Range. Several kilometers to the south the similar quartz monzonite of Herron Creek (Muessig, 1967) is separated from the east side of the graben by a fault slice 2 km wide; however, east of the graben similar quartz monzonite forms a sizeable stock (pl. 1). Both bodies east of the graben cross the crest of the range and thus are exposed through a vertical distance of about 1,200 m. In the horst west of the Republic graben, opposite the Long Alec Creek and Herron Creek stocks, a part of a similar quartz monzonite stock is cut off by the graben fault (pl. 1). This body probably connects with both the Long Alec Creek and Herron Creek plutons to the east at depth within the graben. The age of these plutons is bracketed geologically by the presence of detritus of similar quartz monzonite in the slightly younger Klondike Mountain Formation, as well as by the fact that they intrude Sanpoil Volcanics. Chemical and mineralogic similarities also indicate that these plutons are comagmatic with Sanpoil Volcanics, and it follows that Coryell plutonic rocks are similarly related to Marron Formation, although Monger (1968, p. 32) concludes that "there is no proven relationship" between them.

Evidence presented by Miller and Engels (1975) from the eastern half of plate 1 and adjacent parts of Idaho casts doubt on some of the correlations of plutons made on petrologic characteristics. In this region plutons of various ages are evidently not distinguishable on the basis of texture or mineralogy. A very strong Eocene thermal event has lowered biotite K-Ar ages to about 50 m.y. over a wide area. Where concordant ages are obtained on mineral pairs, biotite plus muscovite or hornblende, Miller and Engels concluded that the age of intrusion can usually be determined; they conceded, however, that ages on both minerals locally could be completely reset by the 50-m.y. event. One rock that gives concordant ages on mineral pairs is the Silver Point Quartz Monzonite, two plutons of which are shown on plate 1. Sample 68 (Miller and Engels, 1975) yields K-Ar ages of 48 m.y. on biotite and 51 m.y. on hornblende, and sample 69 yields 47 m.y. on biotite and 47 m.y. on hornblende. Although plutons that were intruded about the same time as the Sanpoil was extruded (as dated before K-Ar methods) are common in the eastern part of plate 1, these plutons evidently do not resemble the Coryell plutons to the northwest, and they cannot be distinguished from Mesozoic plutons.

In spite of the problems encountered in the K-Ar dating of granitoid rocks in the region of the Shuswap Metamorphic Complex in Canada (Gabrielse and Reesor, 1964) and in the eastern part of the area discussed in this report (Miller and Engels, 1975), our efforts to date the youngest plutons south of the boundary seem to be successful. The ages of one sample each from the quartz monzonite of Long Alec Creek, the quartz monzonite in Kettle River Range, which is probably coextensive with the quartz monzonite of Herron Creek, and the granodiorite from the pluton just west of the Republic graben, do not differ significantly from ages of Sanpoil Volcanics (table 2). The ages of biotite and hornblende from one sample (table 2, A14)) are concordant but slightly older at 52.2±1.7 m.y. and 53.7±2.7 m.y. and are nearly identical in age to a pair of the same minerals from a hypabyssal intrusive of Sanpoil Volcanics (table 2, A2). Yates and Engels (1968) have shown a similar relation between K-Ar ages on satellitic dikes assigned to the Coryell batholith and Sanpoil Volcanics, although samples from the Coryell batholith itself had previously given ages of 54 m.y. and 58 m.y. (Baadsgaard and others, 1961). Our

K-Ar ages reinforce the conclusions of Yates and Engels (1968) that Coryell plutonic rocks correlate with Sanpoil Volcanics.

KLONDIKE MOUNTAIN FORMATION

The youngest and most areally restricted of the Eocene volcanic units is the Klondike Mountain Formation. It consists of a wide variety of volcanic and epiclastic deposits that lie mostly on the eroded surface of Sanpoil Volcanics. The type locality of the formation is on Klondike Mountain, north of Republic. Muessig (1962) described the formation as consisting of three members: the lowest is the Tom Thumb Tuff Member composed of volcanic breccia and tuffaceous shale and sandstone; the middle member is composed of pale-colored volcanic breccias and lavas; the upper member is composed of dark-gray vitric lava flows. The aggregate thickness is about 900 m.

The volcanic rocks of the Klondike Mountain Formation contrast markedly with the underlying Sanpoil Volcanics. Fine-grained thin-bedded to laminated tuff comprises most of the Tom Thumb Tuff Member, but at its base is a variable thickness of volcanic breccia, volcanic conglomerate, and tuff. The thin-bedded tuff is the "lake beds" of earlier reports, which are known for their content of fossil leaves. Flows and volcanic breccias of the middle member are generally light colored, weakly porphyritic, and flow layered. Most of these rocks contain small sparse phenocrysts of labradorite, clinopyroxene, and orthopyroxene set in a flow-layered, stony or glassy groundmass. They are mostly light to medium shades of brown, green, or gray. The lack of well-defined tabular lava flows or bodies of breccia, the presence of pronounced contorted and folded flow layering, and the apparent random mixtures of breccia and nonbrecciated lava indicate that these rocks formed as volcanic domes. The dark-gray glassy rocks of the upper member may, in part, have been lava more fluid than that which formed the domes.

DISTRIBUTION AND CORRELATION

The Klondike Mountain Formation is known in three areas in Washington, and correlative rocks are present in southern British Columbia. In addition to its type locality in the Republic graben, the formation occupies about half the area of the Toroda Creek graben to the west and several square kilometers near Orient on First Thought Mountain, 24 km east of the Republic graben.

The Klondike Mountain Formation now covers an area of about 80 km^2 along the west side of the Republic graben. Although its original extent there is unknown, the few dikes and other possible feeders that have been recognized suggest that it was never very widespread. The Tom Thumb Tuff Member does not extend more than a few miles from its type locality at the Tom Thumb mine. To the north near Curlew (Parker and Calkins, 1964) rocks similar to Muessig's middle member lie in part on Sanpoil Volcanics and in part on pre-Tertiary rocks where the O'Brien Creek and Sanpoil Formations are missing. Although the critical exposures may not be present, several lines of evidence suggest that the pre-Tertiary rocks are a thin slab emplaced as a gravity slide. The slide is presumed to have come from the horst to the west, to have come to rest on Sanpoil Volcanics, and to have been covered later by volcanic rocks of the Klondike Mountain Formation. Such a slide could have produced a dam and a lake in which the Tom Thumb Tuff Member was deposited farther south, accounting for the absence of the Tom Thumb in the Curlew area. These pre-Tertiary rocks are mapped with the Klondike Mountain Formation on plate 1, although they were mapped separately by Parker and Calkins (1964).

In the Toroda Creek graben, the Klondike Mountain Formation consists of lake beds, conglomerate, nonvolcanic breccias, and volcanic rocks that lie on Sanpoil Volcanics, and on pre-Tertiary rocks where the Sanpoil is absent. This graben contains the largest volume of Klondike Mountain rocks known. A 1,200-m stratigraphic thickness of volcanic rocks is present along Toroda Creek; the formation is continuous for 45 km. In addition, a small erosional remnant of a few square kilometers occurs 8 km south of the main mass (pl. 1). Though the volcanic rocks do not continue into Canada, the nonvolcanic breccia continues north of the boundary for about 2 km along the east side of the Toroda Creek graben (Little and Thorpe, 1965; Monger, 1968).

The sequence within the formation in the Toroda Creek graben is generally similar to that at the type locality, but because of some differences and the problem of establishing internal boundaries, the members established by Muessig (1962) have not been mapped. Locally bedded deposits at or near the base consist of tuffaceous shales, sandstones, and conglomerates and are analogous to the Tom Thumb Tuff Member. These deposits are thickest in the northern part of the graben, where they are associated with, and apparently gradational with, nonvolcanic breccias. The nonvolcanic breccias are composed of fragments of quartz monzonite and other intrusive rocks, interpreted to be of Sanpoil age, and of pre-Tertiary metamorphic rocks. These breccias, which contain unbrecciated masses nearly 1 km long, are composed of the same types of rocks as those in the Republic graben in the inferred slab sandwiched between the Sanpoil Volcanics and the Klondike Mountain Formation. They probably originated similarly, as gravity slides derived from the intervening horst, which was presumably a mountain range then. Near the south end of the Toroda Creek graben (pl. 1) where Granite Creek has cut nearly through the Klondike Mountain Formation, about 60 m of locally derived conglomerate, conglomeratic sandstone, and breccia lie on Sanpoil flows or on Cretaceous(?) granodiorite and beneath volcanic rocks of the Klondike Mountain.

The volcanic rocks of the formation in the Toroda Creek graben are similar in most respects to the rocks in the upper two members in the Republic graben, but because they interfinger and are gradational they are not readily divisible into good stratigraphic units. Some flows, found only in the northern part of the Toroda Creek graben, contain phenocrysts of biotite and hornblende that have proved useful in K-Ar dating.

In the Orient area, the Klondike Mountain Formation forms the top and west side of First Thought Mountain. Bowman (1950) assigned these rocks to members of his formation at First Thought Mountain. The rocks lying above the Sanpoil Volcanics on First Thought Mountain include the following: a basal unit of gray tuffaceous shale and sandstone; a middle unit of gray to brown, dull, weakly porphyritic flows and breccias; and an upper unit of dark gray vitric flows. This sequence is almost identical to that on Klondike Mountain, 30 km to the southwest.

Certain volcanic rocks west of the Okanagan Valley in British Columbia may be correlative with the Klondike Mountain Formation. The White Lake Formation (Bostock, 1940; Church, 1973) lies on Marron Formation and is analogous with part of the Tom Thumb Tuff Member. Volcanic breccias interfingering with the bedded deposits are analogous to the middle member of the Klondike Mountain. Nonvolcanic breccias including large unbroken masses are, to judge by the description of Church (1973), identical to the breccias in the Toroda Creek graben. Church included the nonvolcanic breccias in his Skaha Formation, which is younger than the White Lake.

CHEMICAL ANALYSES

Chemical analyses of four samples of Klondike Mountain Formation are listed in table 1. Two of the samples are from a volcanic neck and the other two are from lava flows. These samples are typical of the bulk of the formation, but they probably do not represent its total range in composition. Rocks such as the biotite- and hornblende-bearing lavas used for K-Ar age determination, are lighter colored, possibly more silicic and alkalic, and are not represented among the analyzed samples. According to the Rittmann classification, one of the analyzed samples is rhyodacite, two are quartz latite near rhyodacite, and one is dacite near rhyodacite.

The chemical analyses of the Klondike Mountain are plotted with those of the Sanpoil and O'Brien Creek on the silica variation diagram (fig. 4), but the limited number of analyses of Klondike Mountain rocks are insufficient to fully characterize that unit.

AGE

Tuffaceous shale and siltstone from the Tom Thumb Tuff Member have yielded many plant fossils known as the Republic flora. Through the years of study, paleobotanists have tended to place these fossils at progressively older ages, most recently late Oligocene by R. W. Brown (Muessig, 1967).

Eight K-Ar ages were determined on biotite and hornblende from three samples (table 2) of Klondike Mountain lavas in the Toroda Creek graben. Six ages on two samples (table 2, A10, A11) are nearly concordant and range from 46.3 to 49.1 m.y., averaging 47.6 m.y. A third sample (table 2, A9) yielded two ages, 41.3 and 41.4 m.y., on hornblende. The hornblende and the glassy groundmass in sample A9 appear to be very fresh, and, geologically, no reason for the younger age is known. All three samples were collected in a small area (pl. 1), none more than 450 m from another, and they are probably less than 100 m apart stratigraphically. No younger intrusives or other heating event causing argon loss have been recognized in the vicinity. There is no basis for disregarding the younger ages, and the mean of all eight determinations, 46 m.y., is tentatively accepted for the middle part of the Klondike Mountain.

The three dated samples were collected from lavas that lie about 300 m above plant-fossil-bearing beds that are similar in lithology, stratigraphic position, and fossil content to the Tom Thumb Tuff Member in the Republic graben. The older limit on the age of these fossils is provided by the 50-m.y.-old Sanpoil lavas beneath the fossil-bearing beds. In view of the unconformity beneath the fossil-bearing beds, and the general similarity of the volcanic rocks in these beds to the dated lavas, it is most likely that the age of the fossils is nearer to the 46 m.y. age of the overlying lavas than to the 50 m.y. age of the underlying lavas.

Axelrod (1966) reported a K-Ar age of 55 m.y. on biotite from the Tom Thumb Tuff Member. This age is 10 percent older than the underlying Sanpoil and we consider it to be incorrect. We also collected a biotitic tuff from the Tom Thumb Tuff Member from north of Republic, but laboratory examination showed it to be a tuffaceous sandstone which contained granitic detritus presumably derived from the pre-Tertiary pluton to the west. The anomalous age obtained by Axelrod may well be caused by this kind of contamination. We regard Axelrod's assignment of the Republic flora to the Paleocene (Clarkforkian, provincial age of Wood and others, 1941) as questionable; the Republic flora is more likely latest Bridgerian (provincial age of Wood and others, 1941), according to the recalibration of the Eocene by McKenna and others (1973).

TIGER FORMATION

Crudely bedded conglomeratic beds in several areas along the Pend Oreille River valley were named Tiger Formation by Park and Cannon (1943) after exposures near the village of Tiger (pl. 1). In addition to the conglomerate, sandstone and clayey siltstone beds, locally containing plant fossils, are present. Most of the detritus comprising the formation was derived very locally. Clasts of granitic rocks of the Kaniksu batholith are predominant in some areas, and Cambrian limestone or Ordovician shale clasts are abundant in others. Photographs by Park and Cannon (1943, p. 11) clearly show the characteristic aspects of the formation, particularly the poor sorting and the crude bedding. Near Tiger the formation is about 300 m thick. Dings and Whitebread (1965) reported several other small patches of Tiger Formation (not shown on plate 1) along the Pend Oreille River northward to within 3 km of the international boundary. The Tiger Formation represents fluvial and lacustrine beds that were deposited "in a valley similar to that existing today" (Park and Cannon, 1943, p. 23).

Fifteen to forty kilometers south of the type locality of the Tiger Formation, a large area is underlain by similar beds that Schroeder (1952) and Miller (1971) assigned to the Tiger. These beds lie on the O'Brien Creek Formation, Sanpoil Volcanics, and several Precambrian and Cambrian units east of the Pend Oreille River. Locally the Tiger contains detritus of the Sanpoil Volcanics (Miller, 1974a). The beds on the east side of the valley dip west, toward the trace of the Newport fault, a major thrust that lies west of the valley. Although exposures are poor, the fault marks the approximate western edge of the Tiger outcrop, but some evidence indicates the Tiger overlaps the trace of the fault (Miller, 1971).

Park and Cannon (1943) postulated a Tertiary age for the Tiger because it is little deformed and only moderately indurated. Plant fossils were not diagnostic of age. An Eocene age is suggested here because it seems to be conformable with the Sanpoil Volcanics. The Tiger could be younger than Eocene, in part at least, according to data presented by Miller (1971); the two samples of Silver Point Quartz Monzonite (pl. 1), which give concordant K-Ar ages on biotite and hornblende of 47 m.y. and 50 m.y., lie in the lower plate directly beneath the Newport fault. The Sanpoil Volcanics gives the same K-Ar age as the Silver Point, and is in the upper plate a few kilometers to the north but not in contact with the fault. If the K-Ar ages are correct, fault movement is younger than both units. However, the Tiger lies conformably on the Sanpoil east of the Pend Oreille River but overlaps the trace of the Newport fault west of the river. Miller explained these relations by suggesting that part of the Tiger is older than movement on the fault and part is younger.

SUMMARY

Tertiary volcanism in northeast Washington began with the eruption of quartz latite tuff in early Eocene time, perhaps about 53 m.y. ago. The tuffs were largely reworked and interbedded with nonvolcanic conglomerate. Together these beds constitute the O'Brien Creek Formation which has now been recognized in several places away from its type locality in the Republic graben; it appears in the east almost to Idaho, and in the west tentatively to the Okanogan River valley. Northward in British Columbia, the O'Brien Creek correlates with part of the Kettle River and Springbrook Formations. In the Orient area, the O'Brien Creek had previously been included in the formation at First Thought Mountain of Bowman (1950).

Dark intermediate lavas and breccias of the Sanpoil Volcanics were deposited conformably on the O'Brien Creek and on pre-Tertiary rocks about 51 m.y. ago. The Sanpoil was extruded from a great many vents and probably occupied much of northeast Washington, and its equivalent the Marron Formation appears in large areas to the northwest in British Columbia. The Sanpoil is now preserved in isolated fault blocks. Various stratigraphic names have been applied to the Sanpoil Volcanics, as used in this report, such as formation at First Thought Mountain of Bowman (1950), the Palmer Volcanics of Weaver (1920), part of the Phalen Lake Volcanics of Weaver (1920), the Gerome Volcanics, and the Pend Oreille Andesite.

Structural disturbance and a period of erosion, which may have lasted a few million years, followed deposition of the Sanpoil Volcanics. Much of the Sanpoil was removed during this time, and plutons believed to be comagmatic with the Sanpoil were unroofed.

Large landslides, formed in response to faulting and renewed volcanism, accumulated in the developing grabens. The volcanism that resumed about 46 m.y. ago produced the heterogeneous Klondike Mountain Formation. At first, volcanic breccias and tuffs accumulated on the land and in lakes, which formed as sag ponds along the faults or behind landslide and volcanic-rock dams. Preserved in the fine tuffaceous "lake beds" are fossil plants that constitute the Republic flora. In the Republic area this unit is the Tom Thumb Tuff Member of the Klondike Mountain. Similar beds are present in the Toroda Creek graben and near Orient, where they were mapped as a member of the formation at First Thought Mountain by Bowman (1950). The White Lake Formation in British Columbia is believed to be correlative with the Tom Thumb. Volcanic breccias, flows, and domes of intermediate composition form the middle and upper parts of the Klondike Mountain Formation.

The conglomeratic Tiger Formation lies on the Sanpoil Volcanics in the eastern part of the area where the Klondike Mountain Formation is missing. The apparent conformity between the Tiger and Sanpoil suggests no great difference in age; however, Miller (1971) implied that deposition of the Tiger may have been interrupted by a period of thrusting, in which case it could have spanned a considerably longer time.

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TABLES 1 AND 2

TABLE 1 — *Chemical analyses, norms, and spectrographic*

[For sample localities see plate 1. Chemical analyses of samples 1–3 by Paul Elmore, using methods described in Shapiro and Brannock (1962), supplemented by atomic absorption. Chemical analyses of samples 4–13 by Paul Elmore, Sam Botts, Lowell Artis, Gillison Chloe, and John Glenn by X-ray fluorescence supplemented by methods described in Shapiro and Brannock (1962).

Semiquantitative spectrographic analyses are reported in percent to the nearest number in the series 1, 0.7, 0.5,

Sample No.	1	2	3	4	5	6
Lab No.	D–160773–W	D–160775–W	D–160774–W	D–116166–W	D–116167–W	D–116160–W
Field No.	43bK7	71BM7	49SM7	E8–3–244	B27–2–290	D25–3–311
Form of deposit	tuff bed	tuff bed	intrusive	flow	flow	intrusive
Rock name	rhyodacite	light dacite	quartz latite	rhyodacite	rhyodacite	rhyodacite
Map unit	O'Brien Creek	O'Brien Creek	O'Brien Creek	Sanpoil	Sanpoil	Sanpoil
Rapid rock analyses (percent)						
SiO_2	66.8	64.8	69.7	60.4	60.3	61.9
Al_2O_3	16.4	18.3	15.9	16.7	16.0	16.0
Fe_2O_3	1.7	1.3	1.4	3.1	5.2	2.1
FeO	.92	1.3	.80	1.8	1.1	2.4
MgO	1.0	.74	.50	3.6	2.5	3.0
CaO	2.9	3.7	2.6	5.4	4.7	4.6
Na_2O	4.2	5.1	4.5	3.3	3.6	3.8
K_2O	2.6	2.1	3.3	2.6	2.5	2.4
H_2O^+	2.4	1.4	.62	1.6	1.0	1.6
H_2O^-	.44	.13	.08	.15	1.4	.15
TiO_2	.40	.40	.31	.93	.92	.75
P_2O_5	.15	.12	.14	.43	.41	.43
MnO	.03	.03	.03	.08	.05	.06
CO_2	.08	.55	.02	<.05	.06	.52
Total	100	100	100	100	100	100
Norm						
Q	24.6	18.1	24.3	15.7	17.9	18.1
or	15.6	12.2	19.5	15.6	15.0	14.5
ab	35.6	43.0	38.3	27.8	30.4	32.0
an	13.9	18.4	12.8	23.1	20.0	17.0
C	1.7	1.0	.2	...	...	.9
Wo	...	...	...	.5	.4	...
hy { en	2.5	1.8	1.3	8.9	6.2	7.4
hy { fs	...	.7	...	...	...	1.5
mt	1.9	1.9	1.6	.3	.9	3.0
hm	.5	...	.3	.8	4.6	...
il	.8	.8	.6	1.8	1.8	1.4
ap	...	...	...	1.0	1.0	1.0
cc	.2	1.4	...	...	...	1.2
Semiquantitative spectrographic analyses (percent)						
Ba	0.15	0.15	0.15	0.15	0.1	0.1
Be	L	L	.0015	N	N	N
Ce	N	N	N	N	N	N
Co	.0005	N	N	.0015	.001	.0007
Cr	.002	.001	.0005	.01	.007	.005
Cu	.0005	.0003	N	.0007	.001	.0007
Ga	.002	.002	.002	.002	.002	.002
La	L	L	L	.007	.005	N
Nb	N	N	N	N	N	N
Pb	.0015	.0015	.002	.0015	.001	N
Sc	.0005	.0005	.0005	.002	.0015	.001

analyses of Eocene rocks from northeast Washington

0.3, 0.2, 0.15, and 0.1, etc., which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time. Analyses by Harriet Neiman. Elements looked for but not found — Ag, As, Au, B, Bi, Cd, Ge, Hf, Hg, In, Li, Mo, Ni, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, and Zn. N, not detected; L, detected but below limit of determination]

7	8	9	10	11	12	13
D-116161-W	D-116163-W	D-116159-W	D-116164-W	D-116165-W	D-116169-W	D-116168-W
F27-3-308	161P61	G9-3-310	E36-3-272	A19-3-318d	A19-4-62A	B13-3-175
intrusive	intrusive	intrusive	flow	neck	neck	flow
quartz monzonite	quartz monzonite	grano-diorite	quartz latite	quartz latite	dacite	rhyodacite
Sanpoil	Sanpoil	Sanpoil	Klondike Mountain	Klondike Mountain	Klondike Mountain	Klondike Mountain
			Rapid rock analyses (percent) — Continued			
62.3	67.9	63.1	68.6	67.8	65.5	61.4
15.6	14.5	15.5	15.8	15.2	15.0	15.9
1.3	1.4	1.5	1.3	2.4	1.1	1.9
2.9	1.9	2.9	1.0	1.1	2.6	3.0
2.8	1.3	3.7	.60	1.4	2.5	2.1
4.4	2.3	5.0	2.8	2.3	3.9	4.5
3.5	3.3	3.4	3.6	3.3	4.0	3.6
4.4	4.9	2.7	3.4	3.2	1.6	2.3
.77	.75	.75	.98	1.5	2.2	2.6
.05	.06	.04	.52	1.1	.57	1.1
.75	.52	.70	.33	.44	.46	.92
.63	.37	.48	.26	.28	.26	.43
.05	.03	.06	.00	.00	.07	.06
.12	.05	<.05	.40	.05	<.05	<.05
100	99	100	100	100	100	100
			Norm — Continued			
13.1	23.6	17.0	29.5	30.2	23.0	19.0
26.1	28.9	16.1	20.0	18.9	9.5	13.3
28.8	27.8	28.8	30.4	27.8	34.1	30.4
14.2	8.9	18.9	9.7	9.7	17.8	19.7
...	.5	...	2.7	2.8	.1	.3
1.5	...	1.4	...	...	...	...
6.9	3.2	9.2	1.5	3.5	6.2	5.2
3.0	1.5	3.0	.3	...	3.2	2.5
1.9	2.1	2.1	1.9	2.1	1.6	2.8
...	...	...	...	1.0	...	...
1.4	1.1	1.4	.6	.9	.9	1.8
1.3	1.0	1.0	.7	.7	.7	1.0
.3	...	...	.9	...	...	...
			Semiquantitative spectrographic analyses (percent) — Continued			
0.15	0.1	0.1	0.1	0.1	0.1	0.1
.0001	.0002	N	N	N	N	N
N	.01	N	N	N	N	N
.001	.001	.0007	N	.001	.001	.001
.01	.007	.007	.0015	.007	.007	.002
.0007	.0007	.0007	.001	.0015	.0015	.0007
.002	.002	.002	.0015	.002	.002	.002
.005	.01	N	N	N	N	.007
.001	.003	N	N	N	N	N
.0015	.0015	N	.001	.001	.001	N
.0015	.001	.001	.0007	.001	.001	.0015

TABLE 1. — *Chemical analyses, norms, and spectrographic*

Sample No.	**1**	**2**	**3**	**4**	**5**	**6**
Lab No.	**D-160773-W**	**D-160775-W**	**D-160774-W**	**D-116166-W**	**D-116167-W**	**D-116160-W**
Field No.	**43bK7**	**71BM7**	**49SM7**	**E8-3-244**	**B27-2-290**	**D25-3-311**
Form of deposit	**tuff bed**	**tuff bed**	**intrusive**	**flow**	**flow**	**intrusive**
Rock name	**rhyodacite**	**light dacite**	**quartz latite**	**rhyodacite**	**rhyodacite**	**rhyodacite**
Map unit	**O'Brien Creek**	**O'Brien Creek**	**O'Brien Creek**	**Sanpoil**	**Sanpoil**	**Sanpoil**
Semiquantitative spectrographic analysis (percent) — Continued						
Sr	.15	.2	.15	.15	.1	.1
V	.005	.005	.003	.007	.005	.007
Y	.001	.001	.001	.002	.0015	.001
Yb	.0001	.0001	.0001	.0002	.00015	.0001
Zr	.01	.015	.015	.01	.007	.01

Sample descriptions and locations

1 Greenish-gray crystal lithic tuff containing scattered lapilli as much as 2 cm long from roadcut at BM 1963 on Bridge Creek Road 3.2 km east of Sanpoil River, Keller quadrangle (sec. 33, T. 32 N., R. 33 E.).

2 Greenish-gray crystal lithic tuff containing dark gray chips of argillite 1–3 mm long from massive outcrops near west end of lower Beaver Lake, Bodie Mountain quadrangle (sec. 30, T. 39 N., R. 31 E.).

3 Pale gray biotite-quartz-feldspar porphyry that contains sparse, small clusters of fine-grained biotite and chlorite from cut on logging road 1.3 km north of BM 2408 on Thirtymile Creek, Seventeenmile Mountain quadrangle (sec. 34, T. 33 N., R. 33 E.).

4 Gray lava containing biotite, hornblende, clinopyroxene, and plagioclase phenocrysts from outcrop along Coogan Creek, elev. 1,125 m, Bodie Mountain quadrangle (sec. 8, T. 39 N., R. 31 E.).

5 Rock similar to 4 from 400 m south of Nicholson Creek, elev. 910 m, Bodie Mountain quadrangle (sec. 27, T. 40 N., R. 31 E.).

6 Body intrusive into O'Brien Creek Formation; contains phenocrysts of biotite, hornblende, and clinopyroxene partly altered to chlorite and of plagioclase; sample from roadcut on north side Beaver Lake, Bodie Mountain quadrangle (sec. 25, T. 35 N., R. 30 E.).

analyses of Eocene rocks from northeast Washington — Continued

7	8	9	10	11	12	13
D-116161-W	D-116163-W	D-116159-W	D-116164-W	D-116165-W	D-116169-W	D-116168-W
F27-3-308	161P61	G9-3-310	E36-3-272	A19-3-318d	A19-4-62A	B13-3-175
intrusive	intrusive	intrusive	flow	neck	neck	flow
quartz monzonite	quartz monzonite	grano-diorite	quartz latite	quartz latite	dacite	rhyodacite
Sanpoil	Sanpoil	Sanpoil	Klondike Mountain	Klondike Mountain	Klondike Mountain	Klondike Mountain
Semiquantitative spectrographic analyses (percent) — Continued						
.15	.1	.1	.05	.05	.1	.07
.007	.005	.005	.002	.005	.005	.005
.0015	.002	.001	.001	.0015	.0015	.002
.0002	.0002	.00015	.0001	.00015	.00015	.0002
.01	.01	.007	.007	.01	.01	.01

Sample descriptions and locations— Continued

7 Biotite-hornblende-clinopyroxene quartz monzonite from roadcut on Goodrich Road, 2.6 km south of junction with Toroda Creek road, Bodie Mountain quadrangle (sec. 27, T. 39 N., R. 32 E.).

8 Biotite-hornblende quartz monzonite from Kelly Mountain, Bodie Mountain quadrangle (sec. 5, T. 38 N., R. 32 E.).

9 Fine-grained biotite-hornblende grandodiorite from N. Fork Trout Creek Road, elev. 1,350 m, Bodie Mountain quadrangle (sec. 9, T. 38 N., R. 32 E.).

10 Gray sparsely porphyritic quartz latite from spur 1.9 km northwest of top of Bodie Mountain, Bodie Mountain quadrangle (sec. 36, T. 39 N., R. 31 E.).

11 Sparsely porphyritic dark gray stony lava from prominent volcanic neck 4 km west of Toroda and 0.4 km north of Toroda Creek road, Bodie Mountain quadrangle (sec. 19, T. 40 N., R. 32 E.).

12 Rock similar to 11 except glassy; from same locality.

13 Gray glassy lava containing sparse phenocrysts of orthopyroxene, clinopyroxene, plagioclase, and trace of hornblende from outcrop at elev. 1,170 km on ridge between O'Connor Canyon and Harvey Creek, Bodie Mountain quadrangle (southcentral part of sec. 13, T. 39 N., R. 31 E.).

TABLE 2. — *K-Ar analytical data on minerals from Eocene*

Sample No.	Field No.	Lab No. OKA–	Mineral	K_2O (percent)	$^{40}Ar^{*} \times 10^{-10}$ (mol/g)	Radiogenic argon (percent)	Calculated age (m.y.)
			O'Brien Creek Formation				
Al	60N7	1580	Biotite	7.25	6.94	91.1	53.1 ± 1.5
			Sanpoil Volcanics				
A2	OBP–65–06	1266	Biotite	6.28	5.02	85.2	53.4 ± 2.0
		1262	Hornblende	1.10	.865	75.3	52.6 ± 2.1
A3	OBP–65–01	1272	Plagioclase	.579	.445	66.3	51.1 ± 3.0
A4	OBP–65–02	1259	Biotite	8.16	6.36	94.1	52.1 ± 1.7
A5	OBP–65–03	1268	Biotite	7.97	7.11	87.6	51.2 ± 1.7
		1261	Plagioclase	.714	.517	86.2	48.4 ± 3.0
		1310	Plagioclase	.731	.551	47.9	50.4 ± 2.5
		1308	Biotite	7.97	6.99	88.1	50.1 ± 1.7
		1332	Biotite	7.51	5.88	83.1	52.4 ± 1.8
A6	P–6–2	1851	Biotite	7.28	5.46	90.2	50.2 ± 1.3
A7	PO–6–1	1852	Biotite	8.32	6.28	94.0	50.4 ± 1.3
		1862	Hornblende	1.05	.803	67.2	51.0 ± 1.8
A8	37TL7	1991	Hornblende	.966	.739	89.0	50.3 ± 1.4
			Klondike Mountain Formation				
A9	OBP–65–05	1269	Hornblende	0.712	0.439	86.9	41.3 ± 2.0
		1331	Hornblende	.713	.440	76.4	41.4 ± 1.5
A10	8aBM–7	1592	Hornblende	.655	.454	72.5	46.3 ± 1.7
		1616	Hornblende	.651	.466	78.5	48.0 ± 1.9
		1657	Hornblende	.651	.453	62.1	46.6 ± 1.9
A11	A32–4–81	1264	Biotite	8.24	6.05	86.5	49.1 ± 1.7
		1307	Biotite	8.17	5.79	83.6	47.4 ± 1.6
		1618	Biotite	8.01	5.77	88.6	48.1 ± 1.4
			Quartz monzonite of Long Alec Creek				
A12	OBP–65–08	1263	Biotite	8.54	6.60	91.8	51.7 ± 1.6
			Unnamed quartz monzonites				
A13	OBP–65–04	1260	Biotite	9.15	6.99	89.5	51.1 ± 1.6
A14	OBP–65–07	1265	Biotite	8.20	6.42	95.6	52.2 ± 1.7
		1270	Hornblende	1.28	.683	77.3	53.7 ± 2.7

Sample descriptions and locations

A1 Light-gray to cream-colored, buff-weathering, thin- to medium-bedded quartz latite tuff. Contains biotite and angular quartz, plagioclase, and altered alkali feldspar in clayey matrix. Biotite is in hexagonal plates 0.01–0.02 mm thick and 0.1–0.4 mm diameter. From along logging road on east side of 975 m saddle, 1.1 km south of Moon Hill, southwest corner of Browns Lake quadrangle, SE 1/4 NE 1/4 sec. 9, T. 33 N., R. 44 E.

A2 Gray to greenish-gray, intrusive rhyodacite porphyry. Contains abundant phenocrysts of brownish-green hornblende and slightly altered plagioclase as much as 4 mm long and sparse phenocrysts of biotite intergrown with epidote as much as 1.5 mm long in groundmass of cloudy euhedral feldspar 0.05–0.10 mm diameter. A few remnants of altered pyroxene(?) phenocrysts remain. From outcrop 100 m east of Goosmus Creek road at point 1.7 km from Highway 21, northeast part of Curlew quadrangle, SW 1/4 NW 1/4 sec. 19, T. 40 N., R. 34 E.

A3 Brownish-gray, massive rhyodacite lava. Contains phenocrysts of fresh, zoned oligoclase-andesine, fresh clinopyroxene and orthopyroxene, and almost completely altered hornblende. From talus north of Beaver Creek road, 2.8 km west of Toroda Creek road, Bodie Mountain quadrangle, SW 1/4 SW 1/4 sec. 21, T. 39 N., R. 31 E.

A4 Dark-gray, massive, subvitreous rhyodacite lava. Phenocrysts of plagioclase, biotite, hornblende, orthopyroxene, and clinopyroxene in very fine grained groundmass crowded with crystals and possibly containing glass. From talus below cliffs on east side of Barrett Butte on west side of Highway 21, southwest corner of Republic quadrangle, 610 m south of Tenmile Creek, SE 1/4 SE 1/4 sec. 24, T. 35 N., R. 32 E.

volcanic and intrusive rocks from northeast Washington

Sample descriptions and locations — Continued

A5 Gray, massive rhyodacite lava. Phenocrysts of oligoclase-andesine, brown biotite (rimmed by opacite), two pyroxenes, and a trace of hornblende in a turbid feldspathic groundmass. From talus on northwest side of Eagle Rock beside road through Refrigerator Canyon, Republic quadrangle, SE corner NE 1/4 sec. 35, T. 36 N., R. 33 E.

A6 Brownish-gray, massive rhyodacite lava. Biotite and hornblende appear fresh in hand specimen. From outcrop on east side of jeep trail, 400 m south of point where power line crosses trail, Kettle Falls 7 1/2-minute quadrangle, SE 1/4 NW 1/4 sec. 34, T. 36 N., R. 38 E.

A7 Dark, brownish-gray, massive, lamprophyric rhyodacite lava(?). Conspicuous oxyhornblende phenocrysts as much as 8 mm long and sparse biotite phenocrysts as much as 4 mm long, both rimmed by opacite. Plagioclase and two pyroxenes are microphenocrysts set in a very fine grained low-index groundmass. From small quarry beside road at south end of ridge between Skookum and North Fork Skookum Creeks, Skookum Creek quadrangle, sec. 27, T. 33 N., R. 44 E.

A8 Medium gray rhyodacite lava, slightly altered in light gray zones along limonite-stained fractures. Oxyhornblende phenocrysts as much as 4 mm long rimmed by opacite and sparse plagioclase phenocrysts as much as 2 mm long; microphenocrysts of plagioclase and clinopyroxene in a very fine grained feldspathic groundmass. From same locality as analyzed sample 6W−502B in Becraft and Weis (1963, pl. 1, table 3), Turtle Lake quadrangle, sec. 16, T. 28 N., R. 37 E.

A9 Greenish-gray, subvitreous quartz latite lava. Phenocrysts of brownish-green hornblende and of orthopyroxene as much as 2 mm long in glassy groundmass crowded with flow-oriented plagioclase microlites. From 1,040 m knob east of Gilg Canyon, Bodie Mountain quadrangle, SE 1/4 SW 1/4 sec. 32, T. 40 N., R. 32 E.

A10 Rock similar to A9. From 350 m west of A9; SW 1/4 SW 1/4 sec. 32, T. 40 N., R. 32 E.

A11 Cream-colored, flow-layered quartz latite lava containing small biotite phenocrysts. From outcrop 335 m southeast of A9; SW 1/4 SE 1/4 sec. 32, T. 40 N., R. 32 E.

A12 Medium-grained, black-and-white-speckled, hypidiomorphic granular to seriate porphyritic biotite-hornblende-pyroxene quartz monzonite. Similar to rock illustrated by Parker and Calkins (1964, fig. 7). From roadcut in Long Alec Creek road 100 m west of east edge of Curlew quadrangle, NW 1/4 sec. 27, T. 39 N., R. 34 E.

A13 Similar to A12 except finer grained, average grain size about 1.5 mm. From roadcut on Sherman Creek Pass highway (Highway 30) about 5 miles (road distance) west of the pass, Republic quadrangle, SW 1/4 SE 1/4 sec. 16, T. 36 N., R. 34 E.

A14 Similar to A12 except contains less orthoclase. From roadcut on Highway 64, 5.8 km (map distance) due west from the town of Curlew, Curlew quadrangle, SW 1/4 NW 1/4 sec. 17, T. 39 N., R. 33 E.

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