The Permian and Triassic Seven Devils Group, Western Idaho and Northeastern Oregon

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By TRACY L. VALLIER

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By TRACY L. VALLIER

ABSTRACT

Volcanogenic Permian and Triassic rocks in the Snake River Canyon of western Idaho and northeastern Oregon and in the adjacent Seven Devils Mountains of western Idaho are assigned to the Seven Devils Group. New rock-stratigraphic units are the Windy Ridge Formation of probable Early Permian age, the Hunsaker Creek Formation of Early Permian age, the Wild Sheep Creek Formation of Middle and Late Triassic age, and the Doyle Creek Formation of Late Triassic age. The Pittsburg Formation of former usage is abandoned, the rocks being renamed the Kurry Creek Member and assigned to the newly named Doyle Creek Formation. Overlying strata are the Martin Bridge Limestone of Late Triassic age, the Hurwal Formation of Late Triassic age, the Coon Hollow Formation of Middle(?) and Late Jurassic age, and the Columbia River Basalt Group of Miocene age. Underlying rocks are assemblages of metagabbro, metamorphosed quartz diorite, metabasalt, metadiabase, amphibolite, schist, mylonite, and phyllite that are exposed at The Oxbow of the Snake River near Oxbow, Oreg., along a 7-km segment of the Snake River south of Pittsburg Landing, and near the mouth of the Imnaha River. Gabbro, quartz diorite, and rare granodiorite plutons are concentrated in these assemblages, but some also cut the overlying strata.

The Seven Devils Group is the result of volcanism, tectonism, and sedimentation that occurred within and near volcanic arcs at converging plate boundaries during the Permian and Triassic Periods. Large parts of these old arcs probably were consumed during later subduction, although direct evidence is lacking in the area considered here.

INTRODUCTION

The existence of Permian and Triassic rocks in eastern Oregon and western Idaho has been recognized for many years. Major reports that discuss these rocks include those by Lindgren (1901), Anderson (1930), Gilluly (1932, 1937), Ross (1938), Smith and Allen (1941), Wagner (1945), Cook (1954), Bostwick and Koch (1962), Prostka (1962), Hamilton (1963a, 1963b), Thayer and Brown (1964), Stearns and Anderson (1966), Brooks and Vallier (1967), Vallier (1968, 1974), and Brooks, McIntyre, and Walker (1977). Dissertations and theses concerned with small areas in western Idaho and eastern Oregon that are considered to be major contributions to this study include those by Wetherell (1960), Prostka (1963), Morrison (1964), Nolf (1966), Vallier (1967), Bruce (1971), White (1972), and Hendricksen (1974).

Rocks of Permian, Triassic, and Jurassic age are among the oldest known in extreme western Idaho and northeastern Oregon. Farther east, Precambrian rocks of the Belt Supergroup are intruded by the Idaho batholith; west of the study area in central Oregon, Devonian, Mississippian, Pennsylvanian, and Permian rocks have been mapped along the southwestern side of the John Day uplift (Merriam, 1942; Merriam and Berthiaume, 1943; Buddenhagen, 1967). The Riggins Group (Hamilton, 1963a), which crops out near the western border of the Idaho batholith, may be of Paleozoic age, but no fossils have been reported. Lowry (1974, p. 609) believed that some metamorphic and crystalline rocks in the Ironside quadrangle of eastern Oregon are of pre-Devonian age (probably Precambrian), but neither fossil nor radiometric ages have been determined for these rocks.

Marine volcanogenic rocks of island-arc origin are dominant in Permian and Triassic sequences exposed in the Wallowa Mountains, Snake River Canyon, and the Seven Devils Mountains. Relatively new ideas on the evolution of volcanic rocks in mobile belts place them at consuming margins of lithospheric plates; these rocks may mark ancient subduction zones (Hamilton, 1969; Dickinson, 1970; Dewey and Bird, 1970, among many others). The following points make a description of the stratigraphic relations essential: (1) the proximity of these older island-arc rocks to the Idaho and Wallowa batholiths; (2) the fact that they are the easternmost exposures of marine Permian and Triassic volcanic rocks in western North America; (3) their correlation with rocks of similar ages and origins in Nevada, southwestern Oregon, Washington, western Canada, and Alaska; and (4) their probable relations to early movements and development of the present Pacific Ocean floor.

This paper describes the stratigraphy of Permian and Triassic rocks that are well exposed in the Snake River Canyon of northeastern Oregon and western Idaho and in the adjacent Seven Devils Mountains of western Idaho (fig. 1) and proposes six new rock-stratigraphic units.

The geologic map (fig. 2) is simplified from Vallier (1974). A small section from the Oregon-Washington border to near the mouth of the Grande Ronde River is in part from Glerup (1960) and Shumway (1961). Many data are keyed to the map, but because of the scale, names of most geographic features and localities could

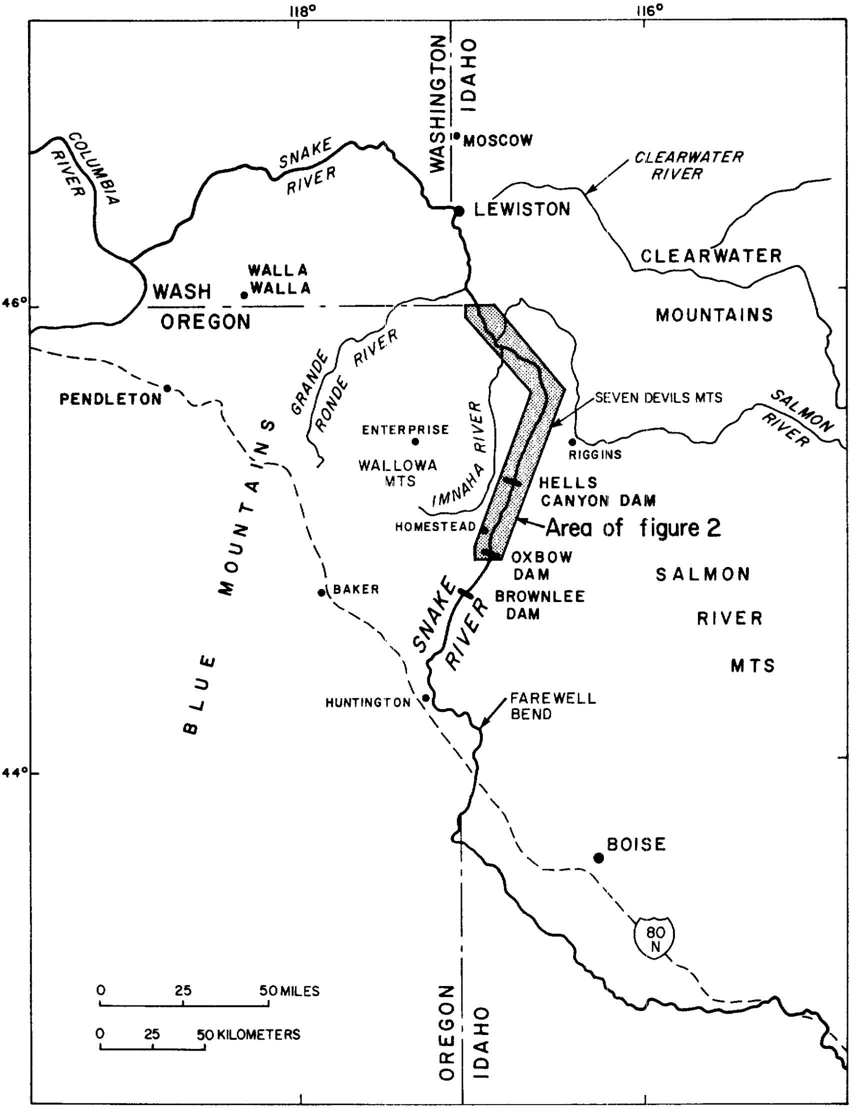

FIGURE 1.—Location map of the Snake River Canyon, northeastern Oregon, western Idaho, and southeastern Washington.

not be included. The reader is encouraged to refer to the topographic maps that served as bases for the geologic map. These include (south to north) Copperfield, Homestead, Cuprum, He Devil, Kernan Point, and Imnaha 15-minute quadrangles and (south to north) the Kirkwood Creek, Grave Point, Wolf Creek,

FIGURE 2.—Geologic map of the Snake River Canyon.

Cactus Mountain, Deadhorse Ridge, Wapshilla Creek, and Jim Creek Butte 7½-minute quadrangles.

Most data reported here were gathered during the 1964, 1965, and 1968 through 1971 field seasons with additional short trips into the area during the spring of 1973 and the summers of 1974 and 1975. The stratigraphic sequences were partly described by Morrison (1963) and Vallier (1967), who mapped the northern and southern parts of the Snake River Canyon, respectively, within the study area. Mapping subsequently has been extended by the author to include all of the Snake River Canyon north of Oxbow, Oreg., to the mouth of the Grande Ronde River and parts of the adjacent Seven Devils Mountains and Salmon River Canyon of western Idaho. Several thousand meters of stratigraphic section, measured and described during the fieldwork, were complemented by studies of more than 600 thin sections plus X-ray diffraction, X-ray fluorescence, atomic absorption, and electron microprobe investigations.

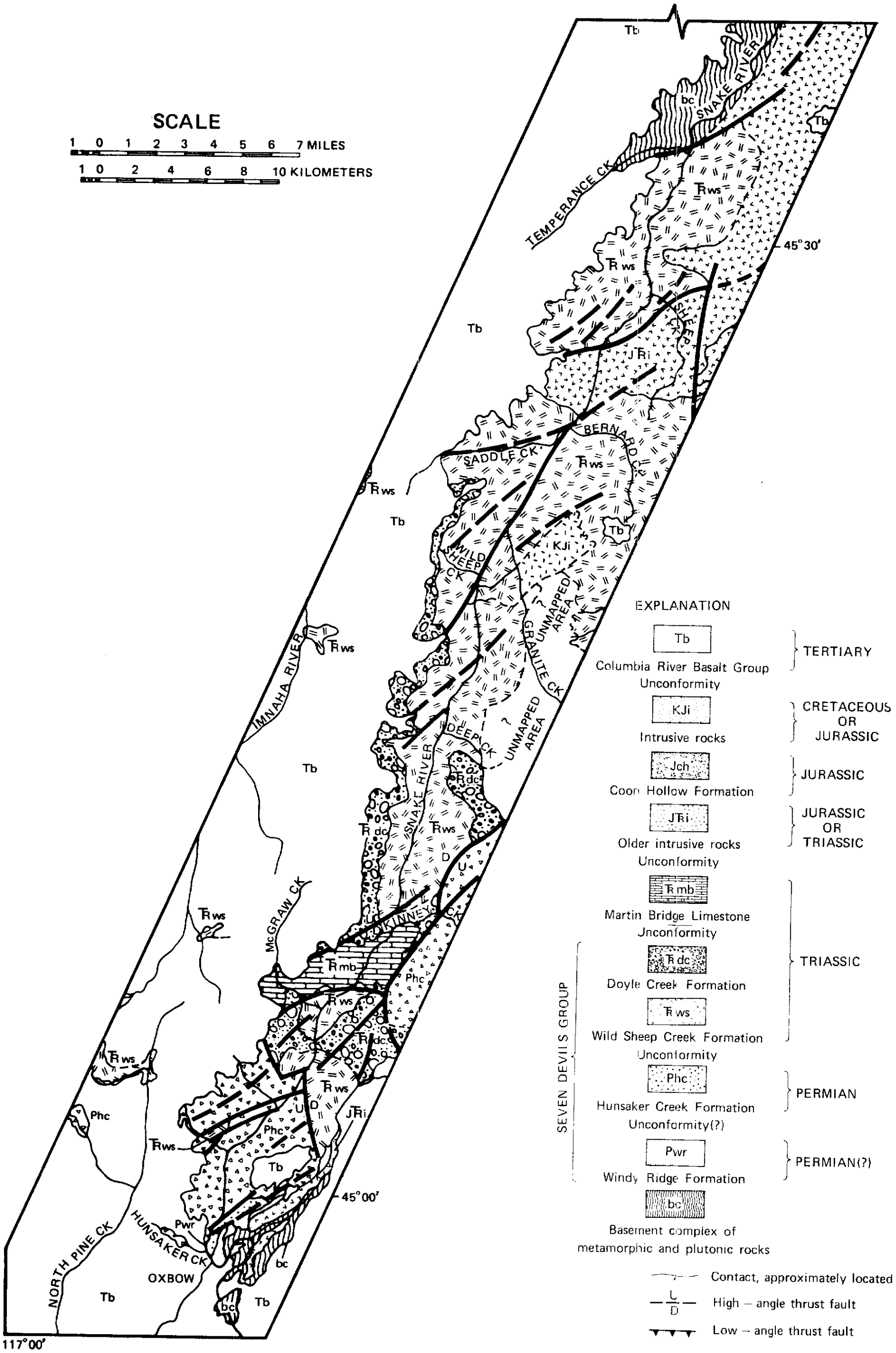

FIGURE 2.—Continued.

Fossils were identified by F. G. Stehli (Permian), N. J. Silberling (Triassic), and R. W. Imlay (Jurassic).

Rocks are dominantly volcanic, with both flow and clastic rocks represented. The term volcaniclastic is used for clastic volcanic rocks whose origin, that is, pyroclastic or epiclastic, is not known. Otherwise, these rocks are named according to their origin and grain size, for instance lapilli tuff and graywacke. Although the Permian and Triassic rocks have undergone low-grade (greenschist) metamorphism, they will generally be referred to according to the original rock type for convenience. An exception is made in descriptions of flow and shallow hypabyssal rocks from stratigraphic sections where thin section studies were used to complement the fieldwork. In these descriptions, for example, the rock names quartz keratophyre and keratophyre are used for metamorphosed high-sodium rhyolite, dacite, and andesite, and spilite is the name used for metamorphosed high-sodium basalt and basaltic andesite.

ACKNOWLEDGMENTS

It is not possible to list all the people who have assisted me with this project. However, some have been outstanding with their encouragement, enthusiasm, and knowledge of adjacent regions which they shared freely. These include Howard Brooks, George Walker, W. H. Taubeneck, R. E. Corcoran, C. Field, David Bostwick, T. Thayer, Bruce Nolf, Rolland Reid, and Hollis Dole. Others who have contributed considerable time and effort are David L. White, David Fredley, Ron Ozier, Jim Waldrip, Stan Shimer, Willis H. White, N. S. Wagner, and Rodey Batiza.

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REGIONAL GEOLOGY

Pre-Tertiary rocks in northeastern Oregon and westernmost Idaho are exposed as inliers in a Cenozoic cover. Pre-Tertiary rocks within this region have been well described: the Baker 30-minute quadrangle by Brooks, McIntyre, and Walker (1977) and the Riggins area by Hamilton (1963a). The area included within the Wallowa Mountains, Seven Devils Mountains, and Snake River Canyon is described in this report.

BAKER QUADRANGLE

In the Baker region, the oldest reported stratified rocks (Taubeneck, 1955) are metamorphosed argillite, chert, lava, tuff, and limestone that overlie and are tectonically mixed with metamorphosed gabbro, diabase, quartz diorite, and ultramafic rocks. This rock association is similar to that reported from a modern-day oceanic crustal section. Stratified rocks are the Elkhorn Ridge Argillite, Burnt River Schist, and Nelson Marble (Gilluly, 1937; Prostka, 1962). Many problems remain concerning the ages of these rocks. For example, limestone bodies in the Elkhorn Ridge Argillite have yielded Pennsylvanian and Early Permian fusulinids (D. A. Bostwick, oral commun., 1975), yet Middle Triassic radiolarians were reported from cherts that are associated with these limestone blocks in an area southwest of John Day, Oreg. (Jones, oral comm., 1977). With the inconclusive age data now available, it is possible to conclude that the Paleozoic limestone bodies are allochthonous blocks in a melangelike unit that tectonically accumulated in the Triassic.

Upper Triassic (Karnian) volcanic rocks crop out in the southern part of the Baker quadrangle near Huntington, Oreg., and also east of the Snake River Canyon in the Sturgill Peak and Cuddy Mountain areas of western Idaho. Correlative Upper Triassic rocks are exposed in the Snake River Canyon north of Oxbow, Oreg., and in the Seven Devils and Wallowa Mountains. Lower and Middle Jurassic flyschlike sedimentary rocks are known to overlie the Karnian volcanic rocks just north of Huntington; however, some of the sedimentary section may be of Late Triassic age in the thicker parts of the exposed sequence (H. C. Brooks, oral commun., 1975). The youngest pre-Tertiary rocks recognized in the region are black mudstone of Late Jurassic (lower Callovian) age exposed at Mineral, Idaho.

The older metamorphosed plutonic rocks that are tectonically associated with the Elkhorn Ridge Argillite and Burnt River Schist are most likely basement rocks upon which the stratified rocks were deposited. Ages of basement rocks are unknown but could include rocks that crystallized at any time in the Pennsylvanian to Late Jurassic interval. Small quartz diorite and granodiorite plutons were intruded during the Late Jurassic and Early Cretaceous Epochs, and regional metamorphism culminated sometime between the deposition of Late Jurassic Callovian sediments and the intrusion of these young plutons. Characteristic of the pre-Tertiary structure throughout most of the Baker quadrangle is the division of the rocks into east- and northeast-trending belts that have parallel fold axes and faults. Some rocks have been folded at least twice along nearly parallel trends. In contrast, the Triassic and Jurassic strata near Huntington have undergone only one deformation.

RIGGINS REGION

In the Riggins region, bordered on the west by the crest of the Seven Devils Mountains and on the east by the Idaho batholith, Hamilton (1963a) described the Riggins Group, a thick sequence of rocks that may be older than the Permian and Triassic Seven Devils Group (Seven Devils Volcanics of Anderson, 1930) exposed in the adjacent Seven Devils Mountains and Snake River Canyon. The Riggins Group is divided into four formations in ascending order: the Fiddle Creek Schist, made up of metamorphosed silicic tuffs and lavas; the Lightning Creek Schist, composed of metamorphosed mafic and silicic tuffs and lavas; the Berg Creek Amphibolite; and the Squaw Creek Schist, which consists of metamorphosed sedimentary rocks. The Riggins Group has been thrust over the Seven Devils Group along the Rapid River thrust. Hamilton (1963a, b) believed that the Riggins Group might reasonably be correlated with rocks of any age from Cambrian through Early Cretaceous.

From reconnaissance field studies in both the Riggins and Baker areas, at least three alternative hypotheses can be considered for the age and origin of the Riggins Group: (1) It is completely unrelated to any other rocks in northeastern Oregon and western Idaho; (2) it is equivalent to the Seven Devils group but is a metamorphosed and greatly deformed facies that was telescoped along the Rapid River thrust and other faults both before and during the intrusion of the Idaho batholith; or (3) it is correlative with the Burnt River Schist, Elkhorn Ridge Argillite, and the Jurassic sedimentary rocks of the Baker region. I prefer the last hypothesis, but additional fieldwork certainly is necessary to solve this problem.

The Squaw Creek Schist retains evidence of flyschlike sediments similar to the Jurassic shale and argillite in the Baker quadrangle, even though it was greatly affected by metamorphism and deformation during the intrusion of the Idaho batholith. The northeasterly structural trends of the pre-Tertiary rocks in the Baker quadrangle can be projected beneath the Cenozoic cover into the Riggins area. Therefore, the Fiddle Creek and Lightning Creek Schists might be correlative with the Elkhorn Ridge Argillite and Burnt River Schist, and the Squaw Creek Schist could be correlative with the Jurassic clastic assemblage. The Berg Creek Amphibolite probably is a metamorphosed (by the Idaho batholith) ultramafic and mafic assemblage that lies between the older Fiddle Creek and Lightning Creek Schists and the younger Squaw Creek Schist. In addition, ultramafic rocks separate the older rocks (Fiddle Creek and Lightning Creek Schists) from the Squaw Creek

Schist near the Salmon River bridge just north of Riggins, Idaho. In the Baker quadrangle, pods of ultramafic and mafic rocks similarly occur along the suture between the Elkhorn Ridge Argillite, Burnt River Schist and associated plutonic rocks, and the Jurassic clastic assemblage.

Hamilton (1976) stated that the suture in the Riggins Group marks the collision of the Seven Devils ensimatic island arc with the continent during late Permian or Triassic time. He regards the Squaw Creek Schist as part of a melange, the ultramafic rocks and adjacent Lightning Creek Schist as an ophiolite assemblage, and the rest of the Lightning Creek and Fiddle Creek Schists as a volcanic arc assemblage.

SNAKE RIVER CANYON

Pre-Tertiary stratigraphy in the Snake River Canyon (fig. 3) is similar to sequences in the Wallowa and Seven Devils Mountains, the southern part of the Baker quadrangle near Huntington, Oreg., and the Cuddy Mountain area. In the Snake River Canyon, rocks of Early Permian, Middle and Late Triassic, and Middle and Late Jurassic age were deposited in island-arc environments. The Upper Triassic limestone and associated shale units formed as platform carbonate and basin deposits over a large part of the region. Jurrassic flyschlike black shale and sandstone units probably are related to deposition in basins associated with the arc. Low-grade regional metamorphism culminated after deposition of Upper Jurassic marine sediments and before the intrusion of some bodies of gabbro and quartz diorite; however, plutonism was common both before and after culminating metamorphism. Structural trends are northeast-southwest and northwest-southeast, with most deformation exemplified by high-angle reverse faults, some of which also had strike-slip movement.

Some of the rocks upon which the Permian and Triassic strata were deposited are exposed in the Snake River Canyon near Oxbow, south of Pittsburg Landing, and east of the Imnaha River mouth. These rocks represent older metamorphic and plutonic terranes that, subsequent to their development, were covered by Permian and Triassic strata and intruded by younger plutons related to both the Late Triassic and Late Jurassic to Early Cretaceous intrusive events. Wide shear zones within these complexes are marked by mylonitic rocks, amphibolite, hornblende and chlorite schists, gneiss, and phyllite. Ages probably range from pre-Permian to at least the Late Jurassic or Early Cretaceous. Details of the tectonic, plutonic, and metamorphic histories have not yet been determined.

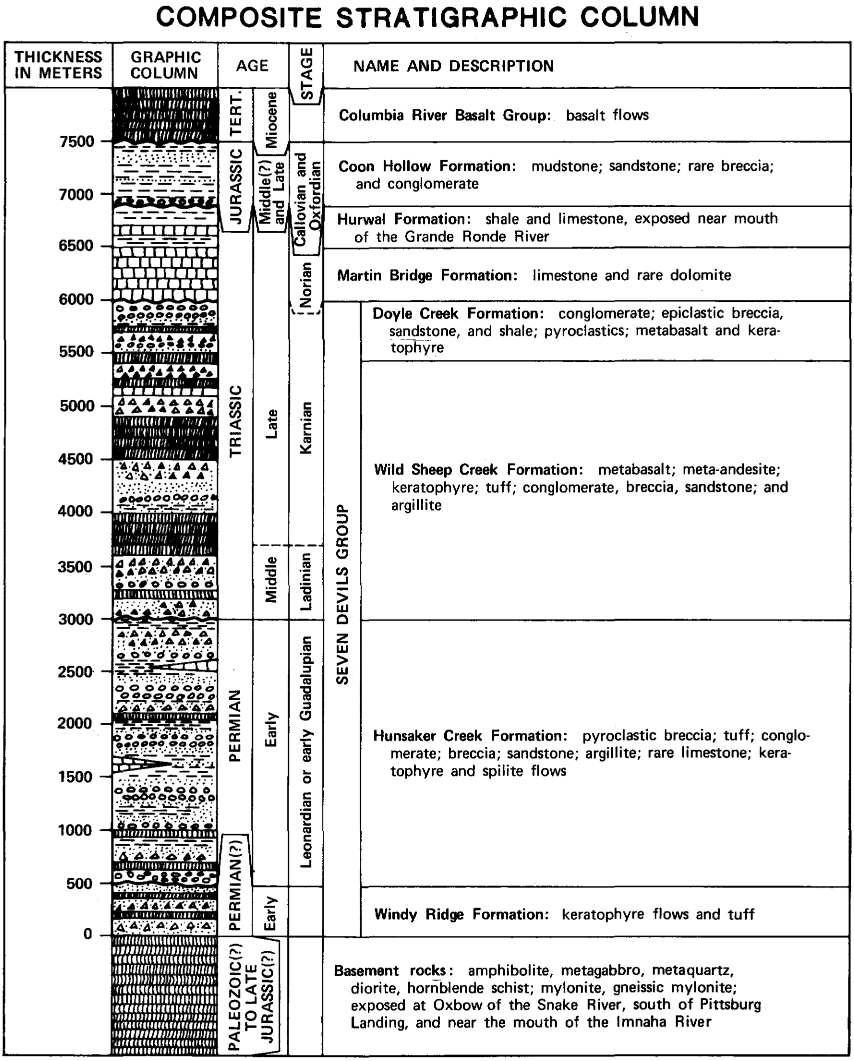

FIGURE 3.—Composite stratigraphic column of pre-Tertiary rocks in the Snake River Canyon north of Oxbow, Oreg.

STRATIGRAPHY

Major stratigraphic units in the Snake River Canyon, Wallowa Mountains, and Seven Devils Mountains are Permian and Triassic volcanogenic rocks, Triassic limestone, Triassic and Jurassic shale and sandstone, Miocene plateau basalt, and Quaternary deposits (fig. 3). The Permian and Triassic volcanic rocks in the Snake River Canyon are assigned to the Seven Devils Group (redefined) which includes four formations and one member. These are the Lower Permian(?) Windy Ridge Formation (new name), Lower Permian Hunsaker Creek Formation (new name), Middle and Upper Triassic Wild Sheep Creek Formation (new name), and the Upper Triassic Doyle Creek Formation (new name), which includes the Kurry Creek Member (new name). These volcanogenic rocks are capped by the Upper Triassic Martin Bridge Limestone, which in turn is overlain by the Upper Triassic Hurwal Formation (the Hurwal Formation in the Wallowa Mountains is in part equivalent to the Lucile Slate in the Seven Devils region), and the Middle and Upper Jurassic Coon Hollow Formation. Miocene basalt caps the pre-Tertiary sequence, and Quaternary glacial, landslide, and alluvial unconsolidated deposits locally mantle the older rocks.

Because of extensive structural complications, pre-Miocene deep erosion, and rapid lithofacies changes, particularly in the volcanogenic Seven Devils Group, thicknesses of the units are not accurately known; exposed contacts are generally tectonic rather than stratigraphic. The composite stratigraphic column for the Snake River Canyon shown in figure 3 is derived from many measured sections but is really a best estimate for thicknesses which may be as much as 30 percent off for some units.

SEVEN DEVILS GROUP

Previous workers generally have followed the terminology of Anderson (1930) by referring to the chiefly metavolcanic rock sequences in the Snake River Canyon and Seven Devils Mountains as the "Seven Devils Volcanics." The name "Seven Devils Group" is here substituted for the "Seven Devils Volcanics" and is defined to include four newly named formations: Windy Ridge Formation, Hunsaker Creek Formation, Wild Sheep Creek Formation, and Doyle Creek Formation. The type area for the Seven Devils Group is in the Seven Devils Mountains and the adjacent Snake River Canyon of western Idaho, Idaho County, He Devil and Cuprum 15-minute quadrangles. The Seven Devils Group includes rock sequences that are lithologically and chronologically similar to the Clover Creek Greenstone (Gilluly, 1937; Ross, 1938) and "Lower Sedimentary Series" (Smith and Allen, 1941, p. 8 and 9) that are well exposed in the Wallowa Mountains. Its upper part can also be correlated with part of the Upper Triassic volcanic sequence exposed along both sides of the Snake River near Huntington, Oreg., and with the Upper Triassic volcanic flow and volcaniclastic rocks in the Cuddy Mountain area.

WINDY RIDGE FORMATION

The name Windy Ridge Formation is here given to a sequence of metamorphosed silicic volcanic flow and volcaniclastic rocks exposed along the south end of Windy Ridge, across the Snake River from Oxbow, Oreg. (fig. 2). Because of poor exposures, indistinct bedding, structural complications and a large number of mafic dikes, no stratigraphic section could be measured. The best exposures, designated the type locality, are along the Idaho Power and Light Company road on the east side of the Snake River in secs. 8 and 17, T. 19 N., R. 4 W., Idaho, north of the bridge at Oxbow. Elsewhere, exposures are very poor and are characterized by scattered, deeply weathered brown-stained outcrops.

The Windy Ridge Formation is easily distinguished from younger formations; it is dominantly grayish-green quartz keratophyre tuff, quartz keratophyre tuff-breccia, and quartz keratophyre flows. No definitely epiclastic rocks occur, and it is concluded that the formation is entirely flow and pyroclastic rocks. This paper follows Schermerhorn's (1973) recommendation that the name "keratophyre" be applied to light-colored sodic intermediate albite porphyritic volcanic rocks and that the name "quartz keratophyre" be applied to leucocratic sodic felsic quartz-albite porphyritic or albite porphyritic volcanic rocks. His conclusion that most keratophyric rocks are in reality quartz keratophyre is strengthened by this study.

Porphyritic quartz keratophyre flow rocks have porcellaneous luster and conchoidal to subconchoidal fracture. Euhedral white phenocrysts of albite and partially resorbed phenocrysts of quartz 0.5–4.0 mm in diameter are set in a light-grayish-green silicified groundmass. In thin section, quartz phenocrysts show bipyramidal to completely rounded shapes, the latter due to magmatic resorption. Albite phenocrysts generally are clear but rarely show clouding due to replacement by fine-grained epidote and white mica. Primary mafic phenocrysts are absent, although chlorite replaces rare amphibole grains. Abundant quartz spherulites probably replace original glassy spherulites and variolites. Groundmass minerals are quartz, albite, chlorite (penninite), sphene, leucoxene, epidote, white mica, and rare hematite and calcite. The chlorite is responsible for the grayish-green color. Modal analyses of four quartz keratophyre flow rocks are given in table 1, and chemical analyses of two quartz keratophyre flow rocks are given in table 2. Chemical analyses of the quartz keratophyre flow rocks show relatively high amounts of SiO_2 and Na_2O and low FeO, Fe_2O_3, MgO, and CaO. Particularly signifi-

TABLE 1.—*Modal analyses of quartz keratophyre flow rocks from the Windy Ridge Formation*

[Approximately 1,000 points were counted for each thin section. VS5-1 and VS5-7 also were chemically analyzed (see table 2). Tr., trace amounts]

Mineral components	VS5-1	VS5-7	VS5-10	VC-127	Average
Albite phenocrysts	16.3	15.5	21.4	20.7	18.5
Quartz phenocrysts	10.2	7.5	6.4	13.8	12.6
Quartz and albite groundmass	62.0	74.5	54.0	61.3	62.9
Chlorite	9.6	....	16.4	2.1	7.0
Epidote	.3	Tr.	.8	.4	.4
Sphene and leucoxene	1.4	2.0	1.0	1.2	1.4
Calcite	....	.5	....	.1	.1
White mica	Tr.	Tr.	Tr.	Tr.	Tr.
Opaque minerals	.2	....	....	.4	.1
Total	100.0	100.0	100.0	100.0	100.0

TABLE 2.—*Chemical analyses of quartz keratophyre flow rocks from the Windy Ridge Formation*

[Analysis of VS5-1 by the U.S. Geological Survey rapid method used in Shapiro's laboratory (Shapiro and Brannock, 1962, supplemented by atomic absorption) and of VS5-7 by Rodey Batiza, supplemented by water and CO2 content determinations by Jerry Bode, Scripps Institution of Oceanography. n.d., not determined]

Oxide	VS5-1	VS5-7
SiO_2	75.70	73.50
TiO_2	.35	.37
Al_2O_3	13.00	12.70
Fe_2O_3	.54	n.d.
FeO	1.60	[1]2.19
MnO	.12	.09
MgO	1.10	2.08
CaO	.00	.50
Na_2O	5.70	4.19
K_2O	.18	.73
P_2O_5	.05	.04
H_2O^+	1.10	1.68
H_2O^-	.11	n.d.
CO_2	.02	.10
Total	99.57	98.17

[1]FeO is total iron.

cant are the high Na_2O and CaO values which reflect the high albite content. No calcic cores are evident in plagioclase of any thin section studied, suggesting that complete albitization occurred during metamorphism.

Low K_2O values probably indicate that the magmas were originally low in alkalis and that the later metasomatism is responsible for high sodium content; however, further studies are necessary to determine the origin of the sodium.

Pyroclastic tuff and tuff-breccia are poorly sorted and poorly stratified. Few bedding planes are apparent, and grading is rare. Clasts range from sand size to as much as 3 cm in diameter. All clastic rocks are composed of debris from a monolithologic quartz keratophyre and keratophyre source. Major components are quartz keratophyre and keratophyre rock fragments, quartz, albite, and recrystallized pieces of pumice set in a quartz and albite matrix.

The base of the Windy Ridge Formation is not exposed. The lower part of the formation is sheared and apparently is tectoncally mixed with underlying metamorphic and plutonic rocks of the Oxbow-Cuprum shear zone (Taubeneck, 1966, p. 2118), a tectonic-stratigraphic-plutonic unit that is well exposed in an area extending from Oxbow Dam northeast along Indian Creek to and beyond Cuprum, Idaho. The Oxbow-Cuprum shear zone consists of mylonite, gneissic mylonite, amphibolite, hornblende schist, plagiogranite (low-potassium trondhjemite, quartz diorite, and albite granite), metagabbro, metadiabase, and metabasalt. Tectonite fabrics parallel the northeast-trending shear zones, faults, and dikes. The Windy Ridge Formation probably was deposited on older plutonic rocks and subsequently incorporated tectonically during shearing and recrystallization.

The top of the Windy Ridge Formation also is difficult to map because of faulting. Along the northwest side of Windy Ridge, the formation is separated from the overlying Lower Permian Hunsaker Creek Formation by a high-angle fault. Elsewhere, along the central part of Windy Ridge, the boundary between the two formations was drawn where the grayish-green flow and volcaniclastic rocks of the Windy Ridge Formation are overlain either by a conglomerate or a mafic breccia of Hunsaker Creek lithology. This contact may be either an unconformity or a fault, but definite relations could not be established. Thickness of the Windy Ridge Formation is estimated at 500 m.

The Windy Ridge Formation is not known to crop out at any other place in northeastern Oregon and western Idaho and seems to be a local accumulation of silicic volcanic rocks, possibly associated both in time and space with the older plagiogranites of the Oxbow-Cuprum shear zone. There is no evidence that indicates whether eruptions were subaerial or submarine. The presumed high viscosity of the magma suggests that eruptions were very local and the deposit may in part represent a local lava and tuff dome. The rocks apparently were erupted prior to the deposition of the Lower Permian Hunsaker Creek Formation, but because of petrologic similarities between keratophyric rocks in both formations, it is possible that the Windy Ridge Formation is a lithofacies of the lower part of the Hunsaker Creek Formation. Until fossil or radiometric dates are available, the Windy Ridge Formation is considered to be either equivalent to or older than the Hunsaker Creek Formation and of probable Early Permian age. Therefore, these may be the oldest known volcanic rocks in a developing Permian island arc.

HUNSAKER CREEK FORMATION

The Hunsaker Creek Formation is here named for a thick sequence of metamorphosed strata exposed along the Snake River Canyon for nearly 15 km north of Oxbow and in the southeastern part of the Wallowa Mountains. Best exposures are in the Snake River Canyon, particularly canyons of tributary creeks including Hunsaker, Homestead, Herman, and Ballard Creeks, which enter the river from the Oregon side.

The type section (fig. 4) is designated as lying between the eleva-

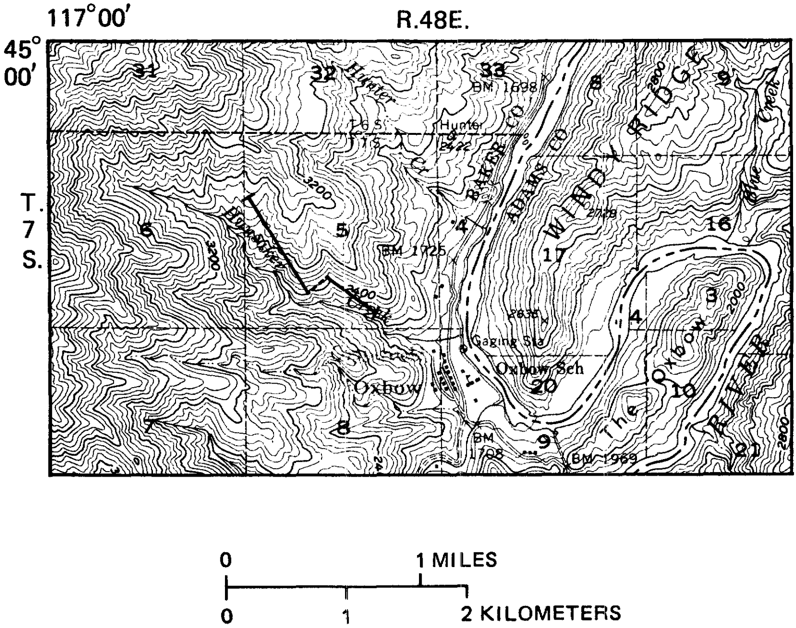

FIGURE 4.—Type section of the Hunsaker Creek Formation. Base from U.S. Geological Survey Copperfield 15-minute quadrangle, 1:62,500, 1957.

tions of 650 and 1,060 m (2,100 and 3,500 ft) on the north side of Hunsaker Creek, the first creek along the Oregon side of the river north of the town of Oxbow. The section is in the SW¼ sec. 5 and the NE¼ sec. 6, T. 7 S., R. 48 E., Copperfield 15-minute quadrangle. Neither the stratigraphic top nor the base of the formation is exposed in the type section, but it is considered to be most suitable because of the small amount of deformation, the thickness exposed (785 m), and the ease of access. Farther north at Ballard Creek a reference section (fig. 5) measures 676 m.

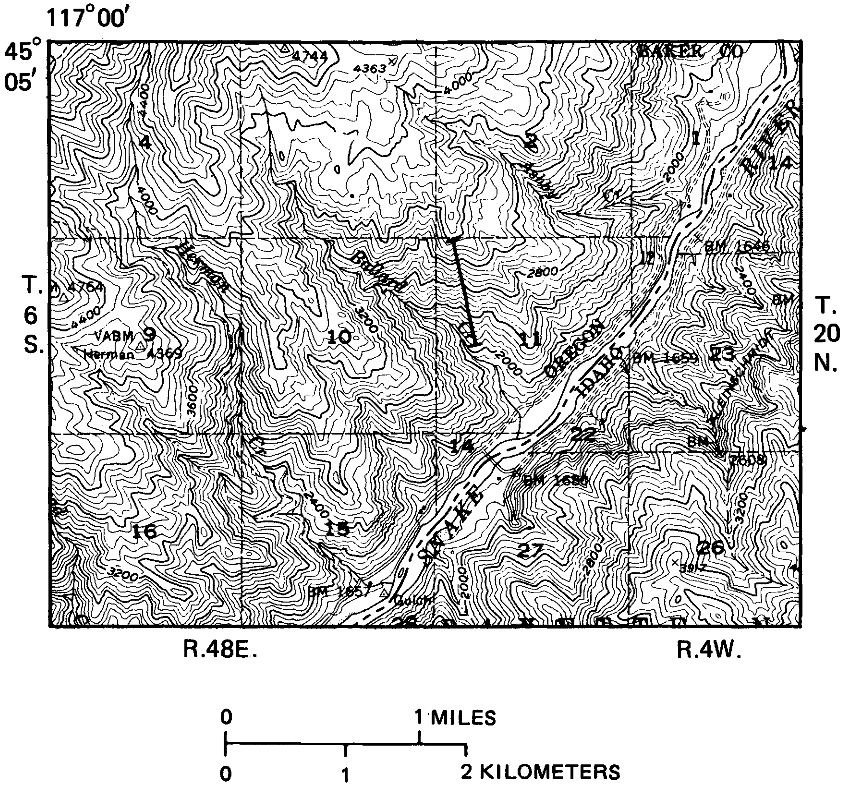

FIGURE 5.—Reference section of the Hunsaker Creek Formation along the north side of Ballard Creek. Base from U.S. Geological Survey Homestead 15-minute quadrangle, 1:62,500, 1957.

Type section, Hunsaker Creek Formation

Location: Copperfield 15-minute quadrangle, SW¼ sec. 5 and NE¼ sec. 6, T. 7 S., R. 48 E.; along north side of Hunsaker Creek between elevations of 650 and 1,060 m (2,100 and 3,500 ft); Hunsaker Creek is the first major creek north of Pine Creek near the town of Oxbow, Oreg.; descriptions aided by thin-section petrography of 35 rocks; measured by Jacobs Staff method. Deeply eroded rocks of the Hunsaker Creek Formation form the top of the measured section. Exact part of the formation is not known but most likely the section is near the base.

Unit	*Description*	*Cumulative thickness above base of section (m)*
33.	Spilite, greenish-black; weathers to dark-yellowish brown; fine grained, amygdaloidal; individual flows 3-5 m thick; forms rugged outcrops	785
32.	Volcanic siltstone (keratophyre tuff?), pale-green; weathers moderate yellowish brown; poorly sorted; angular grains; pebbly, silicified, and recrystallized matrix; graded in beds 30-70 cm thick	758
31.	Volcanic sandstone and volcanic siltstone, pale-red; weathers pale yellowish brown; graded beds 0.25-2 m thick; poorly sorted; angular fragments; probably tuffaceous	745
30.	Volcanic siltstone, grayish-olive; weathers pale yellowish brown; thin bedded; poorly sorted; pebbly; some grading	739
Fault; break in section		
29.	Volcanic siltstone, grayish-olive; weathers moderate yellowish brown; some grading; pebbly; poorly sorted; beds 10-90 cm thick	697
28.	Conglomerate, dark-greenish-gray; weathers yellowish brown; pebble to cobble size with some irregular blocks from 1 to 2 m in diameter; poorly sorted; weakly graded in beds 7-10 m thick, with thin siltstone beds at top of graded units; spilite and keratophyre clasts dominant	689
27.	Volcanic sandstone (keratophyre tuff?), grayish-green; weathers pale yellowish brown; grades to siltstone in 2-3-m-thick beds; moderate to poor sorting; crystals mostly feldspar; scattered pebbles up to 2 cm in diameter; faint cross-laminations in some beds	647
26.	Volcanic siltstone, grayish-olive; weathers light olive brown; silicified and recrystallized; sand in some thin beds 1-2 cm thick	615
25.	Volcanic sandstone (keratophyre tuff?), grayish-green; weathers pale yellowish brown; graded beds 0.5-1.5 m thick; coarse to fine grained; some beds moderately well sorted; faint cross-laminations	609
24.	Conglomerate, grayish-olive; weathers pale yellowish brown; pebble to cobble sizes 3-30 cm in diameter; clasts subrounded, composed of spilite, keratophyre, and volcaniclastic rocks	593
23.	Volcanic sandstone (keratophyre tuff?), grayish-olive; weathers light olive brown; poorly sorted; graded from coarse sand to coarse silt sizes; forms rugged cliffs	583
22.	Spilite, dusky-yellow-green; weathers moderate yellowish brown; fine grained; amygdaloidal; may be a sill; deeply weathered outcrop	570

Type section, Hunsaker Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (m)
21.	Volcanic sandstone (keratophyre tuff?), dusky-yellow-green and brownish-gray; weathers moderate yellowish brown; graded to siltstone in beds 0.3–1.5 m thick; pebbly in some beds; poorly sorted; angular grains, some matrices silicified	567
20.	Volcanic siltstone with some sandstone, breccia, and conglomerate, pale-grayish-green; weathers pale yellowish brown; graded beds; some tuffaceous; individual beds 0.5–2.0 m thick	543
19.	Conglomerate with some volcanic breccia and sandstone beds, pale-green; weathers pale yellowish brown; some grading; bedding planes poorly defined; in part pebbly mudstone; cut by 2-m-thick diabase dike near top; clasts in conglomerate mostly keratophyre with some spilite and volcaniclastic rocks	500
18.	Spilite tuff-breccia, greenish-black; weathers dark yellowish brown; poorly sorted; some interfingering spilite flows 1–2 m thick; deeply weathered; rounded outcrops	474
17.	Volcanic sandstone (keratophyre tuff?), pale-green; weathers pale yellowish brown; weak grading; poorly sorted; interbedded with some volcanic siltstone	458
16.	Spilite, dusky-yellow-green; weathers moderate brown; porphyritic with phenocrysts of feldspar up to 2 mm in diameter; deeply weathered; may be intrusive	449
15.	Volcanic breccia (keratophyre tuff breccia?), pale-green; weathers pale yellowish brown; poorly sorted; angular fragments 0.5–5 cm; keratophyre clasts; silicified matrix	442
14.	Volcanic siltstone (keratophyre tuff?), pale-green; weathers pale yellowish brown; silicified matrix	426
13.	Volcanic breccia; same as unit 15	422
12.	Volcanic breccia and volcanic sandstone, tuffaceous(?); greenish-gray; weathers pale yellowish brown; graded beds 3–5 m thick; poorly sorted, angular fragments; feldspar rich; largest clasts 5 cm in diameter; outcrops form rounded shoulders	415
11.	Spilite, greenish-black; weathers moderate brown; fine grained; may be intrusive	392
10.	Volcanic breccia and volcanic sandstone; same as unit 12	388
9.	Volcanic sandstone (keratophyre tuff?), grayish-green; weathers pale yellowish brown; some grading to coarse silt sizes; poorly sorted; angular fragments up to 2 cm in diameter in a sand matrix; recrystallized matrix	353
8.	Volcanic siltstone, grayish-green; weathers pale yellowish brown; weak grading; silicified matrix	310
7.	Volcanic breccia (keratophyre tuff breccia?), grayish-olive; weathers pale yellowish brown; graded to coarse sandstone in beds 2–3 m thick; clasts in breccia up to 6 cm in diameter; poorly sorted	302

Type section, Hunsaker Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
Fault; break in section		
6.	Spilite, greenish-black; weathers moderate brown; porphyritic with phenocrysts up to 3 mm in diameter; amygdaloidal	291
5.	Volcanic breccia, sandstone, and siltstone (pyroclastic?), grayish-green; weathers pale yellowish brown; graded beds 0.3–2.0 m thick; angular fragments; poorly sorted	289
Diabase dike cuts section here		
4.	Volcanic sandstone (keratophyre tuff?), grayish-green; weathers yellowish brown; poorly sorted; graded from coarse to fine sand in beds 0.7–2.0 m thick; abundant rock (keratophyre) fragments	275
3.	Volcanic sandstone (keratophyre tuff?), volcanic breccia, and quartz keratophyre flows, grayish-green; weathers pale yellowish brown; graded sequence of breccia to sandstone; poorly sorted; recrystallized and silicified matrixes; individual graded beds from 1.5 to 15 m thick; interbedded quartz keratophyre flows of same composition as volcaniclastic rocks	264
2.	Quartz keratophyre, yellowish-brown; weathers grayish orange; porphyritic; phenocrysts 1–3 m in diameter of plagioclase (albite) and quartz	94
1.	Conglomerate, grayish-green, weathers pale yellowish brown; poorly sorted, clasts 0.5–6.0 cm in diameter, well rounded; beds grade to volcanic siltstone; clasts are quartz keratophyre (60 percent), spilite (7 percent), and volcaniclastic rocks (33 percent)	24

Base is not exposed; basalts of the Columbia River Basalt Group overlap the section.

Total thickness of the exposed part of the Hunsaker Creek Formation is 785 m.

Reference section, Hunsaker Creek Formation

Location: Homestead 15-minute quadrangle, W½ sec. 11, T. 6 S., R. 48 E.; along north side of Ballard Creek between elevations of 640 and 1,100 m (2,100 and 3,600 ft); Ballard Creek is at the north end of the road that follows the Snake River on the Oregon side; a power-line road begins near the mouth of Ballard Creek. Descriptions aided by studies of 30 thin sections; measured by tape and Brunton and Jacobs Staff methods. Deeply eroded rocks of the Hunsaker Creek Formation form the top of the measured section. Exact part of the formation is not known but most likely the section is near the top.

Unit	Description	Cumulative thickness above base of section (*m*)
48.	Volcanic siltstone (keratophyre tuff?), grayish-green; weathers pale yellowish brown; graded from fine sand to fine silt in beds 0.3–1.0 m thick; poorly sorted; silicified and recrystallized matrices	676

Reference section, Hunsaker Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
47.	Volcanic breccia and volcanic sandstone, pale-green; weathers pale yellowish brown; graded beds 0.5–2.0 m thick; poorly sorted; rock fragments mostly chloritized mudstone clasts	672
46.	Volcanic sandstone (keratophyre tuff?), dusky-yellow-green; weathers pale yellowish brown; graded beds 1.2-3.0 m thick; upper 2 m is siltstone; poorly sorted; most sands are medium to fine grained; pebbly at some horizons	659
45.	Volcanic breccia and volcanic sandstone; same as unit 47	640
44.	Volcanic siltstone (fine keratophyre tuff?), pale-green; weathers light brown; sandy; poorly sorted; graded in beds 0.2–0.5 m thick	631
43.	Volcanic breccia and volcanic sandstone (keratophyre pyroclastic rocks?), grayish-green; weathers pale yellowish brown; graded beds 0.3–5 m thick; poorly sorted; largest clasts in breccia 3 cm in diameter	622
42.	Spilite; greenish-black; weathers dark yellowish brown; porphyritic, phenocrysts 0.5–1.5 mm in diameter	587
41.	volcanic breccia (keratophyre tuff-breccia?), pale-green; weathers light brown; poorly sorted; faint grading; volcaniclastic rock fragments dominant	575
40.	volcanic siltstone, volcanic sandstone, and volcanic breccia, dark-greenish-gray; weathers moderate brown; spilitic composition; graded beds 0.7–3.5 m thick; spilite breccia 10 m above base	569
39.	Quartz keratophyre, grayish-olive; weathers pale yellowish brown; porphyritic, phenocrysts of albite and quartz 0.2–0.5 mm in diameter; cliff former	549
38.	Volcanic sandstone (keratophyre tuff?), grayish-green; weathers pale brown; graded beds 0.3–1.0 m thick; poorly sorted; feldspar, quartz, and keratophyre rock fragments in a chloritic partly silicified matrix; angular fragments	532
37.	Volcanic breccia (spilite tuff-breccia?), greenish-black; weathers dark yellowish brown; spilitic composition; grades to sandstone (tuff) in beds 1.0–2.5 m thick; poorly sorted; calcareous; chloritic matrix; forms grassy slopes	518
36.	Spilite, greenish-black; weathers dark yellowish brown; porphyritic, phenocrysts 0.1–0.3 mm in diameter; may be a sill	440
35.	Volcanic sandstone and volcanic siltstone (keratophyre tuff?), grayish-green; weathers pale brown; graded in beds 0.2–0.8 m thick; poorly sorted; feldspar, quartz, and rock fragments in a partly silicified matrix	438
34.	Spilite tuff, greenish-black; weathers dark yellowish brown; graded beds 0.2–0.8 m thick; weathers to form grassy slopes	435

Reference section, Hunsaker Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (m)
33.	Volcanic sandstone (keratophyre tuff?), pale-green; weathers light brown; graded from coarse to fine sand; crystal rich with albite dominant	430
32.	Volcanic sandstone and volcanic siltstone, pale-green and dusky-red; weathers in shades of brown; graded in beds 0.2-0.4 m thick; poorly sorted	418
31.	Volcanic breccia (keratophyre tuff breccia?), grayish-green; weathers pale brown; graded; poorly sorted	413
30.	Volcanic sandstone, grayish-green; weathers pale yellowish brown; graded in beds 0.2-0.8 m thick; coarse to medium sand sizes; poorly sorted; some grains are rounded	409
29.	Volcanic sandstone, dusky-red; weathers light brown; medium grained; poorly sorted	396
28.	spilite tuff, greenish-black; weathers dark yellowish brown; fine grained, graded beds 0.2-1.0 m thick	395
27.	Volcanic breccia and volcanic sandstone (keratophyre tuff-breccia and tuff?), grayish-green; weathers light brown; graded beds 0.3-2.0 m thick; angular clasts; poorly sorted	392
26.	Volcanic siltstone (keratophyre tuff?), grayish-green, weathers light brown; poorly sorted; sandy; fine grading in beds 0.1-0.3 m thick	380
25.	Volcanic sandstone, volcanic siltstone, and volcanic breccia (keratophyre tuff and tuff-breccia?), pale-green; weathers light brown; graded beds 1.0-2.5 m thick; poorly sorted; banded on weathered outcrops	377
24.	Volcanic siltstone, very dusky red; weathers dark yellowish brown; fine grained; beds 0.2-0.4 m thick; faint grading	353
23.	Volcanic sandstone and volcanic siltstone (keratophyre tuff?), pale-green; weathers pale brown; graded in beds 0.3-3.0 m thick; poorly sorted; angular fragments; finer grained beds are laminated; cliff former	349
22.	Spilite, greenish-black; weathers dark yellowish brown; porphyritic; phenocrysts 0.2-0.5 mm; may be intrusive	330
21.	Volcanic siltstone (keratophyre tuff?), pale-green; weathers pale brown; fine grained; faint grading	329
20.	Volcanic siltstone and volcanic sandstone (keratophyre tuff?), pale-green; weathers light brown; graded beds 0.3-2.5 m thick; poorly sorted; angular grains	326
19.	Volcanic sandstone and volcanic siltstone (keratophyre tuff?), pale-green; weathers light brown; graded beds 2-30 cm thick; poorly sorted; penecontemporaneous deformation structures common; banded appearance in outcrop	309
18.	Spilite, blackish-green; weathers dark yellowish brown; vesicular; cliff former; flows 3-5 m thick	297

Reference section, Hunsaker Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
17.	Quartz keratophyre flows and tuffs, grayish-green; weathers light brown; flow rocks 1.5–3 m thick and interlayered with crystal tuff of same composition; tuff beds are graded in beds 0.2–1.5 m thick	283
16.	Volcanic siltstone (keratophyre tuff?), greenish-gray, weathers light brown; pebbly; abundant matrix; weakly graded in thin beds	252
15.	Volcanic sandstone and volcanic siltstone (keratophyre tuff?), pale-green; weathers light brown; graded beds 0.7–3.5 m thick; poorly sorted; angular fragments; banding common in finer grained beds; siltstone is silicified	250
14.	Spillite tuff-breccia, brownish-black; weathers dusky yellowish brown; clasts 0.5–5.0 cm; graded beds 0.7–4.5 m thick	232
13.	Volcanic sandstone, volcanic siltstone, and volcanic breccia (keratophyre tuff and tuff-breccia?), pale-green; weathers light brown; graded beds 0.3–3.0 m thick; poorly sorted; large (5 mm) quartz and albite crystals in pale green; partly silicified matrix	183
12.	Spilite, greenish-black; weathers dark yellowish brown; porphyritic, phenocrysts 0.2–2.5 mm in diameter; amygdaloidal	131
11.	Volcanic siltstone, volcanic sandstone, and volcanic breccia (keratophyre tuff and tuff-breccia?), pale-green; weathers light brown; graded beds 1.0–4.5 m thick; angular to subangular grains	124
10.	Volcanic siltstone, grayish-purple; weathers dark yellowish brown; pebbly; poorly sorted; pebbles subrounded	69
9.	Spilite tuff-breccia, greenish-black; weathers dark yellowish brown; clasts 2.0–4.0 cm; weakly graded in beds 1.0–2.5 m thick	68
8.	Spilite, greenish-black; weathers dark yellowish brown; porphyritic; phenocrysts 0.3–1.0 mm in diameter	65
7.	Volcanic sandstone and volcanic siltstone (keratophyre tuff?), grayish-green; weathers light brown; graded beds 0.3–2.5 m thick; poorly sorted; angular fragments; some breccia	64
6.	Volcanic siltstone, grayish-green; weathers light brown; poorly sorted; graded; pebbly; pebbles up to 1.0 cm in diameter and subrounded	52
5.	Spilite tuff, dark-greenish-gray; weathers dark yellowish brown; graded beds 0.2–2.5 m thick; poorly sorted; feldspar phenocrysts and microlites scattered irregularly in a chloritic matrix	51
4.	Volcanic sandstone (keratophyre tuff?), grayish-green and moderate-red; weathers to light brown and dark yellowish brown; graded beds 0.2–3.0 m thick; poorly sorted	37

Reference section, Hunsaker Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
3.	Spilite, dark-greenish-gray; weathers yellowish brown; porphyritic; amygdaloidal	10
2.	Volcanic siltstone and volcanic sandstone (keratophyre tuff?), grayish-green; weathers pale brown; graded; some load casts apparent	5
1.	Spilite tuff, dark-maroonish-black; weathers dark yellowish brown; coarse grained; poorly sorted; spilite rock fragments and feldspar crystals set in a maroonish-black matrix	2

Base of section is near the bed of Ballard Creek about 100 m west of the Idaho Power and Light Company powerline road. This is not the base of the formation.
Total thickness of the reference section is 676 m.

The formation is distinguished from the underlying Windy Ridge Formation by the presence of abundant conglomerate, volcanic sandstone, keratophyric water-laid tuff, mafic breccia, and spilite flows. In most outcrops the formation is difficult to distinguish from the overlying Wild Sheep Creek Formation, the lower part of which is predominantly volcaniclastic rocks of keratophyric (andesitic) composition. The probable base of the formation is exposed on Windy Ridge in the Blue Creek drainage basin, and the top is poorly exposed in the Homestead Creek drainage basin (Vallier, 1967; Brooks and Vallier, 1967) and in the southeastern Wallowa Mountains near Fish Lake (Wetherell, 1960). The upper contact, believed to be an unconformity, is generally difficult to map because of similarities of rock type and structural complications. Angularity of strata across the unconformity cannot be established in either area, although that possibility should not be discarded because the evidence is inconclusive.

The total thickness of the Hunsaker Creek Formation is not known. The sections at Hunsaker and Ballard Creeks probably are not equivalent, and together they total nearly 1,500 m. An estimate of 2,500 m seems valid, although it may be conservative. In the southeastern Wallowa Mountains, if there is no significant repetition due to faulting, the thickness may be as much as 3,500 m.

Rocks are mostly volcanogenic, consisting of pyroclastic breccia, agglomerate, tuff, epiclastic volcanic breccia, conglomerate, sandstone, siltstone, and minor limestone with quartz keratophyre and spilite flow rocks. The flow rocks form only a small part of the formation, but small hypabyssal plutons of quartz keratophyre and metamorphosed mafic rocks are common. Most volcaniclastic beds are vertically graded, and some sequences of graded beds are more than 150 m thick in the Hunsaker Creek area. Many of these clastic beds are feldspathic tuffs, whereas others contain a large diversity of clast types from several different source areas.

Volcanic flow rocks are mostly spilite and quartz keratophyre. Quartz keratophyre flow rocks occur in scattered discontinuous outcrops and range in thickness from 3 to 20 m. Small hypabyssal plutons of the same composition are common. All quartz keratophyre specimens examined in thin section are porphyritic, consisting of albite and quartz phenocrysts set in a felty, trachytic, or completely recrystallized groundmass. Quartz phenocrysts range in shape from bipyramidal to rounded, depending on the amount of resorption.

Mafic minerals are generally absent from the quartz keratophyre; chlorite replaces some small amphibole grains. Major groundmass minerals are quartz, albite, chlorite, calcite, sphene, white mica, and hematite. Minor amounts of epidote and prehnite occur along some thin veins. Mineralogies show a near equilibrium in the greenschist facies, with albite the only plagioclase present. The rocks have undergone variable recrystallization and silica-sodium metasomatism. Recrystallized quartzose groundmasses, which often contain quartz spherulites, probably are the result of glass devitrification and later metamorphism. Low values of potassium and calcium combined with a high sodium content (table 3) indicate significant amounts of large ion mobility, although the time and amount of mobilization are not known.

Spilite occurs as flows and irregular hypabyssal intrusions. Flows are generally no thicker than 5 m. Most specimens are porphyritic, with phenocrysts of plagioclase and clinopyroxene (or chlorite pseudomorphs of clinopyroxene) set in groundmasses having intergranular, diabasic, and pilotaxitic textures. Major oxide composition of two spilites are given in table 3, and modal analyses of three representative spilite specimens are given in table 4. The original basalts probably were low-potassium tholeiites.

Pyroclastic rocks include keratophyre and spilite tuff-breccia, agglomerate, and coarse- and fine-grained tuff. Individual units, generally comprising several beds, reach thicknesses of 50–100 m. Crystal tuff beds in the type section of the Hunsaker Creek Formation are graded, with plagioclase crystals up to 5 mm in length in a chlorite matrix. Clasts in spilitic breccias, some more than 1 m in diameter, are set in a dark-green chlorite matrix.

True epiclastic beds, particularly those of smaller grain sizes, are difficult to distinguish from tuff. However, a large part of the

TABLE 3.—*Quartz keratophyre and spilite chemistries from the Hunsaker Creek Formation*

[Analyses by U.S. Geological Survey laboratory (Shapiro and Brannock, 1962)]

Oxide	VC-15 (Quartz keratophyre)	VC-131 (spilite)	VC-197 (spilite)
SiO_2	78.70	51.90	51.40
TiO_2	.24	1.80	.88
Al_2O_3	11.90	15.90	16.40
Fe_2O_3	1.00	4.30	2.80
FeO	.16	5.10	5.00
MnO	.04	.20	.16
MgO	.24	3.30	7.40
CaO	.00	9.60	6.00
Na_2O	5.80	3.00	4.00
K_2O	.15	.02	.08
P_2O_5	.08	.35	.20
H_2O^+	.57	3.10	4.10
H_2O^-	.15	.36	.79
CO_2	.06	.05	.08
Total	99.09	98.98	99.29

TABLE 4.—*Modal analyses of three spilites, Hunsaker Creek Formation*

[Tr., trace]

Mineral	LS9-3	LS9-4	VC-197
Plagioclase	70.1	73.1	50.6
Augite	....	....	5.9
Opaque minerals	.2	1.1	.2
Chlorite	21.1	25.1	36.5
Calcite	4.4	.1	Tr.
Sphene	.6	Tr.	6.8
Leucoxene	.6	.3	Tr.
Quartz	3.0	.3	Tr.
White mica	....	....	Tr.
Epidote	....	....	Tr.
Total	100.0	100.0	100.0

clastic rocks, estimated to be at least 50 percent of the formation, is epiclastic conglomerate, breccia, sandstone, and siltstone. Dominant components in the coarser grained beds are clasts of quartz keratophyre and spilite. In finer grained beds, crystals of albite, quartz, and lithic fragments are set in a green chlorite matrix. Sandstone mostly is volcanic graywacke (modal analyses of representative volcanic graywackes are given in table 5). Volcanic siltstone makes up a large percentage of the epiclastic rocks. Studies of 41 thin sections show that the siltstone has components with the following ranges: matrix of chlorite, clay, fine-grained fragments, and very fine grained quartz and feldspar (70–80 percent); plagioclase grains (10–15 percent); quartz (3–5

TABLE 5.—*Modal analyses of volcanic graywacke, Hunsaker Creek Formation, in volume percent*

[1,000 points counted. Tr., trace]

Mineral	LS7-23	T-1-1-12	VC-286
Plagioclase	21.1	29.2	68.4
Quartz	30.8	18.8	14.8
Rock fragments	4.6	3.2	1.6
Quartz/albite matrix	40.5	45.5	4.4
Iron ore	1.9	.5	.9
Chlorite	.3	.5	9.1
Calcite	.5	1.7	.3
Sphene/leucoxene	.3	.8	.5
White mica	Tr.	.8	Tr.
Epidote	Tr.	Tr.	Tr.
Totals	100.0	100.0	100.0

percent); and rock fragments (1-3 percent). Minor constituents are calcite, sphene, leucoxene, white mica, epidote, and prehnite.

Conglomerate makes up to least 10 percent of the formation. All gradations exist between pebbly mudstone and well-sorted conglomerate with clasts of cobble and boulder sizes. Some beds are more than 20 m thick and have clasts up to 30 cm in diameter. Pebble counts at six conglomerate outcrops indicate the following clast proportions: quartz keratophyre (50 percent); volcaniclastic rocks (35 percent); spilite (8 percent); and unknowns (7 percent). Rare clasts of quartz diorite and quartz-bearing gabbro also occur.

Current measurements in epiclastic rocks show that many currents were from the southwest and west. Coarse breccia and conglomerate are slightly more abundant in the western part of the mapped area, suggesting a western source. Volcanism was contemporaneous with tectonism, erosion, and deposition; many of the tuff beds probably are the result of subaqueous pyroclastic flows. Clasts of gabbro and quartz diorite in conglomerates indicate deep erosion of the source terrane.

The Hunsaker Creek Formation is of Early Permian age. F. G. Stehli (written commun., 1965) reported that brachiopod faunas are of Leonardian or Guadalupian age and most likely are of Word (Guadalupian) age. Some of the Clover Creek Greenstone in the Wallowa Mountains is of Permian and Triassic age; the Permian rocks probably are equivalent to parts of the Hunsaker Creek Formation.

The Hunsaker Creek Formation records an important step in the evolution of a volcanic arc in the Pacific Ocean during the Early Permian Epoch. Andesitic and dacitic volcanism indicates extensive silicic volcanism and strongly suggests that subduction was occurring along the arc. The exposed Permian rocks are only a small remnant of a previous large and extensive island arc complex, most of which has been subducted and incorporated into the present continental crust. Limestone lenses and pods in the Elkhorn Ridge Argillite are in part correlative with rocks of the Hunsaker Creek Formation. No paleogeographic reconstruction is attempted in this report, however, because the limestone bodies probably are allochthonous and may be floating in chert and argillite of much younger age (Jones and others, 1976). There is a distinct possibility that the Elkhorn Ridge Argillite and Hunsaker Creek Formation were deposited on different plates which are now juxtaposed.

WILD SHEEP CREEK FORMATION

The Wild Sheep Creek Formation is here named for a thick metamorphosed unit of basalt, basaltic andesite and andesite (now mostly spilite and keratophyre) flows and volcaniclastic rocks, graywacke, argillite, and limestone that is widely exposed in the Snake River Canyon and the Seven Devils Mountains. Excellent exposures occur along a large part of the canyon, particularly near Wild Sheep, Bull, Saddle, and Cherry Creeks.

The best exposures are in Bull and Saddle Creeks. The type section (fig. 6) is designated as the spur between Saddle and Hat Creeks, starting near the Snake River from 425 to 900 m elevation (1,400-3,000 ft), where about 830 m of strata are well exposed. The names Saddle Creek and Bull Creek have been used for other rock-stratigraphic units in the United States, so the name Wild Sheep Creek Formation was chosen because Wild Sheep Creek is the nearest geographic feature of note to the type section and because the exposures also are good along it. However, the type section was chosen near Saddle Creek because of good exposure and ease of access. Wild Sheep and Bull Creeks can be reached only by boat from Hells Canyon Dam, whereas Saddle Creek is accessible by boat from the lower parts of the Snake River and by trail from the road that leads to Hat Point from Imnaha, Oreg. A reference section (fig. 7) was chosen from an area farther north, along Cherry Creek, where about 440 m of strata were described.

Type section, Wild Sheep Creek Formation

Location: He-Devil 15-minute quadrangle, unsurveyed part of the Snake River Canyon, Oreg. Spur north of the mouth of Saddle Creek, across Snake River from the NE¼ sec. 30, T. 24 N., R. 2 W., in Idaho. Section is between 425 and 900 m elevation (1,400-3,000 ft). Tape and Brunton method used. Rocks are metamorphosed to the greenschist facies. Assisted by David Fredley. Top of ridge, grassy slope; not top of formation.

Unit	*Description*	*Cumulative thickness above base of section (m)*
21.	Diabase, grayish-black; weathers pale brown; coarse grained; may be a sill	830

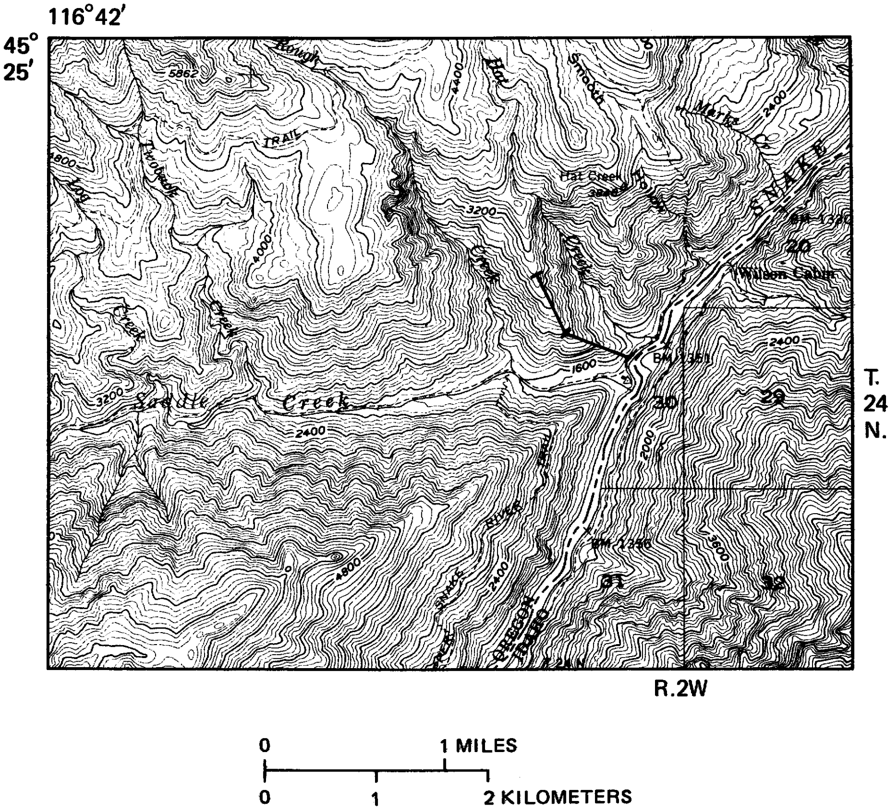

FIGURE 6.—Type section of the Wild Sheep Creek Formation. Base from U.S. Geological Survey He-Devil 15-minute quadrangle, 1:62,500, 1957.

Type section, Wild Sheep Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
20.	Basalt breccia, greenish-black; weathers dark yellowish brown; clasts 1–2 cm in diameter in a chlorite matrix; poorly sorted; bedding is indistinct	822
19.	Volcanic breccia, pale-green; pale-green, gray, and light-gray clasts; weak grading to sand sizes in beds 0.3–4.5 m thick; some quartz in matrix; clasts angular to subrounded; rare volcanic sandstone beds about 0.2 m thick	810
18.	Diabase; see unit 21 for description	792
17.	Volcanic breccia; see unit 19 for description	786
16.	Diabase; see unit 21 for description	759
15.	Volcanic breccia and volcanic sandstone, light-green; weathers to pale brown; clast sizes up to 10 cm but average 1–2 cm; graded units 5 m thick near base and 0.5–1.0 m thick near top; clasts angular to subrounded; clasts	

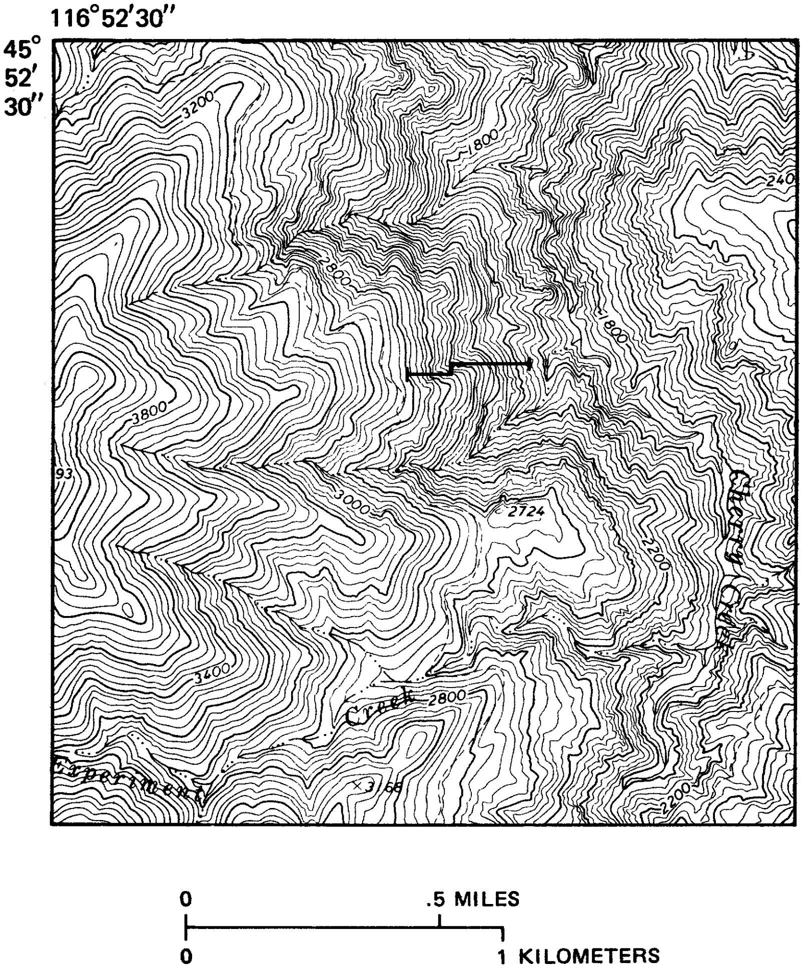

FIGURE 7.—Reference section of the Wild Sheep Formation. Base from U.S. Geological Survey Deadhorse Ridge 7½-minute quadrangle, 1:24,000, 1963.

Type section, Wild Sheep Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
15.	Volcanic breccia, etc.—Continued mostly volcanic flow rocks with some volcaniclastic rocks; much less quartz than in unit 19 but still noticeable in hand specimens	747
14.	Limestone, dark-gray; weathers very pale brown; argillaceous; thin bedded	699

Type section, Wild Sheep Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
13.	Volcanic sandstone and volcanic siltstone, grayish-green; weathers pale brown; graded beds 0.2–4.0 m thick; rare breccias at base of thicker graded beds; siltstones are darker colored and partly silicified; sandstones have abundant feldspar and quartz with some rock fragments	697
12.	Volcanic breccia, volcanic sandstone, and volcanic siltstone in graded beds from 0.1 to 7 m thick; breccias massive in lower parts with clasts up to 5 cm in diameter; sandstones are grayish green with white feldspar and gray quartz crystals up to 0.5 cm in diameter; quartzose volcanic arkoses; siltstones are silicified with rare rip-up clasts of sandstone in some thin beds	646
11.	Basalt, dark-greenish-black; weathers to dark yellowish brown; porphyritic with phenocrysts up to 0.7 cm in length; some thin flow breccia units; flow banding common in porphyritic units; individual flows 10–20 m thick	588
10.	Basalt-breccia, green and grayish-red; weathers yellowish brown; some grading	493
9.	Basalt pillow breccia, greenish-black; weathers dark yellowish brown; clasts, many of them fragments of pillows, are 2–75 cm in diameter; bedding is indistinct	488
8.	Basalt, dark-greenish-black; weathers yellowish brown; series of thin flows 0.5–3 m thick; fine to medium grained; rare amygdules	467
7.	Basalt pillow breccia, dark-greenish-black; weathers dark yellowish brown; monolithologic; clasts 0.1–0.5 m in diameter; indistinct bedding; basalt flows and dikes(?) up to 1 m thick cut the sequence; pillow rinds and some nearly complete pillows are common; matrix is composed of small basalt fragments and chlorite	447
6.	Basalt, dark-greenish-black; weathers dark yellowish brown; medium grained; highly fractured; flows 2–3 m thick	127
5.	Covered area; probably fine-grained volcaniclastic rock	114
4.	Basalt; same as unit 6	98
3.	Basalt pillow breccia; same as unit 7	80
2.	Covered area; probably fine-grained volcaniclastic rock	53
1.	Basalt pillow breccia; same as unit 7; flows, 1–4 m thick, are more abundant than in other units	45

Base of the formation is not exposed; total thickness of the measured type section is 830 m.

Reference section, Wild Sheep Creek Formation

Location: Deadhorse Ridge 7½-minute quadrangle, unsurveyed part of the Snake River Canyon area in eastern Oregon, near the north edge of the quadrangle. Section was measured along north side of an unnamed creek about 1 km north of Experiment Creek, an east-draining tributary of Cherry Creek. Section described beginning near the creekbed of Cherry Creek, elevation from 580 to 855 m (1,900-2,800 ft). Tape and Brunton method used. Rocks are metamorphosed to the greenschist facies. Assisted by David Fredley and Larry Klueh. Top is grassy slope, not top of section.

Unit	*Description*	*Cumulative thickness above base of section (m)*
23.	Breccia, dark-green; weathers moderate brown; clasts 1-10 cm in diameter; clast compositions are siltstone, argillite, and basalt; beds graded, 1-2 m thick	440
22.	Siltstone, argillite, and sandstone, light-green; weathers pale brown; graded beds 0.3-40 cm thick alternating with argillite beds	426
21.	Basalt, dark-greenish-black; weathers yellowish brown; medium grained; porphyritic, with phenocrysts up to 3 mm in length; individual flows 3-15 m thick	417
20.	Basalt, dark-greenish-black; weathers yellowish brown; medium grained; porphyritic, with phenocrysts up to 3 cm in length; thick flows	341
19.	Basalt, greenish-black; weathers dark yellowish brown; fine grained; nonporphyritic; individual flows 2-8 m thick	317
18.	Basalt; same as unit 21	301
17.	Basalt; same as unit 20	296
Section cut by diorite sill, about 5 m thick.		
16.	Basalt; same as unit 21	283
15.	Basalt; same as unit 20	239
14.	Basalt, dark-greenish-gray; weathers yellowish brown; porphyritic, with phenocrysts up to 5 mm in length; one flow unit	236
13.	Basalt breccia, greenish-gray; weathers yellowish brown; clasts up to 3 cm in diameter; faint bedding; chlorite matrix; weathers to grassy slope	230
12.	Basalt; same as unit 21	224
11.	Covered area; probably fine-grained volcaniclastic rocks	181
10.	Siltstone and argillite, black; weathers dark brown; thin beds 1-40 cm thick; faint grading in one bed	176
9.	Covered area; probably same as unit 12	170
8.	Basalt, dark-greenish-black, weathers yellowish brown; flows 2-4.5 m thick; porphyritic, with feldspar phenocrysts 2-4 mm in length; highly fractured	165
7.	Limestone, siltstone, and argillite; beds 1-30 cm thick; some grading; fossil fragments; limestone is dark gray and argillaceous; siltstone is calcareous; some grading in thicker siltstone beds; weathers to gentle grassy slope	152

Reference section, Wild Sheep Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
6.	Basalt, dark-greenish-black; weathers to yellowish brown; flows 2-5 m thick; fine grained; some flows are porphyritic with phenocrysts 2-8 mm in length; fractured rocks	126
5.	Covered area; probably a basalt breccia	81
4.	Basalt; same as unit 6	77
3.	Covered area; fragments of limestone and argillite; probably a limestone, siltstone, and argillite unit similar to unit 7	45
2.	Basalt; same as unit 6	17
1.	Basalt breccia, dark-greenish-gray; weathers yellowish brown; clasts of basalt 3-8 cm in diameter in a chlorite matrix; weakly bedded	6

Base of the formation is not exposed; total thickness of the reference section is 440 m.

Distinguishing characteristics are rugged outcrops, thick flow and volcaniclastic units, dark-green and greenish-black colors on fresh surfaces, and the metamorphosed basalt, basaltic andesite, and andesite compositions of the flows and coarse volcaniclastic beds. Argillite and graywacke form units more than 100 m thick that increase in relative abundance toward the north; excellent exposures are found near the mouth of the Salmon River. Limestone units also are more abundant and thicker in the northern part of the area and are especially well exposed between the mouths of the Salmon and Grande Ronde Rivers.

The Wild Sheep Creek Formation unconformably overlies the Hunsaker Creek Formation in the southern part of the Snake River Canyon. In the Wallowa Mountains, lithologically correlative rocks are assigned to the Clover Creek Greenstone. In the Sparta region, south of the Wallowa Mountains, correlative rocks overlie gabbro and quartz diorite (Prostka, 1963).

The formation is conformably overlain by the Doyle Creek Formation and unconformably by the Coon Hollow Formation near Jim Creek in the northern part of the Snake River Canyon. Where the maroon Doyle Creek Formation overlies the Wild Sheep Creek Formation along the walls of the Snake River Canyon, there is a gradation from dark-green and greenish-black flows and volcaniclastic rocks to maroon volcaniclastic and flow rocks, with conglomerate and other epiclastic rocks becoming more abundant with stratigraphic elevation. Because of rapid lithofacies changes over short distances, structural deformation, and a lack of good fossil control, criteria were not available in all areas to distinguish the formations; therefore, the boundaries will need further refinement after additional studies. Probably the best distinguishing characteristic is the abundance of maroon epiclastic debris in the Doyle Creek Formation; the base of the Doyle Creek Formation may best be placed at the bottom of the lowermost conglomerate or epiclastic sandstone bed in the maroon-colored unit. In the Pittsburg Landing area the contact between the Wild Sheep Creek and Doyle Creek Formations is poorly defined. In general, it was drawn where dominantly brown epiclastic debris overlies greenish-black volcanic flows and thick coarse-grained volcaniclastic units.

In general, three units can be distinguished in the Wild Sheep Creek Formation. The lower part is mostly volcaniclastic, with keratophyric (andesitic) compositions dominant. Good exposures are along the ridge north of Homestead Creek and near the mouth of Salmon River, where argillite and sandstone sequences are exposed. The thick middle unit is mostly spilitic (basaltic) in composition with massive and pillowed flows, thick beds of coarse breccia, and mafic tuff beds dominant. Good exposures of this unit are near Hells Canyon Dam, at Saddle Creek, and along the river near the mouth of Jones Creek. The upper unit is mostly a mixture of spilitic and keratophyric clastic rocks, argillite, and limestone. Sandstone beds are notably quartz rich. Good exposures are near the top of the section in the Bull, Cache, and Saddle Creek areas and in the Cherry and Cook Creek areas. These units are not easily distinguished in the southern part of the area between Ashby Creek and Lynch Creek because of abundant lithofacies changes and structure.

Maximum thickness of the Wild Sheep Creek Formation is estimated to be 2,500 m. Thickest individual sections are near the type area and in the Seven Devils Mountains. The formation seems to thin both to the north and south, although this might be due to structurally related differential erosion.

Major lithologies are massive lava flows, pillow lavas, flow and pillow breccia, and volcaniclastic rocks. Most are of metamorphosed basalt, basaltic andesite, and andesite (spilite and keratophyre) compositions. Epiclastic rocks, including breccia, conglomerate, graywacke, and argillite are important contributors, and in places argillaceous limestone makes up a significant part of the stratigraphic section. All rocks are metamorphosed to the greenschist facies, although most mineral assemblages have not reached equilibrium in that facies.

Basaltic rocks are mostly massive and pillowed flows and flow and pyroclastic breccia. Some flows reach thicknesses of 20 m, whereas local accumulations of breccia are as thick as 100 m. Primary textures in flow rocks are dominantly glomerophyric, pilotaxitic, and porphyritic intergranular. In some flow rocks, phenocrysts are up to 5 cm long and glomerols form clusters and rosettes 3–7 cm in diameter. Dominant minerals are plagioclase, clinopyroxene, iron ore, chlorite, epidote, calcite, quartz, prehnite, sphene, leucoxene, and white mica (table 6). Plagioclase compositions range from labradorite to albite as determined by optics and X-ray diffraction. Common alteration minerals of the plagioclase are epidote, chlorite, calcite, and white mica. Fresh clinopyroxene (augite) crystals occur in many of the flow rocks, but generally they are partly or wholly replaced by chlorite and epidote, rarely by actinolite. Chlorite pseudomorphs after olivine are evident in a few thin sections. Iron ores are mostly magnetite, although titaniferous magnetite and ilmenite, often partially replaced by leucoxene, are common. Calcite occurs in veins, as a pseudomorph mineral, and as granoblastic growths in fine-grained groundmasses.

The flow rocks show a wide range in major oxides (table 7). Most are poor in potassium, and there are wide variations in sodium contents. Silica content ranges from about 50 to nearly 60 percent for the basic rocks and is greater than 60 percent for keratophyric rocks.

Flow rocks of keratophyric composition are light green and light maroon and contain small phenocryst of feldspar in a quartzose groundmass. These probably make up no more than five percent of the flow rocks. However, there are localities where they are more abundant. One of these localities is along the IPALCO (Idaho Power and Light Company) road, across from McGraw Creek, where both flow and pyroclastic rocks are exposed.

Epiclastic and pyroclastic rocks, like the volcaniclastic rocks of the Hunsaker Creek Formation, are difficult to distinguish. This is particularly true of units that have been derived from a monolithologic terrane and have undergone metamorphism. Without good criteria such as the presence of pumice and fine ash, lobate and cuspate volcanic rock fragments, and glass shards, origins generally cannot be distinguished. Volcaniclastic rocks occur in bold outcrops all along the IPALCO road between Limepoint Creek and Big Bar. Many of these probably are pyroclastic. Dark-green, light-green, and maroon clasts are set in a light-green or light-maroon matrix. Some beds are graded, whereas others are massive.

Epiclastic rocks are dominant over pyroclastic rocks in the

TABLE 6.—*Modal analyses of representative flow rocks, Wild Sheep Creek Formation*

[VC-262 groundmass of quartz and plagioclase; Tr., trace; 1,200 points counted]

Mineral	VC-269 (spilite)	VB-87 (spilite)	VB-85 (spilite)	VC-262 (quartz keratophyre)
Plagioclase phenocrysts	24	11	11	12
Plagioclase microlites	39	66	39	15
Clinopyroxene	16	2	36	
Opaque minerals	9	4	2	2
Quartz	3	1		1
Epidote	Tr.	7	4	Tr.
Chlorite	2	6	6	3
White mica	6			
Prehnite	1			
Sphene			1	Tr.
Leucoxene			1	Tr.
Calcite		1		1
Groundmass		2		66
Total	100	100	100	100

TABLE 7.—*Chemical analyses of representative flow rocks from the Wild Sheep Creek Formation*

[Analysis by R. Batiza; see table 6 for rock types]

Oxide	VC-269	VB-87	VB-85	VC-262
SiO_2	50.60	55.60	48.20	73.60
TiO_2	.99	1.20	2.09	.36
Al_2O_3	17.50	15.80	15.00	14.10
FeO(total iron)	9.17	8.59	12.92	2.25
MnO	.19	.19	.22	.05
MgO	4.57	3.95	5.87	.01
CaO	8.17	7.82	7.99	.57
Na_2O	4.74	5.77	4.76	5.99
K_2O	1.00	1.15	.20	.82
P_2O_5	.12		.31	.04
Total	97.05	100.07	97.56	97.79

formation. Most are conglomerate, breccia, graywacke, siltstone, and argillite. Conglomerate is abundant along Grassy Ridge north of Kinney Creek, where beds range in thickness between 1 and 15 m. Clast sizes reach 15 cm; all are well rounded to subrounded and are composed of vesicular basalt (spilite). Breccias are the dominant volcaniclastic deposits; most are composed of basaltic clasts in a chloritic sandy matrix. Clasts in breccias that crop out just north of Pittsburg Landing along the Snake River are as long as 5 m. Graywacke is an abundant rock type. In the lower parts of the formation, graywackes are made up of andesitic rock fragments and feldspar in a matrix of chlorite or calcite or both. In the upper parts of the formation, however, quartz and feldspar are the major components, and many beds are arkosic. Some siltstone and argillite beds are silicified, and one thin section from a silicified argillite on Grassy Ridge contains spherical chalcedonic structures that probably are recrystallized Radiolaria tests.

Limestone beds in the Wild Sheep Creek Formation are exposed in several parts of the Snake River Canyon and in the southeastern Wallowa Mountains. Best exposures are along Bull, Hat, Cherry, and Jim Creeks, where argillaceous limestone occurs in units as much as 100 m thick. Some recrystallized lenses of carbonate as much as 0.5 km in length probably mark massive submarine slides. These protrude as rugged shoulders along the canyon walls and should not be confused with the bedded limestone units.

The Wild Sheep Creek Formation is latest Middle Triassic (Ladinian) on the basis of species of *Daonella* and early Late Triassic (Karnian) on the basis of species of ammonites (age determinations by N. J. Silberling). Correlative rocks include the upper part of the Clover Creek Greenstone in the Wallowa Mountains and the Upper Triassic volcanic rocks (Brooks and others, 1977) that are exposed near Huntington, Oreg.

DOYLE CREEK FORMATION

The Doyle Creek Formation is here named for a thick section of red and green metamorphosed volcaniclastic rocks and volcanic flow rocks that are well exposed in Doyle Creek, the first major creek north of Big Bar on the Oregon side of the Snake River (fig. 8). Rocks of this formation are discontinuously exposed, mostly along the Oregon side of the Snake River, between Ashby and Saddle Creeks in the southern part of the area, at Pittsburg Landing in the central part, and near Cook Creek in the northern part. It also crops out beneath the Martin Bridge Limestone along the Snake River south of the Grande Ronde River mouth.

The distinguishing characteristics of this formation are the red colors and the abundance of epiclastic sediments. The red colors contrast sharply with the underlying green Wild Sheep Creek Formation, and lithologies differ because of the high epiclastic sediment content in the Doyle Creek Formation. Lithofacies changes are rapid, and even closely spaced stratigraphic sections show wide variations in thicknesses of beds and compositions.

The type section along Doyle Creek contains more flow rocks than the two reference sections (figs. 9, 10), which generally were measured in younger strata of the formation and contain more volcaniclastic rocks. The base of the formation is not well defined, because the green flow rocks and volcaniclastic rocks of the Wild Sheep Creek Formation grade into the red dominantly epiclastic

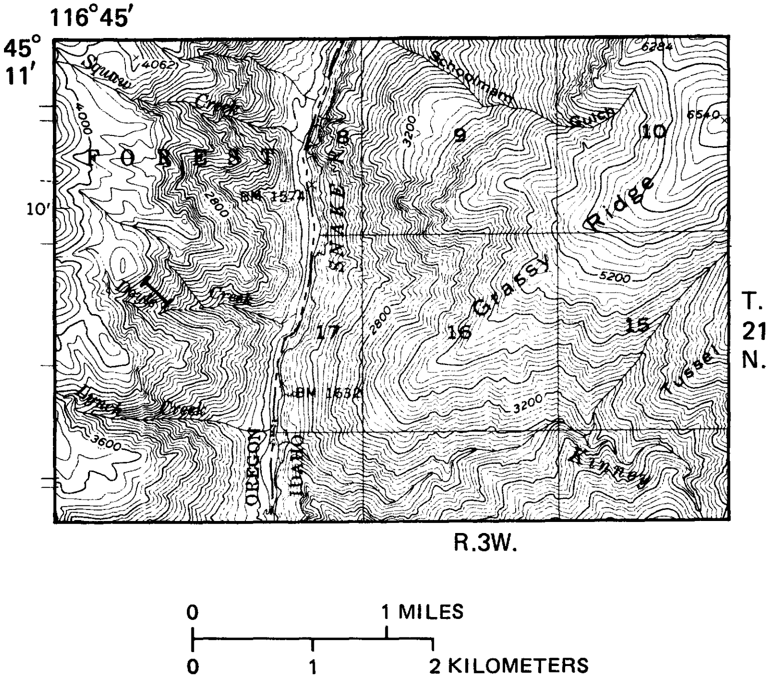

FIGURE 8.—Type section of the Doyle Creek Formation. Base from U.S. Geological Survey Cuprum 15-minute quadrangle, 1:62,500, 1957.

rocks of the Doyle Creek Formation over a vertical distance of 100–200 m. The base of the formation is taken as the bottom of the first thick red epiclastic volcanic breccia at Doyle Creek. The Doyle Creek Formation is most likely conformable on the Wild Sheep Creek Formation in the Doyle Creek area; elsewhere definite relations were not established, but the contact probably is conformable. The formation is overlain, probably unconformably, by the Upper Triassic Martin Bridge Limestone. Excellent exposures of the upper contact are along the south side of Kinney Creek near the IPALCO road and just south of Eckels Creek, along the same road, where the youngest beds are red and green volcanic breccia. Another good exposure is along the north side of McGraw Creek, where the youngest rock in the Doyle Creek Formation also is a thick unit of breccia.

Formation boundaries were most difficult to map in the area between Limepoint Creek and Hibbles Gulch along the Idaho side of the Snake River. Here, the base of the Doyle Creek Formation was mapped below a sequence where red epiclastic rocks are dominant. However, much of the underlying Wild Sheep

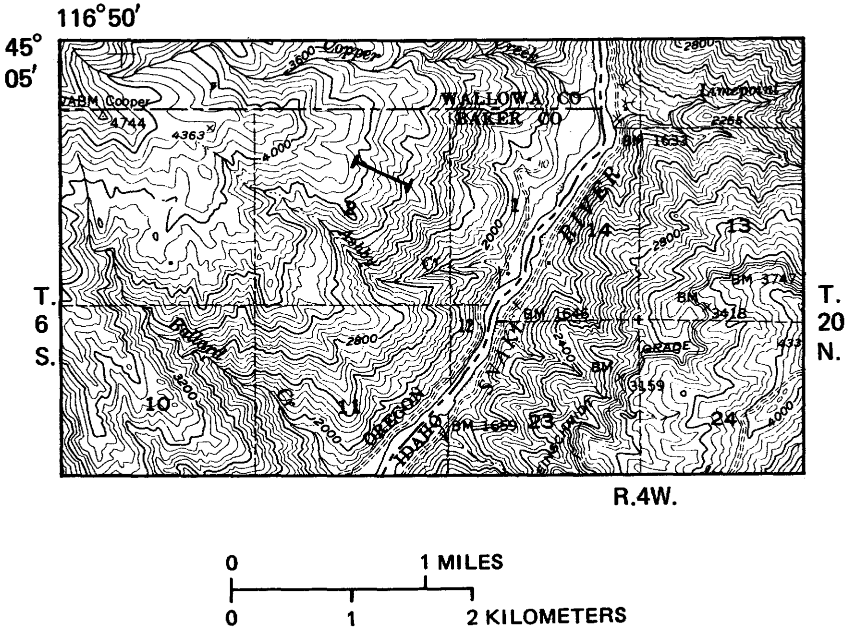

FIGURE 9.—Reference section of the Doyle Creek Formation along the north side of McGraw Creek. Base from U.S. Geological Survey Homestead 15-minute quadrangle, 1:62,500, 1957.

CreekFormation also is made up of volcaniclastic rocks, some of them red, and further refinement of the contact is necessary. The red color by itself is not a good criterion for distinguishing the two formations; rather, the red color should be combined with the abundance of epiclastic rocks to separate the Doyle Creek Formation from the Wild Sheep Creek Formation.

Type section, Doyle Creek Formation

Location: Cuprum 15-minute quadrangle; unsurveyed part of the Snake River Canyon area in Oregon; across the river from the center of sec. 17, T. 21 N., R. 3 W. Measured along the north side of the south fork of Doyle Creek from an elevation of about 855 m (2,800 ft) to the contact with the Columbia River Basalt Group at 1,000 m (3,600 ft). Jacobs Staff and tape and Brunton methods used. Rocks are metamorphosed to the greenschist facies. Top is contact with the Columbia River Basalt Group. It is not the youngest part of the formation.

Unit	*Description*	*Cumulative thickness above base of section (m)*
10.	Conglomerate; dusky-red matrix; weathers pale reddish brown; interbedded sandstone and some volcanic flow rocks; clast sizes 0.2–10 cm; volcanic flow rocks are dominant clast types; some clasts of volcaniclastic and plu-	

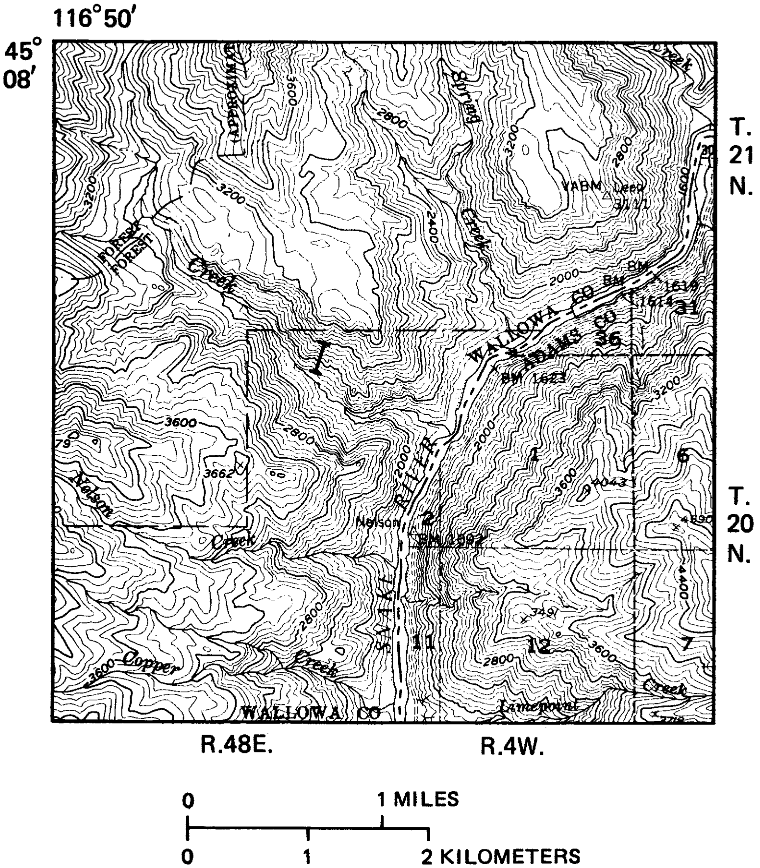

FIGURE 10.—Reference section of the Doyle Creek Formation along the second gully north of Ashby Creek. Base from U.S. Geological Survey Homestead 15-minute quadrangle, 1:62,500, 1957.

Type section, Doyle Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (*m*)
10.	Conglomerate, etc.—Continued tonic rocks; poorly sorted; many beds graded; some cross-lamination in the sandstone beds	301
9.	Basalt, dusky-red; weathers pale reddish brown; porphyritic, with phenocrysts of plagioclase 1 cm long in a medium-grained groundmass	240
8.	Conglomerate; same as unit 10	232
7.	Volcanic breccia (pyroclastic breccia?), dusky-red; weathers moderate yellowish brown; graded bedding; poorly	

Type section, Doyle Creek Formation—Continued

Unit	*Description*	*Cumulative thickness above base of section (m)*
7.	Volcanic breccia, etc.—Continued sorted; reddish-brown volcanic flow, volcaniclastic, and pumice clasts range from 0.1 to 8.0 cm in diameter; breccia grades into sandstone and siltstone in beds 1.0-3.5 m thick	216
6.	Basalt, very dusky red; weathers to dusky brown; individual flows 1.0–2.5 m thick; most flows are porphyritic, with phenocrysts from 0.5 to 2.0 m long; medium-grained groundmass	197
5.	Diorite sill; 12 m thick	
4.	Basalt; same as unit 6; one flow about 15 m thick; some phenocrysts 1 cm long	180
3.	Andesite (keratophyre?), pale-green; weathers dusky yellow; porphyritic, with phenocrysts 0.3-1.0 mm long	72
2.	Volcanic breccia, dusky-red; weathers pale reddish brown; graded bedding; some interbedded thin basalt flows, 1-3 m thick; poorly sorted; clast diameters 0.1–10 cm; clasts subangular, some subrounded; most clasts from flow rocks; epiclastic rock unit	66
Wild Sheep Creek Formation		
1.	Basalt, dusky-red, grayish black, and dark-greenish-gray; weathers dark and moderate yellowish brown; thick sequence of flows 5–15 m thick; some intercalated volcaniclastic (tuffaceous) units; most flows are porphyritic, with phenocrysts from 0.3 to 5.0 mm in length	116

Doyle Creek Formation is 301 m thick at the type section. It conformably overlies flows of the Wild Sheep Creek Formation.

Reference section, Doyle Creek Formation

Location: Homestead 15-minute quadrangle; unsurveyed part of the Snake River Canyon in Oregon. Measured along the north side of McGraw Creek beginning 50 m above the creek bed, elevation 670 m (2,200 ft) and continuing to the contact with the Martin Bridge Limestone at about 855 m (2,800 ft). The mouth of McGraw Creek is across the river from the N½ sec. 1, T. 20 N., R. 4 W., in Idaho. Tape and Brunton method was used to measure thicknesses. Rocks are metamorphosed to the greenschist facies. Top of section is the basal unit of the Martin Bridge Limestone.

Unit	*Description*	*Cumulative thickness above base of section (m)*
Martin Bridge Limestone		
6.	Siltstone, calcareous, pale-green; weathers to pale brown; poorly sorted; angular grains; some cross-laminations	132
Doyle Creek Formation		
5.	Volcanic breccia, dusky-red; dusky-red, pale-green, and greenish-black volcanic flow clasts; weathers dusky brown; weakly graded in beds 2–10 m thick; largest clasts 10 cm in diameter; angular fragments; dacite sill cuts unit above 35 m above base	128

Reference section, Doyle Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (m)
4.	Basalt, dusky-red; weathers dusky brown; porphyritic, phenocrysts 0.5–1.0 mm in length; medium-grained groundmass	52
3.	Volcanic breccia; same as unit 5 with three interlayered basalt flows	49
2.	Basalt, dusky-red; weathers dusky brown; porphyritic, phenocrysts 1.0–2.0 mm in length	39
1.	Basalt and volcanic breccia, dusky-red and pale-green; weathers dusky brown; breccia beds 1–3 m in thickness are weakly graded with clasts up to 5 cm in diameter	35

Base of this section is not the base of the formation.
Measured thickness is 132 m.

Reference section, Doyle Creek Formation

Location: Homestead 15-minute quadrangle; SW¼NE¼ sec. 2, T. 6 S., R. 48 E.; measured along the second gully north of Ashby Creek between the elevations of 945 m (3,100 ft) and 1,130 m (3,700 ft). Tape and Brunton method used. Rocks are metamorphosed to the greenschist facies. Top of section is not the top of the formation. Uppermost unit is a grassy slope about 50 m below the contact between the Doyle Creek Formation and the Columbia River Basalt Group.

Unit	Description	Cumulative thickness above base of section (m)
10.	Conglomerate, dusky-red and grayish-red; weathers pale reddish brown; graded beds 1.5–6.0 m thick; poorly sorted; clasts mostly of volcanic flow rocks; interbedded sandstone; weathers to grassy slopes; clasts up to 20 m in diameter, average 5–10 cm; clasts subangular to subrounded	186
9.	Basalt, very dusky red; weathers reddish brown; glomerophyric with phenocrysts of plagioclase 3–4 cm in length; medium grained groundmass	110
8.	Conglomerate; same as unit 10	107
7.	Basalt, greenish-black and dusky-red; weathers dark yellowish brown and pale redish brown; porphyritic, with feldspar phenocrysts 0.3–1.0 cm in length; flows 3–8 m thick; medium-grained groundmass; forms rounded outcrops	87
6.	Conglomerate, dusky-red; weathers pale reddish brown; graded to sandstone in beds 2–4 m thick; poorly sorted; subangular to subrounded clasts, up to 10 cm in diameter; clasts mostly dusky-red, greenish-black, and pale-green volcanic flow rocks	55
5.	Basalt, greenish-black; weathers yellowish brown; nonporphyritic; individual flows 2–4 m thick; forms rounded outcrops	36
4.	Conglomerate; same as unit 6	22
3.	Basalt, very dusky red; weathers dusky brown; porphyri-	

Reference section, Doyle Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (m)
3.	Basalt, etc.—Continued tic, with phenocrysts 0.2–1.0 cm in length; amygdules filled with chlorite; individual flows 1.5–4 m thick	20
2.	Conglomerate; same as unit 6	8
Wild Sheep Creek Formation		
1.	Basalt, greenish-black; weathers dark yellowish brown; porphyritic, amygdaloidal; individual flows 1.5–4.5 m thick	23

Thickness of the Doyle Creek Formation at this reference section is 186 m. The top of the formation is not exposed.

The Doyle Creek Formation and its correlative units can be mapped over a wide area in northeastern Oregon and western Idaho. It has an estimated thickness of about 500 m.

Flow rocks mostly are porphyritic and coarsely porphyritic metamorphosed basalt, basaltic andesite, andesite, and dacite (many are now spilite and keratophyre). Phenocrysts are set in pilotaxitic, intergranular, and intersertal groundmasses. Dominant components are plagioclase, ranging from albite to labradorite in composition, clinopyroxene, magnetite, and hematite (table 8). An altered iron-rich glassy groundmass makes up from 5 to 60 percent of some flow rocks. Secondary minerals epidote, chlorite, calcite, sphene, leucoxene, white mica, and quartz replace primary minerals and fill fractures and vesicles. The andesitic flow rocks are much more common than in older rocks and probably form as much as 50 percent of the flow rocks. They are light green and pale red and have plagioclase phenocrysts set in a recrystallized felty groundmass.

Pyroclastic breccia and tuff constitute at least half of the clastic rocks in the type area. Farther north near Jim Creek, pyroclastic rocks are rare; most are epiclastic. Major components in the pyroclastic beds are metamorphosed basalt and andesite fragments, plagioclase, and pumice in a fine-grained red hematitic and glassy (altered in most thin sections) matrix. Many beds have abundant pumice fragments; in some, pumice forms reversely graded sequences. Tuff, as observed in 15 thin sections, consists of metabasalt and meta-andesite rock fragments (0–50 percent), pumice (0–9 percent), relict ash and glass (0–60 percent), plagioclase (3–35 percent), clinopyroxene (0–20 percent), and iron-rich clayey matrix (0–40 percent).

Epiclastic volcanic breccia forms thick beds. A good example is

TABLE 8.—*Modal analyses of representative flow rocks from the Doyle Creek Formation*

[VB-105 groundmass of opaque minerals, clay, and feldspar; VS6-5 groundmass of altered tachylite; Tr., trace; 1,000-1,200 points counted]

Mineral	VC-302 (spilite)	VS6-5 (spilite)	VB-105 (keratophyre)	VC-218 (keratophyre)
Plagioclase phenocrysts	19	9		23
Plagioclase microlites	28	3	48	69
Actinolite	6			Tr.
Opaque minerals	Tr.	4	14	4
Quartz	1	3		
Epidote	22		2	4
Chlorite	19		Tr.	
White mica	5	Tr.		
Calcite		6	1	
Groundmass		75	35	
Total	100	100	100	100

exposed along the IPALCO road near Kinney Creek directly underlying the Martin Bridge Limestone. A similar breccia unit in McGraw Creek that includes a few intercalated thin metabasalt flows is more than 70 m thick. Angular clasts of green, dark-gray, red, and dusky-red flow rocks are set in a dusky-red matrix. Some clasts are 30 cm long, but most are from 2 to 8 cm long. Sandstone, mostly arkosic wacke and graywacke, plus siltstone and argillite are important constituents in many sequences. Fine-scale cross-bedding, flame structures, rip-up clasts, cut-and-fill structures, and graded beds are common sedimentary structures that indicate a relatively strong current regime during deposition. Quartz becomes a more important component volumetrically with increasing stratigraphic elevation.

Conglomerate units are particularly noteworthy in the Doyle Creek Formation. Good exposures are found along the Oregon side of the Snake River, just below the contact with the Columbia River Basalt Group, in the drainage basins of Ashby, Dove, Leep, Thirty Two Point, and Jim Creeks. Conglomerate units are sequences of beds which include conglomerate as the dominant rock and subordinate amounts of flow rocks, volcanic breccia, and sandstone. In Ashby Creek, where a 186-m-thick conglomerate unit was measured and described, the rocks are conglomerate (50 percent), flow rocks (42 percent), and breccia plus sandstone (8 percent). The conglomerates generally are very poorly sorted, with angular to well-rounded clasts that range from 0.5 to 10 cm in diameter. Metamorphosed basalt and basaltic andesite clasts are dominant (70 percent); keratophyric (15 percent), clastic (13 percent), and plutonic (2 percent) clasts are subordinate. The increase in amount of plutonic clasts with stratigraphic elevation parallels the increase of quartz content in the sandstone. These conglomerate units are the oldest Upper Triassic beds that contain plutonic clasts. The Kurry Creek Member of the Doyle Creek Formation (see section "Kurry Creek Member") exposed at Pittsburg Landing and Upper Triassic conglomerate in the southern Wallowa Mountains (Prostka, 1963, p. 112) also have plutonic clasts. Plutonic clasts examined in thin section are metamorphosed microtonalite, quartz diorite, and gabbro.

The rocks have been metamorphosed to an inequilibrium mineral assemblage in the greenschist facies. Primary plagioclase and ferromagnesian minerals are wholly or partly replaced by albite, epidote, chlorite, calcite, quartz, and zeolites, and groundmasses and matrices are hematitic and clayey. Morrison (1963, p. 126–128) reported several varieties of zeolites in this formation. They are quantitatively minor and generally are associated with microcrystalline quartz as part of a sparse intergranular cement. Only analcime was observed in X-ray diffraction studies of rocks from the southern part of the mapped area. Chemistry of flow rocks indicate extreme mobility of ions, particularly the alkalis, during metamorphism (table 9).

Most rocks in the formation were deposited in a marine environment, probably in relatively shallow well-oxygenated water near a landmass. Morganti (1972) suggested that some tuff outcrops in the upper part of the Eckels Creek drainage basin may have been subaerial eruptions.

The Doyle Creek Formation most likely is Late Triassic (Karnian and possibly early Norian). Underlying strata in the

TABLE 9.—*Chemical analyses of representative flow rocks from the Doyle Creek Formation*

[Analyses by R. Batiza; see table 8 for rock types]

Oxide	VC-302	VS6-5	VB-105	VC-218
SiO_2	52.50	54.00	58.10	65.20
TiO_2	.80	1.76	1.54	.63
Al_2O_3	17.70	14.50	14.30	16.90
FeO (total iron)	8.20	9.28	9.91	3.21
MnO	.25	.12	.25	.06
MgO	5.85	1.57	3.45	.02
CaO	7.37	13.66	6.19	.75
Na_2O	4.14	.80	3.64	6.02
K_2O	1.28	.07	1.31	2.20
P_2O_5	.31	.30	.20	.20
H_2O (total water)	....	3.47	....	....
CO_2	....	.28	....	....
Total	98.40	99.81	98.89	95.19

Wild Sheep Creek Formation are Karnian, and overlying limestone in the Martin Bridge Limestone is Norian. Local correlative and partly equivalent strata are the so-called Lower Sedimentary Series and the upper part of the Clover Creek Greenstone (Prostka, 1963) in the Wallowa Mountains.

KURRY CREEK MEMBER

The name Kurry Creek Member is here given to a mainly clastic rock sequence within the upper part of the Doyle Creek Formation exposed in the Pittsburg Landing area west of Whitebird, Idaho. It replaces the name Pittsburg Formation (Wagner, 1945). Vallier (1968) and White (1972) described the rock unit in some detail and measured several stratigraphic sections. One of the stratigraphic sections, just southeast of West Creek, is selected as the type section even though the base and top of the member are not included (fig. 11). The rock unit is local and crops out only in the Pittsburg Landing area. It overlies, probably conformably, rocks of the Wild Sheep Creek Formation and is unconformably overlain

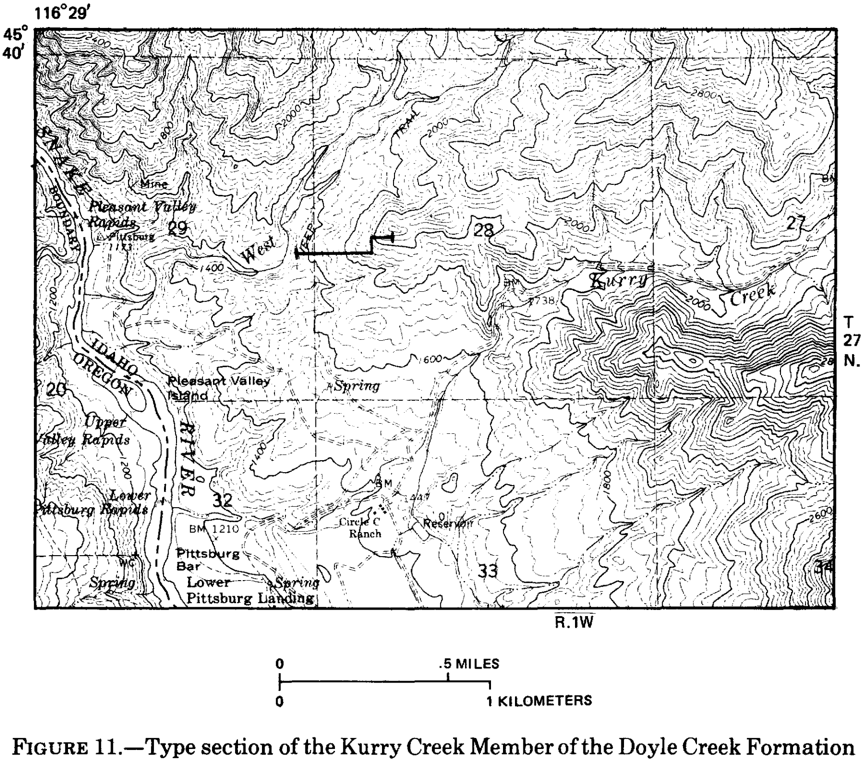

FIGURE 11.—Type section of the Kurry Creek Member of the Doyle Creek Formation measured along a spur southeast of West Creek. Base from U.S. Geological Survey Grave Point 7½-minute quadrangle, 1:24,000, 1963.

by mudstone, argillite, and graywacke of the Jurassic Coon Hollow Formation.

Type section, Kurry Creek Member of the Doyle Creek Formation

Location: Grave Point 7½′ quadrangle; NE¼ SE¼ sec. 29, T. 27 N., R. 1 W., up major spur southeast of West Creek beginning at an elevation of 465 m (1,520 ft) near the jeep trail, thence to the top of the ridge in SW¼ sec. 28. Tape and Brunton method used. Assisted by David L. White. Neither the base nor top of member is exposed.

Unit	*Description*	*Cumulative thickness above base of section (m)*
19.	Pebbly sandstone, greenish-black; weathers dusky brown; coarse-grained matrix; lithic wacke with abundant clasts of volcanic rocks; weakly cross-laminated; angular to subangular grains; some interbedded shale	270
18.	Covered interval; probably shale	245
17.	Pebble conglomerate, dark-brown; weathers pale yellowish brown; poorly sorted; subrounded to well-rounded clasts 4–8 cm in diameter; matrix of coarse sand; grades upward to very coarse sand; clasts mostly of volcanic origin	224
16.	Sandstone, lithic wacke, greenish-black; weathers yellowish brown; fair to moderate sorting; coarse grained; weakly crossbedded; some grading to siltstone	221
15.	Mudstone, dark-brownish-green; weathers pale brown; friable; some thin beds of fine-grained sandstone	206
14.	Sandstone; same as unit 16; some mudstone and siltstone beds up to 2 m thick; slope partly covered	204
13.	Mudstone; same as unit 15	178
12.	Conglomerate, dark-brown; weathers pale yellowish brown; pebble-sized clasts of volcanic origin; well rounded	173
11.	Covered interval; seems to be a sequence of alternating sandstone and mudstone	172
10.	Sandstone; same as units 14 and 16	165
9.	Pebble conglomerate, grayish-green; weathers pale brown; poorly sorted; clasts subrounded to well rounded; matrix mostly of sand; volcanic flow rocks make up all clasts; weakly bedded	156
8.	Pebbly mudstone, grayish-green; weathers pale brown; well-rounded clasts up to 3 cm in diameter in a fine-grained matrix; very poorly sorted; pebbles constitute about 10 percent of the unit; 3-m conglomerate bed 6 m above base of unit; most clasts are porphyritic volcanic flow rocks	154
7.	Conglomerate, dark-brown; weathers pale yellowish brown; cobble to pebble sized; interlayered sandstone and mudstone (10–15 percent) are tops of graded sequences; clasts are well rounded; some units are grayish red; fine-grained beds are mostly covered by soil	120
6.	Conglomerate, dark-brown; weathers pale brown; cobble-size clasts, average 8–12 cm in diameter; clasts are	

Type section, Kurry Creek Member of the Doyle Creek Formation—Continued

Unit	Description	Cumulative thickness above base of section (m)
6.	Conglomerate, etc.—Continued mostly porphyritic volcanic flow rocks; some interlayered sandstone; weak bedding	62
5.	Mudstone and sandstone, greenish-black and dark-brown; weathers dark yellowish brown and pale brown; mudstone beds 10–50 cm thick are interlayered with 1-5-cm-thick sandstone beds; mudstone is friable and has pencil cleavage; *Halobia* abundant on some bedding planes, poorly preserved	58
4.	Covered interval; probably mostly mudstone	43
3.	Conglomerate; dark-green matrix; weathers pale brown; sand-sized matrix with clasts up to 35 cm in diameter; average clast size range is about 3–10 cm; clasts subrounded to well rounded; contains thin beds of coarse sandstone, some weakly cross-laminated; clast count shows dark nonporphyritic volcanic flow rock (36 percent), porphyritic flow rocks (40 percent), volcaniclastic rocks (14 percent), and unknowns (10 percent)	34
2.	Mudstone and sandstone; same as unit 5	26
1.	Conglomerate; same as unit 3	16

Base of section is not the base of the rock unit
Total thickness measured is 270 m.

The Kurry Creek Member is almost entirely clastic rocks, which makes it easy to distinguish from other rocks in the Snake River Canyon region. Rocks are conglomerate, sandstone, tuff, shale, argillite, and limestone. Conglomerate is common and mostly consists of thick beds or sequences of conglomerate beds interlayered with sandstone and shale. Conglomerate beds generally contain poorly sorted materials whose clasts range from angular to well rounded. They generally are crudely graded; some are cross-laminated with steeply dipping foreset beds. These are particularly noticeable where there is a large percentage of sand-sized matrix. Clast compositions are mostly volcanic flow rocks and volcaniclastic rocks, although some beds contain as much as 3 percent plutonic clasts (metamorphosed quartz diorite, trondhjemite, and gabbro).

Sandstones are volcanic wackes (classification of Williams and others, 1954). Colors are dark brown on fresh surfaces and light brown on weathered surfaces. Many sandstone beds are the upper parts of graded units, whereas others occur as individual beds. Components are volcanic rock fragments, plagioclase, and quartz in a matrix of clay, chlorite, plant fragments, calcite, feldspar, rock fragments, and iron ores. Shale units also are dark brown on fresh surfaces; the more calcareous beds are lighter brown. Wood fragments are common constituents in shales at the top of graded sequences. Species of *Halobia* are occasionally observed along bedding planes. Limestone beds are argillaceous and carbonaceous; most have a strong fetid odor on fresh breaks.

Tuffs are abundant. Many are basaltic in composition, and some have much glass and palagonite. One tuff unit, exposed along the road between Pittsburg Landing and Whitebird, Idaho, is composed of basalt rock fragments, labradorite, and augite in an iron-rich glassy and clayey matrix. Grains are sand sized, angular, and fresh.

The rocks were deposited in a marine environment very near a landmass. Because of its local outcrop area and stratigraphy, the member probably represents a submarine inner fan, following the model of Walker (1975), that formed in relatively shallow water near a rugged landmass.

The Pittsburg Formation was thought to be Carboniferous by Wagner (1945). Recent identifications of ammonites and *Halobia* by N. J. Silberling (unpub. data) indicate a Late Triassic (late Karnian to middle Norian) age for the Kurry Creek Member. Correlative and probably partly equivalent rocks are the so-called Lower Sedimentary Series of Smith and Allen (1941) and the upper part of the Clover Creek Greenstone (Prostka, 1963).

MARTIN BRIDGE LIMESTONE

The Martin Bridge Limestone lies stratigraphically above the Seven Devils Group. Exposures of the formation are widely distributed in northeastern Oregon, western Idaho, and extreme southeastern Washington. Earlier studies of the formation in the Snake River Canyon area are those by Lindgren (1901), Ross (1938), Laudon (1956), Cannon (see Hamilton, 1963a), and Vallier (1967). Hamilton (1963a) renamed the Martin Bridge Formation the Martin Bridge Limestone.

The formation is well exposed on both sides of the Snake River at Big Bar just south of Kinney Creek and near the mouth of the Grande Ronde River. The best stratigraphic section is along the south side of Kinney Creek, where about 530 m of limestone and dolomite is exposed (Vallier, 1967). Strata of this formation also crop out on the ridge between Limepoint and Indian Creeks near the Kleinschmidt Grade, a road that connects the IPALCO road with Cuprum, Idaho. At this locality, the Martin Bridge Limestone seems to be in depositional contact with the underlying Doyle

Creek Formation on the east but in fault contact with that formation on the west.

In the Snake River Canyon the basal unit of the formation consists of grayish-green calcareous graywacke, siltstone, and argillaceous limestone that ranges from 0 to 5 m in thickness. This basal unit overlies a thick volcanic breccia of the Doyle Creek Formation in Kinney Creek, Hibbles Gulch, and McGraw Creek. Rock fragments in the green calcareous graywacke are similar to underlying rocks of the Doyle Creek Formation. Because the basal beds thicken and thin and because they overlie different rock types within the Snake River Canyon, the contact is likely an unconformity. The upper contact is not exposed in the Snake River Canyon. However, in the Wallowa Mountains the Martin Bridge Limestone grades upward into the Hurwal Formation (Smith and Allen, 1941) through a series of alternating limestone and shale units.

Rock types are limestone (sparite, biosparite, and micrite), dolomite, and limestone breccia. Some thin beds of calcareous shale are interlayered, but these make up a very small part of the unit. Colors are gray, brownish gray, and black on fresh surfaces and light gray to white on weathered surfaces. Beds range in thickness from 30 cm to 20 m but average about 1.5–2 m; thickest units, massive brecciated partly dolomitized limestone, represent high-energy depositional environments. Other units consist either of thinly laminated carbonaceous argillaceous limestone or of massive recrystallized limestone. Studies of 24 rock samples show that insoluble residues, mostly clay (illite) and carbon, account for 1–21 percent of the rocks by weight. Dolomite in five of the samples ranges from 0 to 95 percent.

There is a general scarcity of terrigenous materials, except for illite and occasional feldspars, in the limestone above the basal unit, which suggests either that the sediments were deposited far from a terrigenous source or that the area was protected by barriers to coarse sediment. There are no definite reef facies in the Snake River Canyon exposures. Fossils do indicate a shallow-water environment, and thick massive units are recrystallized breccias. Nolf (1966) reported a reef facies in the northern Wallowa Mountains, and Laudon (1956) interpreted the sequence in the Snake River Canyon as well-defined reef limestone. The Martin Bridge Limestone seems to fit Wilson's (1974) type II carbonate-platform margin, which consists of knoll-shaped reefs on gentle slopes of a continental shelf.

A well-preserved silicified fauna includes ammonites typical of the *Mojsisovicsites kerri* Zone of earliest Norian (Late Triassic) age (N. J. Silberling, written commun., 1965). Correlative and probably equivalent units are found in several localities within the region: in the Wallowa Mountains, in the eastern part of the Seven Devils Mountains north of Riggins, Idaho, and near the mouth of the Grande Ronde River in southeastern Washington and western Idaho. In all localities, except at Big Bar in the Snake River Canyon, the limestone grades upward into a black shale, sandstone, and mudstone unit which is known as the Hurwal Formation in the Wallowa Mountains and as the Lucile Slate in the Riggins area of western Idaho.

HURWAL FORMATION

The Hurwal Formation (Smith and Allen, 1941) was described in the Wallowa Mountains as a shale and limestone unit of Late Triassic age that overlies the Martin Bridge Limestone. Nolf (1966) found Early Jurassic fossils in the Hurwal Formation of the northern Wallowa Mountains. In the Snake River Canyon, the Hurwal Formation has been mapped only near the mouth of the Grande Ronde River (Glerup, 1960), where two distinct lithologies occur. The lower unit is made up of metamorphosed argillaceous limestone and argillite, and the upper unit consists of metamorphosed mudstone and volcaniclastic rocks. No fossils were found in the formation in the Snake River Canyon, and it is regarded as Late Triassic age in the report area.

COON HOLLOW FORMATION

Morrison (1964) described the Coon Hollow Formation and designated the ridge south of Little Cougar Creek, southern Nez Perce County, northwest Idaho (Jim Butte Creek 7½-minute quadrangle), as its type section. The formation is well exposed at Coon Hollow, Oreg., on the opposite side of the Snake River Canyon, for which it was named. Near the Washington-Oregon boundary, thin-bedded sequences within the formation are folded about northeast-trending axes. Another probable exposure of the formation is at Pittsburg Landing along the south side of Pittsburg Creek in Oregon.

The Coon Hollow Formation is easily distinguished from other formations. Rocks weather rapidly, and the exposures are characterized by rounded slopes, in strong contrast to the rugged outcrops that characterize older formations. The lower and upper boundaries are angular unconformities. In the northern part of the area, the Coon Hollow overlies a truncated section of the Wild Sheep Creek Formation; at Pittsburg Landing it overlies the Kurry

Creek Member of the Doyle Creek Formation. It is overlain by the Columbia River Basalt Group.

The Coon Hollow Formation probably was much more extensive before Nevadan deformation and late Mesozoic and early Tertiary erosion. Deep weathering and folding prevented satisfactory thickness measurements, but Morrison (1964) estimated the thickness to be about 600 m.

Rock types are primarily black and dark-brown mudstone with minor siltstone and sandstone. Rare beds of conglomerate and breccia also occur in the sequence. Bedding is defined by light-colored calcareous siltstone lenses less than 2 cm thick interlayered every few centimeters throughout many of the mudstone units. The mudstone is well indurated and forms distinct beds as much as 20 m thick. Most sandstone and siltstone beds range from 1 to 35 cm in thickness and generally are graded. A basal conglomerate that overlies truncated Upper Triassic strata in the type area contains clasts that are mostly of sedimentary origin; volcanic clasts are less common.

Fossils are rare in the Coon Hollow Formation. Euxinic conditions discouraged the development of benthonic faunas, and deep weathering and fracturing presumably have destroyed fossils. R. W. Imlay reported (Morrison, 1964) that one fossil locale, about 125 m above the base of the formation in the type area close to the Washington-Oregon boundary, contains fragments of the ammonite genus *Cardioceras,* which is diagnostic of the lower part of the Upper Jurassic Oxfordian Stage in Europe. From exposures of probable Coon Hollow beds near Pittsburg Landing, Imlay identified ammonites of the Middle Jurassic Callovian Stage (written commun., 1968).

R. W. Imlay (oral commun., 1976) pointed out that the rock unit exposed at Coon Hollow, which contains an Oxfordian ammonite fauna 125 m above its base, may not be correlative with the rock unit exposed near Pittsburg Landing, which contains a Callovian ammonite fauna near its base. For purposes of this report, however, the two units are considered to be largely correlative for two major reasons: (1) Their lithologies are not easily differentiated in the field and (2) Callovian strata might be present below the Oxfordian beds in the type area. Certainly, these strata deserve much closer scrutiny to determine the relationships.

TERTIARY BOULDER BEDS

A profound unconformity separates the pre-Tertiary rocks from the Miocene basalt flows. The old surface of erosion is visible along most parts of the canyon. Where the basalt has only recently been stripped away, the old erosion surface is overlain by boulder and cobble beds. The boulder beds are well exposed just south of the Grande Ronde River in Washington, where the thickness is as much as 10 m. Compositions are quartzite, pre-Tertiary flow rocks, and unmetamorphosed granitic rocks. Farther south along the unconformity in several places, quartzite boulders are the only ones present; best outcrops of these boulders are on the eroded surface of the Martin Bridge Limestone near McGraw Creek. The source of the cobbles and boulders apparently is some of the Precambrian quartzites that are exposed farther east in Idaho and the metavolcanic and granitic rocks that were derived locally from the Seven Devils Group and the Idaho and Wallowa batholiths.

COLUMBIA RIVER BASALT GROUP

The Columbia River Basalt Group is well exposed in the Snake River Canyon, particularly along the western side in Oregon. This rock unit was originally named the Columbia Lava by Russell (1893) for supposed Eocene through Pliocene basalts of the Columbia Plateau in Washington and Oregon. Merriam (1901) restricted the name to lavas of post-John Day and pre-Mascall age. Waters (1961) divided the rock unit into the Picture Gorge Basalt and the overlying Yakima Basalt on the basis of distinctive outcrop and mineralogic and chemical differences. He traced these formations from central Oregon to the Imnaha River in eastern Oregon. Brown and Thayer (1966) changed the name Columbia River Basalt to the Columbia River Group and included the Picture Gorge Basalt, Mascall Formation, the "rhyolitic marginal facies" that is transitional with the Strawberry Volcanics, and the Yakima Basalt. Griggs (1976) renamed it the Columbia River Basalt Group, restricting the name to predominantly basaltic rocks so as to include the Picture Gorge and Yakima Basalts and to exclude the Mascall and rhyolitic rocks. For purposes of this report, where stratigraphic relationships and lithologic affinities to the type area are still unclear, the name Columbia River Basalt Group is retained.

Along the Snake River Canyon two mappable units are present, an older one that has mineralogic and outcrop characteristics similar to those of the Picture Gorge Basalt, and a younger one similar to the Yakima Basalt as described by Waters (1961). For purposes of this report, however, the basalts are referred to as the lower unit and upper unit.

The lower unit is composed of flows that are mostly porphyritic basalt. It weathers to gentle slopes, and the rocks have a distinctive waxy luster on fresh surfaces. The thickest sections, which range from 200 to 450 m, are exposed near the mouth of the Imnaha River and in the canyon of Pine Creek just southwest of Oxbow, Oreg. The earliest flows were extruded over an irregular topography that had a regional relief of 500–700 m. The lower unit is very well exposed along the Oregon side of the Snake River Canyon between Saddle Creek and the mouth of the Imnaha River.

The contact between the lower and upper unit is marked by a change in topography from the gentle slopes of the lower unit to the steep slopes of the upper unit. At places this break is marked by a line of vegetation.

Flows of the upper unit are exposed in excellent outcrops throughout the area and just south of Saddle Creek for several kilometers. They are the only flows that cap the old topography. This suggests that the lower unit accumulated in low areas around topographic highs, leaving the highs as steptoes until covered by flows of the upper unit. The maximum thickness of the upper unit is about 900 m near the mouth of the Grande Ronde River.

Bingham and Grolier (1966) dated the upper unit as late Miocene and early Pliocene. However, recent radiometric dating appears to restrict the age of the Columbia River Basalt Group to the middle Miocene. Baksi and Watkins (1973) compiled a synthesis of potassium-argon dates from nine sections in northeastern Oregon, western Idaho, and south-eastern Washington. The age range of 112 dates is 13.5±0.3 million years to 15.4±0.3 million years for flows throughout that region, which is in the early middle Miocene Epoch (time scale of Berggren, 1972). Although no dates have been published for rocks in the area considered here, a Miocene age is adopted for the Columbia River Basalt Group in the Snake River Canyon included in this report.

QUATERNARY DEPOSITS

Most Quaternary sedimentary deposits are thin and discontinuous in the Snake River Canyon region and can be broadly divided into glacial, landslide, terrace, and alluvial fan deposits. Glacial deposits occur at higher elevations in the Wallowa and Seven Devils Mountains, and some morainal materials extend down to an elevation of about 1,200 m (4,000 ft). Landslides formed some major topographic features along the Snake River Canyon (Vallier and Miller, 1974). The largest of these is at Big Bar, where a slide from the west wall of the canyon apparently dammed the river. A remnant of that landslide parallels the river for nearly a kilometer and rises 60 m above the valley floor. It is presently almost entirely submerged beneath waters backed up by Hells Canyon Dam. Other major landslide deposits are near the mouth of Copper Creek, about 14 km north of Homestead, at Johnson Bar, and at Pittsburg Landing. Terrace deposits in the Snake River Canyon occur primarily at Pittsburg Landing, Johnson Bar, Temperance Creek, and Big Bar. All have formed in wide parts of the river valley, and in places three levels have been identified. The highest may be related to the Bonneville Flood. Terraces are the result of rapid accumulations of debris (landslide, flood gravels, and alluvial fans) with subsequent smoothing by high water. Deposits of alluvium form fans all along the Snake River Canyon where tributary streams debouch into the Snake River.

CONCLUSIONS

A composite diagram of columns shows the inferred stratigraphic relations in the Snake River Canyon (fig. 12). Important interpretations are the following: (1) Permian strata are confined to the southern part of the area; (2) there is an increase in clastic content of the Wild Sheep Creek Formation toward the north along with a general thinning; (3) the Wild Sheep Creek Formation overlies gabbro, amphibolite, mylonite, and plagiogranite to the north, but overlies Permian strata to the south; (4) the Martin Bridge Limestone is not ubiquitous but overlies the Doyle Creek Formation near Kinney Creek and near the mouth of the Grande Ronde River; it is absent in the Pittsburg Landing area where Jurassic strata overlie the Upper Triassic Doyle Creek Formation; and (5) near the Grande Ronde River mouth the Hurwal Formation of presumable Late Triassic age overlies the Martin Bridge Limestone. Just a few kilometers south, in extreme northeastern Oregon, the Martin Bridge Limestone and Hurwal Formation are absent, and Jurassic strata directly overlie the Wild Sheep Creek Formation.

The pre-Tertiary stratigraphy in the Snake River Canyon attests to the presence of old island arc systems, which are the result of volcanism, tectonism, and sedimentation at converging plate boundaries. In this area an old Pacific plate presumably collided with the northwestward-moving North American plate. The convergence and resultant subduction created the Permian and Upper Triassic island arc, and later subduction probably led to the Idaho batholith magmatic event.

The silicic Permian strata were part of an early volcanic arc which formed on crust of unknown nature. These volcanic flows and associated clastic rocks are correlative with the Lower Permian limestone blocks of the Elkhorn Ridge Argillite. Most of the Permian island arc deposits have been subducted or eroded, and only small remnants still occur in the region.

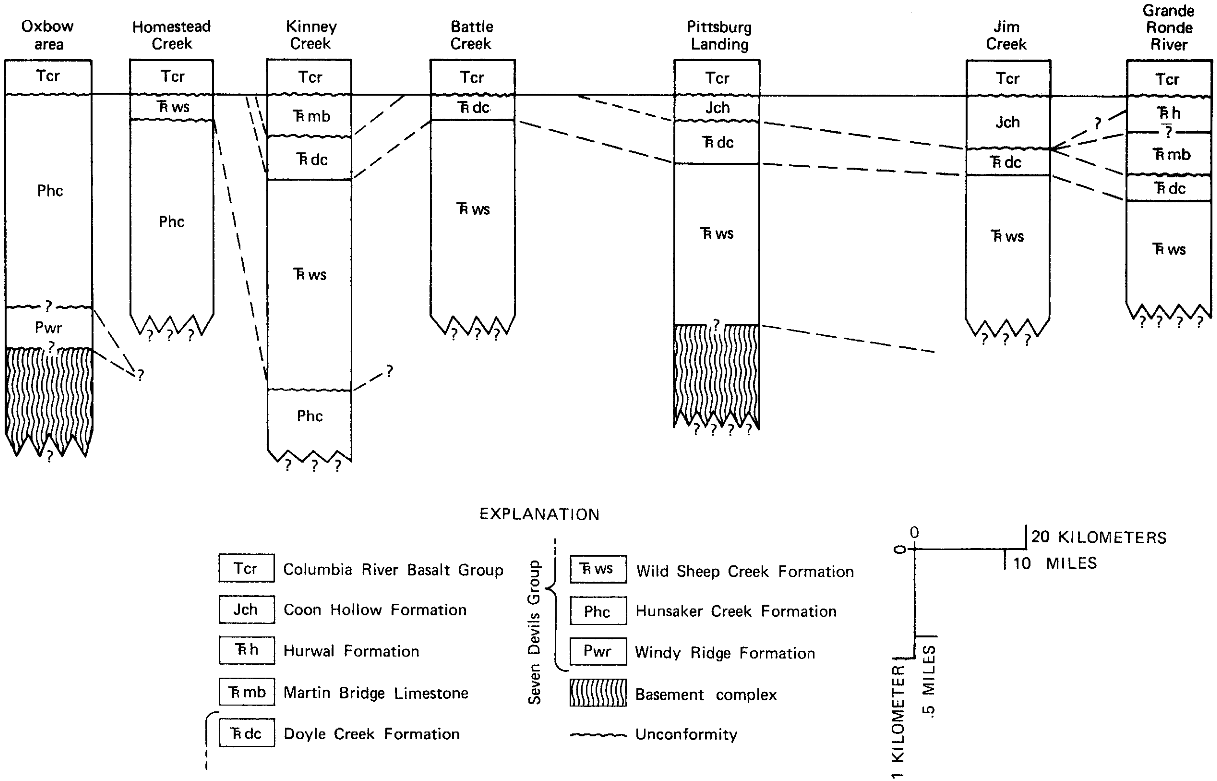

FIGURE 12.—Composite stratigraphic diagram showing stratigraphic relations in Snake River Canyon between Oxbow, Oreg., and the mouth of the Grande Ronde River.

The more mafic Upper Triassic volcanic arc formed on the older arc. Along the southern part of the area described in this report, Upper Triassic volcanic rocks overlie Permian strata; farther north they overlie "basement" that is a composite of plutons (gabbro and quartz diorite) and amphibolite-facies rocks that probably are older metamorphosed sediments and volcanic rocks. The Triassic volcanic rocks were capped by Norian platform limestone and associated basin facies.

During the Jurassic, flyschlike deposits were laid down in arc-related basins in part contemporaneous with culminating orogenic phases, regional metamorphism, and early plutonism that subsequently led to the formation of batholiths in northeastern Oregon and western Idaho.

Culminating pulses of the Nevadan orogeny uplifted and exposed the rocks, which were deeply eroded during Cretaceous and early Tertiary time. Flows of the Columbia River Basalt Group covered the irregular topography during the Miocene Epoch. Basin-and-range faulting, regional uplift, and erosion formed the present topography during late Miocene through Pleistocene time.

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