AN ABSTRACT OF THE THESIS OF

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Title THE GEOLOGY OF PART OF THE SNAKE RIVER CANYON AND ADJACENT AREAS IN NORTHEASTERN OREGON AND WESTERN IDAHO

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The mapped area lies between the Wallowa Mountains of northeastern Oregon and the Seven Devils Mountains of western Idaho. Part of the Snake River canyon is included.

A composite stratigraphic section includes at least 30,000 feet of strata. Pre-Tertiary and Tertiary strata are separated by a profound unconformity. Pre-Tertiary layered rocks are mostly Permian and Triassic volcaniclastic and volcanic flow rocks. At least four pre-Tertiary intrusive suites occur. Tertiary rocks are Miocene and Pliocene plateau basalts. Quaternary glacial materials and stream deposits locally mantle the older rocks.

Permian (?) rocks of the Windy Ridge Formation are the oldest rocks and consist of 2,000 to 3,000 feet of keratophyre, quartz keratophyre, and keratophric pyroclastic rocks. Unconformably (?) overlying the Windy Ridge Formation are 8,000 to 10,000 feet of volcaniclastic rocks and minor volcanic flow rocks of the Hunsaker Creek

Formation of Middle Permian (Leonardian and Wordian) age. Spilitic flow rocks of the Kleinschmidt Volcanics are interlayered with and in part overlie the Hunsaker Creek Formation and comprise a sequence about 2,000 to 3,000 feet thick. The Paleozoic layered rocks were intruded by the Holbrook-Irondyke intrusives, composed of keratophyre porphyry, quartz keratophyre porphyry, diabase, and gabbro.

The Paleozoic rocks were deformed by an orogeny between Middle Permian and Middle Triassic time. Plutonic rocks (Oxbow Complex) of gabbro, quartz diorite, diorite, and albite granite were intruded during Early Triassic (?) time. Movements along the Oxbow-Cuprum shear zone occurred during and after the intrusions.

Middle Triassic (Ladinian) spilitic flow rocks and volcaniclastic rocks of the Grassy Ridge Formation overlie the older rocks with angular unconformity. Thicknesses are 3,000 to 4,000 feet in the northeast part of the map area; no rocks of the Grassy Ridge Formation are exposed in the southwest part. The Imnaha Formation of Late Triassic (Karnian) age overlies the Permian strata unconformably near Fish Lake in the western part of the area. The Doyle Creek Formation of Late Triassic (Karnian) age conformably overlies the Grassy Ridge Formation in the Snake River and Imnaha River canyons and may interfinger with the Imnaha Formation east of Fish Lake. The Doyle

Creek Formation ranges in thickness from 3,000 to 5,000 feet and includes two members - the Ashby Creek Conglomerate and the Piedmont Point Member. The Martin Bridge Formation, represented by 1,750 feet of Late Triassic (Norian) limestone, conformably overlies the Doyle Creek Formation.

At least two intrusive events apparently occurred during the Jurassic Period. The Jurassic (?) intrusives, were emplaced before regional metamorphism and consist of hypabyssal dikes and sills of diorite, quartz diorite, and dacite and andesite porphyries. Subsequently, the Upper (?) Jurassic intrusives were emplaced during a late stage of regional metamorphism and are represented by small stocks of gabbro, norite, quartz diorite, and granodiorite porphyry.

A major orogeny during Middle and Late (?) Jurassic time deformed the rocks. Regional metamorphism produced mineral assemblages characteristic of the greenschist facies.

Columbia River Basalt, 2,000 to 3,000 feet thick, erupted from fissures during late Miocene and early Pliocene time and covered an old erosion surface. Pliocene-Pleistocene uplift, alpine glaciation, and extensive stream erosion are responsible for the present topography.

THE GEOLOGY OF PART OF THE SNAKE RIVER CANYON AND ADJACENT AREAS IN NORTHEASTERN OREGON AND WESTERN IDAHO

by

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THE GEOLOGY OF PART OF THE SNAKE RIVER CANYON AND ADJACENT AREAS IN NORTHEASTERN OREGON AND WESTERN IDAHO

INTRODUCTION

Location and Accessibility

The area of this investigation comprises about 200 square miles in Wallowa County and Baker County, Oregon, and Adams County, Idaho (Plate 1). Approximate boundaries are longitudes 116°40' and 117°06'W. and latitudes 44°58' and 45°11'N.

Oregon State Highway 86 provides access from Baker, Oregon. A paved road, maintained by the Idaho Power and Light Company (IPALCO), parallels the Snake River in the area and connects on the south with Idaho State Highway 71. Graveled roads from Joseph and Imnaha, Oregon, and from Council, Idaho, also serve as access routes. During the summer months, most parts of the area are within four miles of a road easily traversed by a passenger car.

Topography

For descriptive purposes the map area is divided into a plateau region and a canyon region.

The plateau region lies between the Wallowa Mountains on the west and the Snake River canyon on the east. Total relief is about 4,800 feet, but the local relief generally

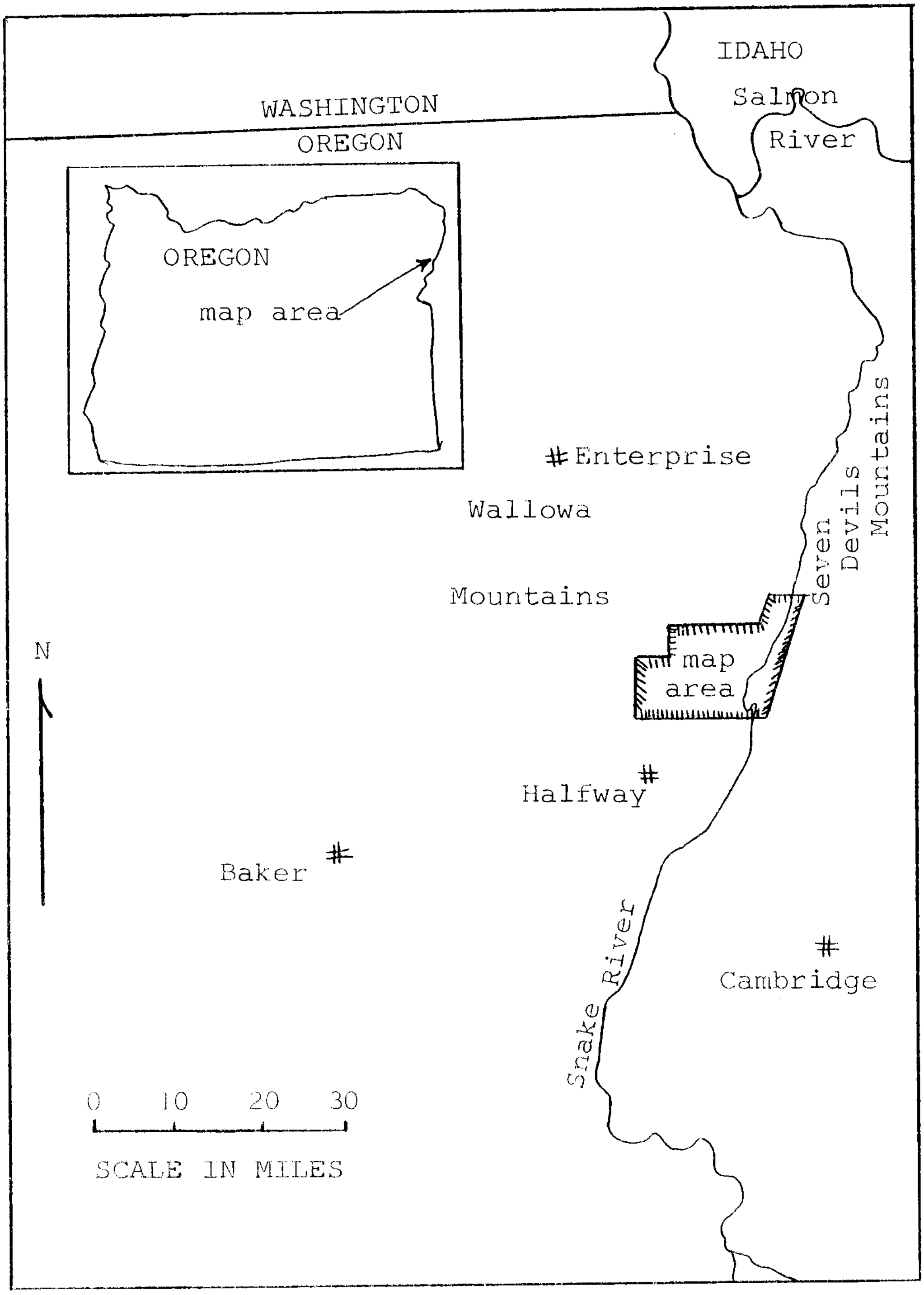

Plate 1. Index map of thesis area.

is no more than 1,500 feet. Near the western edge of the plateau region, Russell Mountain at 7,487 feet, is the highest point in the map area.

The rugged topography of the canyon region (Figure 1) is in sharp contrast to the topography of the plateau region. Local relief in the Snake River canyon is commonly greater than 4,000 feet. The lowest point in the canyon region and in the map area, at an elevation of about 1,575 feet, is near the confluence of Squaw Creek and the Snake River. The highest point in the canyon region is about 6,500 feet on the west side of Kinney Point, Idaho.

Drainage

The map area is drained by the Imnaha River and the Snake River. The Snake River flows northeast through a canyon that is as much as seven miles wide and a mile deep. Most tributary streams enter the Snake River at right angles and are characterized by steep-walled canyons, local waterfalls, and straight stream courses. The tributary streams are raging torrents in the early spring but many are dry in late summer. The principal tributaries, Pine Creek and Indian Creek, enter the Snake River near Oxbow, Oregon.

The major streams in the plateau region are the Imnaha River on the north, East Pine Creek on the west, and North Pine Creek on the east. The Imnaha River flows

Figure 1. Canyon of the Snake River near Kinney Creek.

east through a U-shaped glacial valley and then abruptly turns north and nearly parallels the Snake River. Larger streams in the plateau region are perennial.

Climate and Vegetation

Marked differences in climate and vegetation occur between the canyon region and the plateau region. The canyon region is semiarid with an annual rainfall of 10 to 15 inches. Lower elevations in the Snake River canyon are characterized by mild winters with little snowfall and hot summers with maximum daily temperatures commonly greater than 110°F. Stands of larger trees, generally Douglas fir and Ponderosa pine, are confined to the south sides of tributary canyons with thick covers of brush common in the bottom of stream valleys. Canyon slopes are partly covered by grasses and other herbaceous plants.

The plateau region is characterized by more severe winters with heavy snowfall at higher elevations. Annual precipitation depends largely on elevation and ranges from 15 to 35 inches. On the higher slopes, vegetation includes a mixed conifer forest of Douglas fir, white fir, Ponderosa pine, and Englemann spruce, with an understory of grasses and shrubs.

Purpose of the Investigation

The major purpose of this investigation was to study and describe the pre-Tertiary stratigraphy. Readily accessible and excellent exposures in the Snake River canyon made a somewhat detailed study possible.

The thesis area also presented an opportunity to study the Permian-Triassic boundary. Dott (1961) described the Permian-Triassic boundary problem in western North America and concluded that in most areas which have a geologic history similar to that of the thesis area, Upper Triassic rocks overlie Permian rocks with angular unconformity.

Another goal was to determine the local structural framework and relate it to pre-existing syntheses of regional structure. Proof of the presence of thrust faults was of primary concern because thrust faults were reported in adjacent areas by Livingston (1932) and Hamilton (1963).

Field and Laboratory Procedures

Field Procedures

Field studies required 44 weeks in the summers of 1963 and 1964 and the spring and summer of 1965. U.S. Geological Survey 15-minute maps of the Cornucopia, Halfway, Copperfield, Homestead, and Cuprum quadrangles, enlarged to a scale of 1:24,000, were used as base maps. Low-altitude aerial photographs assisted the mapping.

Reconnaissance stratigraphic sections were measured by compass-altimeter traverses. Detailed sections were measured by compass-tape traverses and by the Jacob's staff. The rock color chart (Goddard et al., 1948) was used for rock descriptions.

Laboratory Procedures

Four hundred thirty-six thin sections were examined and modal analyses of representative samples were obtained with a mechanical stage and point counter. Traverses were made over the entire slide; 500 to 1,000 points were counted.

Feldspar compositions were determined by optical, oil immersion, and X-ray methods. Rock slabs were stained with potassium cobaltinitrite to help identify potassium-bearing minerals.

Clay mineral identifications and calcite-dolomite ratio studies of the Upper Triassic Martin Bridge Formation were made by X-ray diffraction. Insoluble residues were also studied from this formation.

Previous Field Work

Lindgren (1901) was the pioneer geologist in northeastern Oregon; his reconnaissance map included most of the area studied by the writer. He collected fossils of Triassic age from a limestone unit in the Snake River canyon. Livingston and Laney (1920) described the general geology and copper deposits of the Seven Devils Mountains in Idaho and published a geologic map which is overlapped by the writer's map. In 1921, Ross (1938) studied a large area in northeastern Oregon; his reconnaissance map is overlapped by the western part of the writer's map. Dr. Ralph S. Cannon and assistants mapped the Cuprum quadrangle during the summers of 1938 through 1941 but did not publish the results. Hamilton (1963a) published a simplified version of Cannon's map and also recorded some of Cannon's conclusions. Reid (1953) studied about eight square miles near Fish Lake while Cook (1954) included the Idaho part of the map area in his mining report of the Seven Devils Mountains. Wetherell (1960) studied part of the Cornucopia quadrangle including the area near Fish Lake, and Stearns (1964) investigated a small area around Oxbow, Oregon.

STRATIGRAPHY

Classification and Terminology

Introduction

About 90 percent of the layered rocks in the thesis area are volcanic flow rocks and clastic rocks of volcanic derivation. Precise classifications are difficult because of the replacement and recrystallization of primary constituents.

Volcanic Flow Rocks

The terms spilite, keratophyre, and quartz keratophyre are used for albitized basalt, andesite, and dacite, respectively.

Spilite has a high color index. Mafic minerals are commonly replaced by chlorite, actinolite, or epidote. Textures mostly are pilotaxitic, intergranular, and diabasic.

Keratophyre and quartz keratophyre have lighter colors because mafic minerals are uncommon. Textures generally are porphyritic with felty or pilotaxitic groundmasses.

Clastic Rocks of Volcanic Derivation (Volcaniclastic)

For discussions of fragmental rocks of volcanic origin, the classification and grain size limits proposed by Fisher (1961, p. 1411) are used, but with two minor changes (Table 1). Fisher's "autoclastic" type is not included because an autoclastic origin for the rocks could not be definitely established. Similarly, pyroclastic material between 2 and 32 mm in diameter is called tuff breccia rather than "lapillistone." Terms defined by Dickinson and Vigrass (1965, p. 9) are used for some clastic rocks in the stratified column. "Pyroclastic" refers to materials forcibly expelled from volcanic vents as fragmental ejecta, set in motion initially by explosive eruption which owe their grain morphology to processes of eruptive disintegration (most typically, vesiculation). "Epiclastic" refers to materials of either volcanic or nonvolcanic derivation which owe their particulate nature, their grain shapes, and their movement to processes of weathering, erosion, and aqueous transport. "Volcaniclastic" refers to materials of volcanic derivation, whatever their history, with no connotation as to their pyroclastic or epiclastic origin; volcaniclastic beds may be either tuff or sandstone. Terms such as "tuff," "lapilli-tuff," and "tuff-breccia," refer to volcaniclastic rocks composed of pyroclastic debris so little modified by sedimentary processes of sorting or rounding that the original composition and texture of the ejecta are essentially unchanged. Terms such as "volcanic

Table 1. Proposed Classification of Volcaniclastic Rocks. Modified From Fisher (1961, p. 1412).

Predominant Grain Size (mm)	Pyroclastic	Epiclastic*	Equivalent Nongenetic Terms
256	Pyroclastic breccia	Epiclastic volcanic breccia	Volcanic breccia
	Agglomerate	or	or
64		Epiclastic volcanic conglomerate	Volcanic conglomerate
	Tuff breccia		
2			
	Coarse tuff	Epiclastic volcanic sandstone	Volcanic sandstone
1/16			
		Epiclastic volcanic siltstone	Volcanic siltstone
1/256	Fine tuff		
		Epiclastic volcanic claystone	Volcanic claystone

* May be mixed with subordinate nonvolcanic clastic material. Add adjective "tuffaceous" to rocks containing pyroclastic material less than 2 mm in size.

sandstone" and "volcanic conglomerate" refer to volcaniclastic rocks whose composition, texture, or structure give clear indication of reworking sufficient to appreciably modify the original volcanic character of the source materials. "Sandy tuff" is used for a rock composed predominately of pyroclastic debris whereas "tuffaceous sandstone" denotes a rock composed mostly of epiclastic debris.

For petrographic description of sandstones, the terminology of Gilbert (1955, p. 289-297) is used.

Indisputable criteria for distinguishing between pyroclastic and epiclastic origins of altered volcaniclastic rocks are unavailable. Commonly, no one criterion is sufficient to prove either origin. Volcaniclastic rocks are considered epiclastic: (1) if several different lithologies are represented in the debris; (2) if abundant, rounded rock and mineral fragments are present; (3) if there are no pumice fragments, glass shards, or their relicts; (4) if the rocks contain fossils that are in place; (5) if the crystals and fragments are not distorted and drawn-out; or (6) if the rocks have primary sedimentary structures, such as ripple marks or cross-bedding, which are typical of deposits formed by the action of currents. Volcaniclastic rocks are considered pyroclastic: (1) if the rock fragment and mineral content indicates a monolithologic source; (2) if the deposit has abundant pumice fragments, glass shards, or their relicts; (3) if the rocks have distorted or drawn-out crystals and rock fragments or the rock fragments have cuspate, unrounded margins; and (4) if the gross composition of the bed is uniform through a considerable thickness of strata, reflecting no sorting of material by hydraulic processes.

Stratigraphic Relationships of the Pre-Tertiary Rocks

Introduction

The major purpose in this section is to synthesize stratigraphic sequences from other parts of northeastern Oregon and western Idaho (Figure 2). Another purpose is to correlate rocks of the thesis area with similar strata in California, Nevada, British Columbia, and Alaska (Figure 3).

Stratigraphic Column in the Seven Devils Region

Pre-Tertiary volcanic flow rocks and volcaniclastic rocks in the Seven Devils Mountains and the Snake River canyon were named the Seven Devils Volcanics by Anderson (1930, p. 13). The type locality was the Seven Devils Mountains; the age suggested for the rocks, on the basis of Phosphoria fauna found by Laney near Homestead, Oregon, was Permian. Later workers followed this usage, although

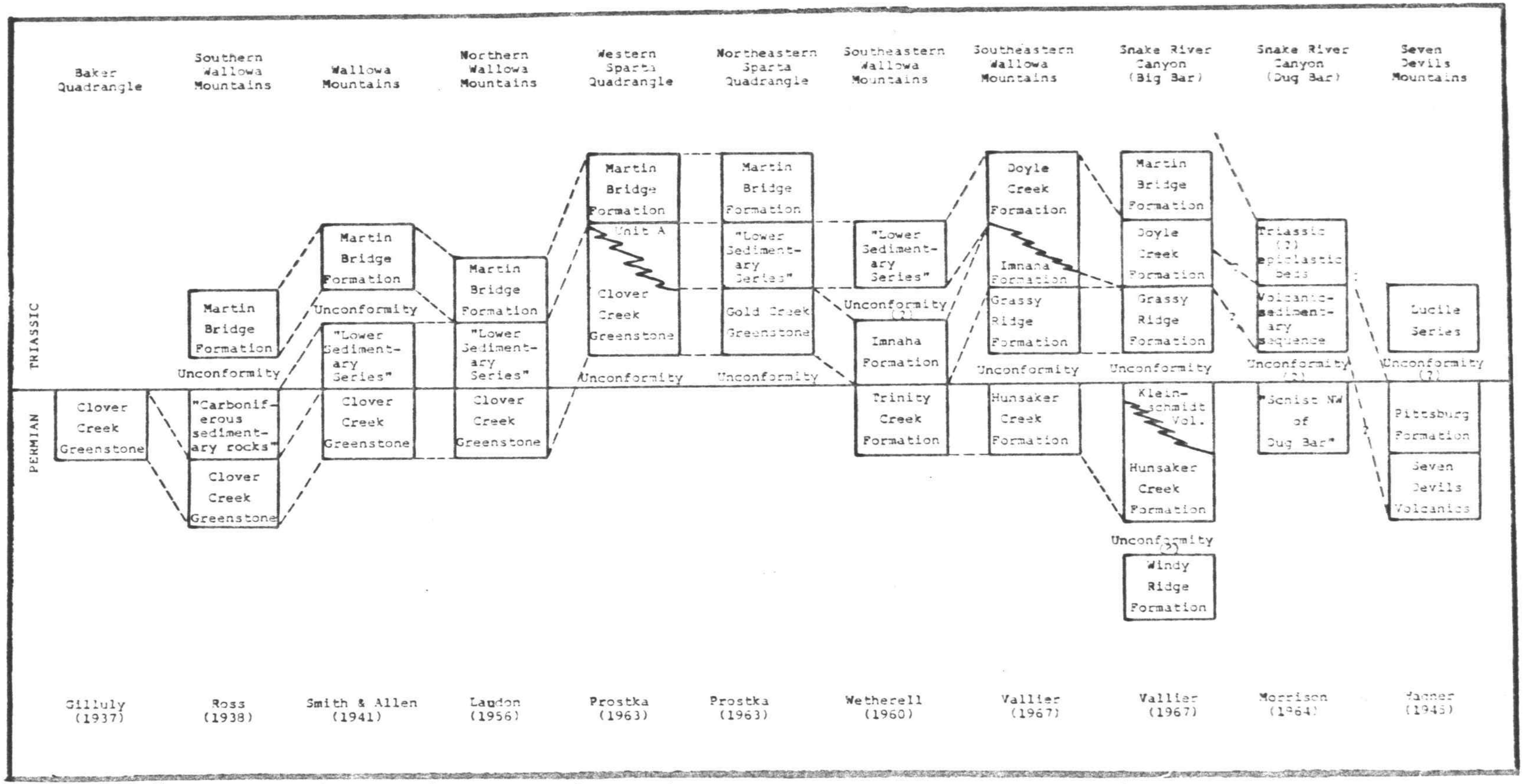

Figure 2. Stratigraphic relationships and proposed correlation of rocks of northeastern Oregon and western Idaho (in part from Prostka, 1963). No formation thicknesses are implied.

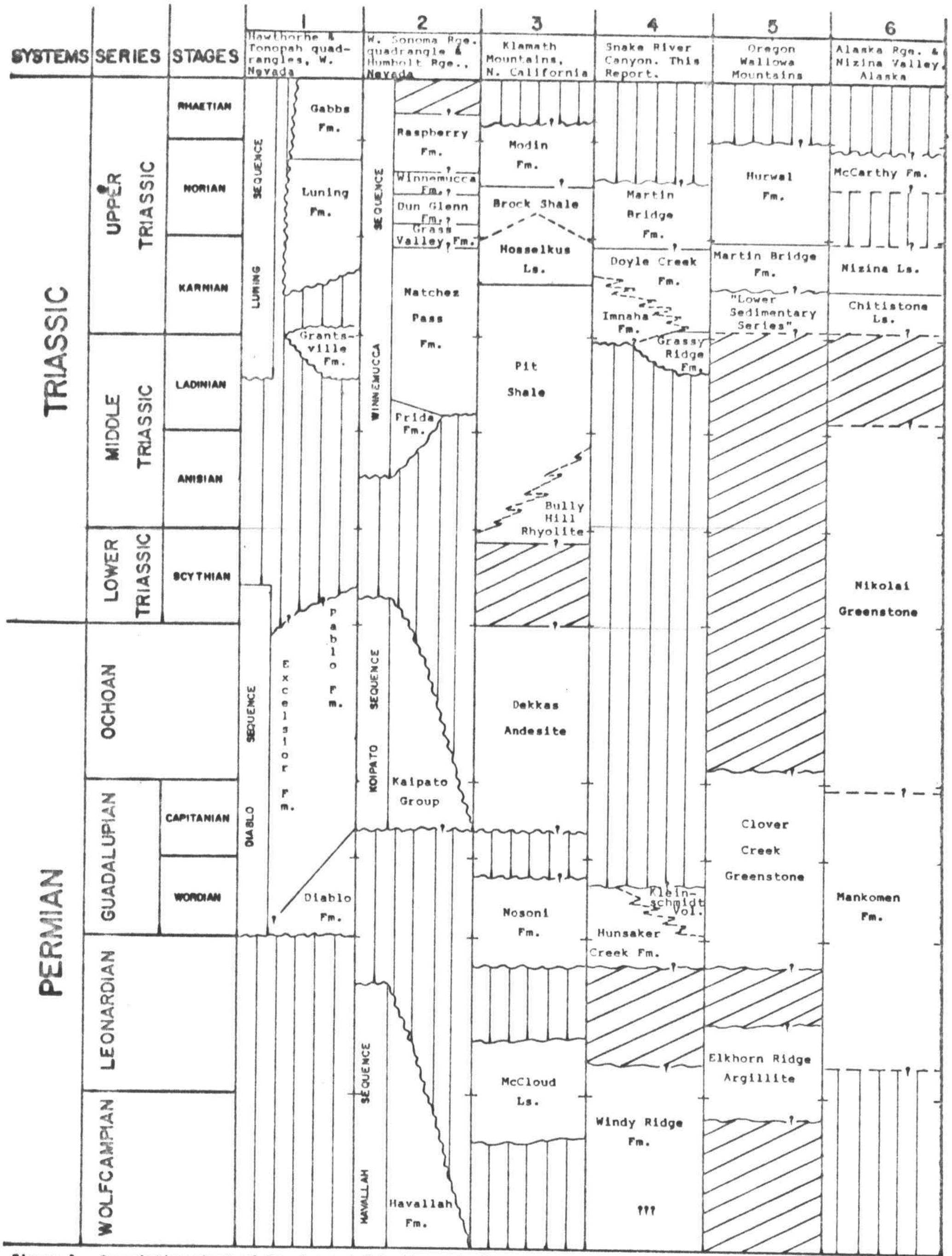

Figure 3. Correlation chart of Permian and Triassic rocks in parts of the Cordilleran Eugeosyncline. Stratigraphic hiatus is indicated by vertical ruling. Lack of data indicated by diagonal ruling. Columns 1-2 from Silberling and Roberts (1962), 3 from Albers and Robertson (1961), 5 and 6 from McLearn (1953), Reeside _et al._ (1957), and Dunbar _et al._ (1960).

Cannon (Cook, 1954, p. 3) reported both Permian and Triassic fossils in the Seven Devils Volcanics. Hamilton (1963a, p. 7) tentatively correlated the Seven Devils Volcanics with the Clover Creek Greenstone described by Gilluly (1937) in the Baker quadrangle, Oregon. Hamilton also described another rock unit, the Riggins Group, which is in fault contact with the Seven Devils Volcanics along the Rapid River thrust. Hamilton (1963a, p. 35-36) suggested that the Riggins Group is not correlative with the Seven Devils Volcanics and could be of any age from Cambrian through Early Cretaceous. Morrison (1964) described two major units in the Snake River canyon near Dug Bar. Informally named the volcanic-sedimentary sequence, the lower unit was correlated with the Upper Triassic rocks of the Clover Creek Greenstone and in part with the Seven Devils Volcanics. The upper unit, the Triassic (?) epiclastic beds, was tentatively correlated with the Pittsburg Formation (Wagner, 1945, p. 4-5) and with the Hurwal Formation of the Wallowa Mountains. Morrison was greatly handicapped by a scarcity of fossils.

Stratigraphic Column in the Wallowa Mountains

Lindgren (1901, p. 577-582) described the pre-Tertiary rocks in the southern Wallowa Mountains and in the Snake River canyon north of Huntington, Oregon. Gilluly (1932, p. 4) reported that the pre-Tertiary greenstone in the southern Wallowa Mountains was Permian in age and later stated (Gilluly, 1935, p. 227) that the Permian greenstone extended into the Snake River canyon near Homestead, Oregon. Gilluly (1937, p. 9-27) subsequently divided the pre-Tertiary "supracrustal rocks" into three formations: the older two were named the Burnt River Schist and the Elkhorn Ridge Argillite; the younger one, of Permian age, was called the Clover Creek Greenstone. Since Gilluly's studies, altered greenstones in other parts of northeastern Oregon have been correlated with the Clover Creek Greenstone on the basis of similar lithologies.

Ross (1938, p. 21-25) correlated a thick sequence of metamorphosed volcanic flows and volcaniclastic rocks in the southeastern Wallowa Mountains with the Clover Creek Greenstone and thereby extended the Clover Creek Greenstone as far north as the Imnaha River. The predominantly sedimentary unit that overlies the Clover Creek Greenstone and underlies the Martin Bridge Formation was called the "Carboniferous (?) sedimentary rocks". The rocks appeared conformable on the Clover Creek Greenstone and unconformably overlain by the Martin Bridge Formation. Therefore, Ross concluded that the rocks between the Clover Creek Greenstone and the Martin Bridge Formation were Permian.

Smith and Allen (1941, p. 7) correlated the greenstone in the northern Wallowa Mountains with the Clover Creek Greenstone. The conformable overlying sedimentary rocks were named the "Lower Sedimentary Series" whose rocks were believed to be overlain by the Martin Bridge Formation with "strong unconformity". Although Late Triassic fossils were collected from the "Lower Sedimentary Series", Smith and Allen (1941, p. 8) maintained that the sequence was conformable on the Clover Creek Greenstone and that the Clover Creek Greenstone was probably Permian in age.

Laudon (1956, p. 17-18), in a detailed study of the Martin Bridge Formation, found no evidence for an unconformity between the "Lower Sedimentary Series" and the Martin Bridge Formation. As Triassic fossils were discovered in strata that had been mapped by Smith and Allen (1941) as Clover Creek Greenstone, Laudon redefined the lower boundary of the "Lower Sedimentary Series" to include these Triassic rocks. Laudon maintained that there was a time break between the basal Triassic rocks and the underlying lithologically similar greenstone which he thought was Permian.

Wetherell (1960) mapped part of the southeastern Wallowa Mountains and found Permian fossils in a thick sedimentary sequence which he informally named the Trinity Creek Formation. From Late Triassic fossils in sedimentary beds of the overlying rocks, he concluded that most was Triassic in age. This thick sequence of greenstone and volcaniclastic rocks was informally named the Imnaha Formation and divided into the Russell Member and the Norway Member. Wetherell suggested that the Russell Member of the Imnaha Formation was conformable on the Permian Trinity Creek Formation, and that the Russell Member was possibly Early Triassic (op.cit., p. 50). Wetherell also proposed that the "Lower Sedimentary Series" overlies the Norway Member of the Imnaha Formation with angular unconformity (op.cit., p. 92).

In the northeastern part of the Baker quadrangle, Bostwick and Koch (1962, p. 421) reported Triassic fossils in the Clover Creek Greenstone. This discovery, plus that of Wetherell, posed a problem of distinguishing Permian strata from Triassic strata.

Prostka (1963) studied the stratigraphy of the Sparta quadrangle, south of the Wallowa Mountains. The volcanic flow rocks and volcaniclastic rocks that underlie the Martin Bridge Formation in the Sparta quadrangle exhibit extreme lithofacies changes. Prostka concluded that the Clover Creek Greenstone in the Sparta quadrangle was of Late Triassic age and suggested that the formation was a lithofacies of the Gold Creek Greenstone and the "Lower Sedimentary Series".

Nolf (1966) mapped and described the Clover Creek, Martin Bridge, and Hurwal formations in the northern

Wallowa Mountains. The total thickness of the units is about 11,000 feet. The Clover Creek Formation was informally divided into three members (Nolf, 1966, p. 11); in decreasing age they are the Mount Howard Member, Chief Joseph Member, and Dunn Creek Conglomerate. Nolf (op. cit., p. 37) reported that Smith and Allen (1941) included in the "Lower Sedimentary Series" approximately the same beds on Chief Joseph Mountain as those of the Chief Joseph Member and the Dunn Creek Conglomerate of the Clover Creek Formation. Structural interpretations by Nolf indicated that rocks designated by Smith and Allen as part of the "Lower Sedimentary Series" are overturned beds of the Hurwal Formation, structurally repeated beneath the Martin Bridge Formation by isoclinal folding. Nolf (op.cit., p. 41) also divided the Martin Bridge Formation into three members: the Hurricane Creek; B C Creek; and Scotch Creek members. The Hurricane Creek and B C Creek members are interfingering parts of a reef. The contact between the Clover Creek and Martin Bridge formations is conformable.

Stratigraphic Column in the Thesis Area

A generalized columnar section records the thicknesses, lithologies, and ages of the major stratigraphic units in the map area (Table 2). A diagrammatic cross section shows the east-west stratigraphic relationships

Table 2. Generalized Columnar Section of the Stratigraphic Units in the Map Area.

Period	Formation	Approx. Thickness	General Lithology	Age
TERTIARY	Columbia River Basalt	2,000-3,000	Basalt, minor basalt breccia and tuffaceous sediment	No fossils; probably Miocene and early Pliocene
	Unconformity			
TRIASSIC	Martin Bridge Fm.	1,750	Limestone and dolomitic limestone	Ammonites of Norian age
	Doyle Creek Fm.	3,000-5,000	Spilite, volcaniclastic rock, minor keratophyre, and limestone pods	No fossils, bracketed as Karnian age
	Imnaha Fm.	5,000-10,000	Spilite, volcanic breccia, volcanic conglomerate, and minor limestone pods	Pelecypods of Karnian (?) age
	Grassy Ridge Fm.	0-4,000	Volcaniclastic rock, spilite, and minor keratophyre	Ammonites of early Karnian age and pelecypods of Ladinian age
	Unconformity			
PERMIAN	Kleinschmidt Volcanics	2,000-3,000	Spilite and minor volcaniclastic rock	No fossils; probably of Guadalupian age
	Hunsaker Creek Fm.	8,000-10,000	Volcaniclastic rock, keratophyre, conglomerate, minor spilite, mudstone, and limestone	Brachiopods of Leonardian and Guadalupian ages
	Unconformity(?)			
PERMIAN (?)	Windy Ridge Fm.	2,000-3,000	Keratophyric flow rock and keratophyric pyroclastic rock	No fossils; may be older than Permian

(Figure 4).

The base of the Martin Bridge Formation is a convenient and easily-recognized horizon, below which the rocks are characterized by marked lithofacies changes and recurrent rock types. These characteristics, plus the lenticular nature of some units, the complex structure, and poor outcrops in some areas made thickness measurements and other stratigraphic studies difficult.

Perhaps the most impressive feature in the geologic history of the map area is the dominant role played by volcanism. Volcanic rock occurs in all the pre-Quaternary stratigraphic units except the Martin Bridge Formation. Much of the volcanic activity was probably submarine.

Windy Ridge Formation (Pwr)

Definition, Distribution, and General Character

The Windy Ridge Formation is a sequence of altered volcanic flow rocks and volcaniclastic rocks exposed in the nose of a faulted anticline (?) along the south end of Windy Ridge. The outcrop area of the formation is in secs. 7, 8, 16, and 17, T. 19 N., R. 4 W. The type locality extends along the Idaho Power and Light Company (IPALCO) road for more than two miles north of Oxbow, Oregon. Exposures elsewhere are very poor and are characterized by scattered, deeply weathered, and

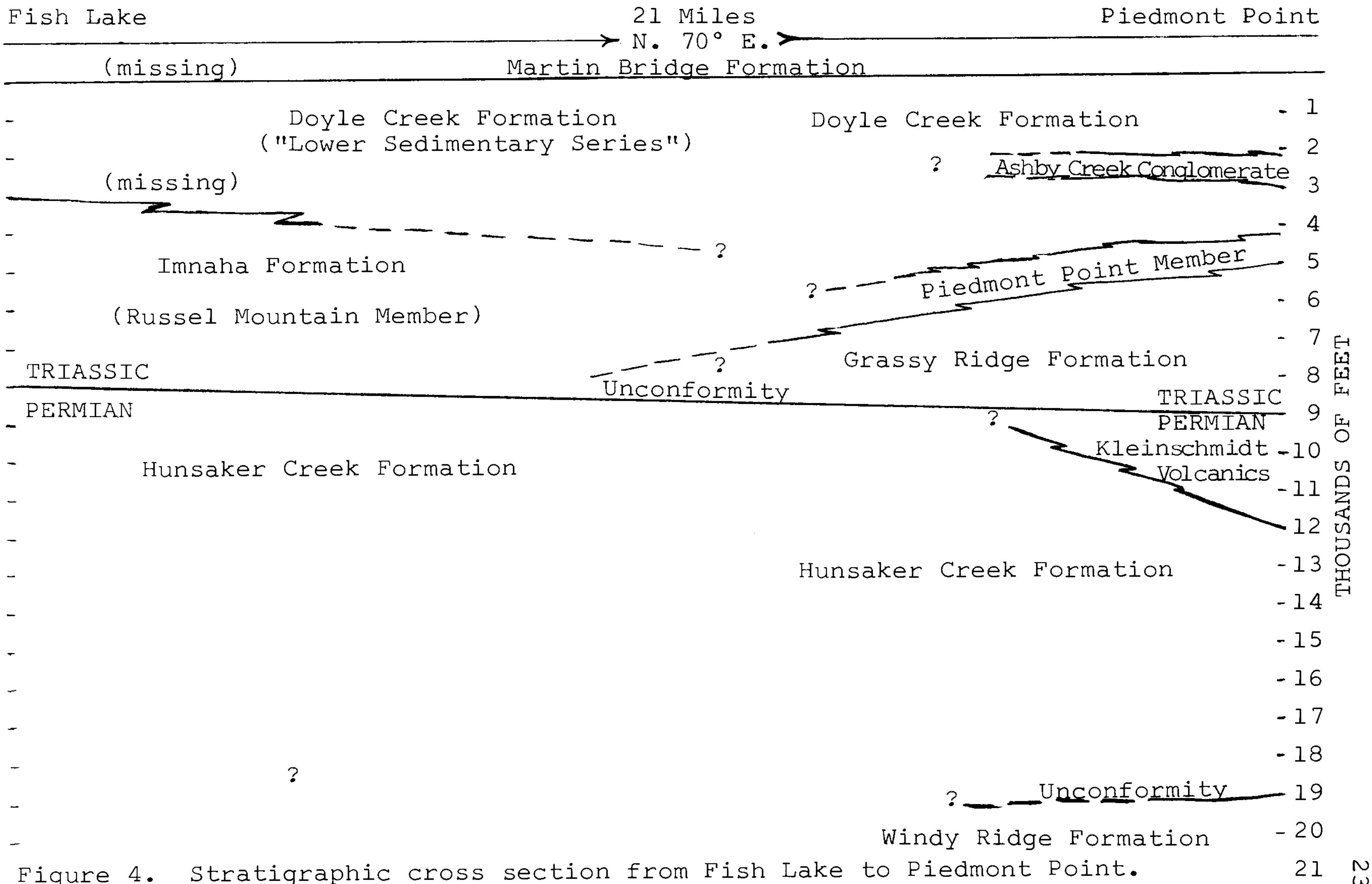

Figure 4. Stratigraphic cross section from Fish Lake to Piedmont Point. Vertical scale is exaggerated.

brown-stained outcrops. Beds generally strike N. 50°-65° E. and dip 20°-60° southeast. However, northwest-dipping strata occur near the top of the ridge. A detailed section could not be measured. Rocks along the IPALCO road are keratophyre and quartz keratophyre flow rocks and their pyroclastic equivalents.

The Windy Ridge Formation is easily distinguished from younger formations. The following characteristics help define the unit: (1) grayish-green volcanic flows and volcaniclastic rocks are cut by abundant dusky-green to greenish-black mafic dikes; (2) euhedral, white feldspars and clear to milky quartz crystals occur in the volcanic flow rocks and in the volcaniclastic rocks; (3) coarse tuff and tuff breccia are poorly sorted; (4) some bedding is graded but most bedding planes are indistinct; (5) conglomerate, mafic flow rocks, and fossils are absent; and (6) light brown is a typical weathering color of the keratophyric rocks, but dark, reddish-brown streaks are noticeable where mafic dikes have weathered.

Stratigraphic Relationships and Thickness

The base of the Windy Ridge Formation is not exposed in the map area and the top of the formation is difficult to find and trace. Along the northwest side of Windy Ridge the formation is separated from the overlying Hunsaker Creek Formation by a high-angle fault. Elsewhere, the boundary was drawn where the grayish-green flows and clastic rocks of the Windy Ridge Formation are overlain by either a conglomerate or a mafic breccia of the Hunsaker Creek Formation. A good exposure that shows contact relationships is along the west side of Blue Creek at an elevation of about 2,650 feet, in the E½NE¼NE¼ sec. 9, T. 19 N., R. 4 W., where a maroon and black conglomerate overlies the Windy Ridge Formation. A conglomerate of the overlying Hunsaker Creek Formation, containing clasts very similar to the major rock types of the Windy Ridge Formation, is exposed in a small gulch northwest of Blue Creek at an elevation of about 2,800 feet in the SE¼NE¼NE¼ sec. 9, T. 19 N., R. 4 W. The contact is probably an unconformity, but angularity of strata on either side of the contact could not be demonstrated. Criteria that suggest an unconformity are the following: (1) an abrupt change in lithology occurs between the grayish-green flows and volcaniclastic rocks of the Windy Ridge Formation and the conglomerate, mafic breccia, and other volcaniclastic rocks of the Hunsaker Creek Formation; (2) the mafic dikes characteristic of the Windy Ridge Formation are rare in the overlying rocks; and (3) conglomerate in the lower part of the Hunsaker Creek Formation contains rounded clasts that are very similar to rocks of the Windy Ridge Formation.

Rocks of the Windy Ridge Formation are mixed intimately with rocks of different character along the west side of Blue Creek where shearing and intrusive phenomena characteristic of the Oxbow-Cuprum shear zone (Taubeneck, 1966) are present. In places, intrusive rocks of the Oxbow Complex apparently are gradational into quartz keratophyre and keratophyric clastic rocks of the Windy Ridge Formation, suggesting that metasomatism connected with shearing and intrusion of quartz diorite was instrumental in developing some of the different rock types. An excellent outcrop to investigate this possibility is at an elevation of 2,010 feet along the west side of the road that leads to the top of Windy Ridge, in the NW¼NE¼SE¼ sec. 17, T. 19 N., R. 4 W. General absence of bedding planes and poor outcrops prevented detailed structural and stratigraphic studies. The Windy Ridge Formation has an estimated thickness between 2,000 and 3,000 feet.

Lithology and Petrography

The Windy Ridge Formation contains keratophyre, quartz keratophyre, keratophyric tuff, and keratophyric tuff breccia. No unequivocal epiclastic rocks were distinguished.

Keratophyre and Quartz Keratophyre

Volcanic flow rocks are porphyritic keratophyre and quartz keratophyre. The color of fresh samples is grayish green (10 G 4/2); the weathered color is moderate yellowish brown (10 YR 5/4). Porcelaneous lusters and concoidal or subconcoidal fractures are characteristic. Major minerals are quartz and albite (An_{3-7}), which occur as phenocrysts and in the groundmass. Phenocrysts range from 1 to 5 mm in diameter and are set in a felty or recrystallized groundmass. Albite phenocrysts comprise between 15 and 20 percent of the rocks. Quartz phenocrysts in the quartz keratophyre comprise from 5 to 15 percent. Many albite phenocrysts form glomeroporphyritic aggregates of three or four crystals. Albite generally is clear but some crystals are altered by fine-grained epidote and white mica. Some quartz phenocrysts are bipyramidal whereas others are rounded. Rounded grains were probably shaped by magmatic resorption. Dust trails are common but larger inclusions are absent in the quartz phenocrysts. No primary mafic minerals were observed.

Penninite, sphene, leucoxene, white mica, epidote, calcite, magnetite, and hematite occur in the groundmass in addition to quartz and albite (Table 3). Sample VS5-7 has 70 percent quartz spherulites. Penninite is scattered irregularly through the groundmass and is responsible for the grayish-green color of the rocks.

The flow rocks were probably andesite and dacite before metamorphism. Modifications of the original rocks

Table 3. Modal Analyses of Porphyritic Quartz Keratophyre of the Windy Ridge Formation. Samples were Collected Along the IPALCO Road. The T Signifies Trace Amounts.

Mineral Name	VS5-1	VS5-7	VS5-10	VC-127
Albite phenocrysts	16.3	15.5	21.4	20.7
Quartz phenocrysts	10.2	7.5	6.4	13.8
Iron ore	0.2	-	-	0.4
Penninite	9.6	-	16.4	2.1
Epidote	0.3	T	0.8	0.4
Calcite	-	0.5	-	0.1
Sphene-leucoxene	1.4	2.0	1.0	1.2
White mica	T	T	T	T
Prochlorite	T	-	-	-
Quartz-albite groundmass	62.0	74.5	54.0	61.3
Total	100.0	100.0	100.0	100.0

include groundmass recrystallization, albite pseudomorphs, and replacement veins of quartz and albite. Low-grade metamorphic minerals indicate that the rocks belong to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1960).

Tuff and Tuff Breccia

All tuff and tuff breccia are composed of volcaniclastic debris from a monolithologic source. Major components are rock fragments of quartz keratophyre and keratophyre, pumice (?), and crystals of quartz and albite, set in a quartz-rich matrix. In outcrop, some tuff resembles the flow rocks and is distinguished only on weathered surfaces or by thin section study. Massive keratophyre tuff shows no sedimentary features and is generally tens of feet thick. Laminated tuff is not common and has weakly graded beds.

The keratophyre tuff is uncontaminated by foreign rock fragments of spilitic, "granitic", or sedimentary origin. Although indisputable evidence of pumice fragments and glass shards was not found, some recrystallized fragments may be relicts.

Conditions of Deposition, Transportation, and Provenance

Rocks of the Windy Ridge Formation were probably erupted, transported, and deposited in a submarine environment. However, evidence cited by Fiske (1963, p. 402-405) for subaqueous eruption and deposition was not noted because of post-depositional changes. Monolithology, a lack of epiclastic debris, and the intercalated tuffs and flows suggest that the materials were erupted from the same magma as quiet flows and violent pyroclastic eruptions. In a submarine environment, large phreatic eruptions should be expected. Transportation of the clastic material probably was by subaqueous pyroclastic flows.

Age and Correlation

The age of the Windy Ridge Formation is unknown. No fossils were collected and similar rocks have not been described in surrounding areas. The formation is overlain, probably unconformably, by the Hunsaker Creek Formation of Middle Permian age. Since no fossils older than Permian have been reported in the Wallowa Mountains and Seven Devils Mountains, the Windy Ridge Formation is tentatively assigned to an Early or Middle Permian age. However, the rocks may be older.

Hunsaker Creek Formation (Phc)

Definition, Distribution, and General Character

Hunsaker Creek Formation is the name given to a metamorphosed sequence of volcaniclastic rocks and volcanic flow rocks that are widely exposed south of Fish Lake and along both sides of the Snake River canyon (Plate 3). The type section is along the north side of Hunsaker Creek between the elevations of 2,100 and 3,500 feet in the SE¼ sec. 5 and the NE¼ sec. 6, T. 7 S., R. 48 E. (Appendix A. Table 23). A reference section is along Ballard Creek between the elevations of 2,150 and 3,600 feet in the W½ sec. 11, T. 6 S., R. 48 E. (Appendix A, Table 24). Other well-exposed sections that could be studied as reference sections include the north side of Herman Creek near the center of sec. 15, T. 6 S., R. 48 E., the valley of Elk Creek near the center of T. 6 S., R. 47 E., the north side of Duck Creek, south of the Trinity Guard Station from the NW¼ sec. 27 to the center of sec. 21, T. 6 S., R. 46 E., and along the ridge south of Fish Lake in sec. 16, T. 6 S., R. 46 E. Other good outcrops are in Whiskey Gulch, Homestead Creek, and along the south side of the Imnaha River canyon near Indian Crossing. In general, outcrops are poorly exposed in the Fish Lake area but are well exposed in tributary canyons of the Snake River.

Rocks of the Hunsaker Creek Formation were informally named the Trinity Creek Formation by Wetherell (1960, p. 15). Hunsaker Creek Formation is a preferable name because of a more representative stratigraphic section and better exposures in Hunsaker Creek.

Rocks of the Hunsaker Creek Formation are difficult to distinguish from those of the overlying Middle Triassic Grassy Ridge Formation because both include graded beds, are colored in several shades of green, contain significant amounts of conglomerate, and have similar topographic expression. However, the Hunsaker Creek Formation has less spilitic flow rocks, contains more volcaniclastic detritus, has more fine-grained clastic rocks, and weathers to grays, light browns, and yellows in contrast to the dark reddish browns of the Grassy Ridge Formation. Furthermore, keratophyre clasts are the major rock type in the conglomerates of the Hunsaker Creek Formation whereas spilitic clasts predominate in the conglomerates of the Grassy Ridge Formation.

Stratigraphic Relationships and Thickness

The Hunsaker Creek Formation overlies the Windy Ridge Formation with probable unconformity, interfingers with and is in part overlain by the Permian (?) Kleinschmidt Volcanics, and is overlain with angular unconformity by the Grassy Ridge Formation in the Snake River and Imnaha canyons and by the Imnaha Formation in the Fish Lake region.

The base of the Hunsaker Creek Formation is exposed along the west side of Blue Creek. The Kleinschmidt

Volcanics are in fault contact with the Hunsaker Creek Formation on the west side of Windy Ridge but interfinger with and, in part, overlie the Hunsaker Creek Formation on the east side of Windy Ridge in the SW¼ sec. 25, T. 20 N., R. 4 W. The Grassy Ridge Formation overlies the Hunsaker Creek Formation with angular unconformity in the canyons of Homestead Creek, Ashby Creek, Elk Creek, Whiskey Gulch, and the Imnaha River. The Russel Mountain Member of the Imnaha Formation overlies the Hunsaker Creek Formation with unconformable relationships near Fish Lake.

The estimated thickness is between 8,000 and 10,000 feet. Lithofacies changes, repetitious beds of similar lithologies, structural complications, and discontinuous exposures contribute to the difficulty of measuring the total thickness. A 2,367 foot section measured in Hunsaker Creek is interrupted by faulting. A section of 1,898 feet was measured in Ballard Creek (Figure 5). Correlation of beds between the two sections was not possible although parts may be equivalent.

Lithology and Petrography

Major rock types in the Hunsaker Creek Formation are of volcaniclastic origin. Pyroclastic rocks seem subordinate to epiclastic rocks, but are probably more abundant than available evidence suggests. Volcanic flow rocks form a minor part of the formation. As all rocks have

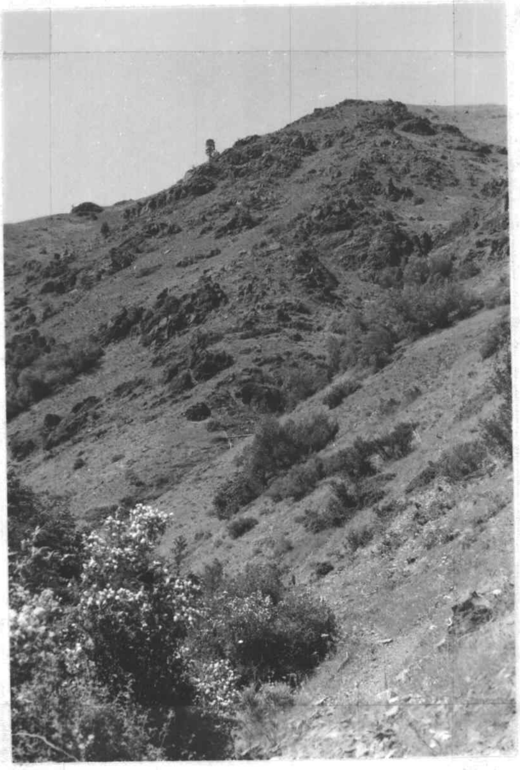

Figure 5. Reference section of the Hunsaker Creek Formation along the north side of Ballard Creek, Oregon.

undergone low-grade regional metamorphism, secondary minerals have replaced the pre-existing components.

Keratophyre and Quartz Keratophyre

Keratophyre and quartz keratophyre flows occur in scattered, discontinuous outcrops and range in thickness from 10 to 60 feet. Keratophyric flow rocks are exposed along the Kleinschmidt Grade, in Hunsaker Creek, along the IPALCO road, and in Azurite Gulch.

Eleven keratophyres and 11 quartz keratophyres (more than 5 percent quartz phenocrysts) were examined optically. All are porphyritic, consisting of plagioclase or plagioclase and quartz phenocrysts set in a felty, pilotaxitic, or completely recrystallized groundmass (Figure 6). Colors range from olive gray (5 Y 3/2), grayish green (10 GY 5/2), and brownish gray (5 YR 6/1), to pale red (5 R 6/2) and pale red purple (5 RP 6/2).

Albite phenocrysts are from 0.2 to 6.0 mm in length and commonly occur in glomeroporphyritic groups of 3 to 6 crystals. In two samples, albite occurs with quartz as a micrographic intergrowth (Figure 7). White mica and calcite are common alteration minerals, but a dusky-brown cryptocrystalline material in some albite phenocrysts was not identified. In a few samples, the edges of feldspar phenocrysts appear corroded by the groundmass.

Quartz phenocrysts commonly are bipyramidal, although

Figure 6. Photomicrograph (about X 40, crossed nicols) of a porphyritic keratophyre of the Hunsaker Creek Formation. The albite phenocryst is set in a felty groundmass.

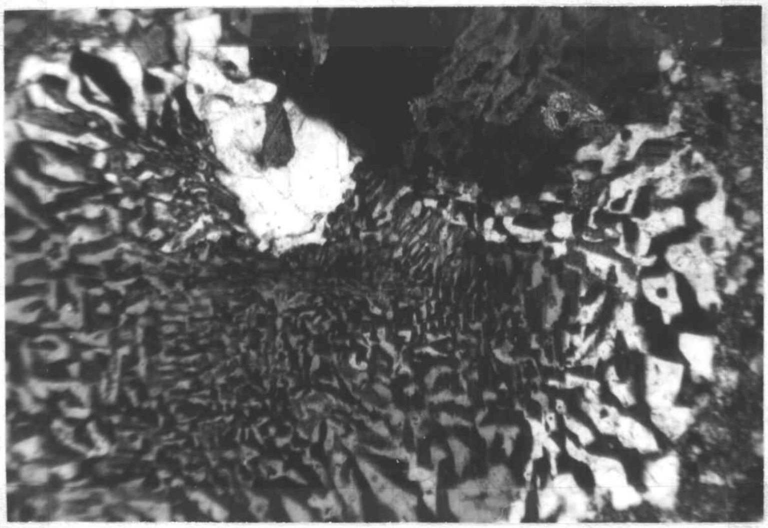

Figure 7. Photomicrograph (about X 40, crossed nicols) of micrographic texture in a quartz keratophyre of the Hunsaker Creek Formation.

many crystals show magmatic resorption. Light-brown dust trails are common but larger inclusions are absent. Mafic minerals apparently comprised a very small percent of the original rock. In a few samples, chlorite has pseudomorphed scattered amphibole.

Major groundmass minerals are quartz, albite, chlorite, calcite, sphene, leucoxene, white mica, and hematite. Minor amounts of epidote and prehnite occur in a few slides. Chlorites are separated into two types, prochlorite and penninite. Prochlorites are faintly pleochroic from colorless to pale green, or more strongly pleochroic from pale yellowish green to moderate yellow green. Yellowish-gray, grayish-green, and even reddish-brown interference colors are common. Birefringence and interference colors apparently vary with ferric iron content. Penninite is easily distinguished by purple, dark-brown, and anomalous blue interference colors. Interestingly, in the keratophyric flows of the Hunsaker Creek Formation, only one type of chlorite occurs in each rock. Calcite is present as patch replacements of the groundmass, as feldspar pseudomorphs, and in veins.

The keratophyric flow rocks have undergone variable recrystallization and soda-silica metasomatism. Recrystallized quartz-rich groundmasses and quartz veins suggest an increase in silica. The ubiquitous occurrence of albite phenocrysts and albite-rich groundmasses suggest soda additions. Probably, the rocks were originally dacite and andesite; it is very improbable that any rock has been preserved in an unaltered condition.

Spilite

Spilite occurs as flows and dikes in the Hunsaker Creek Formation but comprises only a small percent of the rocks. Spilite weathers more rapidly than most adjacent rocks, but good outcrops are along the north side of Ballard Creek and along the IPALCO road.

Pillow structure, commonly associated with spilitic flow rocks, is absent. The flows are massive and generally are no more than 10 feet thick. Most samples are porphyritic; some are amygdaloidal. Phenocrysts of plagioclase and clinopyroxene are set in a groundmass having intergranular, diabasic, or pilotaxitic textures (Figure 8). Feldspar phenocrysts range in length from 0.2 to 4.0 mm and average about 0.5 mm. Amygdules range in diameter from 0.3 to 5.0 mm. Colors of fresh rocks are greenish black (5 GY 2/1), dark greenish gray (5 G 4/1), and grayish green (10 G 4/2). Major minerals are albite, clinopyroxene, chlorite, calcite, sphene, and quartz (Table 4). Chlorites are the major mafic minerals and include alteration products of glass.

Albite comprises from 45 to 75 percent of the spilites and is the only feldspar in all but one sample, which

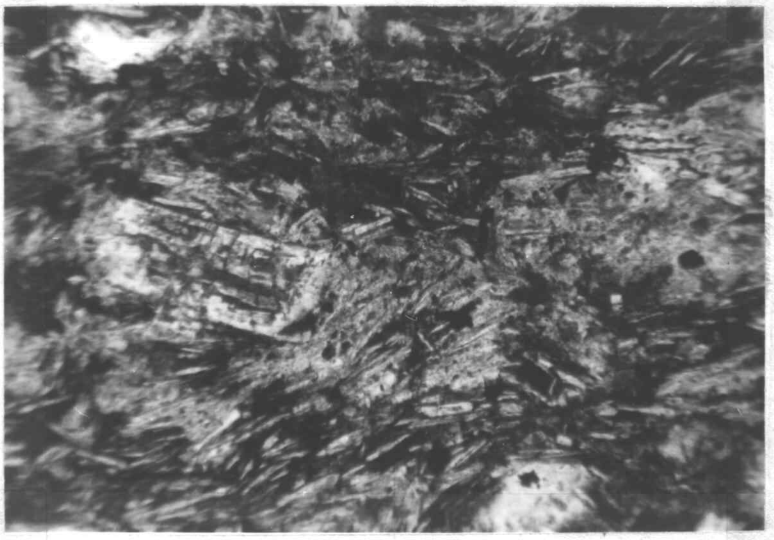

Figure 8. Photomicrograph (about X 40, crossed nicols) showing a pilotaxitic texture in a spilite of the Hunsaker Creek Formation.

Table 4. Modal Analyses of Three Spilites of the Hunsaker Creek Formation.

Mineral Name	LS9-3[1]	LS9-4[2]	VC-197[3]
Albite	70.1	73.1	50.6
Augite	-	-	5.9
Iron ore	0.2	1.1	0.2
Penninite	21.1	21.6	36.5[4]
Prochlorite	-	3.5	
Calcite	4.4	0.1	T
Sphene	0.6	T	6.8
White mica	-	-	T
Epidote	-	-	T
Leucoxene	0.6	0.3	T
Quartz	3.0	0.3	T
Total	100.0	100.0	100.0

[1] Ballard Creek Section, sec. 11, T. 6 S., R. 48 E., elevation 2,190 feet.

[2] Ballard Creek Section, sec. 11, T. 6 S., R. 48 E., elevation 2,200 feet.

[3] Elevation 1,960 feet, SE¼SW¼ sec. 21, T. 6 S., R. 48 E.

[4] Total chlorite.

contains relicts of a more calcic plagioclase. Albite microlites are dominant over the phenocrysts. Calcite, chlorite, white mica, and a dusky-brown cryptocrystalline material commonly replace the feldspars. Clinopyroxene is present in 6 of 18 thin sections. Stubby prisms are replaced in part or wholly by chlorite and epidote.

Basaltic volcanism was subordinate to andesitic volcanism. The spilite flows are interbedded with volcanic sediments and commonly are related to adjacent spilite breccia. Spilite flows, spilite tuff, and spilite clasts in some conglomerate indicate that basaltic volcanism was a significant but minor contributor to the total volume of rocks in the Hunsaker Creek Formation.

Pyroclastic Rocks

Pyroclastic rocks include pyroclastic breccia, tuff breccia, and coarse and fine tuff. Although most clastic material probably is in part tuffaceous, only deposits that most likely are of pyroclastic origin are considered. Pyroclastic rocks are distinguished from epiclastic rocks by homogeneity of composition, by the absence of hydraulically produced features like cross-bedding and rounded clasts, and, in some places, by an association with volcanic flow rocks of the same composition. Pyroclastic breccia is exposed along the IPALCO road in the NE¼ sec. 8, T. 19 N., R. 4 W. This spilitic breccia is characterized by a greenish-black color, by angular fragments, by poor sorting, by abundant matrix, and by thicknesses of over 30 feet. A peculiar monolithic volcanic breccia crops out along the north side of Ashby Creek at an elevation of about 3,250 feet. Oval, round, and tear-shaped vesicular fragments as much as 30 cm in length are scattered through a green, chloritic, tuffaceous matrix. Sorting is poor, no grading occurs, and the smaller fragments are angular. A thick keratophyric pyroclastic (?) breccia is exposed at an elevation of about 6,550 feet in the NW¼NW¼ sec. 27, T. 6 S., R. 46 E. (Figure 9).

Tuff breccia and tuff generally contain more matrix than the pyroclastic breccia. In outcrop, individual tuff beds range in thickness from less than one inch to tens of feet. The settling of pyroclastic debris into fine-grained tuffaceous material on the sea floor formed peculiar load casts and other sedimentary structures (Figures 10 and 11). Post-depositional slumping contorted the bedding (Figure 12).

Albite, quartz, and volcanic rock fragments are the major components in the pyroclastic rocks. The beds consist mostly of rock fragments, or of quartz and albite crystals, or mixtures of rock fragments and crystals. Albite is the only feldspar; no calcic plagioclase relicts were observed. Quartz crystals are bipyramidal or rounded; the rounding probably represents magmatic

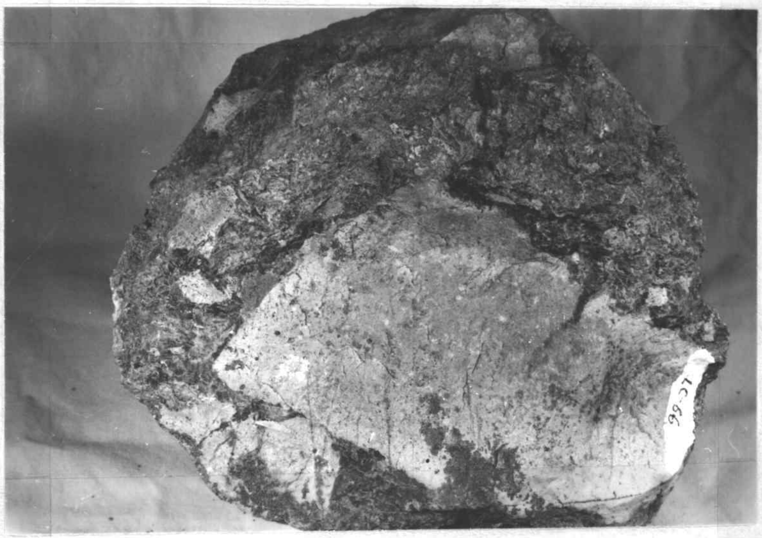

Figure 9. Keratophyric pyroclastic breccia of the Hunsaker Creek Formation. Keratophyre clasts are set in a dark-green, chloritic, tuffaçeous matrix. The diameter of the specimen is about six inches.

Figure 10. Sample showing sedimentary structures in tuff (?) beds of the Hunsaker Creek Formation. Part of a pyroclastic flow is represented in the upper left corner of the sample.

Figure 11. Sedimentary structures in tuff (?) beds of the Hunsaker Creek Formation. Elevation 5,960 feet, west-center sec. 28, T. 6 S., R. 46 E.

Figure 12. Contorted beds of tuff (?) in the Hunsaker Creek Formation. Elevation 6,900 feet, SW¼ sec. 15, T. 6 S., R. 46 E.

resorption prior to eruption. Matrices, generally recrystallized, comprise a large part of most units. No glass shards or pumice fragments were identified.

Tuff breccia, tuff, tuffaceous sandstone, and tuffaceous siltstone probably comprise more than 50 percent of the Hunsaker Creek Formation.

Epiclastic Volcanic Rocks

The epiclastic rocks are volcanic breccia, volcanic conglomerate, volcanic sandstone, and volcanic siltstone. Most are of mixed origin, part pyroclastic and part epiclastic. Post-depositional changes destroyed original features and obscured diagnostic evidence of origin.

Volcanic Breccia. Volcanic breccia is characterized by poor sorting, angular fragments, and heterogeneity of constituents. Rock fragments are the dominant component, generally making up more than 50 percent of the rock. Rounded clasts commonly occur but are everywhere subordinate to the angular fragments. Outcrops are graded or massive and can be from one foot to tens of feet thick. Colors are shades of green, ranging from greenish black (5 G 2/1) and grayish green (10 GY 5/2, 5 G 5/2) to pale green (5 G 7/2, 10 G 6/2). Fragment diameters range from two mm to several feet.

A volcanic breccia of mixed pyroclastic and epiclastic origin crops out on the north side of Hunsaker

Creek at an elevation of about 2,880 feet. Angular clasts of spilite, some over six feet long, are mixed with subordinate and partly rounded keratophyre clasts in a chloritic, tuffaceous matrix. The spilitic fragments and chloritic matrix were probably erupted and deposited contemporaneously with the rounded epiclastic keratophyre clasts.

Volcanic Sandstone. Volcanic sandstone is abundant in the Hunsaker Creek Formation. Most sandstone is volcanic graywacke but volcanic arenite also occurs. Bedding ranges from a few inches to 20 feet in thickness and is generally planar. Cross-bedding, grading, flow casts, and load casts are the dominant sedimentary structures.

The relationships of feldspars, rock fragments, and quartz grains of the volcanic sandstones are shown in Figure 13, whereas Figure 14 shows the relationships of matrix, rock fragments plus feldspars, and stable grains.

Volcanic graywacke contains angular to subrounded grains of feldspar, quartz, and rock fragments set in a matrix of quartz, albite, chlorite, calcite, and leucoxene (Figure 15). Modal analyses indicate that quartz and plagioclase comprise from 48 to 83 percent of the rocks, whereas rock fragments are not as abundant (Table 5). Plagioclase is albite in all but one sample where calcic feldspar is rimmed by clear albite. Plagioclase content in 16 thin sections ranges from 16 to 68 percent and

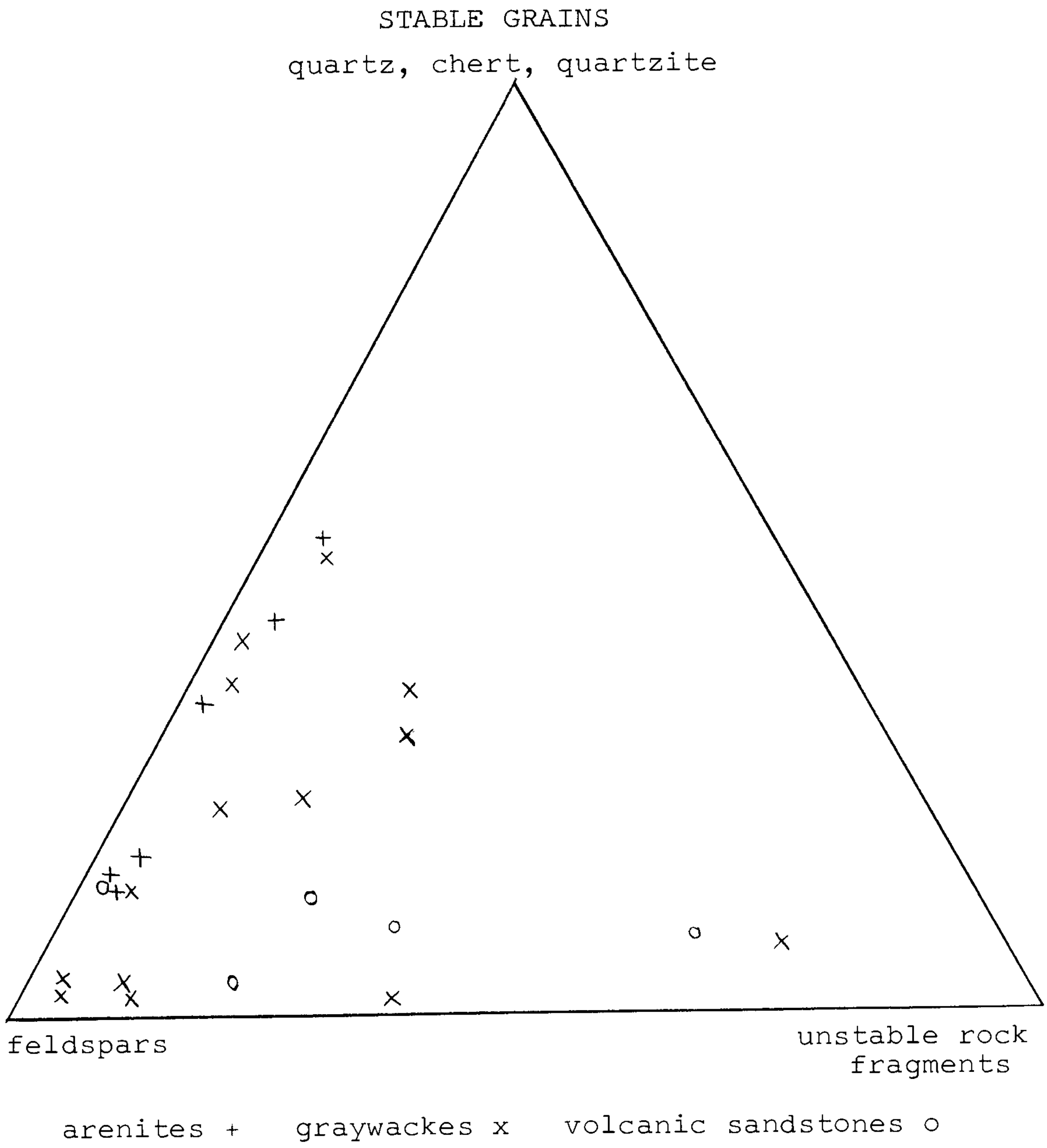

Figure 13. Triangular diagram showing volume percent of sand-sized constituents in sandstones of the Hunsaker Creek Formation.

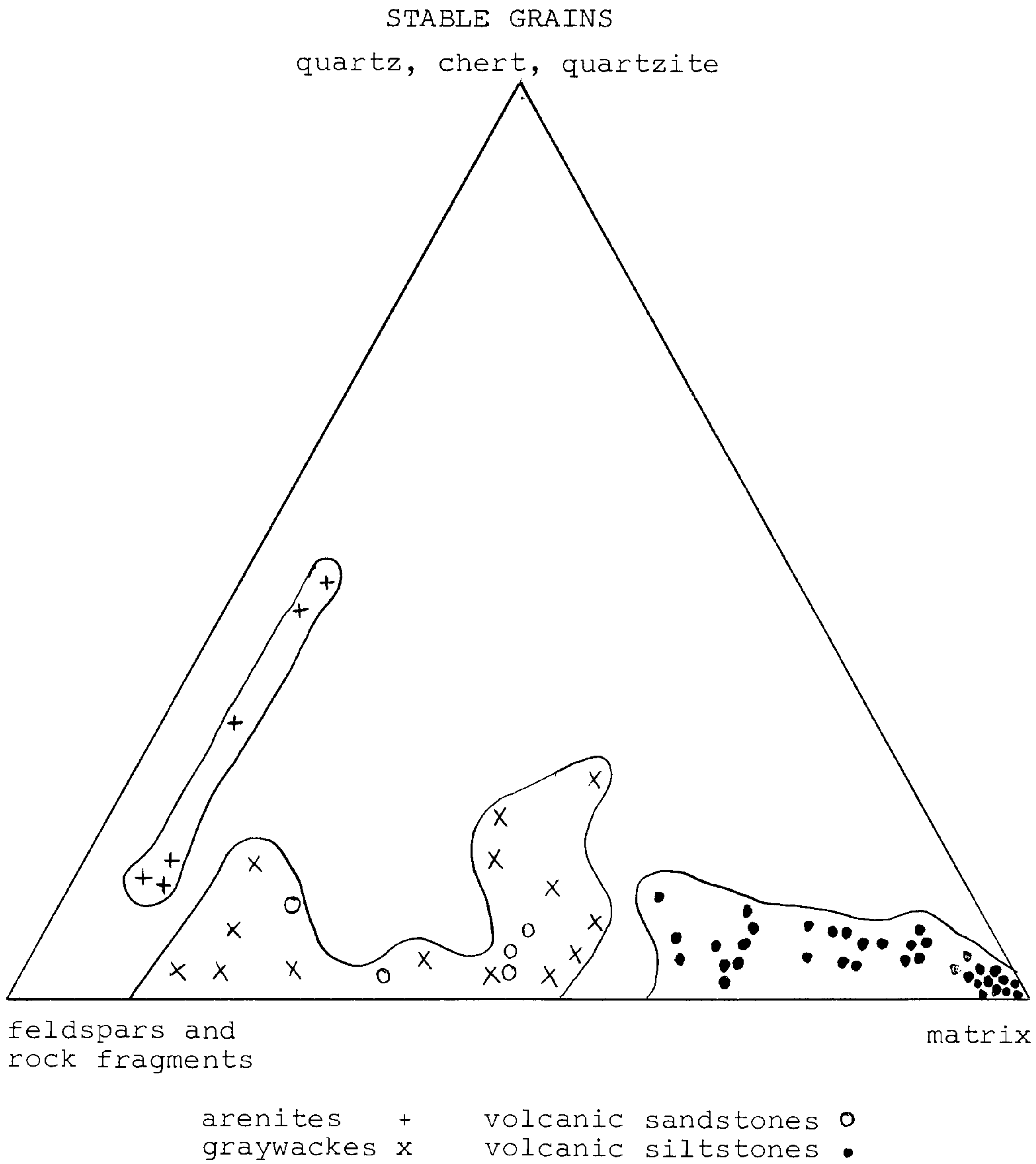

Figure 14. Triangular diagram showing volume percent of the major constituents in finer-grained rocks of the Hunsaker Creek Formation.

Table 5. Modal Analyses of Three Volcanic Graywacke of the Hunsaker Creek Formation.

Mineral Name	T-1-1-12[1]	LS7-23[2]	VC-286[3]
Plagioclase	29.2	21.1	68.4
Quartz	18.8	30.8	14.8
Rock fragments	3.2	4.6	1.6
Quartz-albite matrix	45.5	40.5	4.4
Iron ore	0.5	1.9	0.9
Penninite	-	-	9.1
Prochlorite	0.5	0.3	T
Calcite	1.7	0.5	0.3
Sphene-leucoxene	0.8	0.3	0.5
White mica	0.8	T	T
Epidote	T	T	T
Total	100.0	100.0	100.0

[1] Elevation 6,480 feet, SW¼SE¼SE¼ sec. 21, T. 6 S., R. 46 E.

[2] Elevation 2,660 feet, Hunsaker Creek, SW¼NW¼ sec. 5, T. 7 S., R. 48 E.

[3] IPALCO Road, NW¼ sec. 23, T. 20 N., R. 4 W.

averages 44 percent. Quartz content ranges from 1 to 31 percent and averages 14 percent. Quartz grains are generally more rounded than the plagioclase grains and rock fragments, probably because of the original shape rather than transportation effects. In addition, overgrowths on quartz occur in five samples. Quartz is free of inclusions except for some large grains in sample T-1-1-12 which have abundant iron ore. Plumulose chalcedonic growths are in two samples and micrographic intergrowths of quartz and albite occur in two other samples. Matrices commonly corrode quartz grains. Rock fragments comprise from 1 to 53 percent of the specimens and average about 10 percent. Most rock fragments were derived from flow rocks and pre-existing volcaniclastic rocks. The matrices are comprised of quartz, albite, penninite, prochlorite, calcite, white mica, leucoxene, siderite (?), epidote, hematite, and prehnite.

Volcanic arenite, a minor rock type, is characterized by having 10 percent or less matrix. Grains are subangular to well-rounded; sorting is moderate to good. Major components are quartz (15-47 percent), albite (39-76 percent), and rock fragments (1-4 percent). Calcite, prochlorite, and white mica are the other major minerals. All samples show compaction effects such as numerous contacts per grain, interpenetrating or sutured grains, and fracturing of grains at contacts. One thin section contains quartz overgrowths. Well-sorted crystal tuff is very similar to volcanic arenite in the field.

The volcanic sandstone was deposited in a submarine environment. Graded bedding and planar contacts between beds suggest that the major transporting medium was turbidity currents. Volcanic activity, probably both submarine and subaerial, added pyroclastic material to the epiclastic detritus.

Volcanic Siltstone. Volcanic siltstone comprises a large percent of the rocks. Siltstone is distinguished from sandstone by having a matrix content greater than 50 percent. Included with volcanic siltstone are sandy and pebbly siltstone, rocks of possible pyroclastic origin whose matrices have been recrystallized, and claystone that is very similar to chert in the field but may be fine-grained tuff. Volcanic siltstone weathers more rapidly than coarser-grained deposits. Generally, volcanic siltstone is the fine-grained upper part of graded units. Fresh rocks are grayish green (10 GY 5/2, 5 G 5/2) and less commonly dark gray (N 3) and pale red (10 R 6/2).

The best exposures of volcanic siltstone are along Hunsaker Creek and along Ballard Creek. Dark-gray siltstone, containing abundant pyrite, occurs near the confluence of Duck Creek and North Pine Creek and in the southwestern part of the map area near East Pine Creek. These dark-gray siltstones are not common.

Studies of 34 thin sections show that the approximate percentages of the components are as follows: matrix and fine-grained fragments of rocks and minerals (70-80 percent); plagioclase (10-15 percent); quartz (3-4 percent); and rock fragments (1-3 percent). Feldspar is albite but commonly is replaced in part by calcite, chlorite, or quartz. Quartz overgrowths were noted in one sample. Rock fragments are keratophyre, spilite, and stringy, chlorite-replaced siltstone or pumice.

Matrices are recrystallized and quartz-rich. Chalcedony forms fan-shaped growths in some matrices (Figure 16). Quartz and albite, plus chlorite, calcite, sphene, leucoxene, white mica, siderite (?), epidote, and prehnite comprise the finer-grained parts of the volcanic siltstone. Prochlorite is dominant over penninite; epidote occurs in only six samples. Calcite is present in veins, as feldspar replacement, and as irregular patches throughout the matrices.

Chert is an important rock type in eugeosynclinal terranes. However, no true chert was observed. Instead, chert-like rocks are silicified siltstone, claystone, and fine-grained tuff.

Conglomerate. Conglomerate may comprise as much as 10 percent of the formation. All gradations exist between pebbly mudstone (Crowell, 1957) and well-sorted conglomerate with clasts of boulder and cobble size. Outcrops in the Fish Lake region are discontinuous and generally cannot be traced over 100 feet laterally. In the Snake River canyon, conglomerate beds as much as 50 feet in thickness protrude as rugged shoulders along the canyon walls. Conglomerate near Fish Lake and in the Imnaha River canyon

Figure 15. Photomicrograph (about X 40, crossed nicols) of a volcanic graywacke of the Hunsaker Creek Formation.

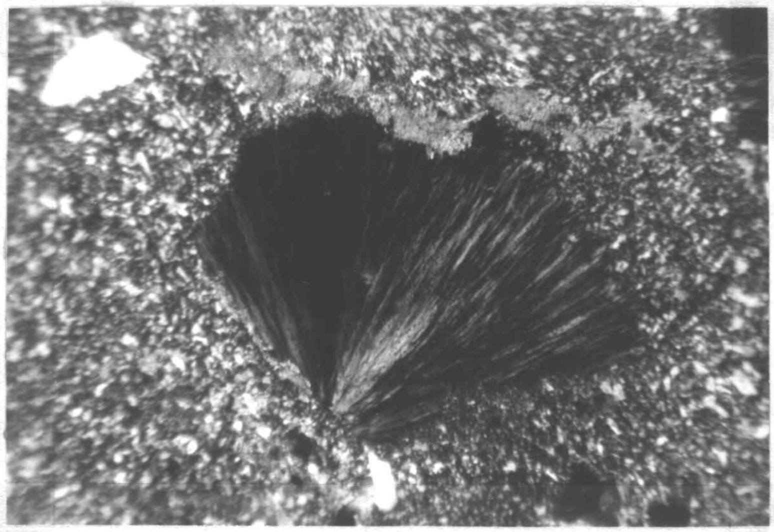

Figure 16. Photomicrograph (about X 40, crossed nicols) of a fan-shaped chalcedonic growth in a volcanic siltstone.

is coarser grained, better sorted, and more massive (Figure 17) than conglomerate in the Snake River canyon. Most are pebble conglomerate, characterized by well-rounded clasts in a fine-grained, light-green matrix that may have been tuffaceous. Cobble and boulder conglomerate, containing clasts ranging from 2 to 12 inches, are subordinate.

Pebble counts of six conglomerates are given in Table 6. Among nearly 900 clasts, about 51 percent were keratophyric flow rocks, 35 percent were volcaniclastic rocks, six percent were spilites, and over seven percent were not identifiable in the field. The dominance of keratophyric clasts over spilitic clasts suggests that andesitic volcanism was prevalent during deposition; some conglomerate is composed of more than 70 percent keratophyric clasts. Conglomerate in the Fish Lake area contains as much as 10 percent of angular and elongate siltstone clasts mixed with well-rounded clasts. Apparently the siltstone clasts were plucked from the sea floor and incorporated during transportation.

Clasts of particular interest are those derived from plutonic rocks. The clasts are metamorphosed quartz diorite, diorite, and gabbro. Only four clasts were studied optically; two are quartz diorite, one is a diorite, and the other is a gabbro (Table 7). Wetherell (1960, p. 24) reported a "granitic" clast in the Permian rocks near

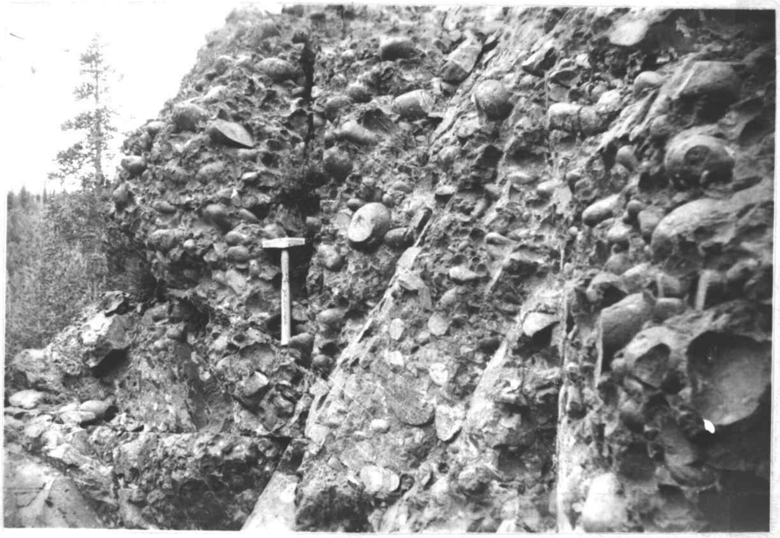

Figure 17. Volcanic conglomerate of the Hunsaker Creek Formation, elevation 6,700 feet in the NE¼SE¼ sec. 21, T. 6 S., R. 46 E., Oregon.

Table 6. Pebble Counts of Hunsaker Creek Conglomerate. Volcaniclastic Rocks are Probably Tuffaceous.

Location	Total Counted	Kinds of Clasts	Percent
SW¼NW¼ sec. 15, T. 6 S., R. 46 E.; elevation 6,660 feet; about half a mile southeast of Fish Lake, Oregon	180	Keratophyre and quartz keratophyre	49.5
		Volcanic sandstone	40.5
		Volcanic siltstone	6.2
		Quartz diorite clasts	0.5
		Unknown	3.3
SE¼SW¼ sec. 5, T. 7 S., R. 48 E.; elevation 2,100 feet in Hunsaker Creek, Oregon	132	Keratophyre and quartz keratophyre	63.6
		Volcanic sandstone	15.9
		Volcanic siltstone	4.6
		Spilite	6.8
		Spilite breccia	5.3
		Unknown	3.8
SW¼NW¼SW¼ sec. 32, T. 21 N., R. 4 W.; elevation 2,610 feet; Eckels Creek, Idaho	210	Keratophyre and quartz keratophyre	41.3
		Volcanic sandstone	29.5
		Volcanic siltstone	10.0
		Volcanic breccia	3.8
		Spilite breccia	7.6
		Spilite	2.3
		Unknown	5.5
SW¼NW¼ sec. 21, T. 6 S., R. 48 E.; elevation 2,150 feet; north side of Irondyke Creek, Oregon	92	Keratophyre and quartz keratophyre	31.7
		Volcanic sandstone and siltstone	22.8
		Spilite	19.6
		Volcanic breccia	9.7
		Plutonic clasts	2.1
		Unknown	14.1
T. 5 S., R. 47 E.; elevation 5,200 feet; north side of Duck Creek about half a mile west of Grave Creek, Oregon	128	Keratophyre and quartz keratophyre	71.8
		Volcanic sandstone and siltstone	12.6
		Spilite	7.0
		Volcanic breccia	4.7
		Unknown	3.9
T. 6 S., R. 47 E.; elevation 4,420 feet; north side of Elk Creek near bend in stream course, Oregon	156	Keratophyre and quartz keratophyre	49.2
		Volcanic sandstone and siltstone	16.8
		Volcanic breccia	11.8
		Spilite	8.1
		Spilite tuff (?)	1.9
		Unknown	12.2

Table 7. Modal Analyses of Four Plutonic Clasts From Conglomerate of the Hunsaker Creek Formation.

Mineral Name	TC-1[1]	TC-22[2]	VC-34[3]	VC-136[4]
Plagioclase	54.1	57.6	84.3	67.2
Quartz	25.4	28.8	4.4	4.5
Hornblende[5]	12.8	4.8	-	0.4
Augite	-	-	-	13.9
Iron ore	3.6	2.3	-	8.0
Chlorite	1.0	2.0	8.5	4.7
Epidote	0.6	4.1	-	0.5
Pyrite	-	-	1.8	-
Calcite	1.0	T	0.4	0.6
Prehnite	-	-	-	T
Sphene-leucoxene	0.5	0.4	0.6	0.2
White mica	T	T	T	T
Total	100.0	100.0	100.0	100.0

[1] Quartz diorite; SW¼NW¼ sec. 15, T. 6 S., R. 46 E.

[2] Quartz diorite; SE¼NW¼ sec. 28, T. 6 S., R. 46 E.

[3] Quartz-bearing diorite; NW¼SE¼NE¼ sec. 29, T. 6 S., R. 48 E.

[4] Quartz-bearing gabbro; SE¼NW¼NW¼ sec. 2, T. 6 S., R. 48 E.

[5] Generally actinolitic.

Fish Lake but attached no particular significance to its occurrence.

The presence of plutonic clasts in Permian rocks is of regional significance. Gilluly (1965, p. 5) stated: "A period-by-period review of the geology of the western states shows that although orogeny and basaltic volcanism have persisted more or less continually throughout Phanerozoic time, and siliceous Ordovician and younger volcanics abound, no pre-Triassic granitic plutons of Phanerozoic age have yet been certainly recognized." Gilluly further explained some possible reasons for the absence of Paleozoic plutons (op.cit., p. 23). "The complete absence of identified Paleozoic plutons may possibly be explained in part by concealment of critical contacts by younger rocks, by later metamorphism, or by inadequate sampling for radiometric determinations, but such plutons unquestionably are minor - even trivial - in both numbers and bulk as compared to those of later time." The plutonic clasts in the Permian Hunsaker Creek Formation indicate that quartz diorite, diorite, and gabbro were exposed and eroded in the Permian period. No exposures of known Paleozoic plutonic rocks are recorded in northeastern Oregon and western Idaho, but the Canyon Mountain magma series possibly was intruded as early as Leonardian time in parts of eastern Oregon (Thayer and Brown, 1964, p. 1257). The plutonic clasts in the Hunsaker Creek

Formation are very similar to the gabbro and quartz diorite of the Sparta area (Gilluly, 1933; Prostka, 1963) and to some rocks of the Canyon Mountain Complex (Thayer, 1963).

The quartz diorite clasts are extensively albitized. Rare, zoned plagioclase relicts and highly altered cores of some plagioclase possibly are more calcic than albite. In sample TC-1, over 30 percent of the rock is a micrographic intergrowth of quartz and albite. Quartz is abundant and generally interstitial or is associated with albite in micropegmatite. Potassium feldspar was not detected. Alteration minerals are epidote, chlorite, calcite, white mica, sphene, and leucoxene.

Limestone

Limestone comprises a very small percent of the formation. Most is clastic and contains fragments of shells, limestone, and volcanic rocks along with grains of quartz and feldspar. Small beds are in Homestead Creek at elevations of about 2,400 feet and 2,680 feet. A small limestone lens, about 20 feet thick, crops out near Hunsaker Creek at an elevation of 3,050 feet. Other small limestone beds are scattered irregularly throughout the formation.

Conditions of Deposition, Transportation, and Provenance

Rocks of the Hunsaker Creek Formation are predominantly volcaniclastic. Flow rocks and their hypabyssal equivalents are subordinate. Features that have a bearing on conclusions regarding the provenance, transportation, and deposition of the rocks are the following: (1) graded bedding; (2) load casts; (3) cross-bedding; (4) coarse-grained, well-rounded conglomerate; (5) fossils, often associated with coarse conglomerate and breccia in graded sequences; (6) limestone lenses and beds; (7) lateral lithofacies changes from east to west; (8) isolated units of dark-gray, pyritiferous siltstone; (9) mixed epiclastic and pyroclastic debris, associated with probable unmixed deposits of each; (10) hypabyssal intrusions prior to sediment consolidation; (11) textural and compositional immaturity of the sandstone; (12) dominance of keratophyre clasts in conglomerate; and (13) quartz diorite, diorite, and gabbro clasts in the conglomerate.

The graded beds, load casts, and fossils in thick graded sequences suggest transportation by turbidity currents, perhaps from a shelf or slope environment into a basin. Some turbidity currents were probably formed by pyroclastic flows, both subaerial and subaqueous. Hypabyssal rocks intruded into volcaniclastic deposits suggest that volcanism was contemporaneous with erosion and deposition. Limestone beds and the presence of marine fossils indicate a marine environment of deposition, whereas isolated units of pyritiferous, black and dark-gray siltstone suggest anaerobic bottom conditions in small, isolated basins within the larger basin(s) or trough(s). Pelecypods associated with cross-bedded sandstone suggest that surface currents were active and that the water was probably shallow. Textural and compositional immaturities of the sandstone suggest abundant volcanism and/or source areas of high relief and humid climate. The dominance of keratophyric clasts in the conglomerate indicates that the eroded land mass was comprised mostly of andesitic or dacitic rocks. Clasts of quartz diorite, diorite, and gabbro indicate that plutonic rocks were exposed and that orogenic movements probably had occurred; supracrustal rocks were uplifted and stripped off in places, thereby allowing the erosion of plutonic rocks.

Lateral lithofacies changes occur in the Hunsaker Creek Formation between Snake River and the Fish Lake region. A land mass probably was present to the west during the deposition of the Hunsaker Creek Formation as suggested by the following: (1) an apparent lack of Permian rocks of comparable lithologies and thickness west of the map area; (2) an increase in clast size, frequency, and sorting of conglomerates towards the west; (3)

pelecypod "reefs" associated with cross-bedded sandstone near Fish Lake; (4) mud cracks in a siltstone at an elevation of 6,620 feet, southeast of the Trinity Guard Station near Fish Lake; and (5) current direction measurements which indicate that north and northeast-flowing currents were dominant (Figure 18).

Vertical lithofacies changes are not as noticeable as lateral changes, perhaps partly because the stratigraphic sequences are structurally disturbed. However, in the Snake River canyon a gradual decrease of grain size coincides with stratigraphic elevation. Finer-grained sediments are exposed at higher elevations and at higher stratigraphic positions in Homestead Creek, Herman Creek, and Ballard Creek.

The preceding facts suggest: (1) that a land mass (or land masses) of high relief, composed of volcanic and sedimentary supracrustal rocks and plutonic subcrustal rocks, was exposed to the west; (2) that andesitic and dacitic volcanism was dominant over basaltic volcanism; (3) that the depositional basin was fragmented; (4) that the rocks were autocannibalistic; and (5) that pyroclastic activity, aided by submarine phreatic explosions, was the dominant source of detritus.

Age and Correlation

The age of the Hunsaker Creek Formation is documented

Figure 18. Cross-bedding azimuths from 12 beds of the Hunsaker Creek Formation. One to three measurements taken at each outcrop.

by fossil evidence (Appendix B). Professor Francis G. Stehli, Western Reserve University, examined the fossils and stated: "Most of the brachiopod fossils that are present, are either large spiriferoids or productids. In most cases, these are fragmentary or decorticated so as not to be generically identifiable. One small productid called Megousia, which has a very distinctive ornamentation on the dorsal valve, is recognizable in a number of your samples. This genus is known from Leonard and Word rocks in the Glass Mountains and a number of other areas. I am reluctant to try to identify your material to species though it appears most like the species described by G. Arthur Cooper from Word age rocks near El Antimonio in western Sonora. Samples which contain this genus are then, I feel, of either Leonard or Word age and most probably of Word age."

Locally the rocks correlate with part of the Clover Creek Greenstone (Gilluly, 1937), perhaps in part with the Elkhorn Ridge Argillite (Taubeneck, 1955), and in part with the Seven Devils Volcanics (Anderson, 1930). Regionally the Hunsaker Creek Formation is correlated in part with the Diablo Sequence in the Hawthorne and Tonapah quadrangles of Nevada (Ferguson and Muller, 1949), the Mankomen Formation of the Alaska Range in Alaska (Buddington and Chapin, 1929), and the Nosoni Formation of the Klamath Mountains of California (Albers and Robertson, 1961).

Kleinschmidt Volcanics (Pkv)

Definition, Distribution, and General Character

Kleinschmidt Volcanics is the name given to a thick sequence of spilite and minor amounts of spilite breccia and spilite tuff which is exposed along the west side of Windy Ridge (Plate 3). Structural complications and poor exposures prevented the measurement of a meaningful and adequate type section. The most representative sequence of rocks begins in a small gulch, elevation about 2,400 feet, in the NE¼NW¼NE¼ sec. 23, T. 20 N., R. 4 W. and extends along the gulch to the Kleinschmidt Grade, elevation 3,300 feet, in the SW¼NE¼NW¼ sec. 24, T. 20 N., R. 4 W. Several hundred feet of porphyritic flow rocks are exposed. All rocks examined microscopically are spilites, commonly amygdaloidal. Pyroclastic rocks are exposed in places, but are minor in amount.

Stratigraphic Relationships and Thickness

Some rocks of the Kleinschmidt Volcanics are similar to the porphyritic flow rocks of the Doyle Creek Formation. Structural intercalations of the Martin Bridge Formation and older rocks (?) near the top of Windy Ridge in the center of sec. 18, T. 20 N., R. 3 W., suggest that fault slices of the Doyle Creek Formation also occur within the Kleinschmidt Volcanics. As exposures are poor at the higher elevations on Windy Ridge, relationships are uncertain. However, the Kleinschmidt Volcanics generally can be distinguished from rocks of the Doyle Creek Formation because the Kleinschmidt Volcanics (1) have a greater percent of flow rocks, (2) have interbedded greenish-black tuffs, (3) generally weather more easily and form rounded, soil-covered outcrops, (4) are sheared more than rocks of the Doyle Creek Formation, and (5) have dusky-brown, greenish-black, and dusky-red colors, whereas rocks of the Doyle Creek Formation are mostly dusky red.

The base of the Kleinschmidt Volcanics is exposed on the east side of Windy Ridge, in the SW¼ sec. 25, T. 20 N., R. 4 W., where grayish-green volcaniclastic rocks of the Hunsaker Creek Formation are interlayered with dusky-brown flow rocks of the Kleinschmidt Volcanics. The top of the formation was not observed. No rocks similar to the Kleinschmidt Volcanics are near Fish Lake or in the Imnaha River canyon and no Kleinschmidt Volcanics were observed along the west side of the Snake River. The proposed interlayering of the Hunsaker Creek Formation and Kleinschmidt Volcanics on the east side of Windy Ridge is strengthened by exposures along the south side of Lynes Saddle in the E½ sec. 8, T. 20 N., R. 4 W. where conglomerate of the Hunsaker Creek Formation is interlayered with flow rocks similar to those of the Kleinschmidt Volcanics.

The fault (?) contacts between the Kleinschmidt Volcanics and the Doyle Creek Formation are difficult to map in the south fork of Limepoint Creek because of poor outcrops. Rocks on the north side of Limepoint Creek are not diagnostic of either formation. In no place could a rock unit be traced across the creek.

The estimated thickness of the Kleinschmidt Volcanics is between 2,000 and 3,000 feet.

Lithology and Petrography

Spilite is the major rock type in the Kleinschmidt Volcanics. Minor rock types are spilitic tuff breccia and spilitic tuff. Epiclastic volcanic rocks are uncommon or absent.

Spilite

Fresh samples of spilite, porphyritic and generally amygdaloidal, are dusky brown (5 YR 2/2), greenish black (5 G 2/1), grayish brown (5 YR 3/2), dusky green (5 G 3/2), and dark red (5 R 2/6). Outcrops weather to dark yellowish brown (10 YR 4/2) and moderate brown (5 YR 4/4). The rocks form rounded and soil-covered outcrops on the interstream ridges and upper slopes but are cliff-formers in the stream valleys (Figure 19).

Figure 19. Spilite flows of the Kleinschmidt Volcanics at an elevation of 2,850 feet in the NE¼NE¼ sec. 23, T. 21 N., R. 4 W., Idaho.

Eleven thin sections show that the dominant texture is porphyritic intergranular. Albite comprises 50 to 80 percent and clinopyroxene as much as 30 percent of the rocks. Pseudomorphs of olivine occur in two specimens. Iron ore, present in all thin sections, ranges between 3 and 10 percent. Minor minerals are chlorite, calcite, epidote, quartz, sphene, prehnite, actinolite, hematite, and white mica. Chlorite replaces olivine, pyroxene, and glass (?), and occurs in amygdules and veins. Calcite fills amygdules, replaces feldspars, and also occurs in veins. Quartz is interstitial and occurs in veins. Epidote is abundant in three thin sections where it fills amygdules and veins and replaces plagioclase and pyroxene.

Spilite Tuff Breccia and Spilite Tuff

Pyroclastic rocks are minor in the Kleinschmidt Volcanics. All are composed of spilitic ejecta with spilite rock fragments and pumice (?) comprising from 60 to 90 percent of the rocks. Albite is the only feldspar. Tuffs crop out along the Kleinschmidt Grade at elevations of 3,100 to 3,400 feet. The pyroclastic rocks weather more easily than the flows and cannot be traced more than a few feet.

Conditions of Deposition, Transportation, and Provenance

Interlayered rocks of the Kleinschmidt Volcanics and the Hunsaker Creek Formation and the apparent limited distribution of the Kleinschmidt Volcanics suggest (1) that deposition of the Hunsaker Creek Formation and the Kleinschmidt Volcanics was in part contemporaneous, (2) that the Kleinschmidt Volcanics accumulated close to volcanic vents, and (3) that rocks of the Kleinschmidt Volcanics were, at least in part, deposited in a marine environment.

The pile of flow rocks represents a local accumulation, perhaps a volcano that grew up on the sea floor in a manner similar to the present seamounts in the northeastern Pacific Basin.

Age and Correlation

Stratigraphic interlayering of the Kleinschmidt Volcanics and the Hunsaker Creek Formation indicates that the two formations are in part the same age. Therefore, the Kleinschmidt Volcanics are probably Permian and can be correlated regionally with the same rocks that correlate with the Hunsaker Creek Formation.

Grassy Ridge Formation (Ꞧgr)

Definition, Distribution, and General Character

Grassy Ridge Formation is the name given to a metamorphosed sequence of volcaniclastic rocks and flow rocks mostly exposed in the canyons of the Snake River and the

Imnaha River (Plate 3).

The type section is on the west side of Grassy Ridge from the IPALCO road in the extreme NE¼ sec. 17, elevation 2,000 feet, to the NW¼ sec. 16, T. 22 N., R. 3 W., elevation 2,840 feet. A detailed stratigraphic section was not measured because of structural complications, but several hundred feet of rocks are exposed. Reference sections are along the north side of McGraw Creek from the Snake River to an elevation of about 2,200 feet, and on the north side of the Imnaha River canyon from the river to the morainal material at the top of the ridge. Good outcrops occur in Elk Creek, along the IPALCO road south of Hibbles Gulch, and between Homestead Creek and Herman Creek.

Volcaniclastic rocks are more abundant than flow rocks in the Grassy Ridge Formation. The formation is characterized by (1) green volcaniclastic rocks, (2) greenish-black and olive-gray flow rocks, (3) dark-gray carbonaceous limestone, (4) thick, grayish-green and gray volcanic breccia, (5) conglomerate with more than 90 percent of the clasts derived from spilitic flow rocks, (6) graded volcaniclastic deposits, and (7) thin-bedded, carbonaceous, cherty rocks.

Rocks of the Grassy Ridge Formation are difficult to distinguish from those of the Hunsaker Creek Formation. However, the Grassy Ridge Formation (1) has less conglomerate, (2) contains mostly spilitic clasts in contrast to keratophyric clasts in the conglomerate of the Hunsaker Creek Formation, (3) has thin, dark gray, carbonaceous limestone beds, whereas the limestone of the Hunsaker Creek Formation is light gray and mostly of clastic origin, (4) weathers to a dark-brown color, and (5) contains a greater amount of thick, grayish-green and light-gray volcanic breccia.

The overlying Doyle Creek Formation (1) has more volcanic flow rocks, many of which are dusky red, (2) contains less greenish-gray and more dusky-red volcaniclastic rocks, (3) has thick units of dusky-red pyroclastic deposits, and (4) exhibits rugged outcrops formed by thick volcanic flows.

Stratigraphic Relationships and Thickness

The Grassy Ridge Formation overlies the Hunsaker Creek Formation with angular unconformity and is conformably overlain by the Doyle Creek Formation. The base of the Grassy Ridge Formation is exposed in the canyons of Homestead Creek, Ashby Creek, Elk Creek, and the Imnaha River. The top of the Grassy Ridge Formation is exposed (1) on the north side of the Imnaha River where dark dusky-red and greenish-black volcanic flows of the Doyle Creek Formation overlie the grayish-green volcaniclastic rocks of the Grassy Ridge Formation (Figure 20), (2) at

Figure 20. Contact of the Doyle Creek Formation and the Grassy Ridge Formation along the north side of the Imnaha River canyon, Oregon. Grassy Ridge Formation is left of the dashed line.

an elevation of 5,560 feet on the north side of the most prominent rôche moutonnée along the south side of the Imnaha River across from the U.S. Forest Service "Hidden Campground", (3) at an elevation of 2,200 feet on the first spur north of McGraw Creek where dusky-red volcanic flows and volcaniclastic rocks overlie grayish-green volcaniclastic rocks of the Grassy Ridge Formation, and (4) along the west side of Grassy Ridge where greenish-black spilitic breccia and volcanic flows of the Piedmont Point Member of the Doyle Creek Formation overlie the volcaniclastic rocks of the Grassy Ridge Formation.

Lithologic changes characterize the Grassy Ridge Formation in both east-west and north-south directions. The formation apparently thins and pinches out toward the west accompanied by a westward increase in conglomerate and other epiclastic rocks. Dark-gray limestone pods disappear toward the west whereas dusky-red volcaniclastic rocks increase westward. Limestone and fine-grained epiclastic deposits increase southward in the Homestead area. Furthermore, the amount of conglomerate with rounded, vesicular spilitic clasts increases to the northeast.

No definite vertical changes in lithology were recognized. In the Imnaha River canyon, a possible decrease in grain size and an increase in dusky-red clastic beds may occur with stratigraphic elevations.

The true thickness of the formation is unknown. The calculated thickness on the north side of the Imnaha River canyon is over 2,000 feet. As the formation thins to the south and west and thickens to the north and east, the thickness is at least 3,000 feet and perhaps as much as 4,000 feet in the northeastern part of the map area. The Grassy Ridge Formation probably ranges in thickness from 0 to 4,000 feet in the map area.

Lithology and Petrography

Volcaniclastic rocks are the major rock type; pyroclastic deposits are more abundant than epiclastic deposits. Flow rocks comprise about 10 to 15 percent of the formation. Limestone pods are uncommon. Transformations occurred in the rocks during regional metamorphism but relict textures, ghosts of glass shards, and pumice fragments are distinguishable.

Keratophyre

Keratophyre comprises a very small part of the formation, probably less than two percent. A keratophyre flow is exposed on the first spur north of McGraw Creek at an elevation of 2,140 feet; another occurs along the trail about 400 yards north of Spring Creek at an elevation of 1,950 feet. A thick flow crops out along the IPALCO road, directly across from McGraw Creek. The keratophyre flows range in thickness from 10 to 20 feet. Colors are generally grayish red (5 R 4/2), pale red (10 R 6/2) and olive black (5 Y 2/1). Textures are porphyritic with felty and pilotaxitic groundmasses. In one rock, the phenocrysts form aggregates as much as six mm in diameter. Albite occurs as phenocrysts and microlites. Albite phenocrysts are euhedral, range in length from 0.2 to 2.5 mm, and commonly are altered to a light-brown, unidentified mineral. Unaltered mafic minerals are absent; the present mineralogy indicates that mafic minerals were not abundant in the original rocks. The major alteration minerals in the groundmass are calcite, leucoxene, and epidote.

Spilite

Spilite is the dominant flow rock. Good outcrops occur throughout the formation but the best are in the type section along the west side of Grassy Ridge. Some spilitic rocks are porphyritic, others are aphanitic, and many are amygdaloidal. Groundmass textures are intergranular or pilotaxitic. Colors of fresh rocks range from grayish green (10 G 4/2, 5 G 5/2) and dusky green (5 G 3/2) to greenish black (5 G 2/1).

Plagioclase comprises from 50 to 70 percent of the spilite. Albite is dominant but plagioclase of higher calcium content is present in some specimens. Sodic labradorite (An 52± 3) was identified in one specimen.

Calcite, chlorite, and prehnite are alteration products of the feldspars. Clinopyroxene, present in five samples, comprises 20 percent of one specimen. Iron ore, generally titaniferous, comprises 1 to 4 percent of the samples.

Pyroclastic Rocks

Pyroclastic rocks comprise about 50 percent of the Grassy Ridge Formation (Figures 21 and 22). Graded beds, poor to moderate sorting, and monolithology characterize the pyroclastic deposits. Colors range from grayish green (10 G 4/2, 5 G 5/2) and grayish olive green (5 GY 3/2) to dusky green (5 G 3/2) and dark greenish gray (5 G 4/1).

Epiclastic debris probably is mixed with the pyroclastic material but it is difficult to distinguish the two in the field. The most valuable criteria for establishing a pyroclastic origin in thin section studies are the presence of pumice and fine ash, lobate and cuspate volcanic rock fragments, and shadows of glass shards.

A pyroclastic breccia with clasts up to 20 cm in length crops out in the canyon of the Imnaha River near the west entrance to the U.S. Forest Service "Hidden Campground". Amygdaloidal spilite clasts, very poor sorting, and the absence of graded beds are characteristics of this deposit. The matrix is composed of chlorite, calcite, plagioclase, and fine-grained spilitic rock

Figure 21. Volcaniclastic rocks (tuffs ?) of the Grassy Ridge Formation, elevation 2,500 feet, SE¼ SE¼ sec. 31, T. 22 N., R. 3 W.

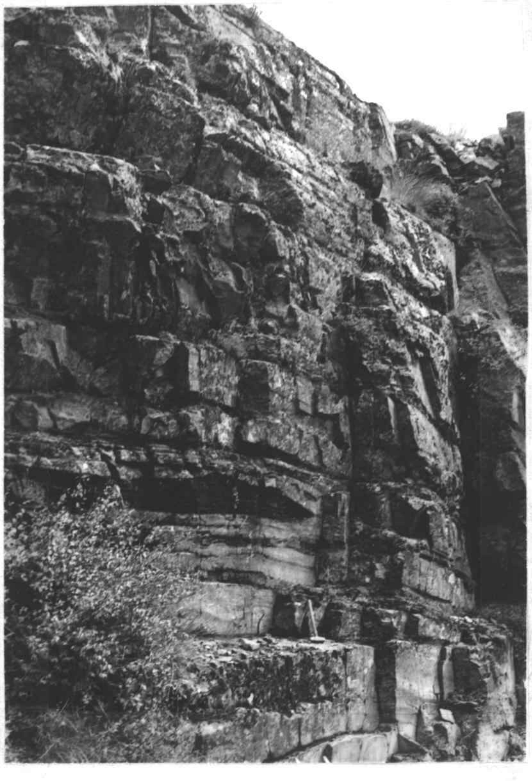

Figure 22. Volcaniclastic rocks (tuffs ?) of the Grassy Ridge Formation, elevation 5,100 feet along the north side of the Imnaha River canyon, Oregon. Hammer denotes scale.

fragments. Because of abundant carbonate in the matrix, weathered exposures have a honey-comb appearance. Pyroclastic (?) breccia occurs along the IPALCO road south of Hibbles Gulch. Grayish-green breccia with light-gray, blackish-green, and pale-red clasts is poorly to moderately well sorted and forms deposits as much as 40 feet thick.

Pumice, plagioclase, and rock fragments of spilitic origin are the dominant constituents in the tuff breccia and coarse tuff (Table 8). Albite is the only feldspar recognized and is present in all 14 pyroclastic rocks studied. Augite occurs in eight thin sections. In the finer-grained deposits, volcanic ash and shadows of glass shards are evident. Five rocks contain a small amount of quartz.

Alteration minerals are the same as those of the spilitic flow rocks. Calcite is ubiquitous and occurs as a vein-filler and as a replacement mineral. Chlorite comprises more than one percent in nine thin sections. Sphene and leucoxene are common and epidote is uncommon.

Epiclastic Deposits

The epiclastic volcanic deposits are breccia, conglomerate, sandstone, and siltstone. Conglomerate is more abundant to the west whereas sandstone and siltstone are dominant to the south near Homestead. Some fine-grained

Table 8. Modal Analyses of Two Pyroclastic Rocks of the Grassy Ridge Formation.

Mineral Name	VC-214[1]	VC-235[2]
Spilitic rock fragments	29.6	43.4
Pumice and ash	1.9	-
Plagioclase	34.5	18.1
Iron ore	0.6	0.3
Clinopyroxene	0.3	1.2
Quartz	T	1.0
Calcite	3.6	2.8
Chlorite	13.9	10.3
Sphene	T	0.9
Leucoxene	T	T
Pyrite	-	0.2
Matrix[3]	15.6	21.8
Total	100.0	100.0

[1] Elevation 2,090 feet, first spur north of McGraw Creek, extreme east side of T. 5 S., R. 48 E.

[2] Elevation 2,940 feet, Grassy Ridge, SE¼NW¼NW¼ sec. 16, T. 21 N., R. 3 W.

[3] "Matrix" has optically unresolvable ashy material that contains chlorite, sphene, and leucoxene.

rocks contain carbonaceous material in thin laminations or as the dominant detritus in the matrices. The carbonaceous beds probably were deposited during quiescent periods when marine organisms settled to the sea floor.

Epiclastic volcanic breccia is poorly sorted, has a large quantity of matrix, and contains minor subrounded to well-rounded clasts associated with the dominant angular clasts. Breccia is most abundant in the Elk Creek and Imnaha River areas but also occurs in the Snake River canyon.

Volcanic sandstone is poorly to moderately well-sorted, generally is graded, and contains a large quantity of feldspar crystals. Good exposures are on the south side of the ridge between Homestead Creek and Whiskey Gulch. Beds range in thickness from a few inches to several feet. Colors are mostly grayish green (10 GY 5/2), grayish olive green (5 GY 3/2), and greenish gray (5 G 5/1); subordinate colors are dusky yellowish green (10 GY 3/2) and blackish red (5 R 2/2). Plagioclase comprises from 50 to 80 percent of the sandstone; rock fragments and matrix are the other dominant components. Quartz and clinopyroxene are subordinate. Minor minerals are prochlorite, calcite, leucoxene, pyrite, prehnite, hematite, sphene, and epidote.

Siltstone, best exposed on the ridge north of Homestead Creek, is subordinate to sandstone. A specimen studied optically has a matrix of carbonaceous, cryptocrystalline quartz (62 percent) with clasts of plagioclase (21 percent), rock fragments (4 percent), and radiolarian (?) detritus (13 percent). The radiolarians (?) are spherical, recrystallized, and range in diameter from 0.1 to 0.3 mm. An epiclastic origin was not confirmed for other volcanic siltstone. Dark, carbonaceous, cherty rocks in the type section and on the ridge north of Whiskey Gulch, however, indicate that much of the fine-grained materials may be of epiclastic origin.

Conglomerate forms a small percent of the formation. The major characteristics are graded beds, poor to moderate sorting, and subrounded to rounded clasts that range from pebble to cobble size. Beds range in thickness from 5 to 40 feet. Matrices are composed of chlorite, calcite, feldspar, and small rock fragments. Pebble counts show that most clasts are dark-green flow rocks, probably spilitic in composition (Table 9).

A conglomerate in the type section on Grassy Ridge, elevation 2,260 feet in the SW¼NW¼NW¼ sec. 16, T. 21 N., R. 3 W., is unique. All clasts are vesicular, greenish-black spilite which are set in a chloritic, calcareous matrix. Clast diameters range from 2 to 25 cm and average about seven cm. The clasts are subrounded to well-rounded and constitute about 80 percent of the unit. Optical studies show about 70 percent albite microlites,

Table 9. Pebble Counts of Three Conglomerates of the Grassy Ridge Formation.

Location	Number Counted	Rock Types	Percent
SW¼NW¼NW¼ sec. 16, T. 21 N., R. 3 W., elevation 2,260 feet on the west side of Grassy Ridge	121	Greenish-black vesicular flow rocks (spilite)	96.7
		Volcaniclastic rocks	2.1
		Unknown	1.2
			100.0
T. 5 S., R. 47 E., elevation 4,960 feet on the north side of the Imnaha River, N. 62° E. from Indian Crossing	82	Greenish-black flow rocks (spilite)	82.1
		Rusty-red flow rocks (spilite)	16.0
		Unknown	1.9
			100.0
West central part, T. 6 S., R. 47 E., elevation 4,940 feet along the east side of Elk Creek, 150 feet above the creek	70	Dark grayish-green and greenish-black flow rocks (spilite)	92.8
		Volcaniclastic rocks	5.7
		Unknown	1.5
			100.0

less than one percent iron ore, and around 25 percent amygdules. The aligned albite microlites curve around the amygdules and form a pilotaxitic texture. Amygdules are filled with penninite and calcite.

A conglomerate on the east side of Elk Creek, elevation 4,940 feet, has moderate sorting and well-rounded clasts. The largest clasts measure 8 to 10 cm in diameter, but most clasts are about half as large. Over 90 percent of the clasts are of spilitic flow rocks.

Limestone

Small pods and lenses of dark-gray (N 3), recrystallized limestone are irregularly distributed throughout the Grassy Ridge Formation. The limestone occurs between lava flows, between lava flows and clastic rocks, and within clastic sequences. *Daonella*, a flat Triassic pelecypod, occurs along bedding planes. The rocks are composed of limestone and flow rock clasts, calcite grains, calcite cement, carbonaceous clays, and plagioclase crystals. Pyrite is a common secondary mineral.

Best outcrops are along the ridge between Homestead Creek and Whiskey Gulch where beds comprise sequences several feet thick.

Conditions of Deposition, Transportation, and Provenance

The major characteristics of the Grassy Ridge Formation that are of significance in considerations of provenance, transportation, and deposition of the rocks are the following: (1) dominance of pyroclastic debris; (2) composition of conglomerate clasts; (3) compositional and textural immaturities of volcaniclastic rocks; (4) general lack of current structures; (5) ubiquitous graded bedding; (6) well-rounded clasts in the conglomerate; (7) dark-gray limestone lenses that contain *Daonella* fossils; (8) abundant carbonaceous material in the finer-grained beds;

(9) presence of radiolarians (?) in cherty siltstone; and (10) apparent thinning of the formation to the west.

The dominance of pyroclastic material suggests that explosive activity was more prevalent than quiet effusive activity. Clasts of conglomerate, mostly of spilitic flows, indicate that the landmasses were partly covered by flow rocks. Compositional and textural immaturities show that the rocks are mostly of pyroclastic origin or were eroded from volcanic terranes of high relief and humid climate. Graded beds suggest that the transporting mechanism was turbidity currents. Quiet conditions of deposition are corroborated by the presence of carbonaceous laminations, and by the existence of carbonaceous limestone beds which were formed as pelecypod reefs. The occurrence of radiolarians (?) in the cherty siltstone suggests clear water with abundant nutrients at the surface. As the radiolarians (?) are not masked by other debris, bottom conditions were quiet for extended periods.

Preceding inferences suggest that (1) a land mass or land masses of volcanic origin and high relief was exposed to the west, (2) basaltic volcanism was dominant over andesitic volcanism, (3) pyroclastic activity was the prevalent source for the clastic materials, (4) the rocks were deposited in a marine environment in a basin, or isolated basins, where quiet, reducing bottom conditions prevailed between volcanic paroxysms, (5) turbidity currents were the dominant transporting mechanisms, (6) the basin was of limited extent, and (7) the water depth was not great enough to impede the precipitation of limestone.

Age and Correlation

The age of the Grassy Ridge Formation is well documented by fossil evidence (Appendix B). Dr. N.J. Silberling, in reference to the fossils *Daonella frami* Kittl and *Daonella* cf. *Daonella degeeri* Böhm, wrote: "These 'flat clams' occur singly or together at a number of places in Alaska and in the western and Arctic parts of Canada. Wherever they have been dated by associated ammonite faunas, their age is Ladinian and older than latest Ladinian." In reference to F 56 Silberling reported: "*Daonella* (is) similar to *D. degeeri*...but consistently different in ribbing and better characterized as *Daonella* cf. *D. indica*. The age of *D. indica* is late Middle Triassic (mid or late Ladinian)."

Concerning the ammonite fauna (F 50) that was collected stratigraphically above (?) *Daonella*-bearing limestones, Silberling wrote: "Any age assignment based on the ammonite impressions...is somewhat shaky, but the association of forms that may belong to *Trachyceras* (sensu stricto) and *Clionitites* suggests relation to faunas that are considered early Karnian in age in North America.

Some European authorities regard these same faunas as of latest Ladinian age." Later, he added: "One ammonite fragment showing ventral ornamentation confirms the presence of Trachyceras (sensu stricto), tentatively recognized from this locality in my report to you of 5/3/65, and hence an earliest Late Triassic (lowest Karnian) age (in North American usage)."

Therefore the rocks of the Grassy Ridge Formation are of Middle Triassic (Ladinian) and Late Triassic (lowest Karnian) age.

The Grassy Ridge Formation is correlated with the Natchez Pass Formation of the western Sonoma Range, Nevada (Silberling and Roberts, 1962), the Grantsville Formation of the Hawthorne and Tonopah quadrangles, Nevada (Silberling and Roberts, 1962), and the Pit Shale of northern California (Albers and Robertson, 1961).

Imnaha Formation: Russel Mountain Member (TRir)

Definition, Distribution and General Character

The Imnaha Formation is a name informally proposed by Wetherell (1960, p. 32) for "...greenstone and associated sedimentary rocks exposed in a wide belt trending northeast through the south-central portion of the Cornucopia quadrangle." Exposures rimming the Imnaha River canyon for several miles east from its junction with

Cliff River were designated the type locality. Wetherell divided the Imnaha Formation into four rock-stratigraphic units; the Russel Member which includes the Sugarloaf Lentil, and the Norway Member which includes the Blue Creek Lentil.

The Russel Member consists of (Wetherell, 1960, p. 32) "...a series of thick lava flows, intercalated breccia and conglomerate, and minor pods of recrystallized limestone." The Sugarloaf Lentil is comprised of (p. 51) "...fossiliferous siltstone, sandstone, and conglomeratic limestone." The Norway Member consists of (p. 56) "... heterogeneous clastic material and intercalated pillow lavas," and the Blue Creek Lentil is (p. 80) "...composed predominantly of fine light-colored conglomerate and coarse sandstone."

The maximum thickness of the Imnaha Formation is probably no more than 10,000 feet because the units interfinger complexly.

The Russel Member is redefined as the Russel Mountain Member for typical exposures on Russel Mountain. Other units of the Imnaha Formation are not exposed in the map area. However, the Norway Member and the Sugarloaf Lentil were also examined and the divisions made by Wetherell seem valid. The units differ lithologically and are mappable. Each member probably could be raised to formation rank. The lentils could be designated as members because of the difficulty in determining the shape of the units.

The Russel Mountain Member covers about two and a half square miles in the extreme northwest part of the map area. Reconnaissance studies in the Imnaha River canyon indicate that the Russel Mountain Member probably crops out over a total area of 10 or more square miles in the southeastern part of the Wallowa Mountains. Taubeneck (1965) mentioned similar rocks in the northern Wallowa Mountains. No thick units similar to the Russel Mountain Member were mapped in the Snake River canyon but dusky-red glomeroporphyritic flow rocks in the Doyle Creek Formation may be equivalent. Best exposures of the Russel Mountain Member are on the northwest side of Russel Mountain where rounded rôches moutonnées and irregular benches exhibit good outcrops. Typical outcrops of the Russel Mountain Member north of the map area are in Rock Creek canyon (Wetherell, 1960, p. 33).

Rocks of the Russel Mountain Member are deformed but the lack of bedding, discontinous outcrops, absence of stratigraphic marker beds, and apparent rapid changes in lithofacies make structural interpretations difficult. Intrusive bodies of the Fish Lake Complex have locally deformed and metamorphosed the rocks. In general, the beds strike northwest and dip to the northeast. About five or six miles west of the map area, beds strike northeast and dip northwest.

The outstanding characteristic of the Russel Mountain Member is monolithology. Lava flows and volcaniclastic rocks are composed of porphyritic and glomeroporphyritic spilite, metabasalt, and meta-andesite.

Stratigraphic Relationships and Thickness

The Russel Mountain Member unconformably overlies the Hunsaker Creek Formation and probably interfingers with the Norway Member to the west and with the lower part of the Doyle Creek Formation to the east. Wetherell (1960, p. 50) concluded that the Russel Mountain Member conformably overlies the Permian strata (Wetherell's Trinity Creek Formation) and "...interfingers lithosomally with the Norway Member." The rocks mapped by Wetherell as the "Russel Member" on the ridge south of Fish Lake are probably Permian in age as they are very similar to Permian volcanics in other parts of the Hunsaker Creek Formation.

Dikes and sills (?) that possibly served as feeders for volcanics of the Russel Mountain Member, cut the uppermost beds of the Grassy Ridge Formation along the north side of the Imnaha River canyon at elevations of between 5,000 and 5,400 feet, north-northeast of the U.S. Forest Service "Hidden Campground". Dikes also cut the lowest part of the Doyle Creek Formation along the north side of the large rôche moutonée on the south side of the Imnaha River canyon at an elevation of 5,450 feet. Dikes are glomeroporphyritic, greenish-black and black spilite, metabasalt, or meta-andesite (?). Plagioclase phenocrysts reach lengths of over three cm and glomeroporphyritic aggregates have diameters as much as five cm. The dikes indicate that at least part of the Russel Mountain Member is younger than the lower part of the Doyle Creek Formation. Support for this conclusion is found in the Snake River canyon where dusky-red glomeroporphyritic flow rocks, which are probably equivalent in part with the Russel Mountain Member, are interlayered with volcaniclastic rocks in the lower part of the Doyle Creek Formation.

The thickness of the Russel Mountain Member cannot be accurately measured. Exposures on the north side of Russel Mountain suggest a thickness of more than 5,000 feet.

Lithology and Petrography

The major rock types of the Russel Mountain Member are flow rocks, volcanic breccia, volcanic conglomerate, and limestone. The flow rocks seem dominant but may actually be subordinate to the volcanic breccia.

Flow Rocks

Flow rocks are porphyritic and glomeroporphyritic spilite, metabasalt, and meta-andesite. Nonporphyritic rocks are rare. Flow rocks are difficult to distinguish from some volcanic breccia because of the similarity of composition and a lack of bedding in the breccia.

The rocks are greenish black to black. Plagioclase phenocrysts as much as three cm long are set in a fine-grained groundmass; clustered phenocrysts form aggregates as much as five cm in diameter. Plagioclase is pale green to greenish gray in hand specimen. No primary mafic minerals were observed.

Microscope studies show that the porphyritic rocks have altered groundmasses which originally had intergranular and pilotaxitic textures. Minerals are plagioclase, iron ore, chlorite, epidote, calcite, actinolite, quartz, prehnite, white mica, sphene, and leucoxene.

Plagioclase ranges in composition from albite to sodic labradorite. Wetherell (1960, p. 35) reported a range of An_{42-44} to An_{54-58}. X-ray studies of large grains of altered plagioclase indicate a composition of An_{15-20} denoting that the feldspar has been albitized. One metabasalt, VC-402, contains sodic labradorite (An_{50-52}). Common alteration products of the plagioclase are sausserite, white mica, and chlorite. Epidote is the most abundant alteration mineral and occurs as euhedral crystals or in fine-grained masses that completely mask the feldspars. As groundmass feldspar may be essentially unaltered or completely altered, only vague outlines of grain boundaries remain in some samples.

No primary mafic minerals were observed but chlorite-epidote-actinolite pseudomorphs of clinopyroxene occur. Chlorite, epidote, and actinolite are responsible for the green color of the rocks. Quartz occurs interstitially and with chlorite and epidote in pseudomorphs of pyroxene. Calcite forms granoblastic growths in the groundmass. Prehnite, white mica, sphene, and leucoxene are uncommon.

Originally, most rocks were probably basalts. Relicts of calcic plagioclase, associated with more sodic plagioclase, and the occurrence of other metamorphic minerals indicate a disequilibrium metamorphic assemblage of the greenschist facies of regional metamorphism.

Volcanic Breccia

Volcanic breccia is the most abundant type of volcanic sediment; finer-grained material is uncommon.

Good exposures are along the Fish Lake-Twin Lakes road at an elevation of about 6,900 feet in the NW¼NE¼SE¼ sec. 10, T. 6 S., R. 46 E. Poorly sorted units with clasts of porphyritic flow rocks are in a matrix of broken plagioclase crystals, chlorite, epidote, and iron ore.

Clasts are difficult to distinguish from the matrix in most specimens. Clasts are very angular and monolithologic. No bedding occurs in the deposits, although some units are over 100 feet thick. Volcanic flow rocks of the same composition are intimately intermixed.

Most breccia probably was formed by explosive activity when the flow rock came in contact with sea water; other breccia probably was formed as normal flow breccia. Great masses of material flowed down steep slopes and accumulated as non-bedded deposits on the sea floor. Pyroclastic activity was very minor or completely absent.

Volcanic Conglomerate

Volcanic conglomerate constitutes a minor part of the Russel Mountain Member. Clasts are composed of porphyritic flow rock or volcanic breccia. The matrices consist of plagioclase, rock fragments, iron ore, and secondary minerals. Clasts and matrices have the same composition; all were derived from porphyritic volcanic material. Rounded clasts range from 3 to 40 cm in diameter, but are remarkably uniform in each deposit. Some units are over 40 feet thick. Most conglomerate is poorly sorted with matrices comprising as much as 50 percent of some units; other conglomerates are moderately-well sorted. Rounded clasts in poorly sorted deposits seem to "float" in a matrix of angular material.

The volcanic conglomerate has at least two origins. The better sorted units have rounded clasts that probably were eroded from an adjacent land mass and transported into the basin. However, the rounded clasts that "float" in the angular material possibly were formed during transport over the sea floor. A moving slurry of volcanic rubble should be able to round large fragments during transport.

Limestone

Limestone, a minor rock of the Russel Mountain Member, generally forms lenticular outcrops, enclosed by volcanic flows and breccia (Figure 23). Best outcrops are along the Fish Lake-Twin Lakes road, elevation 6,780 feet, in the NE¼SW¼SW¼ sec. 2, T. 6 S., R. 46 E. Another good outcrop is at an elevation of 6,580 feet along the north side of Big Elk Creek in the NE¼NW¼ sec. 11, T. 6 S., R. 46 E. In addition, limestone is exposed near the contact of the Fish Lake Complex, elevations 6,800 to 6,900 feet, along the eastern edge of sec. 3, T. 6 S., R. 46 E.

The limestone is dark gray and fine-grained. Individual beds range in thickness from 1 to 8 inches. Outcrops generally are small, but they can be as long as 80 to 100 yards and as wide as 40 yards. No fossils were observed but Wetherell (1960, p. 45) found a single,

Figure 23. Limestone pod of the Russel Mountain Member of the Imnaha Formation. NE¼NW¼ sec. 11, T. 6 S., R. 46 E.

poorly preserved ammonite.

Conditions of Deposition, Transportation, and Provenance

Important factors in interpreting the provenance, transportation, and environment of deposition are the following: (1) deposits are thick and clastic units are not bedded; (2) clastic units are generally poorly sorted and are not graded; (3) rounded clasts float in a matrix of coarse-grained volcaniclastic material; (4) clastic rocks have the same color and mineral composition as the intercalated flow rocks; (5) small limestone bodies are irregularly distributed within the rock unit; (6) rapid changes in lithology occur between Russel Mountain and the Snake River canyon; and (7) similar rocks crop out over a small area in the northern Wallowa Mountains.

Rocks of the Russel Mountain Member were formed mostly by volcanic processes and were deposited in a submarine environment. The writer proposes that the rocks were erupted on the sea floor and formed seamounts that extended for several miles. Some seamounts rose above sea level and were eroded. Fringing limestone bodies formed in protected areas along the sides of the seamounts. Deposits of mud, sand, and conglomerate like those of the Sugarloaf Lentil collected in local lagoons or bays. Gravity flows, similar to mud flows, cascaded to the sea floor along oversteepened slopes and deposited thick masses of breccia.

Age and Correlation

No fossils were found in the Russel Mountain Member. However, fossils occur in the Sugarloaf Lentil which either interfingers with or overlies the Russel Mountain Member. Wetherell (1960, p. 51) described the Sugarloaf Lentil as "...completely enclosed by the remainder of the Russel Member." Dr. N.J. Silberling studied a small fossil fauna collected by the writer from the Sugarloaf Lentil and reported: "*Chamys* ? sp., *Minetrigonia* ? sp., and *Septocardia* ? sp. This assemblage of pelecypods, though not amenable to accurate identification, suggests an Upper Triassic stratigraphic assignment."

Therefore, the Russel Mountain Member is probably of Late Triassic age. As glomeroporphyritic dikes that resemble flow rocks of the Russel Mountain Member cut the Doyle Creek Formation, the dike relationships suggest that the member is not older than the Doyle Creek Formation.

Locally the rocks are tentatively correlated with the lower part of the Doyle Creek Formation, specifically the Piedmont Point Member. The Russel Mountain Member may be in part correlative with the Gold Creek Greenstone described by Prostka (1963) in the Sparta quadrangle.

Doyle Creek Formation (TRdc)

Definition, Distribution, and General Character

Doyle Creek Formation is the name given to a sequence of red and green flow rocks and volcaniclastic rocks exposed in the Snake River canyon, the Imnaha River canyon, and in the valleys of Elk Creek and Duck Creek. The Piedmont Point Member and the Ashby Creek Conglomerate constitute at least a quarter of the rocks in the formation.

The type section of the Doyle Creek Formation is on the north side of Doyle Creek from the Snake River to an elevation of 3,850 feet, where the rocks are overlain by Columbia River Basalt. The type section includes the upper part of the Piedmont Point Member and over 900 feet of overlying Doyle Creek strata. Neither the base nor the top of the formation is exposed in this sequence. Appendix C gives descriptions of the type section and four reference sections. Reference sections are along the north side of McGraw Creek, where both the base and the top of the formation are exposed but the central part is faulted out, along the south side of the ridge between Limepoint Creek and Hibbles Gulch, and north of Ashby Creek. The stratigraphic descriptions are not detailed; thicknesses were hand-leveled or estimated from altimeter traverses. In addition, good exposures are on the north side of the Imnaha River canyon, between Ashby Creek and

McGraw Creek, and in the Lynch Creek area (Figure 24).

Calculations of thicknesses from three measured stratigraphic sections and six reconnaissance sections show that blackish-green and black flow rocks comprise 26 percent of the formation, red flow rocks comprise 35 percent, red volcanic breccia makes up 23 percent, volcanic conglomerate constitutes seven percent, and finer-grained volcaniclastic rocks constitute the remaining nine percent (Table 10).

Where thick stratigraphic sequences occur, the Doyle Creek Formation can be distinguished from the underlying Grassy Ridge Formation and from the Imnaha Formation. However, isolated outcrops of greenish-black or dark-gray flows are difficult to assign to one of the three formations. Some distinguishing features of the Doyle Creek Formation are an abundance of red rocks, thick beds, and rugged cliff-forming outcrops.

Stratigraphic Relationships and Thickness

The Doyle Creek Formation conformably overlies the Grassy Ridge Formation, interfingers (?) with and overlies the Imnaha Formation, and is conformably overlain by the Martin Bridge Formation.

Best exposures of the conformable contact between the Doyle Creek Formation and the underlying Grassy Ridge Formation are along Grassy Ridge in secs. 9 and 16, T. 16

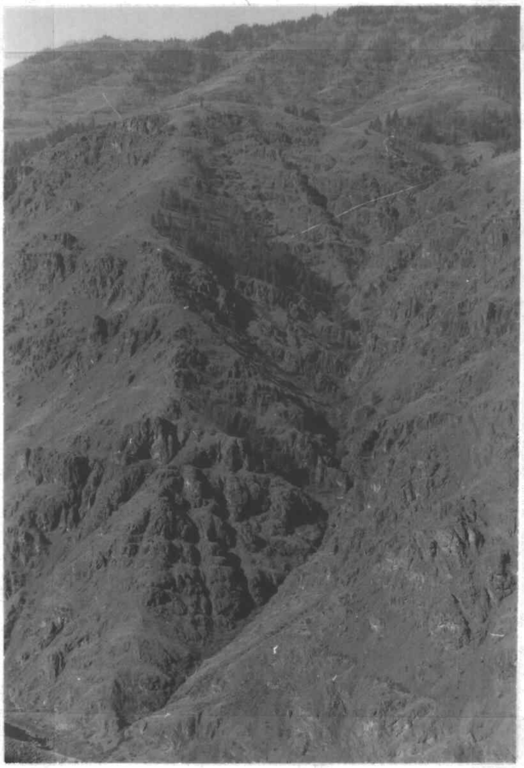

Figure 24. Typical exposures of the Doyle Creek Formation at Lynch Creek, just south of the type section at Doyle Creek.

Table 10. Approximate Percentages of Different Lithologies in the Doyle Creek Formation.

Lithology	1	2	3	4	5	6	7	8	9
Greenish-black and dark-gray volcanic flows	30.7	23.0	15.8	60.5	26.5	19.0	2.1	21.7	9.6
Dusky-red and purplish volcanic flows	24.4	46.2	46.4	15.2	40.0	20.2	35.7	35.0	47.4
Dusky-red and black volcanic breccia	26.4	20.1	30.1	4.6	19.5	43.2	35.6	15.0	11.2
Dusky-red volcanic sandstone and siltstone	10.2	7.1	5.2	4.4	1.5	2.0	11.7	3.4	12.4
Volcanic conglomerate	-	-	-	9.4	5.1	7.0	14.9	10.9	19.4
Black volcanic breccia and sandstone	-	-	-	-	-	-	-	14.0	-
Covered area	7.4	3.6	2.5	5.9	7.4	8.6	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1 = Section between McGraw Creek and Nelson Creek, approximate thickness 1,600 feet.
2 = Section on south side of Nelson Creek, thickness about 1,200 feet.
3 = Section on north side of Copper Creek, thickness about 800 feet.
4 = Section between Ashby Creek and Copper Creek, thickness about 900 feet.
5 = Section from Hibbles Ridge, thickness about 1,000 feet.
6 = Section from the top of Hibbles Ridge, thickness about 400 feet.
7 = Measured section, north side of McGraw Creek, thickness over 900 feet.
8 = Doyle Creek, type section, thickness over 1,600 feet.
9 = Hibbles Ridge section, south side, thickness about 1,300 feet.

N., R. 3 W., on the north side of McGraw Creek at an elevation of about 2,100 feet, and along the north side of the Imnaha River.

Best exposures of the conformable contact between the Doyle Creek Formation and the overlying Martin Bridge Formation are on the south side of Kinney Creek near the IPALCO road and along both sides of McGraw Creek.

The Doyle Creek Formation is not exposed in the Fish Lake area. Similar rocks, however, are exposed farther west in the Wallowa Mountains where they are part of the "Lower Sedimentary Series" (Smith and Allen, 1941).

Rocks of the Imnaha Formation seem to overlie part of the Doyle Creek Formation in the western part of the thesis area. No interlayering was noted at Fish Lake, but in the upper reaches of Elk Creek, red and black volcanic flows of the Doyle Creek Formation are overlain by glomeroporphyritic flows of the Russel Mountain Member. A greenish-black glomeroporphyritic dike cuts rocks of the lower part of the Doyle Creek Formation at an elevation of 5,450 feet on the south side of the Imnaha River on the rugged rôche moutonnée south of "Hidden Campground." In the Snake River canyon, the Doyle Creek Formation contains dusky-red glomeroporphyritic flows. The glomeroporphyritic flows, except for color, are very similar to those of the Russel Mountain Member and may be equivalent.

The thickness of the formation is unknown. A reconnaissance along the Snake River north of the map area showed greater thicknesses, suggesting that the Doyle Creek Formation thickens to the northeast towards the Seven Devils Mountains. In the map area, thicknesses probably range from about 3,000 to 5,000 feet. The larger figure is for the northeastern part of the map area.

Lithology and Petrography

The Doyle Creek Formation is composed of about 60 percent flow rocks and 40 percent clastic rocks of predominantly pyroclastic origin. Carbonate rocks are uncommon. Sixty-five thin sections of rocks from the formation were studied.

Red color is the most distinctive lithologic feature. The red color and the bold, rugged outcrops of flow rocks distinguish the formation in reconnaissance studies.

Spilite is the dominant flow rock whereas coarse-grained pyroclastics are the dominant clastic rocks. Most plagioclase is albitized and most primary mafic minerals are altered. The pilotaxitic and intergranular textures, abundance of augite in the less altered rocks, and the abundance of iron ore suggest that the flow rocks originally were basalts.

Spilite

Most spilites are flows but some may be sills, especially the thick units with coarser textures. Outcrops are rugged and form sheer cliffs. Porphyritic textures are dominant; phenocrysts are set in a pilotaxitic, intergranular, or diabasic groundmass. Some phenocrysts form aggregates as much as six cm in diameter. Colors of fresh rocks range from grayish red (5 R 4/2), grayish red purple (5 RP 4/2), and dusky red (5 R 3/4) to greenish black (5 GY 2/1, 5 G 2/1) and dark greenish gray (5 GY 4/1).

Simple mineralogy characterizes the spilitic rocks. Plagioclase and iron-rich, devitrified glass (?) are the dominant components; clinopyroxene is subordinate. Iron-rich devitrified glass (?) constitutes from 5 to 60 percent of the rocks and averages about 25 percent. X-ray diffraction studies of plagioclase from one specimen showed an anorthite content between 8 and 12 percent. However, two flow rocks sampled in the Imnaha River canyon have labradorite (An_{50-53}) as the principal plagioclase. Other minerals are penninite, prochlorite, calcite, sphene, actinolite, leucoxene, hematite, prehnite, epidote, and white mica. A characteristic modal analysis of a spilite is albite (59.8 percent), iron-rich, devitrified glass (?) (16.1 percent), clinopyroxene (10.1 percent), epidote (9.3 percent), penninite (5.8 percent), calcite (2.3 percent), sphene (0.6 percent), and trace amounts of white mica and quartz.

Glomeroporphyritic spilite in the Doyle Creek Formation may be of stratigraphic significance for correlation purposes. The characteristic rock of the Russel Mountain Member of the Imnaha Formation is a greenish-black glomeroporphyritic flow rock. The Doyle Creek Formation has several flows of dusky-red glomeroporphyritic spilite exposed along the top part of the ridge between Limepoint Creek and Hibbles Gulch and along the ridge north of Ashby Creek. Possibly, the glomeroporphyritic flows of both formations represent lava that was erupted from the same magma chamber.

Pyroclastic Rocks

Pyroclastic rocks are the dominant volcaniclastic rocks of the formation. Pyroclastic rocks of the Piedmont Point Member are greenish black and dark gray but those of the upper part of the formation are shades of red.

Pyroclastic Breccia and Tuff Breccia. Breccia is well-exposed along McGraw Creek and in the upper part of the type section at Doyle Creek. Pumice, cuspate boundaries of fragments, monolithology of rock fragments, ghost glass shards, and graded beds suggest a pyroclastic origin. Reversed grading, with pumice near the top, is present at an elevation of about 2,850 feet, on the first ridge south of Buck Creek in the northernmost part of the map area. Vertical grading in the 20 foot bed shows dense lapilli at the base grading upwards to a fine tuff and then to a fine tuff with large pumice fragments. Higher in the bed, the pumice fragments become dominant and in turn grade to a fine tuff. The origin of this tuff may have been very similar to that suggested by Fiske and Matsuda (1964, p. 95); "In the closing stages of the eruption practically all of the dense accessory fragments had already settled so that the debris reaching the sea floor near the vent consisted almost entirely of pumice lapilli and crystals of plagioclase and quartz. Thus, the later parts of the pyroclastic flow were much more pumiceous than the earlier parts."

The best example of a volcanic breccia underlies the Martin Bridge Formation with apparent conformity. The breccia, here informally called the Kinney Creek breccia, is best exposed along the IPALCO road south of Kinney Creek and along the same road south of Eckels Creek (Figure 25). The Kinney Creek breccia, generally intercalated with volcanic flows, is over 200 feet thick in McGraw Creek. Angular clasts of green, dark-gray, and red flow rocks are set in a dusky-red matrix. Clasts over 30 cm in length occur but most are between 2 to 8 cm in greatest dimension. Weak grading defines bedding in

Figure 25. Volcanic breccia (Kinney Creek breccia), Doyle Creek Formation, from exposures along the IPALCO road, SE¼NE¼ sec. 31, T. 21 N., R. 4 W.

some exposures, but contacts between most beds are not sharp. The major characteristics of this breccia are as follows: (1) nearly all clasts were derived from flow rocks; (2) good bedding planes are uncommon; (3) very few rounded or subrounded clasts occur; (4) poor sorting is characteristic although some thin beds do contain moderately well-sorted breccias; and (5) the matrix is hematite-rich.

Volcanic breccia elsewhere is not as thick, has some volcaniclastic rocks as fragments, and in some places has more subrounded clasts. All breccia examined in the upper part of the formation is red of various shades. Rock fragments comprise as much as 75 percent of the breccia. Pumice generally is less abundant than spilitic rock fragments, but pumice in some beds comprises a large percent of the rock (Figures 26 and 27).

Tuff. Tuff, as seen in 12 thin sections, contains spilitic rock fragments (0-50 percent), pumice (0-90 percent), ash and glass relicts (0-60 percent), plagioclase (2-35 percent), clinopyroxene (0-20 percent), and iron-rich matrix (0-40 percent). Coarse-grained tuff is poorly sorted with angular to subangular fragments. In outcrop studies, tuff commonly is difficult to distinguish from epiclastic sandstone and siltstone.

Figure 26. Tuff breccia partly composed of pumice fragments. Doyle Creek Formation, elevation 2,080 feet, extreme east-central part of sec. 11, T. 21 N., R. 4 W.

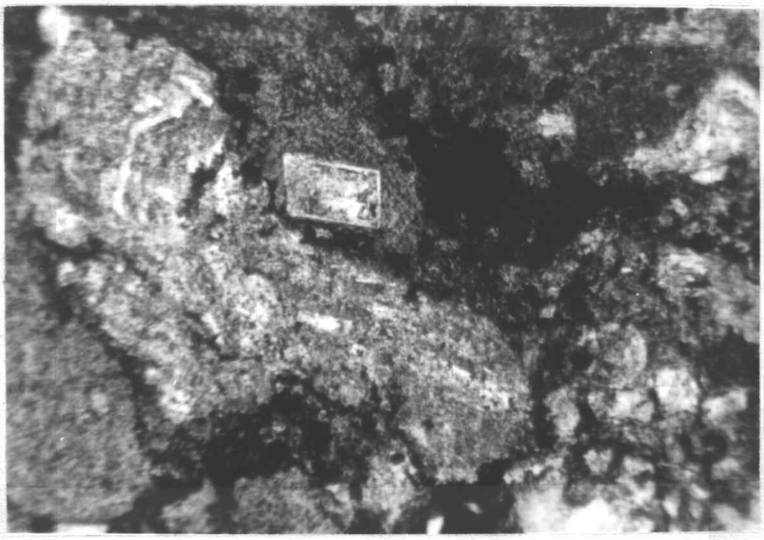

Figure 27. Photomicrograph (about X 40, crossed nicols) of a coarse-grained tuff of the Doyle Creek Formation. Note the clear albite surrounding the feldspar and the albite patches in the pumice fragment.

Epiclastic Volcanic Rocks

Epiclastic rocks are apparently subordinate to pyroclastic rocks. Volcanic breccia, at least in part of epiclastic origin, is characterized by containing some subrounded to well-rounded clasts and little or no pumice. The breccia is poorly sorted and generally grades upward to volcanic sandstone and siltstone. Colors are shades of red. Major components are spilitic rock fragments, volcaniclastic rock fragments, plagioclase, and hematite. Hematite-rich, clay matrices comprise as much as 35 percent of some rocks.

Volcanic sandstone and volcanic siltstone are characterized by cross bedding, rounded pebbles, and are generally the graded upper parts of volcanic conglomerate or breccia. Sandstone is poorly to moderately well sorted. Spilitic rock fragments, plagioclase, and hematite are the dominant components. Colors are shades of red.

Carbonate

Carbonate occurs as scattered pods and lenses but comprises a very small percent of the rocks. The best outcrop is at an elevation of about 2,350 feet on the north side of Ashby Creek. The carbonate unit is recrystallized and contains no fossiliferous debris. Some carbonate units are intimately mixed with volcanic breccia, perhaps signifying contemporaneous transport and deposition.

Piedmont Point Member

The Piedmont Point Member (Plate 3) of the Doyle Creek Formation is best exposed at Piedmont Point on the east side of the Snake River in sec. 8, T. 22 N., R. 3 W. The member overlies the Grassy Ridge Formation conformably and is overlain conformably by, and is interlayered with, the Doyle Creek Formation. A stratigraphic section of the upper part of the Piedmont Point Member is included in the type section of the Doyle Creek Formation (Appendix C, Table 25). The basal unit is a black spilite followed by a sequence of black and dark-gray spilites and tuff breccias. Best exposures of the basal unit are along the east side of Grassy Ridge at Piedmont Point. The top of the member is the black flow which underlies the first red bed of the Doyle Creek Formation. The member thins to the south and west but apparently thickens northeast of the map area. In McGraw Creek, several miles south of Piedmont Point, the member is represented by a 15 foot thick, black, tuff breccia. The thickness of the Piedmont Point Member near the north border of the map area is at least 600 feet.

The Piedmont Point Member is composed of volcanic flows and pyroclastic rocks. Colors are greenish black

(5 GY 2/1), grayish black (N 2), and dusky brown (5 YR 2/2). Flow rocks are subordinate to the pyroclastic deposits. Most flow rocks are porphyritic, with plagioclase phenocrysts from 0.2 to 4.5 mm in length, set in an intergranular, pilotaxitic, or diabasic groundmass. As all rocks have undergone low grade regional metamorphism, secondary minerals such as albite, chlorite, and epidote have replaced primary minerals. Major minerals as seen in six thin sections are plagioclase (60-80 percent), clinopyroxene (0-15 percent), and iron ore (4-30 percent). Minor minerals are chlorite, calcite, epidote, actinolite, sphene, leucoxene, prehnite, and hematite.

Pyroclastic rocks are mostly tuff breccia and coarse tuff. At Piedmont Point (Figure 28), a striking cliff east of the Squaw Creek rapids, at least 300 feet of grayish-black tuff breccia and intercalated spilite flows are exposed. Poor sorting, angular fragments that have diameters as much as 10 cm, and grading are characteristic. Major components in five thin sections are spilitic rock fragments (60-80 percent), pumice (0-10 percent), plagioclase (5-10 percent), clinopyroxene (1-2 percent), and iron ore (3-10 percent). Subordinate minerals are epidote, penninite, leucoxene, sphene, hematite and quartz. Coarse tuff, best exposed north of Squaw Creek at elevations between 2,000 feet and 2,400 feet, is poorly sorted, graded, and of grayish-black or greenish-black color. Components are similar to those of the tuff breccia.

Intercalated volcanic flows within the pyroclastic deposits may indicate that the materials were expelled from volcanic vents as alternating quiet flows and explosive eruptions. Subaqueous pyroclastic flows were probably an important transporting mechanism. Source vents are not exposed in the map area.

Ashby Creek Conglomerate

Ashby Creek Conglomerate, a name given to a member of the Doyle Creek Formation, consists of volcanic conglomerate, volcanic breccia, fine-grained volcaniclastic rocks, and intercalated flow rocks. The type section is on the ridge north of Ashby Creek at elevations between 3,100 feet and 3,800 feet where about 600 feet of rocks are well-exposed (Figure 29). An excellent reference section is in Kirby Creek at elevations between 3,300 feet and 3,600 feet where dusky-red conglomerate and volcanic sandstone are interbedded. Other good exposures are along the ridge north of Limepoint Creek.

The Ashby Creek Conglomerate is interlayered between greenish-black and red flow rocks and volcaniclastic rocks of the Doyle Creek Formation (Appendix C, Table 29). Major features of the conglomerate are dusky-red color, a dominance of spilite clasts, and poor sorting.

Figure 28. Piedmont Point Member of the Doyle Creek Formation. The massive outcrop is composed mostly of tuff-breccia, tuff, and spilite. Squaw Creek rapids of the Snake River are in right-center of the photograph.

Figure 29. Ashby Creek Conglomerate, north side of Ashby Creek, center sec. 2, T. 6 S., R. 48 E., Oregon.

Well-rounded clasts are in some places mixed with very angular clasts. Clasts range from 0.4 to 10 cm in diameter.

The dusky red matrices are composed of silt, clay, hematite, plagioclase, and rock fragments. At the type locality, nearly all clasts are of flow rocks that resemble flows of the Doyle Creek Formation. At Kirby Creek, a pebble count of 126 clasts gave 52.8 percent of red flow rocks, 15.8 percent of reddish-gray flow rocks, 19.3 percent of dark-gray flow rocks, 12.7 percent of dusky-red volcaniclastic rocks and 1.3 percent of plutonic clasts. The only clasts studied optically were those of plutonic character; modal analyses of five clasts are given in Table 11.

The Ashby Creek Conglomerate is the first unit of Triassic age in the map area that contains plutonic clasts. Triassic and Paleozoic plutons are rare in the western United States; radiogenic ages imply only two Triassic plutons (Gilluly, 1965, p. 11-13). Significantly, Prostka (1963, p. 112) also reported "granitic" clasts in Late Triassic rocks of northeastern Oregon. Accordingly, the clasts indicate the erosion of one or more plutons near the Oregon-Idaho boundary during the Late Triassic.

Table 11. Modal Analyses of Plutonic Clasts of the Ashby Creek Conglomerate. All Clasts were Collected at an Elevation of About 3,400 Feet on the South Side of Kirby Creek.

Mineral Name	VC-104B[1]	VC-105B[2]	VC-200A[3]	VC-200B[4]	VC-257[5]
Plagioclase	84.4	75.8	63.4	63.2	70.2
Quartz	1.9	0.5	25.9	21.9	11.9
Amphibole[6]	7.4	-	3.9	9.0	5.1
Pyroxene[7]	-	20.0	-	-	-
Iron ore	1.6	3.7	3.5	4.1	3.6
Chlorite	0.4	T	0.5	-	4.8
Calcite	1.0	-	2.3	0.8	4.4
Sphene	0.9	-	0.6	1.0	T
White mica	-	-	-	T	-
"Matrix"[8]	2.4	-	-	-	-
Total	100.0	100.0	100.0	100.0	100.0

[1] Quartz-Bearing Andesite porphyry

[2] Gabbro.

[3] Microtonalite.

[4] Microtonalite.

[5] Quartz diorite.

[6] "Amphibole" is generally actinolite but is altered to chlorite and epidote in places.

[7] "Pyroxene" is altered clinopyroxene.

[8] "Matrix" is included to account for optically indeterminable cataclastic material in VC-104B.

Conditions of Deposition, Transportation, and Provenance

The Doyle Creek Formation was deposited in a marine basin or basins. Source rocks were adjacent volcanic landmasses and submarine (?) volcanic vents. Plutonic clasts show that some plutonic rocks were exposed. The northeast-thickening, pyroclastic deposits and intercalated flow rocks of the Piedmont Point Member suggest a major volcanic source to the northeast.

Age and Correlation

Fossils from the Doyle Creek Formation are not identifiable. The underlying Grassy Ridge Formation is of late Middle Triassic (Ladinian) and early Late Triassic (Karnian) age, and the overlying Martin Bridge Formation is of early Late Triassic (latest Karnian) and middle Late Triassic (earliest Norian) age. Therefore, a Late Triassic (Karnian) age is assigned to the Doyle Creek Formation.

Correlatives in the Wallowa Mountains are the "Lower Sedimentary Series" (Smith and Allen, 1941) and part of the Imnaha Formation (Wetherell, 1960). Northeast of the map area, the Seven Devils Volcanics (Wagner, 1945) are in part correlative. Perhaps part of the "Triassic (?) volcanic-sedimentary sequence" described by Morrison (1964) is also correlative. Regionally the Doyle Creek

Formation is correlated with Nizina Limestone and Chitistone Limestone of the Nizina Valley, Alaska, the Pit Shale of northern California, and the Winnemuca sequence and the Luning Formation of Nevada.

Martin Bridge Formation (Ꞧmb)

Definition, Distribution, and General Character

In the northeast part of the map area near Big Bar, Idaho, a thick unit of Upper Triassic limestone is exposed in a broad, southwest-trending syncline (Plate 3). From fossil identifications and stratigraphic position, the limestone is assigned to the Martin Bridge Formation.

Lindgren (1901, p. 581) described a limestone sequence in the Snake River canyon near Big Bar. Ralph Cannon measured a stratigraphic section which was included in a report by Hamilton (1963, p. 9-12). Laudon (1956) also measured a stratigraphic section near Big Bar as part of a more detailed stratigraphic and paleontologic study of the Martin Bridge Formation in the Wallowa Mountains.

The best stratigraphic section in the map area is along the south side of Kinney Creek (Figure 30) where about 1,750 feet of limestone is present (Appendix D, Table 30). Reference sections are in Eckels and Allison creeks, Idaho, and in McGraw Creek, Oregon. Good

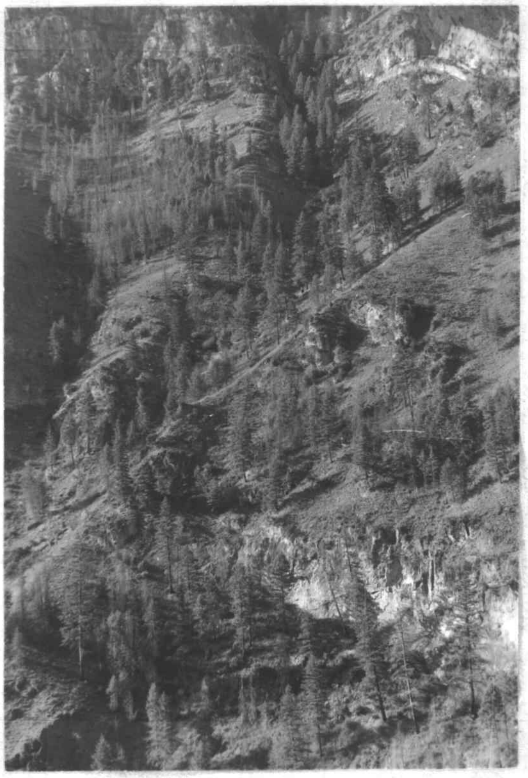

Figure 30. Reference section of the Martin Bridge Formation, south side of Kinney Creek, Idaho.

exposures are in Spring, Leep, and Kirby creeks, Oregon. Fault slices of the limestone are exposed on Lime Saddle east of the map area in the center of sec. 18, T. 21 N., R. 3 W. and at Limepoint Peak in the center of sec. 12, T. 21 N., R. 4 W.

The limestone is gray to black on fresh surfaces and weathers light gray to white. Beds range in thickness from 1 to 75 feet, but average about five feet. Steep cliffs characterize outcrops in Allison, Eckels, and Kinney creeks.

Stratigraphic Relationships and Thickness

The Martin Bridge Formation conformably overlies the Doyle Creek Formation. As the top unit of the Martin Bridge Formation is not exposed in the map area, the total thickness is unknown. The limestone along the south side of Kinney Creek has a thickness of about 1,750 feet. Elsewhere, the formation is apparently not as thick as near Big Bar. Prostka (1963, p. 100) estimated the thickness at 1,500 feet in the southern Wallowa Mountains and Nolf (1966, p. 39) estimated a thickness of between 1,100 and 1,200 feet in the northern Wallowa Mountains.

Lithology and Petrography

Descriptions of 24 thin sections and calcite-dolomite and insoluble residue studies are presented in Appendix D, Tables 31 and 32. Folk's (1959) classification of limestones was followed for optical descriptions. X-ray techniques were those of Tennant and Berger (1957) for the calcite-dolomite ratios and a modified procedure used by the Department of Soils at Oregon State University for clay mineral studies. Insoluble residue procedures were those of Ellingboe and Wilson (1964).

The amount of insoluble residue ranges from 3 to 22 percent and averages 6.7 percent. Maximums of 22 percent and 14 percent are caused by an abundance of quartz and clay, respectively. Authigenic quartz forms irregular pod-like segregations along bedding planes, is disseminated throughout the rock, and occurs in veins. Clays generally comprise most of the insoluble residues.

Clay minerals are illite and chlorite. Chlorite and illite are in the bottom sample, 3B, but only illite occurs in two samples, 7B and 7T, near the top of the formation.

The abundance of carbonaceous material is striking. In the breakdown of the limestone for insoluble residue studies, thick scums of black, oily material collected on the surface of the dilute acid. This black, fetid material occurs disseminated throughout the rocks and also as distinct laminae. Lucas (1952, p. 122) believed that the fetid carbonaceous material in many limestones is an organic phosphorous salt, essentially free of sulfur, and that it probably is related to planktonic activity. The material can occur in either closed or open basins, but is more common in closed basins that essentially lack benthonic fauna.

Dolomitic limestone is irregularly distributed: units two and three have traces of dolomite; the bottom bed of unit five is nearly 90 percent dolomite; and four of six samples from different beds in unit six contain dolomite. Dolomite probably is entirely of replacement origin, since it occurs as euhedra in sparry calcite, and as distinct rhombs in quartz veins. Therefore, part of the dolomitization occurred after lithification and after the formation of quartz veins. A greater sampling density is needed before dolomitization problems can be adequately considered.

Some rocks are completely recrystallized to a coarse sparite, whereas others are still micritic. Sparites, biosparites, and micrites are the dominant rock types in the formation.

Age and Correlation

Correlation between isolated bodies of limestone in eastern Oregon and western Idaho generally is not possible because diagnostic fossils are scarce. Several Upper Triassic units are known. Deposition in separate areas probably occurred throughout much of Late Triassic time.

Smith (1927, p. 9-10) assigned a Late Triassic age to the limestone near Martin Bridge in the southern Wallowa Mountains. He described a stratigraphic section and concluded that one coral zone was, "lower Noric and represents the Fischerweise fauna of the Alps." Smith and Allen (1941, p. 56) reported fossils which were dated by S.W. Muller as Late Triassic (late Karnian). Nolf (1966, p. 54) collected fossils that were identified by N.J. Silberling as belonging to the *Mojsisovicsites kerri* Zone of earliest Norian age. Squires (1956) suggested a Norian age for a fauna from limestone near Lewiston, Idaho.

The Martin Bridge Formation at Big Bar also was assigned an early Norian age by N.J. Silberling (Appendix B). As the fossils were collected about 800 to 1,000 feet above the base of the formation, the lower part could be latest Karnian.

Regionally, the Hosselkus Limestone of northern California, the Luning Formation of western Nevada, the Nizina Limestone of Alaska, the Nicola Group of the Ashcroft, British Columbia area, and the Maude Formation of Queen Charlotte Islands correlate in part with the Martin Bridge Formation.

Conditions of Deposition

At least four contrasting environments of deposition are suggested by the fossils and lithologies of the Martin Bridge Formation. The first, and most easily recognized, is an environment where benthonic fauna lived in clear, shallow, and warm waters. As corals and crinoids grew, somewhat quiet conditions prevailed. Micritic limestones that contain a very small percent of carbonaceous material possibly precipitated as lime muds, perhaps on a wide, shallow platform that was below wave base. In a second environment, limestone and fossils were eroded by waves or slumping, transported into surrounding basins, and deposited as limestone breccia and calcarenite in graded beds as much as 20 feet thick. A third environment is indicated by the massive beds near the middle of the sequence. Whether these represent old reef cores is uncertain. A fourth environment is suggested by abundant carbonaceous material deposited as thin laminae. Apparently, lethal bottom conditions existed where no benthonic organisms could survive and the carbonaceous material probably was formed as decaying planktonic organisms drifted to the bottom.

Laudon (1956, p. 51) reported, "The limestone is 1,690 feet thick and in the central part there is a 265 foot interval in which there is no sign of bedding. This represents an old reef and marginal beds can be seen dipping off the old reef core when the sequence is observed from a distance." Thick, massive units do occur near the middle of the section but dipping marginal beds or reef facies were not distinguished. Nolf (1966, p. 52-53) reported a reef facies in the northern Wallowa Mountains.

The Martin Bridge Formation probably was deposited in reef and shallow platform environments on a slowly subsiding volcanic platform. Lack of coarse-grained terriginous debris suggests that land masses were at a great distance or that the terriginous debris was effectively blocked by barriers.

Columbia River Basalt (Tcr)

Definition, Distribution, and General Character

The Columbia River Basalt is the most widespread stratigraphic unit in the map area. Basalt flows comprise most of the unit, but basaltic breccia and tuffaceous siltstone also occur. The Columbia River Basalt is recognized as a group that consists of two formations, the Picture Gorge Basalt and the Yakima Basalt (Waters, 1961). As the emphasis of this study is on the pre-Tertiary rocks, the two formations were not differentiated, although both occur in the map area.

Best exposures of basalt are along the west side of the Snake River canyon and on both sides of North Pine Creek. Other good outcrops are in Lake Fork Creek, Dry Creek, Fish Creek, Little Elk Creek, and McGraw Creek

(Figure 31). Intracanyon flows crop out along the bend of the Snake River across from Oxbow, Oregon, in the north-central part of sec. 20, T. 20 N., R. 4 W. Feeder dikes are widespread. A description of their distribution, lithology, and petrography is postponed. Tuffaceous siltstone occurs along the old road on the southeast side of Windy Ridge, in the E½NW¼ sec. 16, T. 20 N., R. 4 W., at elevations of about 2,000 feet to 2,200 feet.

Stratigraphic Relationships and Thickness

The Columbia River Basalt overlies the pre-Tertiary rocks with angular unconformity and is overlain unconformably by Quaternary unconsolidated deposits. Most flows range in thickness from 20 to 40 feet. Total thickness near the mouth of Pine Creek is more than 3,000 feet. Thickness along the ridge between the Snake River and North Pine Creek is between 1,500 feet and 2,000 feet.

Lithology and Petrography

Fresh surfaces of the Columbia River Basalt are grayish black; weathered surfaces are light brown to reddish brown. Most flows are fine-grained, but some have feldspar phenocrysts as much as two cm in length. The best example of porphyritic Columbia River Basalt is the basal flow in Irondyke and McGraw creeks. Most flows are vesicular, particularly near the top. Columnar jointing is

Figure 31. Columbia River Basalt in McGraw Creek canyon, Oregon.

common; curved columnar joints mark intracanyon flows on the south side of Windy Ridge. Glass-rich basalt breccias and flows occur along the road between the Oxbow dam and the town of Oxbow, Oregon.

Major components are plagioclase, clinopyroxene, iron ore and glass. Olivine and alteration minerals also occur. No modal analyses of the flows were obtained, but several dike rocks were studied. Data for dike rocks are listed in Table 19.

Age

The Columbia River Basalt is Miocene and early Pliocene (Waters, 1961).

Quaternary Unconsolidated Deposits

Glacial Deposits

The most extensive glacial deposits are on the ridges between the Imnaha River and Duck Creek and between Duck and Elk creeks. The valley of Lake Fork Creek has a thin covering of glacial drift (Plate 3). Lateral moraines are in the valley of East Pine Creek west of the map area in sec. 20, T. 6 S., R. 46 E. Less obvious moraines are along the valley walls of Duck Creek, Elk Creek, Lake Fork Creek, and the Imnaha River. Deposits near the confluence of Lake Fork Creek and Pole Creek in the southwest part of T. 6 S., R. 47 E. suggest a breached terminal moraine.

Limits of ice movement were determined in the valleys of Lake Fork Creek, Duck Creek, and the Imnaha River. Glacial deposits extend to elevations of 4,900 feet in Lake Fork Creek, 4,000 feet in Duck Creek, and to approximately 4,000 feet in the Imnaha River.

Landslide Debris

Conspicuous landslide deposits occur along the Snake River at Big Bar, between Ashby and Copper creeks, and north of the confluence of Dove Creek and the Snake River. A less conspicuous landslide is near the junction of the north and south forks of Limepoint Creek in the SW¼ sec. 12, T. 22 N., R. 4 W. Large angular blocks of locally derived rocks are characteristic of the landslide deposits.

Terrace Gravels and Recent Alluvium

Best examples of terrace gravels are on the south end of Big Bar, south of the mouth of Copper Creek, and along both sides of the mouth of Bob Creek.

Alluvium occurs along all major streams; the alluvial fans along the Snake River are conspicuous. The most notable alluvial fans are at the mouths of Ballard Creek, Ashby Creek, Leep Creek, and Spring Creek (Figure 32).

Figure 32. Typical alluvial fan in the Snake River canyon. Spring Creek, Oregon.

The fan at Ballard Creek covers about 25 acres. Alluvial fans from Allison and Eckels creeks have partly filled the depression behind the landslide deposit at Big Bar.

Volcanic Ash

Volcanic ash is exposed at several places along the Snake River. Notable deposits are near the IPALCO road a few yards south of Allison Creek, and in the valley of the major stream between Ashby and Copper creeks at an elevation of about 1,800 feet in the SE¼NW¼ sec. 1, T. 6 S., R. 48 E. In addition, thin ash deposits are in other creek beds along the Snake River.

INTRUSIVE UNITS

Introduction

Igneous rocks in the map area represent at least one intrusive event in the late Paleozoic Era, three in the Mesozoic Era, and one in the Cenozoic Era. Mafic dikes that cut the Windy Ridge Formation may record the first late Paleozoic intrusive event. However, the principal late Paleozoic event was the emplacement of the Holbrook-Irondyke gabbro, diabase, and keratophyre porphyry. Mesozoic intrusive episodes were: (1) Lower Triassic (?) intrusions of gabbro, diorite, microtonalite, quartz diorite, and albite granite of the Oxbow Complex; (2) Jurassic (?) intrusions of andesite and dacite porphyries, quartz diorite, and diorite; and (3) the Upper Jurassic (?) intrusions which include norite, hyperite, gabbro, and quartz diorite of the Fish Lake Complex, the Duck Lake gabbro, the Eckels Creek granodiorite porphyry, and the gabbro, norite, and quartz diorite of the Duck Creek Complex. The only recognized Cenozoic intrusive event was the emplacement of Columbia River Basalt dikes.

Paleozoic Intrusives

Mafic Dikes in the Windy Ridge Formation

Abundant metamorphosed mafic dikes intrude the Windy

Ridge Formation north of the Oxbow. The best exposures are along the IPALCO road north of Oxbow, Oregon. Dikes range in width from 1 to 30 feet.

The dikes apparently were intruded along joints and faults in the Windy Ridge Formation. Contacts are sharp but chill zones were destroyed by later metamorphism. Offsets are common; five northeast-trending dikes offset northwest-trending dikes.

Diabase is the dominant rock type but gabbro also occurs. Both rocks are characterized by dusky-green (5 G 3/2) and greenish-black (5 GY 2/1) colors. In the diabase, albite is the only feldspar recognized; altered plagioclase may be more calcic. Clinopyroxene is replaced in part by epidote, chlorite, and quartz. Epidote is very abundant in some samples and is responsible for the dusky-green color but the large percent of epidote in sample VS5-3 is atypical (Table 12). Gabbro is highly altered. Actinolite and chlorite are the major alteration minerals. As feldspars are altered, compositions could not be obtained by optical methods.

Mafic dikes in the overlying Hunsaker Creek Formation are similar to those in the Windy Ridge Formation, but are not as abundant. Two possibilities exist for the intrusion of the dikes that cut the Windy Ridge Formation. Either they were intruded before the deposition of the Hunsaker Creek Formation, or more dikes were intruded

Table 12. Modal Analyses of Mafic Dikes of the Windy Ridge Formation.

Minerals	VS5-3[1]	VS2-2[2]
Albite	34.6	66.5
Clinopyroxene	10.2	10.9
Iron ore	0.4	11.3
Penninite	6.4	10.4
Prochlorite	-	T
Sphene-leucoxene	6.7	0.7
Epidote	39.4	0.2
Quartz	2.3	-
Total	100.0	100.0

[1] Diabase: SW¼SW¼ sec. 17, T. 20 N., R. 4 W., along the IPALCO road.

[2] Diabase: center sec. 17, T. 20 N., R. 4 W., along the IPALCO road.

along the southern end of Windy Ridge than elsewhere in the map area during deposition of the Hunsaker Creek Formation. If the first possibility is correct, the mafic dikes of the Windy Ridge Formation are older than the Hunsaker Creek Formation (pre-late Leonardian). If the second possibility is correct, the mafic dikes were intruded during or after the deposition of the Hunsaker Creek Formation and may be related to the Holbrook-Irondyke intrusives.

Holbrook-Irondyke Intrusives

The Holbrook-Irondyke intrusives are metamorphosed plugs, dikes, and sills of gabbro, diabase, keratophyre porphyry, and quartz keratophyre porphyry that are best exposed in the Holbrook Creek and Irondyke Creek areas (Plate 3). Outcrops also occur in the southwestern part of the map area, near the confluence of Duck Creek and North Pine Creek, and in the Ashby Creek area.

The best outcrops of gabbro are along the east side of Windy Ridge, on both sides of Homestead Creek, in Ashby Creek, near the confluence of Trinity and East Pine creeks, and near the confluence of Duck and North Pine creeks (Plate 3). Hand specimens of gabbro are dusky green (5 G 3/2) to greenish black (5 G 2/1) and grayish green (10 G 4/2) to dark greenish gray (5 G 4/1). Most specimens are medium-grained, equigranular rocks that weather to a dusky brown. Irregular dike and plug-like bodies are characteristic, but a sill about 30 feet thick extends along the west side of the Snake River canyon between Homestead Creek and Herman Creek. Modal analyses of four gabbros are given in Table 13. Albite is the major feldspar but one specimen contains labradorite (An_{50-52}).

Diabase apparently is a minor rock type of the Holbrook-Irondyke intrusives. Because of the difficulty in

Table 13. Modal Analyses of Gabbro of the Holbrook-Irondyke Intrusives.

Minerals	VC-92[1]	VC-137[2]	TC-19[3]	VC-369[4]
Plagioclase	63.5	72.8	56.6	54.8
Clinopyroxene	19.6	5.4	19.9	23.3
Iron ore	5.6	4.9	5.6	7.1
Epidote	0.9	0.8	7.5	1.4
Chlorite	9.6	14.0	8.9	12.4
Prehnite	0.8	0.8	-	1.0
White mica	T	-	T	-
Sphene-leucoxene	-	T	0.9	T
Quartz	-	T	-	-
Calcite	-	1.3	0.6	-
Pyrite	-	T	-	-
Total	100.0	100.0	100.0	100.0

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[1] SW¼SW¼NW¼ sec. 2, T. 6 S., R. 4 W., elevation 3,510 feet, north side of Ashby Creek.

[2] NE¼SW¼NW¼ sec. 2, T. 6 S., R. 4 W., elevation 3,720 feet, north side of Ashby Creek.

[3] SE¼SW¼ sec. 34, T. 6 S., R. 46 E., elevation 4,500 feet on ridge east of Clark Creek.

[4] Elevation 3,640 feet, north side of Duck Creek, a quarter of a mile west of confluence with North Pine Creek.

distinguishing between flows and small intrusives, diabase is reported only where intrusive relationships are evident. The best outcrops of diabase are along the north side of Bob Creek from elevations of 2,800 feet to 3,400 feet in the northern part of sec. 34, T. 6 S., R. 48 E. Outcrops are black, rugged, and cliff-forming. The medium-grained diabase is dark greenish gray (5 GY 4/1). Albite and clinopyroxene are the major minerals; epidote, chlorite, calcite, prehnite, sphene, and leucoxene are minor minerals. Another diabase crops out at an elevation of 2,740 feet along the north side of Holbrook Creek. Minerals are albite (44 percent), clinopyroxene (9.1 percent), iron ore (3.9 percent), chlorite (20.3 percent), calcite (17.6 percent), epidote (3.1 percent), and prehnite (trace). Small amygdules are filled with epidote.

Keratophyre porphyry and quartz keratophyre porphyry occur in discontinuous and irregular outcrops. Flow rocks of the same composition in the Hunsaker Creek Formation are difficult to distinguish from the intrusives. Best outcrops are in Ballard Creek, on the ridge between Holbrook and Irondyke creeks, along the ridge south of Holbrook Creek, and along the ridge northwest of Homestead, Oregon (Figure 33). Colors of fresh specimens range from grayish yellow (5 Y 8/4) to grayish yellow green (5 GY 7/2) and from pale yellow orange (10 YR 8/6) to moderate pink (5 R 7/4). All are porphyritic, with plagioclase

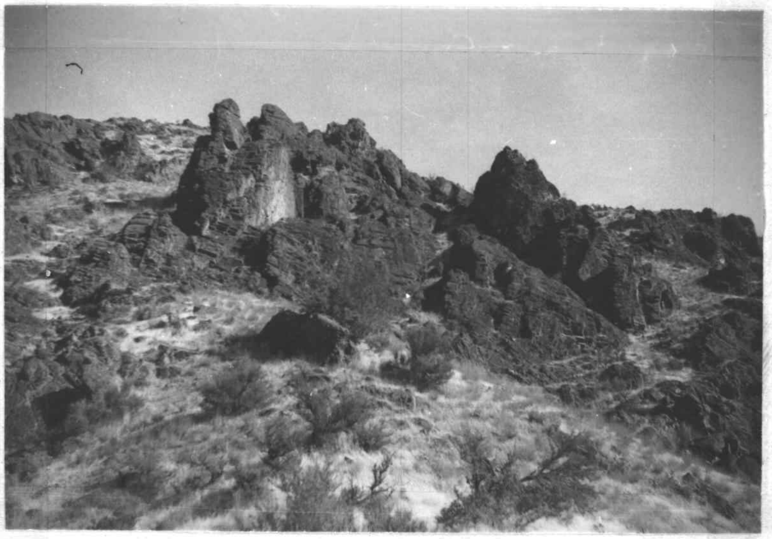

Figure 33. Keratophyre porphyry on the north side of Homestead Creek in the NE¼ sec. 21, T. 6 S., R. 48 E. Note the horizontal columnar jointing.

and quartz phenocrysts set in a felty or pilotaxitic groundmass. Albite phenocrysts are euhedral and average about one mm in length. As maximum extinction angles of albite twins are 17 degrees, the anorthite content is probably about 4 to 6 percent. Quartz phenocrysts are commonly bipyramidal but many are rounded by magmatic resorption. Primary mafic minerals are absent. Secondary minerals are calcite, white mica, chlorite, epidote, sphene, leucoxene, iron carbonate, and pyrite.

The Holbrook-Irondyke intrusives were emplaced during and perhaps after deposition of the Hunsaker Creek Formation, but before deposition of the Grassy Ridge Formation. Some keratophyre porphyry bodies may have served as feeders. A similarity of the keratophyric porphyries and the keratophyric extrusives strengthens the suggestion. The Holbrook-Irondyke intrusives probably were emplaced during Middle Permian time.

Mesozoic Intrusives

The Oxbow Complex

Major rocks of the Oxbow Complex are gabbro, diorite, microtonalite, quartz diorite, and albite granite. Dark-colored gabbro, diorite, quartz diorite, and microtonalite form a somewhat older plutonic series that was intruded by lighter-colored quartz diorite and albite granite.

Gabbro is the major rock of the older plutonic series. The two distinct plutonic series probably were intruded at close intervals. All rocks were regionally metamorphosed; post-intrusive tectonism sheared the rocks. Shearing and recrystallization produced cataclasite, mylonite, and gneissic mylonite. Locally, quartz diorite and albite granite were converted to cataclastic rocks, composed of epidote and quartz (epidosites).

Gabbro, Diorite, Quartz Diorite, and Microtonalite

Metamorphism has transformed the original mineralogy of most rocks, whereas shearing and recrystallization have changed the textures along shear zones. On the west side of Indian Creek, pods and dike-like bodies of undeformed rocks occur in the foliated zone of the Oxbow-Cuprum shear zone but were not mapped. Primary textures of relatively undeformed rocks are porphyritic, hypidiomorphic granular, and micrograniti c. Grain sizes range from 0.5 to 7.0 mm in diameter.

As feldspars are altered, compositions are difficult to determine. However, X-ray and optical studies indicate compositions of An_{45}-An_{55} for gabbro and An_{30}-An_{40} for diorite. Albite rims surround calcic plagioclase; in some samples albite completely replaces the more-calcic plagioclase. Veins of albite are common. Quartz is strained or crushed in some rocks. Clinopyroxene in gabbro is replaced by actinolitic amphibole; no relicts of clinopyroxene were observed. Primary hornblende occurs in the diorite, quartz diorite, and microtonalite. Secondary minerals are epidote, chlorite, albite, actinolite, sphene, leucoxene, calcite, prehnite, white mica, pyrite, hematite, and tourmaline (Table 14).

The dark color is diagnostic of the oldest plutonic rocks. Ultramafic rocks may be present but were not detected in this preliminary study. Serpentinite was reported at the mouth of Powder River, approximately 15 miles south of the Oxbow (Livingston, 1932), so there is a possibility that small bodies of ultramafic rocks occur in the Oxbow Complex.

Quartz Diorite and Albite Granite

The younger intrusive rocks of the Oxbow Complex are quartz diorite and albite granite. Xenoliths of the older gabbro and diorite occur in the younger quartz diorite and albite granite; contacts between units are sharp (Figure 34). The largest, most accessible outcrop is on the east side of the Snake River between Scorpion Creek and Indian Creek (Figure 35). Bodies of quartz diorite are dike-like and trend northeast. Some, over 100 feet wide, are separated from other quartz diorite by screen-like masses of dark-colored gabbro or diorite.

Hand specimens of quartz diorite are greenish gray

Table 14. Modal Analyses of Rocks of the Older Plutonic Series in the Oxbow Complex.

Mineral	VC-53[1]	VC-59[2]	VC-77[3]	VC-140[4]
Plagioclase	42.8	55.9	52.9	40.1
Amphibole	48.3	31.5	36.9	45.1
Quartz	0.2	4.6	5.2	1.1
Iron ore	6.1	4.3	0.6	4.9
Epidote	0.3	0.3	0.8	6.4
Chlorite	1.6	1.1	3.4	0.3
Pyrite	0.4	-	-	T
Sphene-leucoxene	T	2.3	T	2.1
Prehnite	T	-	0.2	-
White mica	0.3	T	T	T
Calcite	T	T	-	T
Total	100.0	100.0	100.0	100.0

[1] Gabbro: elevation 2,880 feet, center sec. 10, T. 20 N., R. 4 W.

[2] Quartz-bearing microdiorite: elevation 3,200 feet, center sec. 10, T. 20 N., R. 4 W.

[3] Quartz diorite porphyry: elevation 2,900 feet, SW¼SE¼ NW¼ sec. 2, T. 20 N., R. 4 W.

[4] Cataclastic microdiorite: elevation 2,180 feet, north-center sec. 21, T. 20 N., R. 4 W.

Figure 34. Sharp contact between quartz diorite and gabbro in the Oxbow Complex, east of the Oxbow Dam, elevation 2,140 feet. Gabbro is on the left.

Figure 35. Rugged outcrops of quartz diorite. Relatively flat surface of gabbro and diorite in the background is capped by the Columbia River Basalt. View is northeast of the Oxbow Dam.

to light gray and medium to coarse-grained; grain diameters range from 2 to 5 mm (Figure 36). Plagioclase, quartz, and hornblende are the conspicuous primary minerals. Commonly, quartz diorite grades into albite granite.

Microscope studies show that hypidiomorphic granular textures are dominant in the unsheared quartz diorite. Euhedral to subhedral plagioclase and hornblende crystals are separated by interstitial quartz. Compositions of plagioclase range from andesine to albite. Zoned, saussuritized cores generally are rimmed by clear albite. No potassium feldspar was identified by optical or staining techniques. Hornblende is the dominant mafic mineral although altered biotite occurs in some samples. Actinolite, chlorite, and epidote are common alteration products. Epidote is ubiquitous and occurs as veins, as feldspar alteration, and interstitially. Sphene-leucoxene and penninite also are common secondary minerals (Table 15).

Albite granite commonly is sheared and some is mylonite and gneissic mylonite. The general field and microscopic features described by Gilluly (1933) are duplicated in the albite granite of the Oxbow-Cuprum shear zone. Hand specimens are medium gray to grayish green. Major minerals are plagioclase, quartz, epidote, and chlorite. The amount of primary mafic minerals decreases as shearing and recrystallization increase. Blue quartz

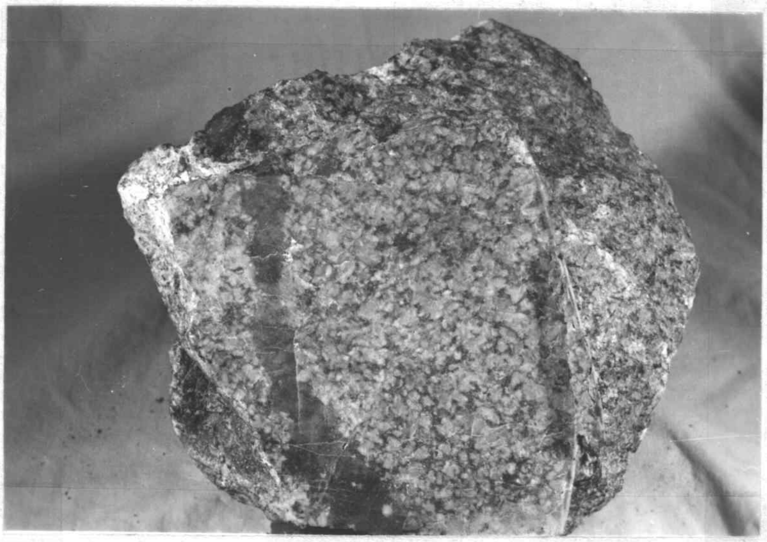

Figure 36. Hand specimen of quartz diorite with a ghost-like xenolith of darker rock. Height of specimen is about seven inches.

Table 15. Modal Analyses of Quartz Diorite, Albite Granite, and Transitional Rocks of the Younger Plutonic Series in the Oxbow Complex.

Minerals	VC-158[1]	VC-54[2]	VC-173[3]	VC-182[4]	VC-183[5]
Plagioclase	58.7	61.8	66.8	72.7	69.4
Quartz	28.2	36.6	21.3	18.9	20.9
Hornblende[6]	4.0	0.8	-	-	-
Iron ore	2.6	0.4	0.5	0.9	0.7
Actinolite	-	-	0.1	-	-
Chlorite	1.7	T	4.0	3.3	5.6
Epidote	4.3	0.2	5.1	2.9	3.4
Sphene-leucoxene	0.5	0.2	1.2	1.3	T
White mica	T	-	T	T	T
Total	100.0	100.0	100.0	100.0	100.0

[1] Quartz diorite: elevation 2,100 feet, SE¼NE¼SE¼ sec. 16, T. 20 N., R. 4 W.

[2] Transitional rock; elevation 2,890 feet, SE¼NW¼ sec. 10, T. 20 N., R. 4 W.

[3] Transitional rock: elevation 1,760 feet, SE¼NW¼ sec. 16, T. 20 N., R. 4 W.

[4] Albite granite: elevation 2,580 feet, NE¼SW¼ sec. 10, T. 20 N., R. 4 W.

[5] Albite granite: elevation 2,760 feet, NE¼NW¼ sec. 11, T. 20 N., R. 4 W.

[6] Actinolite included.

porphyroblasts, as defined by Gilluly (1933, p. 68), are uncommon. Quartz can comprise over 50 percent of the rock.

Field separation of albite granite from quartz diorite is difficult. Generally, distinctions must be made optically. The major microscopic differences between quartz diorite and albite granite are textural characteristics and plagioclase composition. Both quartz diorite and albite granite have granitic, cataclastic, and crystalloblastic textures, but micrographic textures are dominant in the albite granite (Figure 37). Quartz forms vermicular lobes and graphic penetrations into the plagioclase; some plagioclase appears as islands in a sea of quartz (Figure 38). Quartz diorite has plagioclase that displays oscillatory and normal zoning. Clouded cores of andesine are rimmed by clear albite. Albite (An_{6-8}) is the plagioclase of albite granite and can contain zones of inclusions or be glassy clear; cores of many grains are obscured by sausserite. Primary mafic minerals are more abundant in quartz diorite than in albite granite. Epidote generally comprises 5 to 10 percent of the rocks but 40 percent is common in gneissic epidosite which was probably quartz diorite before shearing and recrystallization. Chlorite, sphene, and white mica are other secondary minerals.

A notable characteristic of the rocks is the

Figure 37. Photomicrograph (about X 40, crossed nicols) of cataclastic albite granite.

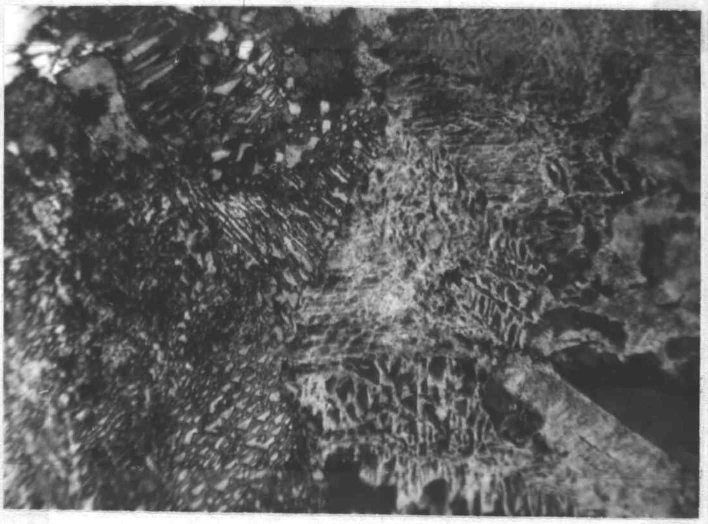

Figure 38. Photomicrograph (about X 40, crossed nicols) of micrographic texture in albite granite of the Oxbow Complex.

relationship between the intensity of crushing and the increase in minerals characteristic of the albite granite. The relationships suggest that the major changes took place in the rock during the last stages of crystallization or after complete solidification. Albitization is localized along shears in both the quartz diorite and the gabbroic rocks. Textural evidence including micrographic and cataclastic features, plus mineralogic features including albite pseudomorphs and vermicular growths of quartz (formed by eutectic crystallization or replacement), suggest that the albite granite was derived from the quartz diorite by replacement (Figure 39). Abundant epidote, the bluish color of some quartz, and veins of albite strengthen the hypothesis (Figure 40). Most of these criteria are similar to those cited by Gilluly (1933, p. 74). He concluded (op.cit., p. 65) that: "The albite granite...is thought to be a product of albitization and partial silicification of an earlier quartz diorite. These changes are attributed to late magmatic and post-magmatic replacement of the almost completely solidified quartz diorite by solutions derived probably through filter pressing from lower portions of the same mass. These solutions were guided, at least in part and probably entirely, by brecciated zones in the quartz diorite."

Figure 39. Photomicrograph (about X 40, crossed nicols) of vermicular intergrowths of quartz and albite in albite granite.

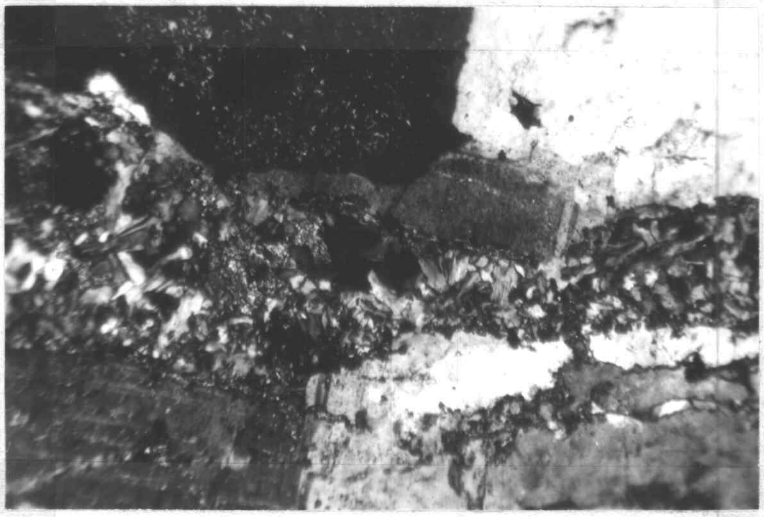

Figure 40. Photomicrograph (about X 40, crossed nicols) of an albite vein cutting quartz diorite of the Oxbow Complex.

Jurassic (?) Intrusives

Dacite porphyry, andesite porphyry, diorite, and quartz diorite occur irregularly in the pre-Tertiary rocks of the map area. As the intrusives cut the Upper Triassic Martin Bridge Formation and were subjected to Middle Jurassic (?) regional metamorphism, they are informally named the Jurassic (?) intrusives. Modes of a diorite and a quartz-bearing andesite porphyry are given in Table 16.

Metamorphosed dacite and andesite porphyry are grayish green (10 GY 5/2), yellowish gray (5 YR 8/1), pale yellowish green (10 GY 7/2), and pale green (10 G 6/2). Most bodies are dikes, which range in width from 5 to 20 feet. Best outcrops are on both sides of McGraw Creek at elevations of 2,300 feet to 2,800 feet, and along the IPALCO road in the SE¼ sec. 2, T. 21 N., R. 4 W. (Figure 41). Plagioclase is as calcic as andesine (An_{35-40}) and as sodic as albite (An_{4-6}). Relict oscillatory zoning occurs in some plagioclase; other grains are completely altered and rimmed by clear albite. Groundmass feldspars commonly are associated with white mica in a felty texture. White mica forms large crystals and smaller groundmass laths which comprise as much as 30 percent of some samples. Quartz phenocrysts have bipyramidal outlines although many have been resorbed. Actinolite, epidote,

Table 16. Modal Analyses of a Diorite and an Andesite Porphyry of the Jurassic (?) Intrusives.

Minerals	VC-99[1]	VC-241[2]
Plagioclase	59.6	83.5
Amphibole	33.9[3]	3.0[4]
Iron ore	0.3	0.4
Muscovite	-	0.2
Quartz	-	2.1
Epidote	1.9	8.6
Chlorite	4.0	2.2
White mica	T	T
Sphene	0.3	T
Total	100.0	100.0

[1] Diorite: elevation 3,850 feet on SW¼ sec. 7, T. 21 N., R. 3 W. ridge between north and south forks of Limepoint Creek.

[2] Quartz-bearing andesite porphyry: a quarter of a mile south of Buck Creek along the Snake River.

[3] Actinolitic.

[4] Hornblende pseudomorphed by epidote and chlorite.

Figure 41. Meta-andesite porphyry dike of the Jurassic (?) intrusives cutting the Doyle Creek Formation along the south side of McGraw Creek, Oregon. Thickness of dike in the foreground is about 15 feet.

and chlorite pseudomorph hornblende. Other minerals are calcite, sphene, and leucoxene.

Metamorphosed diorite and quartz diorite occur as sills and dikes. Best outcrops are along the north side of McGraw Creek below the Martin Bridge-Doyle Creek contact and on the south side of Kirby Creek at an elevation of about 3,400 feet. Other good outcrops are at an elevation of 2,850 feet on the ridge north of Doyle Creek and on the ridge south of Squaw Creek, elevation 3,350 feet. Medium-grained, equigranular textures prevail in hand specimens of diorite and quartz diorite. Hornblende, plagioclase, and quartz are distinguishable minerals. Colors are grayish olive green (5 GY), dusky yellow (5 Y 6/4), and pale yellowish green (10 GY 7/2). A study of thin sections shows that plagioclase, hornblende, and quartz are set in a hypidiomorphic granular texture. As plagioclase is generally sausseritized, compositions are difficult to determine. However, most grains apparently are andesine (An_{32-38}). Complex twinning is visible but zoning is not well-developed. Minor minerals are actinolite, epidote, chlorite, calcite, white mica, sphene, and leucoxene. Apatite and iron ore are common accessories.

Upper Jurassic (?) Intrusives

At least four intrusive bodies were emplaced during the late stages of regional metamorphism or after regional metamorphism, and before the extrusion of Columbia River Basalt. These units are the Duck Lake gabbro, the Duck Creek Complex, the Eckels Creek granodiorite porphyry, and the Fish Lake Complex. None was studied in detail but typical samples were collected. The Fish Lake Complex was studied by Ross (1938), Reid (1953), and Wetherell (1960).

Duck Lake Gabbro

The Duck Lake gabbro (Plate 3) is a small intrusive about a quarter of a mile east of Duck Lake. Outcrops are rounded by glacial scour and contacts are buried beneath glacial deposits. Leucocratic dikes (Figure 42) as much as three inches across cut the gabbro.

The Duck Lake gabbro probably was emplaced during the later stages of regional metamorphism and is possibly of Late Jurassic age.

Duck Creek Complex

The Duck Creek Complex crops out over a small area in the northeast corner of T. 6 S., R. 47 E. As glacial drift and Columbia River Basalt probably cover most of the intrusive, outcrops may represent only a small part of a larger body. Best exposures are at an elevation of about 4,800 feet along the forest service road between Duck and Deer creeks.

Figure 42. Duck Lake gabbro cut by small albite-quartz dikes. Knife for scale.

Biotite quartz diorite is the dominant rock in the Duck Creek Complex; hornblende gabbro and hornblende norite are minor. Modal analyses of three rocks are given in Table 17.

Sharp contacts occur where the hornblende gabbro and quartz diorite are juxtaposed, but the order of intrusion is uncertain. The Duck Creek Complex probably was emplaced during the late stages of regional metamorphism, possibly during Late Jurassic time.

Eckels Creek Granodiorite Porphyry

The Eckels Creek granodiorite porphyry is exposed on the west side of Horse Mountain along the eastern border of the map area (Plate 3). Dacite porphyry of the Jurassic (?) intrusives is intimately associated with the granodiorite porphyry, which was intruded along northeast trending fractures in gabbro and diorite of the Oxbow Complex. Contacts are sharp. Screen-like bodies of gabbro separate dike-like bodies of the granodiorite porphyry. Some bodies of granodiorite porphyry are over 200 feet wide.

The major rock is granodiorite porphyry with oligoclase-andesine, perthitic potassium feldspar, quartz, biotite, and white mica (muscovite ?) as the major minerals. White mica is abundant and forms large crystals, rims biotite, and occurs in the fine-grained groundmass.

Table 17. Modal Analyses of Three Rocks of the Duck Creek Complex.

Minerals	VC-366[1]	VC-367[2]	VC-368[3]
Plagioclase	15.9	47.0	66.7
Quartz	2.9	1.7	14.1
Biotite	-	1.8	16.0
Hypersthene	0.8	21.9	-
Hornblende	57.7	19.3	-
Clinopyroxene	20.4	2.2	-
Potassium feldspar	-	-	0.6
Iron ore	T	1.0	1.1
Actinolite	T	5.1	1.1
Chlorite	1.5	-	T
Epidote	0.8	-	T
Calcite	-	-	0.4
White mica	T	-	T
Total	100.0	100.0	100.0

[1] Hornblende gabbro.

[2] Hornblende norite.

[3] Biotite quartz diorite.

Quartz forms an estimated 20 percent of the rock and potassium feldspar comprises about 15 percent. Potassium feldspar, quartz, and white mica are the groundmass minerals. Alteration effects are minimal.

The Eckels Creek granodiorite porphyry apparently was emplaced after regional metamorphism, probably in Late Jurassic or Early Cretaceous time.

Fish Lake Complex

Ross (1938) mapped the Fish Lake Complex as one intrusive unit during a reconnaissance study of the southeastern Wallowa Mountains. Reid (1953) divided the Fish Lake Complex into four stocks: the Northeast Stock composed of gabbro; the Central Stock composed mostly of gabbro, but also of quartz diorite in the central part; the Little Stock composed of gabbro; and the West Stock composed of gabbro, quartz diorite, intrusive breccia, and lamprophyre dikes. He reported that all stocks contain inclusions and are surrounded by thermal aureoles. Wetherell (1960, p. 108) described the Fish Lake Complex as, "...composite, consisting of two or more magmatic units, which were emplaced in mafic to felsic sequence." Four stocks were informally named the Clear Creek Stock, Fish Lake Stock, Russel Mountain Stock, and the Melhorn Stock. Wetherell reported hyperite, tonalite, and trondhjemite as the major rock types.

Rocks of the Fish Lake Complex were not studied in detail by the writer; samples were collected only from the northeastern stock (Northeast Stock of Reid). Excellent exposures are in the NE¼ sec. 3, T. 6 S., R. 46 E. (Figure 43). The major rock types apparently are hornblende norite and hornblende melanorite (Table 18).

Reid (1953) suggested that the Fish Lake Complex was "post-Mesozoic-orogeny in age" in agreement with Ross (1938). Feldspar alteration, probably clinozoisite, indicated to Reid a late, low temperature phase of regional alteration. Reid (op.cit., p. 12) postulated that, "A dying surge of movement accompanied by low-temperature hydrothermal solutions developed a strong joint system and partly altered the feldspar in all the rocks."

Wetherell (1960, p. 134) concluded that, "...the complex was intruded after metamorphism had begun in the Imnaha Formation, but before all regional metamorphism had ceased. However, no definite age can be given. This complex may be related to early units of the Wallowa batholith to the west, generally considered to be Cretaceous."

The alteration of the feldspars, chloritization, and actinolitization of hypersthene as seen in thin sections probably is due to regional metamorphism. Therefore, the Fish Lake Complex probably was emplaced during the latter part of regional metamorphism, possibly during Late Jurassic time.

Figure 43. Fish Lake Complex, northeast stock, NE¼ sec. 3, T. 6 S., R. 46 E., Oregon.

Table 18. Modal Analyses of Three Rocks From the Northeast Stock of the Fish Lake Complex, Elevation 7,000 to 7,150 Feet, SW¼NE¼ sec. 3, T. 6 S., R. 46 E.

Mineral	VC-398[1]	VC-399[2]	VC-400[3]
Labradorite	60.2	34.5	19.0
Hypersthene	2.8	8.3	4.6
Hornblende	34.7	53.4	66.7
Biotite	0.8	-	-
Clinopyroxene	-	T	-
Iron ore	0.3	T	T
Quartz	1.2	T	T[5]
Actinolite	-	3.9[4]	T
Chlorite	T	0.1	9.7
Epidote	T	T	T
White mica	T	-	-
Calcite	-	-	T
Total	100.0	100.0	100.0

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[1] Quartz-bearing hornblende norite.

[2] Hornblende melanorite.

[3] Hornblende melanorite.

[4] Alteration product of hypersthene.

[5] Veins.

Cenozoic Intrusives

Columbia River Basalt Dikes

Columbia River Basalt dikes are widespread in pre-Tertiary rocks near the Snake River (Plate 3). Mapped dikes are traceable for distances of at least 100 feet but other dikes occur. Only a few dikes were noted in the timbered plateau region near Fish Lake, not necessarily because they are less abundant. Dikes in pre-Tertiary rocks weather more rapidly than the host rocks and consequently the dikes are poorly exposed in timbered areas. Undoubtedly, dikes also occur in Columbia River Basalt but as the basalt was not studied, no dikes were observed cutting basalt.

Dikes range in thickness from one foot to more than 40 feet. The thickest dikes are south of Piedmont Point along the IPALCO road in sec. 8, T. 22 N., R. 3 W., near the mouth of Kirby Creek, elevation 1,800 feet, and along the topographic depression in the SE¼ sec. 1, T. 21 N., R. 4 W. Other good exposures are along the IPALCO road, in the east-central part of sec. 5, T. 7 S., R. 48 E., between Nelson and McGraw creeks, and near the road in the Imnaha River canyon about one mile east of Indian Crossing.

Dikes have a decided northerly trend. Mapped dikes trend mostly N. 10° W. to N. 10° E., but some trend east as much as N. 45° E. or west as much as N. 25° W. Many follow faults or joints.

Dikes are grayish black on fresh surfaces but weather to a light brown or reddish brown. Most basalts have intergranular or diabasic textures. Minerals cannot be recognized even with a hand lens in finer-grained rocks, but phenocrysts of plagioclase as much as three mm in diameter occur in coarse-grained porphyritic specimens. Vesicles are surprisingly abundant in some dikes and reach diameters of two mm.

Five dike rocks were examined optically. Sodic labradorite is the dominant mineral. Phenocrysts and groundmass tablets are euhedral. Some larger phenocrysts display slight oscillatory zoning. Monoclinic pyroxene occurs as microphenocrysts and interstitially between feldspar laths. No olivine was noted. Accessory and alteration minerals are chlorophaeite, apatite, zeolites (?), and clays. Modal analyses of four rocks are given in Table 19. The abundance of glass and lack of olivine indicates that the four dikes probably were feeders for Yakima Basalt.

Table 19. Modal Analyses of Columbia River Basalt Dikes.

Mineral	LC-15[1]	VC-210[2]	VC-227[3]	VS5-9[4]
Plagioclase	55.5	51.2	57.1	37.3
Clinopyroxene	16.6	24.3	29.9	25.1
Glass	12.8	15.2	0.2(?)	27.9
Chlorophaeite	6.0	3.3	-	4.2
Iron ore	8.8	8.0	3.6	5.5
Zeolite (?)	0.3	-	-	-
Clay minerals[5]	-	-	10.2	-
Total	100.0	100.0	100.0	100.0

[1] Elevation 3,260 feet, in small saddle of first ridge south of Kirby Creek, T. 5 S., R. 49 E.

[2] Elevation 3,890 feet, NE¼SE¼ sec. 1, T. 21 N., R. 4 W.

[3] Dike from near IPALCO road south of Piedmont Point, elevation 2,250 feet, NE¼SE¼ sec. 8, T. 22 N., R. 3 W.

[4] Dike rock along IPALCO road, west-central sec. 17, T. 20 N., R. 4 W.

[5] Montmorillinite and reddish-brown nontronite (?).

METAMORPHISM

Introduction

Most pre-Tertiary rocks in the map area are characterized by greenschist facies regional metamorphism. Minor mineralogic changes in the Upper Jurassic (?) intrusives suggest that these small plutons possibly were intruded during the latter stages of regional metamorphism. The Eckels Creek granodiorite porphyry apparently was emplaced after regional metamorphism.

Thermal aureoles around the Upper Jurassic (?) intrusives include higher grade assemblages than those of the greenschist facies. The Oxbow-Cuprum shear zone contains rocks that are partly the product of dynamic metamorphism.

Dynamic Metamorphism

Dynamic metamorphism is the structural and mineralogical reconstitution caused by orogenic movements (Turner, 1948, p. 5). Dynamic metamorphism in the map area was not widespread. However, stress applied to the rocks during deformation produced fractures that possibly facilitated the transfer of materials during later regional metamorphism.

The Oxbow-Cuprum shear zone includes rocks that were changed structurally and texturally during deformation;

schistose, gneissose, mylonitic, and cataclastic rocks indicate intense deformation. Structural and textural changes apparently preceded the regional metamorphism that raised most pre-Tertiary rocks in the map area to the same metamorphic grade. Heat generated by deformation of the Oxbow-Cuprum shear zone probably was not great enough to metamorphose the rocks. Turner and Verhoogen (1960, p. 660) stated that there is, in general, very little correlation between times of deformation and times of recrystallization.

Igneous Metamorphism

According to Albers and Robertson (1961, p. 44), igneous metamorphism is broadly grouped as thermal metamorphism, where rocks adjacent to an intrusive recrystallize to an assemblage of minerals stable under the prevailing temperature conditions, and contact metasomatism, where metasomatic replacement produces masses of skarn.

Thermal metamorphic aureoles containing minerals of the pyroxene-hornfels and hornblende-hornfels facies (Wetherell, 1960, p. 130-134) encircle the Fish Lake stocks. On the eastern edge of the map area, the writer collected rocks of the hornblende-hornfels facies about 300 feet from the contact of the "Deep Creek" stock. Thermal metamorphic aureoles around older plutons were destroyed by regional metamorphism.

A short distance west of the map area, metasomatic replacement produced masses of skarn in limestone near the Fish Lake Complex.

Regional Metamorphism

Most pre-Tertiary rocks were transformed by one or more periods of regional metamorphism and are characterized by greenschist facies minerals such as chlorite, epidote, albite, calcite, and actinolite. Relict plagioclase, pyroxene, and amphibole suggest that all rocks did not attain equilibrium. Most Upper Jurassic (?) intrusives show minor mineralogic changes and probably were intruded during the last stages of regional metamorphism.

Two periods of regional metamorphism are possible for rocks of Permian age. Although metamorphic grade is the same in both Permian and Triassic rocks, the Permian rocks have some different textural and mineralogic features. Few primary textures remain in the Permian rocks; tuffaceous rocks contain no relict glass shards or pumice, and calcic plagioclase or pyroxene relicts are uncommon. In contrast, relict glass shards and pumice occur in the Triassic tuffaceous rocks; calcic plagioclase and pyroxene relicts are abundant. Silicification is also more widespread in Permian rocks than in the Triassic rocks. The differences, combined with the evidence for an angular unconformity between Permian and Triassic rocks, suggest that the Permian rocks have undergone an additional period of deformation and possibly were metamorphosed twice. However, deep burial also might account for a closer approach to mineral equilibrium in the Permian rocks.

In any rock unit, the mineralogic changes probably occurred simultaneously. Major mineralogic changes involved albitization, silicification, chloritization, and epidotization but only albitization and silicification are considered in the following discussion.

Albitization

Most pre-Tertiary rocks contain albite. Albite commonly is the lone feldspar, but rocks that contain calcic plagioclase also are common, particularly in the Triassic formations.

Albitization is suggested by (1) amygdules rimmed by euhedral albite crystals, (2) fractures filled with albite, (3) altered plagioclase rimmed and embayed by clear albite, (4) clear phenocrysts of albite with discontinuous twin lamellae similar to those recognized by Albers and Robertson (1961, p. 47), and (5) matrices and groundmasses showing wholesale volume for volume replacement by fine-grained albite or albite and quartz.

Albite can be clear or highly altered. Compositions are generally An_{5-10} but more sodic plagioclase probably occurs. The absence of calcite, epidote, and prehnite in specimens that are completely albitized suggests that replacement of calcic plagioclase by albite was not a simple breakdown of the anorthite molecule to albite and a calcium-bearing alteration product. Instead, sodium was introduced and calcium was removed. Concentrations of calcite, epidote, and prehnite in shear zones and other fractures imply that the original calcium of the rocks now occurs as the calcium-bearing minerals of the fractures and shear zones.

Metamorphic albite in veins, as amygdule filling, and as lobate replacements of calcic plagioclase, suggests that albite in other rocks probably is pseudomorphic after more calcic plagioclase.

The origin of albitizing solutions and therefore albitic rocks has received much attention since Dewey and Flett (1911) proposed that albitic rocks belong to a natural family of igneous rocks, the "spilitic suite." Metamorphosed rocks in the map area probably were albitized in more than one way. As greater albitization is associated with shearing in rocks of the Oxbow-Cuprum shear zone, apparently soda-rich solutions were guided by shears. Albitized rocks that seem unrelated to shears perhaps formed from processes involving exchange with sea water similar to the process suggested by Gulbrandsen and Cressman (1960).

Silicification

Widespread silicification, especially in Permian rocks, was a major factor in the destruction of primary textures. Quartz veinlets, quartz-filled amygdules, and quartz overgrowths are evidences of silicification. Rocks of the Windy Ridge Formation have the most silicification features.

Some plagioclase phenocrysts are partly replaced by quartz in the intensely silicified rocks; other plagioclase phenocrysts are not replaced by quartz, even though the surrounding groundmasses are silicified. Some quartz phenocrysts have narrow overgrowths of fine-grained quartz. Intense silicification of volcaniclastic rocks along some shear zones produced silicified rocks that are more resistant to erosion than the surrounding rocks and resemble dikes. As silicification of rocks in the Paleozoic rocks is more intense than in Mesozoic rocks, silicification might serve as complementary evidence for two periods of silicification and regional metamorphism of the Paleozoic rocks.

Widespread silicification and an absence of quartz impoverished rocks within the map area, suggest that silica was metasomatically introduced from an outside source.

Conditions and Times of Regional Metamorphism

The regionally metamorphosed rocks have mineral assemblages characteristic of the greenschist facies, specifically the quartz-albite-muscovite-chlorite subfacies.

Turner and Verhoogen (1960, p. 534) stated: "Estimates of temperatures and pressures of low-grade regional metamorphism are little better than a guess. A possible range compatible with experimental data on the stability of greenschist minerals, and taking into account the general lack of metamorphism in many deeply filled geosynclines, is 300° to 500° C. and P_{H_2O}= 3,000 to 8,000 bars."

The last, and perhaps only, regional metamorphism probably occurred during the Middle Jurassic. However, some evidence suggests that an earlier metamorphism occurred during Late Permian or Early Triassic time.

STRUCTURAL GEOLOGY

Introduction

Major pre-Tertiary structural trends in Oregon and Idaho in the general vicinity of the map area are northeast-southwest. Trends within the map area are northeast (N. 40°-80° E.) and northwest (N. 10°-20° W. and N. 70°-80° W.). Rock deformation increases from northwest to southeast and reaches a maximum in the Oxbow-Cuprum shear zone (Taubeneck, 1966), a major structural feature of possible regional importance in tectonic interpretation. Tertiary rocks essentially are undeformed.

Faults are the dominant structures; folds are subordinate. Faults dip steeply where measured and are defined in some exposures by wide zones of breccia and gouge. Angular unconformities occur at the Permian-Triassic and the late Mesozoic-middle Tertiary boundaries.

Folds

Folds are well-displayed in the Martin Bridge Formation (Figure 44); faults characterize deformation of the more competent older rocks. Axial traces of most folds parallel the regional northeast trend.

The most conspicuous fold, a compound syncline, occurs in the Martin Bridge Formation (Plate 3). Beds are steeply folded into a series of anticlines and synclines

Figure 44. Folds in the Martin Bridge Formation along the south side of Leep Creek, Oregon.

on the west flank but dip almost homoclinally towards the axis on the east flank. Two poorly-defined large folds also occur in the map area. An anticlinal nose is present on the south end of Windy Ridge where the oldest rocks are exposed. A north-plunging syncline apparently occurs between the Snake and Imnaha rivers near the north boundary of the map area, but is mostly covered by Columbia River Basalt. Axial traces of the poorly-defined large folds are not shown on Plate 3.

Several anticlines and synclines in the Martin Bridge Formation have axial traces that trend N. 70°-80° E. Some axial traces appear to merge along strike with small reverse faults that are along the north side of McGraw Creek. Chevron folds occur in thin-bedded limestone near the mouth of Kirby Creek. Other folds are in the Grassy Ridge Formation south of Hibbles Gulch and in the Hunsaker Creek Formation south of Fish Lake in T. 6 S., R. 46 E.

Minor folds, 3 to 5 feet in height, occur in the Hunsaker Creek Formation in secs. 27, 28, and 32, T. 21 N., R. 4 W. along the IPALCO road. Fold axes approximately parallel the major faults and plunge southwest.

Faults

Whereas limestones of the Martin Bridge Formation deformed plastically during deformation, more competent formations ruptured. Fault planes dip steeply and apparent slips change from reverse to normal or normal to reverse along strike. Shear zones as wide as 50 feet characterize many faults. At four localities, slices of the Martin Bridge Formation occur along faults (Figure 45). Fault-line traces are straight over short distances but curve as much as 30 to 40 degrees over distances of several miles (Plate 3). Apparent stratigraphic displacement along the "Kinney Creek" fault (Figure 46) is at least 10,000 feet. According to Moody and Hill (1956, p. 1214), many of these features are characteristic of wrench faults, but are not wholly diagnostic. The writer suggests that most of the major faults are wrench or strike-slip faults. The direction of lateral slip is uncertain along most faults but apparently both left-lateral and right-lateral movements occurred. Major faults are listed in Table 20. The latest movement along the faults occurred after the deposition of the Martin Bridge Formation, probably during the Jurassic period.

No thrust faults such as described by Livingston (1932) and Hamilton (1963) were recognized.

Permian-Triassic Unconformity

Permian rocks were deformed before deposition of Middle Triassic rocks. In general, Permian rocks (1) exhibit more shearing than Triassic rocks, (2) contain a

Figure 45. Fault slice of Martin Bridge Formation between the Permian Hunsaker Creek Formation on the left and Triassic Grassy Ridge Formation on the right. The junction of two faults is in the middle foreground. Eckels Creek, elevation 2,400 feet.

Figure 46. Kinney Creek fault. Permian rocks on extreme left, Martin Bridge Formation on the right. Fault trace from top center to middle of left edge. Several smaller faults occur in the foreground.

Table 20. Description and Location of Major Faults.

Fault Name	Location	Approx. Trend	Approx. Length (miles)	Inferred Slip	Strati-graphic Separation	Best Exposures of Fault Zone
Kinney Creek	East side sec. 6, T. 21 N., R. 3 W.	N.10°W.	1.0	Right lateral	10,000 feet or more	2,800 feet elev. SW¼SE¼ NE¼ sec. 29, T. 22 N., R. 3 W.
	Secs. 32, 29, 28, and 21, T. 22 N., R. 3 W.	N.30°E.	3.5			
	Secs. 21 and 16, T. 22 N., R. 3 W.	N.5°E.	1.2			Along fault trace between Kinney and Eckels creeks
	Secs. 9 and 10, T. 22 N., R. 3 W.	N.40°E.	1.2			
Limepoint Peak	SE corner sec. 11 through sec. 12, T. 21 N., R. 4 W. to south-center sec. 6, T. 21 N., R. 3 W.	N.40°E.	2.0	Lateral (?)	Several thousand feet	Limepoint Peak area in center, sec. 12, T. 21 N., R. 4 W.
	South-center sec. 6 to intersection with Kinney Creek fault, secs. 31 and 32, T. 22 N., R. 3 W.	N.25°E.	1.3			
McGraw Creek	Nelson Creek to Spring Creek	N.55°E.	2.0	Left lateral	Several thousand feet	McGraw Creek along north ridge, elev. 3,200 feet
	Spring Creek to Snake River	N.80°E.	1.0			
	Snake River to Eckels Creek, sec. 31, T. 22 N., R. 3 W.	W-E	0.8			Spring Creek, north ridge

Table 20. (Continued)

Fault Name	Location	Approx. Trend	Approx. Length (miles)	Inferred Slip	Stratigraphic Separation	Best Exposures of Fault Zone
Kirby Creek	Leep Creek, elev. 3,350 feet, to Snake River	N.50°E.	2.1	Left lateral (?)	Several thousand feet	Kirby Creek, elev. 2,850 feet
	Snake River to intersection with Kinney Creek fault (?)	N.50°E.	1.6			
Ashby Creek I	Ashby Creek, elev. 2,750 feet to Copper Creek, elev. 3,600 feet	N.20°W.	1.5	Lateral or reverse	More than 5,000 feet	Ashby Creek, elev. 2,600 feet
Ashby Creek II	Ashby Creek, south side, intersection with Ashby Creek, to Snake River. May be southern part of Limepoint Peak fault	N.83°E.	0.8	Left lateral	Several thousand feet	Ashby Creek, elev. 2,480 feet
Kleinschmidt	Windy Ridge, extreme SE corner, sec. 26, T. 21 N., R. 4 W. to Snake River, center sec. 14, T. 21 N., R. 4 W.	N.5°W. N.35°W.	1.7 0.6	Lateral (?)	More than 1,000 feet	Below Kleinschmidt Grade, between elev. of 2,850 feet
Homestead	Holbrook Creek, elev. 2,700 feet to Snake River	N.50°E.	1.5	Reverse (?)	Several hundred feet	South side Irondyke Creek

Table 20. (Continued)

Fault Name	Location	Approx. Trend	Approx. Length (miles)	Inferred Slip	Stratigraphic Separation	Best Exposures of Fault Zone
Windy Ridge	Snake River, sec. 8, T. 20 N., R. 4 W. to Tcr cover near top of Windy Ridge	N.50°E.	1.7	Reverse or lateral	Several hundred feet (?)	No good exposures. Best expression in sec. 8, northeast of the IPALCO road
Duck Creek	Duck Creek, elev. approx. 4,650 feet to Imnaha River west of map area, elev. approx. 4,500 feet	N.60°W. to N.75°W.	2.0 to 4.0 (covered in part)	Reverse (?)	Several thousand feet (?)	No good exposures
Elk Creek	Between south ridge of Packsaddle Creek to north ridge of Elk Creek	N.10°W. to N.30°W.	0.8	Reverse or lateral	Several thousand feet (?)	No good exposures
Homestead Creek-Herman Creek Group	Oregon side Snake River between Homestead Creek and Snake River	N.60°E. to N.70°E.	2.0 to 3.0	Reverse or lateral	Several hundred feet (?)	Creek beds of Homestead and Herman creeks
Windy Ridge Group	Snake River to intersection with Kleinschmidt Fault	N.30°E. to N.60°E.	1.0 to 3.0	Lateral or reverse	(?)	Creek beds along west side of Windy Ridge

greenschist facies assemblage more nearly in equilibrium, (3) show more post-depositional textural changes, (4) differ in attitudes from overlying Triassic strata, and (5) have undergone at least one additional intrusive episode.

Three areas are critical in demonstrating angularity of strata between Permian and Triassic rocks. In the Homestead Creek area, Daonella-bearing limestone beds of the Grassy Ridge Formation overlie Megousia-bearing volcaniclastic rocks of the Hunsaker Creek Formation. Best outcrops to study the unconformity are at an elevation of about 2,380 feet along the south side of Homestead Creek. Attitudes on both sides of the unconformity differ, but care is needed in measuring attitudes because of the amount of deformation (Plate 2). At an elevation of about 3,800 feet in Ashby Creek, fine-grained sandstone and spilitic flow rocks of the Grassy Ridge Formation overlie conglomerate, volcanic sandstone, and tuff of the Hunsaker Creek Formation. Permian rocks strike about N. 10° E. and dip northwest. Triassic strata strike about N. 70° E. and dip southeast.

The Permian-Triassic unconformity is best exposed at elevations between 4,730 and 4,750 feet about a quarter of a mile N. 30° E. from Indian Crossing on the Imnaha River. Fine-grained, pale-green volcanic siltstone of the Hunsaker Creek Formation is overlain by greenish-black flow rocks and volcanic sediments of the Grassy

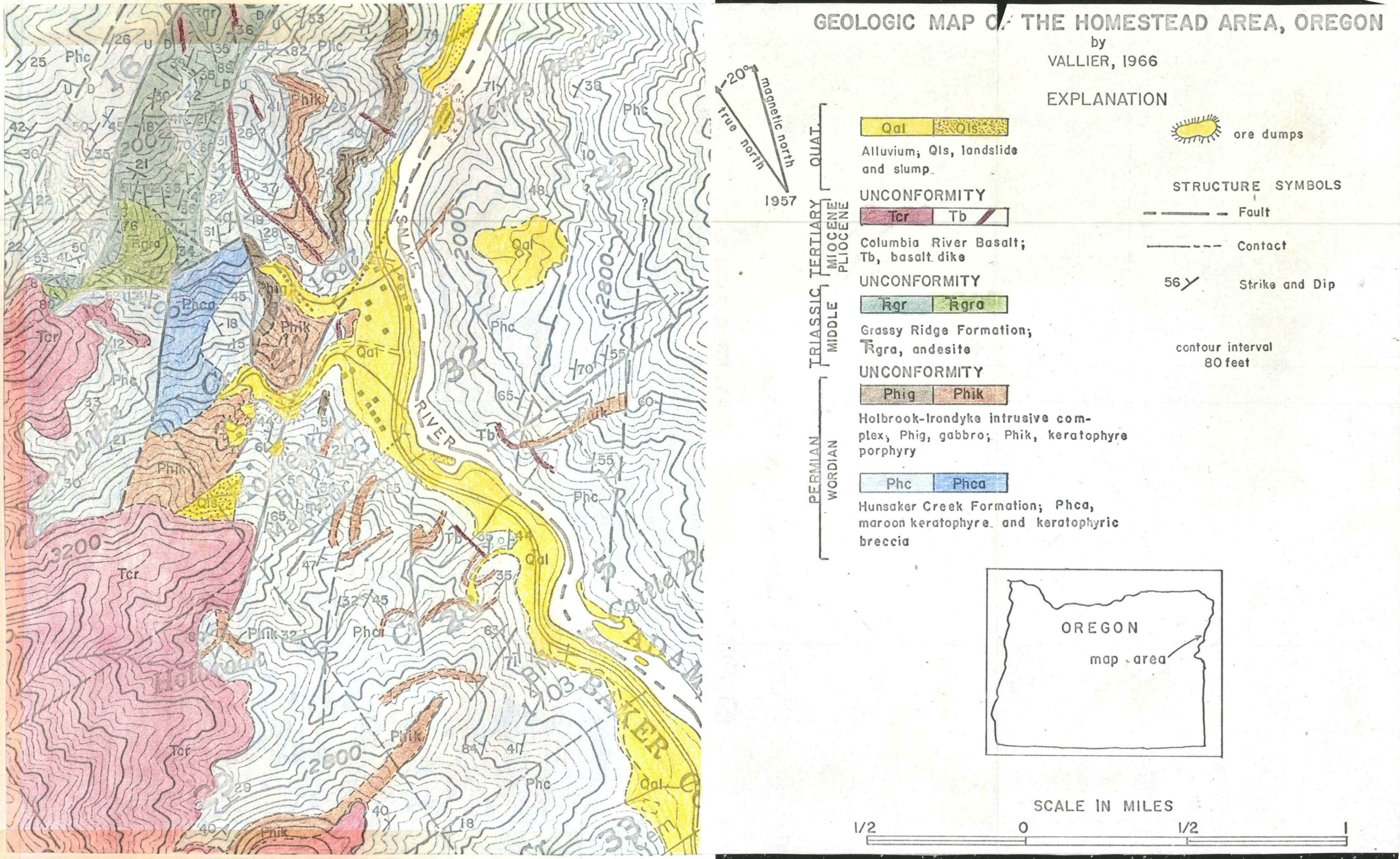

Plate 2. Geologic map of the Homestead area, Oregon.

Ridge Formation (Figure 47). Average attitudes of Permian rocks are N. 30° E., 20° S.; average attitudes of Triassic rocks are N. 25° W., 20° N.

The angular unconformity between Permian and Triassic rocks in the map area supports the conclusion of Dott (1961) that there was an orogeny between Permian and Late Triassic time in northeastern Oregon and western Idaho.

Mesozoic-Tertiary Unconformity

An angular unconformity is present between pre-Tertiary rocks and the Columbia River Basalt of Miocene-Pliocene age. Best exposures are along the west side of the Snake River canyon where folded, faulted, and eroded pre-Tertiary rocks are overlain by nearly flat-lying Columbia River Basalt.

Oxbow-Cuprum Shear Zone

The Oxbow-Cuprum shear zone is a major structural feature in the map area. From near the Oxbow of the Snake River, the shear zone trends N. 40°-50° E. for about 12 miles along the eastern border of the map area (Plate 3). The shear zone contains many anastomosing faults. A foliated zone, between the crest of Windy Ridge and Indian Creek, is characterized by a northeast-trending, nearly vertical foliation.

The shear zone exerts some control on topography.

The configuration of the Oxbow and the channels of Indian and Blue creeks in part are controlled by individual faults. Best outcrops of the major rock types and structures in the shear zone are on both sides of the Snake River between the Oxbow dam and Indian Creek (Figures 48 and 49).

Hamilton (1963, p. 7) reported a major northeast-trending shear zone extending across the Cuprum quadrangle. However, a southwest extension to the Oxbow was not mentioned.

Three broad groups of rocks in the shear zone are (1) volcanic flow rocks and volcaniclastic rocks, (2) plutonic rocks, and (3) brecciated, cataclastic, mylonitic, schistose, and gneissose rocks. All transitions are present from unsheared rocks to cataclastic, mylonitic, and gneissose rocks (Figures 50, 51, 52, 53, and 54). Terms used for deformed rocks are those of Reed (1964).

Unsheared rocks of the Windy Ridge Formation and the Hunsaker Creek Formation also are in the foliated zone near Blue and Indian creeks. Plutonic rocks on the east side of Indian Creek are less sheared than the older rocks but shear zones as wide as 50 feet occur where the plutonic rocks were converted to foliated rocks of quartz and epidote. The original character of strongly sheared rocks generally is apparent because in many outcrops they

Figure 47. Best exposure of the Permian-Triassic boundary. Light-colored, fine-grained volcanic sediments of the Hunsaker Creek Formation are unconformably overlain by volcanic flows of the Grassy Ridge Formation. Knife and pencil define the contact. Elevation about 4,750 feet, northeast of Indian Crossing on the north side of the Imnaha River canyon.

Figure 48. Folded, mylonitic rocks in the foliated zone of the Oxbow-Cuprum shear zone, east side of the Oxbow Dam, Idaho. Note syncline axis dipping to the left. Quartz diorite and gabbro in left background.

Figure 49. Nearly vertical mylonitic rocks in the foliated zone of the Oxbow-Cuprum shear zone. Oxbow Dam spillway, Idaho.

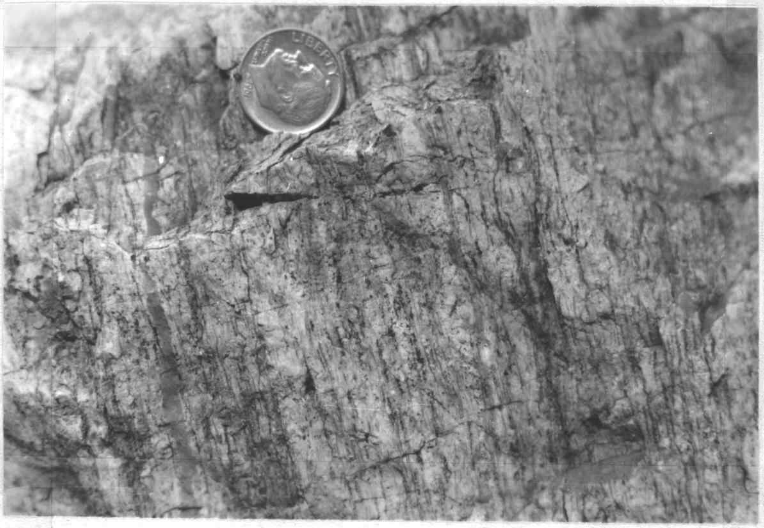

Figure 50. Mylonite of the Oxbow-Cuprum shear zone, elevation 2,000 feet, NW¼ sec. 10, T. 7 S., R. 48 E., Oregon.

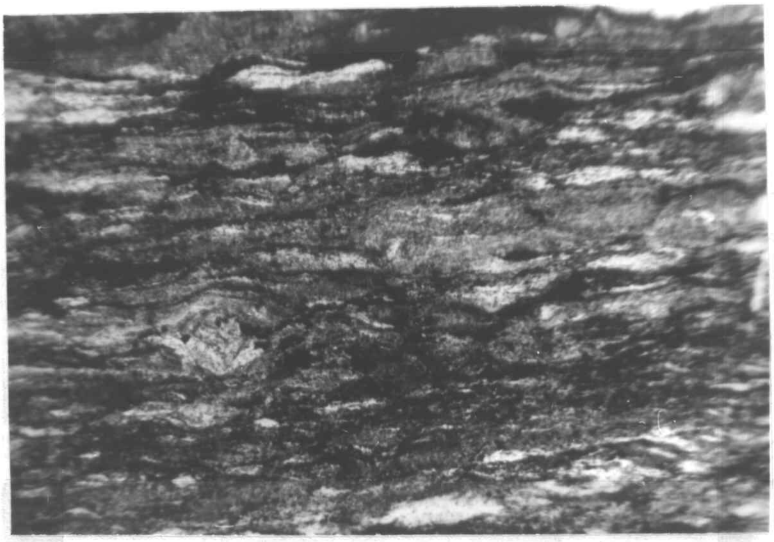

Figure 51. Photomicrograph (about X 40, crossed nicols) of a mylonite (originally a keratophyre of the Windy Ridge Formation) of the Oxbow-Cuprum shear zone.

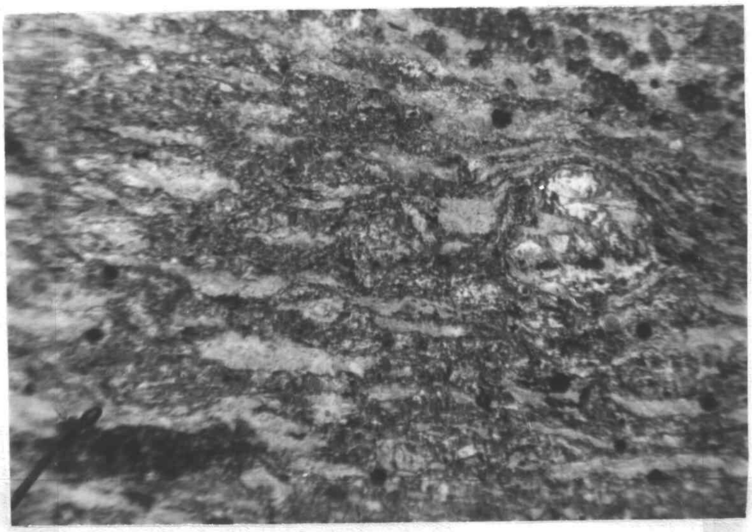

Figure 52. Photomicrograph (about X 40, plane light) of a mylonitic spilite of the Oxbow-Cuprum shear zone. Albite porphyroclast in right-center.

Figure 53. Photomicrograph (about X 40, plane light) of an augen mylonite. Albite porphyroclast in center.

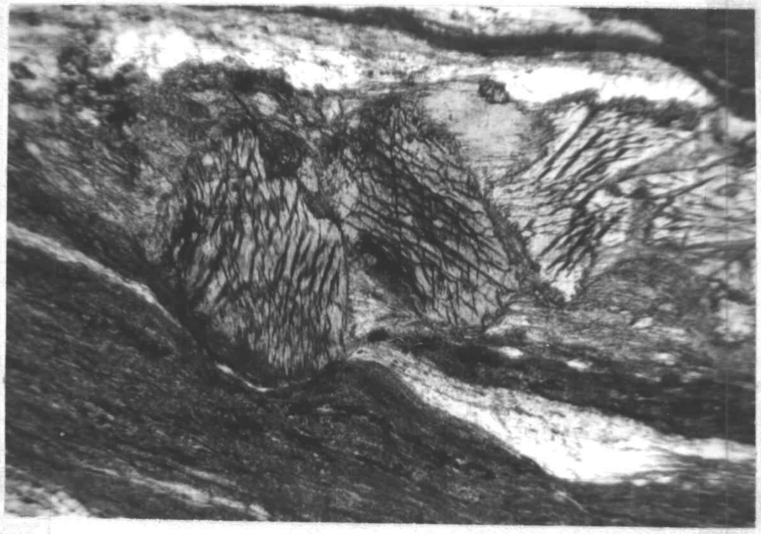

Figure 54. Photomicrograph (about X 40, plane light) of mylonite derived from a diorite of the Oxbow-Cuprum shear zone. Hornblende porphyroclasts in center of photograph.

occur between less deformed rocks.

In summary, the most prominent and perhaps significant features of the Oxbow-Cuprum shear zone are linearity, extreme deformation, parallelism of faults and foliation, intrusive localization, and the presence of rocks similar to those of the Canyon Mountain Complex (Thayer, 1963). Deformation and contemporary plutonism occurred after deposition of the Hunsaker Creek Formation (Guadalupian) but before deposition of the Grassy Ridge Formation (Ladinian). Accordingly, the Canyon Mountain magma series probably was intruded during the Late Permian or Early Triassic. The writer suggests that the Oxbow-Cuprum shear zone is a major wrench fault and that it possibly is of special significance in the tectonic framework of northeastern Oregon and western Idaho. Southwest of Oxbow, overlying Columbia River Basalt conceals the shear zone. The northeast extension is unknown but W.H. White (doctoral candidate, Oregon State University) presently is studying the shear zone northeast of Cuprum. The shear zone may have an exposed length of more than 30 miles.

GEOMORPHOLOGY

Introduction

Most geomorphic features in the thesis area were formed by running water, glaciers, and mass wasting. Faults were a major controlling factor in the development of present drainage patterns.

Geomorphic features warrant dividing the thesis area into a plateau region and a canyon region. The plateau region has less relief and a drainage pattern that apparently is unrelated to structural trends. The canyon region has greater relief and a drainage pattern more closely related to structural trends. River terraces and landslides are notable geomorphic features in the canyon region.

Plateau Region

Glacial Features

Glacial features in the plateau region include U-shaped valleys, lake basins, rôches mountonnées, rock striae, and moraines.

Good examples of glacial valleys are those of the Imnaha River, Lake Fork Creek, and Duck Creek (Figure 55). Morainal material extends down the valleys to elevations of less than 4,000 feet along the Imnaha River, about

Figure 55. Duck Creek canyon, a typical U-shaped valley gouged in Permian and Triassic rocks.

4,000 feet along Duck Creek, and about 4,900 feet along Lake Fork Creek.

Duck Lake, Fish Lake, and Horse Lake occupy basins formed by glacial gouging or by morainal blocking of stream valleys. Duck Lake was formed by glacial gouging. Fish Lake, the largest lake in the plateau region, was formed by glacial gouging and morainal damming. Horse Lake fills a small basin that formed behind a lateral moraine.

The best examples of rôches moutonnées are along the south side of Duck Creek, on both sides of the Imnaha River, and around Duck Lake. Striae and glacial grooves are conspicuous. Excellent glacial grooves occur at an elevation of 5,700 feet on the most prominent rôche moutonnée on the south side of the Imnaha River.

Non-Glacial Features

The present drainage pattern in the plateau region probably evolved from a radial drainage system that formed during late Tertiary uplift of the Wallowa Mountains. Later, some streams courses adjusted to structure. Some stream valleys are remarkably straight; the Imnaha River flows east from the Wallowa Mountains along a straight course before abruptly changing to a northeast trend. The course of Duck Creek is partly controlled by a northwest-trending fault (Plate 3).

Remnants of stream terraces occur along Lake Fork Creek, Duck Creek, and the Imnaha River. Rôches moutonnées rise above the terraces.

Canyon Region

General Features

The most striking feature in the canyon region is the deep Snake River canyon, divisible into two parts in the map area. North from Big Bar, the Snake River enters a narrow gorge which is from 6 to 8 miles wide and nearly a mile deep. South of Big Bar, the canyon is wider and has less relief.

The canyon region is at a youthful stage in the fluvial erosion cycle. The principal characteristics are (1) V-shaped river and stream canyons, (2) extension of tributary streams by headward erosion, (3) absence of flood-plains, (4) steep-sided valleys, (5) waterfalls where tributary streams cross resistant strata, (6) narrow and sharp stream divides, and (7) rapids in the Snake River where the channel is confined by alluvial fans. Table 21 gives gradients of the major perennial streams in the canyon region.

The topography of the Snake River canyon changes at Big Bar, Idaho, where the canyon floor is cut in limestone of the Martin Bridge Formation. Big Bar is over

Table 21. Gradients of the Major Perennial Streams in the Canyon Region.

Stream Name	Location Measured	Horizontal Distance (miles)	Gradient
Snake River below the Oxbow	Oxbow, Oregon to Squaw Creek	17.5	0.0017
McGraw Creek	Between 2,800 ft. and 1,680 ft. elevations	2.5	0.085
Kinney Creek	Between 6,800 ft. and 1,600 ft. elevations	5.6	0.176
Copper Creek	Between 3,680 ft. and 1,680 ft. elevations	2.0	0.190
Squaw Creek	Between 4,000 ft. and 1,600 ft. elevations	1.4	0.325
Indian Creek	The Oxbow to the bend near the Kleinschmidt Grade	7.6	0.050

two miles long, has a maximum width of half a mile and covers more than 300 acres. Big Bar is not a river bar but consists of landslide debris, terrace gravels and alluvial fan deposits (Figure 56). A high ridge, along the west side, rises nearly 200 feet above the river and is underlain by landslide debris. A count of 200 blocks on this ridge showed that over 90 percent are volcaniclastic rocks of the Doyle Creek Formation and less than 10 percent are limestones from the Martin Bridge Formation. Some blocks measure over 10 feet in diameter and most are very angular, showing that they were not transported by

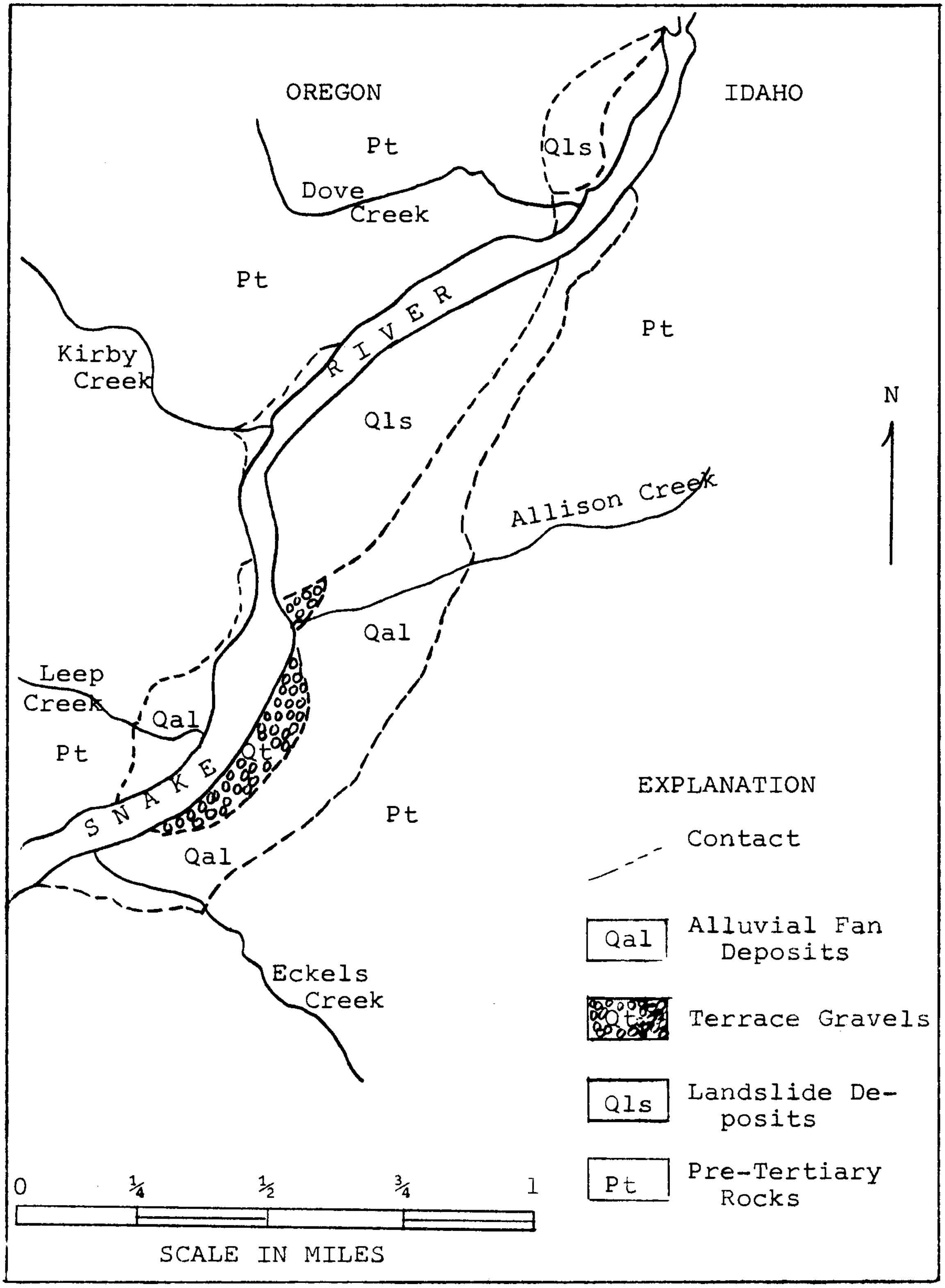

Figure 56. Geologic sketch map of Big Bar, Idaho.

streams. The blocks probably came from a landslide scar which is north of the mouth of Kirby Creek.

Other landslides created irregular landforms in the Snake River canyon. The most prominent is in Oregon opposite the mouth of Limepoint Creek; another is north of the mouth of Dove Creek (Plate 3).

River terraces are exposed along the Snake River near Bob Creek, Copper Creek, and Eckels Creek. Remnants of the highest terrace in the Snake River canyon occur along the north side of Bob Creek at an elevation of about 1,850 feet.

Pre-Miocene Erosion Surface

An extensive erosion surface formed during Late Cretaceous and early Cenozoic time, after intrusion of the Wallowa batholith (Nolf, 1966, p. 8). Good exposures occur in the canyon region on the erosion-truncated Martin Bridge Formation between McGraw and Spring creeks, T. 5 S., R. 49 E. Lapies on the surface form sharp ridges. Caves and sinkholes indicate extensive solution of limestone. Pot holes up to four feet deep, and rounded quartzite boulders and cobbles scattered over the surface indicate fluvial erosion and transport and suggest the former existence of a stream channel or pediment surface. Nolf (1966) and Stearns (1954) described a similar surface. The source of the quartzite boulders is unknown, but diameters as large as 16 inches suggest that the fluvial agent had high competency.

The Geomorphic History of the Snake River

Introduction

Disagreement concerning the geomorphic history of the Snake River exists because (1) much evidence is concealed by Tertiary volcanics, (2) differential uplift along late Tertiary faults makes elevations of streams, wind gaps, and old lake shorelines difficult or impossible to correlate, and (3) catastrophic flooding and lake spillovers as well as normal downcutting by runoff during the melting of glaciers, probably contributed to the erosion of the canyon.

Careful field studies throughout a large area are needed to resolve some problems. Such studies were beyond the scope of this investigation.

Summary of Preceding Studies

Early speculations concerning the origin of the Snake River include those of Lindgren (1898), Livingston and Laney (1920), and Livingston (1928).

Studies by Wheeler and Cook (1954) culminated in the following conclusions: (1) the former course of the Snake River extended to the Pacific Ocean via southeastern

Oregon, northwestern Nevada, and northern California; (2) the late Pliocene and/or early Pleistocene Idaho Lake was created by deformational (and perhaps volcanic) damming of the former course; (3) there was a capture or spillover at the Oxbow, where Idaho Lake drained into a northward flowing tributary of the Salmon River, thus creating the present course of the Snake River; (4) the capture probably occurred during early Pleistocene time; and (5) the Snake River course in northeastern Oregon that was postulated by Livingston did not exist.

Observations in the Map Area

Detailed investigations of conclusions of Wheeler and Cook (1954) were impossible during this study. However, some of their conclusions were based on evidence from specific localities in or near the map area. Different interpretations are possible for relationships at some localities.

Wheeler and Cook (op.cit., p. 532) concluded that three of the streams upstream from the Oxbow are barbed. They stated: "...the barbed tributary pattern above the Oxbow is strong indication of drainage reversal, especially in view of the fact that no barbed tributaries exist downstream in analagous structural situations." However, Indian Creek is a structurally controlled stream and may not be barbed because of drainage reversal. The channel of Indian Creek parallels faulting and foliation and is cut in pre-Tertiary rocks that were sheared, folded, and faulted along the northeast-trending Oxbow-Cuprum shear zone. "Analagous structural situations" such as the one in the Oxbow-Indian Creek area do not occur downstream from the Oxbow for at least 30 miles. Wildhorse Creek and Salt Creek were not studied and may be barbed tributaries as Wheeler and Cook suggest.

Wheeler and Cook (1954, p. 532) speculated that the initial capture of the Snake River, by a tributary of the Salmon River, probably took place near the mouth of McGraw Creek. They noted a significant change in gradient at that point. The river flows on resistant flow rocks and coarse volcaniclastic rocks of the Doyle Creek Formation above McGraw Creek. However, below McGraw Creek, the river flows on the more easily eroded sandstone and tuff of the Grassy Ridge Formation and on the limestone of the Martin Bridge Formation. Changes of gradient generally occur in a young river where the channel crosses boundaries between different lithologies.

Wheeler and Cook (1954, p. 529) stated that the Snake River canyon is cut in Columbia River Basalt upstream from the Oxbow whereas the canyon is cut in Permian and Triassic rocks below the Oxbow. The Snake River upstream from the Oxbow does flow mostly on Tertiary lavas for more than 25 miles. However, pre-Tertiary rocks are exposed and are incised by the Snake River for several miles north of Huntington, Oregon.

Wheeler and Cook suggested that the ancestral Snake River followed a southwesterly route from western Idaho, through southeastern Oregon via the lower Owyhee River and Crooked Creek, across northwestern Nevada to Chilcoot Pass, and then down Feather River to the Pacific Ocean. No former course of the Snake River along this proposed route is recognized in southeastern Oregon (Baldwin, 1960, p. 137). Taylor (1960) described a distribution pattern of fossil and living mollusks, especially *Pisidium ultramontanum*, and certain fossil and living fish, and concluded that there were former river and lake connections between southern Idaho and northeastern California. Therefore, an undetected channel may occur.

Former elevations of the Tertiary erosion surface and former shoreline levels of Lake Idaho (Wheeler and Cook, 1954, p. 529) should not be used as evidence for a spillover unless the entire area was stable or unless the relative amounts of movements throughout the area are known.

Origin of the Oxbow

The Oxbow of the Snake River is a conspicuous physiographic feature that is characterized by abrupt bends and straight segments (Figure 57).

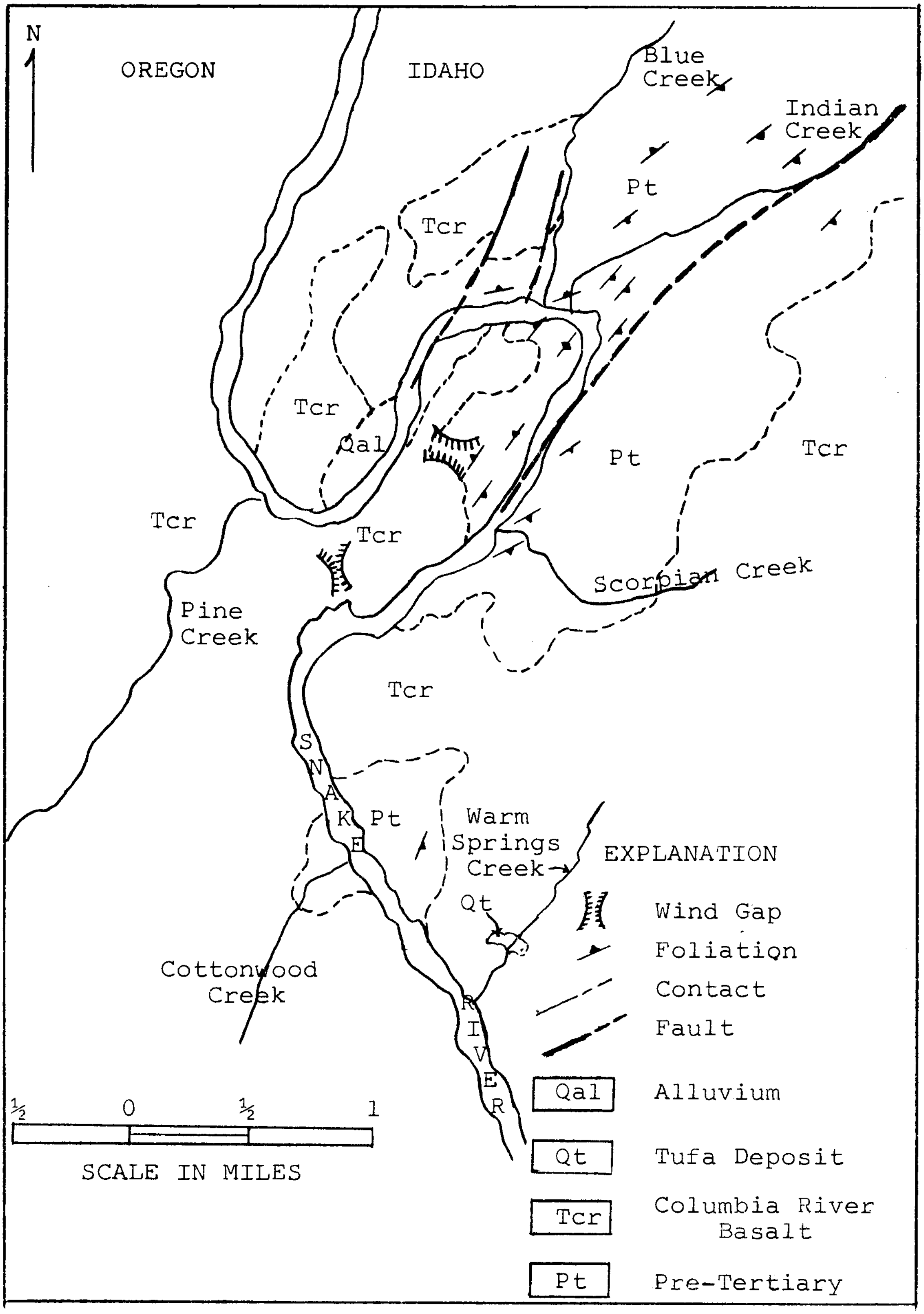

Figure 57. Geologic sketch map of the Oxbow.

The present investigation confirms Wheeler and Cook's (1954, p. 529) conclusion that, "... the straightline segmentation of...the strange configuration is due to control by a set of pre-Columbia Basalt faults...". The fault trends and foliations in the pre-Tertiary rocks within the Oxbow Shear Zone range from N. 30° E. to N. 80° E. and seemingly control the Snake River course in the Oxbow area. Two wind gaps cross the ridge between the southeast and northwest legs of the Oxbow. The Oxbow probably was carved when the river was superposed from the overlying Columbia River Basalt onto the pre-Tertiary rocks, but the precise sequence of events is not clear.

Conclusions

No conclusive evidence was found to refute Wheeler and Cook's hypothesis of a spillover or a capture of the Snake River. More data are needed before the geomorphic development of the Snake River is evident. Proof of a pre-Pleistocene river course through Nevada and California would make the capture hypothesis more creditable. Detailed stratigraphic studies of the Idaho Formation and better regional knowledge of tectonic movements would facilitate an appraisal of the hypothesis.

ECONOMIC GEOLOGY

Introduction

An active search for copper and precious metals in the Snake River canyon characterized the early part of the century. General optimism of local residents suggests that the search has not ended. The canyon region is pockmarked with tunnels, prospects, and ore dumps, whereas the plateau region shows little evidence of mining ventures. The mineral resources of former value in the map area were copper, gold, and silver. Most mining ventures were unprofitable.

Exploration and drilling were in progress at the Red Ledge Mine, about six miles north of the map area, during the summers of 1963 and 1964, and at the Peacock Mines, about one mile east of the map area, during the summer of 1965.

Lindgren (1901, p. 747-752) described some early mining activity in the Snake River canyon. Swartley (1914, p. 99-116) and Parks and Swartley (1916) described the deposits in more detail. Livingston and Laney (1920, p. 39-40) presented short descriptions of three Idaho mines. A compilation of reports concerning the Oregon deposits was published in the Oregon Metal Mines Handbook (1939, p. 57-64). Cook (1954, p. 13-15) described some Idaho deposits. Since 1954, no significant publications have discussed the deposits in the map area.

Copper Deposits of the Snake River Canyon

Most copper deposits in the canyon region are along shear zones and other fractures. Some disseminated ore occurs at the Irondyke Mine, but this mineralization is closely associated with the massive lode deposits and fissure veins of the adjacent shear zones. The copper deposits are of hydrothermal origin and probably formed during or after the last major intrusions in the Wallowa and Seven Devils mountains.

Information on copper mines and prospects is available in the cited literature. The common ore minerals are chalcocite, bornite, chalcopyrite, and their alteration products. Pyrite commonly is a closely associated gangue mineral. Small amounts of gold and silver occur with the copper minerals.

As surface outcrops are discontinuous and tunnels have caved, a detailed investigation was beyond the scope of this report.

Gold Placer Deposits

Gold placer claims were staked along the Snake River during the last quarter of the nineteenth century. Mining was intermittent; the last serious activity was in the 1930's. According to Lindgren (1901, p. 759-761), the gold is extremely fine and floury, and occurs in thin and nonpersistant streaks. Placer mining was not extensive or very profitable.

GEOLOGIC HISTORY

The great thickness of the pre-Tertiary stratigraphic column and the character of the rocks indicate that deposition occurred in a eugeosynclinal environment. Rock distributions suggest that the trough or basin was elongate in a roughly north-south direction and that landmasses persisted to the west-southwest during Permian and Middle Triassic and to the east-northeast during Middle and Late Triassic times. Archipelagos and individual islands or seamounts probably formed within or near the main trough and volcanic materials were ejected subaerially and submarine. Autocannibalism, whereby much of the material was derived from a redistribution of rocks within the trough, was probably a common process.

Table 22 records the geologic history of the mapped area. The earliest recognizable events were the volcanic eruptions of flows and pyroclastics of the Permian (?) Windy Ridge Formation. Andesitic and dacitic materials erupted from submarine (?) vents and collected in a basin or trough. Nearby land masses probably were absent as no epiclastic rocks occur. The unconformably (?) overlying Hunsaker Creek Formation was deposited during Leonardian and Wordian (Middle Permian) time. Characteristics of the Hunsaker Creek Formation indicate relatively uninterrupted deposition of volcaniclastics and minor volcanic flows,

Table 22. Geologic History of the Mapped Area.

Period or Part of Period	Stratigraphic Units	Sedimentation	Volcanism	Plutonism	Tectonism
Pleistocene and Recent	Alluvium (Qal), glacial drift (Qgm), landslide deposits (Qls)	Valley fills, glacial drift, alluvial fans, landslide deposits, river terraces	No record	No record	Uplift and erosion
Early Pliocene-late Miocene	Columbia River Basalt (Tcr)	Local tuffaceous deposits, probably lacustrine	Quiet effusion of flood basalt from fissures	No record	Gentle subsidence and erosion
Miocene-Early Cretaceous		No record	No record	No record	Uplift and erosion
Late and Middle Jurassic		No record	No record	Intrusions of Upper Jurassic (?) gabbro, norite, quartz diorite, and granodiorite porphyry (Flc), (Dlg), (Dcc), (Ecg)	Orogeny, strong folding and faulting; regional metamorphism

Table 22. (Continued)

Period or Part of Period	Stratigraphic Units	Sedimentation	Volcanism	Plutonism	Tectonism
Early (?) Jurassic and Late Triassic (Rhaetian)		No record	No record	Hypabyssal intrusions of quartz diorite, diorite, dacite and andesite porphyry	Gentle uplift and erosion, minor warping (?)
Late Triassic (Norian and late Karnian)	Martin Bridge Formation (Ŧmb)	Limestone deposition in reef and shallow platform environments	No record	No record	Gentle subsidence of a volcanic platform
Late Triassic (Karnian)	Doyle Creek Formation and Imnaha Formation (Ŧdc) and (Ŧir)	Marine deposition of volcaniclastic materials with minor limestone	Flows and pyroclastic eruptions of basaltic and andesitic material, partly submarine	No record	Rapid subsidence; deep tectonic basin; local seamounts and volcanic landmasses; contemporaneous uplift-erosion and subsidence-deposition
Middle Triassic (Ladinian)	Grassy Ridge Formation (Ŧgr)	Marine deposition of volcaniclastic materials, minor limestone	Pyroclastic and flow eruptions of basaltic material, partly submarine	No record	Strong subsidence of local basin; uplift and erosion to west and northeast (?)

Table 22. (Continued)

Period or Part of Period	Stratigraphic Units	Sedimentation	Volcanism	Plutonism	Tectonism
Middle Triassic-late Permian		No record	No record	Oxbow Complex; gabbro, diorite, albite granite (TRod) and (TRog)	Permian-Triassic Orogeny; faulting and warping, uplift and erosion
Permian (Wordian and Leonardian)	Kleinschmidt Volcanics and Hunsaker Creek Formation (Pkv) and (Phc)	Marine deposition of volcaniclastic materials, minor limestone	Pyroclastic and flow eruptions of dacitic, andesitic and basaltic materials, partly submarine	Holbrook-Irondyke intrusives of gabbro, andesite and dacite porphyry, and diabase (Phi)	Local tectonic basin; strong (orogenic) uplift and erosion of landmasses to the southwest and northeast (?)
Permian (?)	Windy Ridge Formation (Pwr)	Marine (?) deposition of pyroclastic materials	Pyroclastic and flow eruptions of andesite and dacite, probably all submarine	No record	Subsidence of local basin, followed by uplift (?) and erosion (?)

with episodic influxes of conglomerates. Tectonic activity raised highlands to the west-southwest and possibly to the northeast, which contributed volcanic materials. Submarine eruptions also occurred. Local volcanic highs, probably seamounts, formed within the trough. Basaltic flows (Kleinschmidt Volcanics) interfingered with volcaniclastic deposits of the Hunsaker Creek Formation. Contemporaneous hypabyssal intrusives, the Holbrook-Irondyke intrusives, formed dikes, sills, and small stocks of gabbro, diabase, and andesite-dacite porphyry. Some of the small intrusives probably were feeders for surface eruptions.

A strong orogeny (Permian-Triassic orogeny) deformed the Permian and older (?) rocks between Wordian (middle Permian) and Ladinian (Middle Triassic) time. Intrusions of gabbro, diorite, quartz diorite, and albite granite (Oxbow Complex) were emplaced. Tectonism and erosion probably accompanied the plutonism.

Volcaniclastic and basaltic flow rocks of the Grassy Ridge Formation accumulated during subsidence of a basin or trough in Ladinian time. Interlayered volcanic conglomerates were derived from northeast and southwest (?) landmasses. Pelecypod limestone beds accumulated during quiet periods between volcanic paroxysms. In Karnian (Late Triassic) time, rapid growth of seamounts and islands (archipelago ?) formed thick, local accumulations of volcanic flow and minor volcaniclastic rocks in the western part of the map area (Imnaha Formation). Simultaneously, basin fragmentation and subsidence caused thick piles of volcanic materials (Doyle Creek Formation) to accumulate in the eastern part of the area. The Doyle Creek Formation transgressively covered rocks of the Imnaha Formation. Thick conglomerates (Ashby Creek Conglomerate) within the Doyle Creek Formation indicate erosion of a nearby landmass during parts of the Karnian epoch.

Volcanic quiescence and slow subsidence of a volcanic platform during late Karnian and early Norian times allowed limestone reef and platform (?) facies to form (Martin Bridge Formation).

Dikes and sills of diorite, quartz diorite, and andesite-dacite porphyry were emplaced in the Early (?) Jurassic. A major orogeny (Nevadan) occurred during Middle and Late Jurassic time and was characterized by strong folding and faulting. Greenschist facies regional metamorphism apparently was contemporaneous in part with the orogeny. Upper (?) Jurassic intrusives of gabbro, norite, and quartz diorite probably were emplaced during the late stages of regional metamorphism. Granodiorite porphyry probably was emplaced after regional metamorphism.

Between Late Jurassic and middle Miocene time, no sedimentation, volcanism, or plutonism is recorded in the map area. Apparently, the area was tectonically active at times; a pediment (?) surface formed between Late Cretaceous and Miocene time.

In late Miocene and early Pliocene, fissure eruptions of Columbia River Basalt spread over the area. Pliocene-Pleistocene uplift, alpine glaciation, and intensive stream erosion are responsible for the present topography. Alluvial fans, river terraces, and landslides formed along the Snake River during Recent time.

missing map noted

[illegible]

Plate is attached as a seperate file.

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APPENDICES

Appendix A

Table 23. Type Section, Hunsaker Creek Formation; Measured by Jacob's Staff Along the North Side of Hunsaker Creek, Oregon. Top and Bottom of the Formation are not Exposed.

Unit	Description	Thickness(feet)	
		Unit	Total
Unit 36.	Spilite: greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); fine-grained; amygdaloidal; flows 10-15 feet thick cut by diabase dikes; forms rugged outcrops	88	2367
Unit 35.	Volcanic Siltstone (Tuff ?): dusky yellowish-green (10 GY 3/2), weathers moderate yellowish-brown (10 YR 5/4); poorly sorted, angular grains; pebbly; silicified, recrystallized matrix; graded in beds 1-2 feet thick	42	2279
Unit 34.	Volcanic Sandstone and Volcanic Siltstone: pale-red (10 R 6/2), weather pale yellowish-brown (10 YR 6/2); graded beds 1-5 feet thick; poorly sorted; angular fragments; probably tuffaceous	19	2237
Unit 33.	Volcanic Siltstone (Tuff ?): grayish-olive (10 Y 4/2), weathers pale yellowish-brown (10 YR 6/2); thin-bedded; some grading; poorly sorted; pebbly	138	2218
	Fault: Break in Section.		
Unit 32.	Volcanic Siltstone (Tuff ?): grayish-olive (10 Y 4/2), weathers moderate yellowish-brown (10 YR 5/4); some grading; pebbly; poorly sorted	8	2080
Unit 31.	Conglomerate: dark greenish-gray (5 GY 4/1); pebble to cobble size with 3-6 foot blocks; poorly sorted; spilite and keratophyre clasts;		

Table 23. (Continued)

Unit	Description	Thickness (feet) Unit	Thickness (feet) Total
	weak grading; beds 20-30 feet thick; thin volcanic siltstone near top of thick beds	132	2072
Unit 30.	Volcanic Sandstone (Tuff ?): grayish-green (10 GY 5/2), weathers pale yellowish-brown (10 YR 6/2); grades to siltstone in 5-10 foot thick beds; moderate to poor sorting; crystal-rich, mostly feldspar; scattered pebbles up to 2 cm in diameter; faint cross-bedding in some beds	106	1940
Unit 29.	Volcanic Siltstone: grayish-olive (10 Y 4/2), weathers light olive-brown (5 Y 5/6); fine-grained; silicified and recrystallized; sandy in some thin beds	20	1834
Unit 28.	Volcanic Sandstone (Tuff ?): grayish-green (10 GY 5/2), weathers pale yellowish-brown (10 YR 6/2); graded beds 2-5 feet thick; medium to coarse-grained; some beds well-sorted; faint cross-bedding; angular to subangular grains	54	1814
Unit 27.	Conglomerate: grayish-olive (10 Y 4/2); cobble to pebble sizes; clasts subrounded; clasts up to 40 cm	33	1760
Unit 26.	Volcanic Sandstone: grayish-olive (10 Y 4/2), weathers light olive-brown (5 Y 5/6); poorly sorted; graded; angular fragments measure 1-2 mm; feldspar-rich; probably tuffaceous; cliff-former	42	1727
Unit 25.	Spilite: dusky yellow-green (10 GY 3/2), weathers moderate yellowish-brown (10 YR 5/4); fine-grained; amygdaloidal; may be a sill or dike; discontinuous outcrop	9	1686

Table 23. (Continued)

Unit	Description	Thickness(feet)	
		Unit	Total
Unit 24.	Volcanic Sandstone (Tuff ?): dusky yellow-green (5 GY 5/2); weathers moderate yellowish-brown; graded beds 1-3 feet thick; poorly sorted; angular grains	11	1676
Unit 23.	Volcanic Sandstone: pale-green (10 G 6/2), weathers moderate yellowish-brown (10 YR 5/4); fine-grained; poorly sorted; graded beds; pebbly; silicified matrix; diabase dikes cut unit	44	1665
Unit 22.	Volcanic Sandstone: brownish-gray; poorly sorted; graded to siltstone in beds 1-4 feet thick; abundant spilitic rock fragments	22	1621
Unit 21.	Volcanic Siltstone, Volcanic Breccia, and Conglomerate: grayish-green (5 G 5/2), weather pale yellowish-brown (10 YR 6/2); some sandstone; graded beds; tuffaceous; beds 2-6 feet thick; cut by diabase dikes	132	1599
Unit 20.	Conglomerate, Volcanic Breccia, and Volcanic Sandstone: pale-green (10 G 5/2), weather pale yellowish-brown (10 YR 6/2); some grading; bedding poorly defined; in part pebbly mudstone; cut by 6 foot diabase dike near top	83	1467
Unit 19.	Spilitic Tuff Breccia: greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); poorly sorted; interfingering spilite flows; matrix-rich; deeply-weathered; rounded outcrops	52	1384
Unit 18.	Volcanic Sandstone (Tuff ?): pale-green (5 G 7/2), weathers pale yellowish-brown (10 YR 6/2); weak grading; crystal-rich near top; poorly sorted; interbedded with volcanic		

Table 23. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
	siltstone (fine tuff ?)	30	1332
Unit 17.	Spilite: dusky yellow-green (10 GY 3/2), weathers moderate-brown (5 YR 4/4); porphyritic; deeply weathered; may be intrusive	22	1302
Unit 16.	Volcanic Breccia (Pyroclastic ?): pale-green (5 G 7/2), weathers pale yellowish-brown (10 YR 6/2); poorly sorted; angular fragments measure 0.5-5.0 cm; silicified matrix; clasts keratophyric	51	1280
Unit 15.	Volcanic Siltstone (Tuff ?): pale-green (5 G 7/2), weathers pale yellowish-brown (10 YR 6/2); silicified	12	1229
Unit 14.	Volcanic Breccia (Pyroclastic ?): Same as Unit 16	21	1217
Unit 13.	Volcanic Breccia and Volcanic Sandstone: greenish-gray (5 G 6/1), weather pale yellowish-brown (10 YR 6/2); graded beds 15-25 feet thick; poorly sorted; angular fragments; feldspar-rich; largest clasts over 5 cm in diameter; weathers to rounded shoulders; tuffaceous	70	1196
Unit 12.	Spilite: greenish-black (5 G 2/1), weathers moderate-brown (5 YR 4/4); fine grained; may be a sill	13	1126
Unit 11.	Volcanic Breccia and Volcanic Sandstone (Tuff ?): grayish-green (10 GY 5/2), weather pale yellowish-brown (10 YR 6/2); graded beds 5-15 feet thick; poorly sorted; angular fragments, rock fragments and feldspar crystals dominant components; matrices recrystallized	110	1113
Unit 10.	Volcanic Sandstone (Tuff ?):		

Table 23. (Continued)

Unit	Description	Thickness(feet)	
		Unit	Total
	grayish-green (10 G 6/2), weathers pale yellowish-brown (10 YR 6/2); some grading; poorly sorted; angular fragments up to 2 cm in diameter; recrystallized matrix; beds grade to coarse-grained siltstone.........	43	1003
Unit 9.	Volcanic Siltstone: grayish-green (10 G 4/2), weathers pale yellowish-brown (10 YR 6/2); very fine grading	25	960
Unit 8.	Volcanic Breccia (Pyroclastic ?): grayish-olive (10 Y 4/2), weathers pale yellowish-brown (10 YR 6/2); graded to coarse sandstone in beds 7-10 feet thick; clasts in breccia up to 6 cm, measure 1-2 cm in diameter; poorly sorted.......................	34	935
	Fault: Break in Section.		
Unit 7.	Spilite: greenish-black (5 G 2/1), weathers moderate-brown (10 YR 4/2); porphyritic; amygdaloidal; may be intrusive............................	7	901
Unit 6.	Volcanic Breccia, Volcanic Sandstone, and Volcanic Siltstone (Pyroclastic ?): grayish-green (5 G 5/2), weather pale yellowish-brown (10 YR 6/2); graded beds 1-6 feet thick....	42	894
Unit 5.	Diabase Dike or Sill: greenish-black (5 GY 2/1), weathers moderate-brown (10 YR 4/2); fine-grained; amygdaloidal........................	-	-
Unit 4.	Volcanic Sandstone (Tuff ?): grayish-green (10 G 4/2), weathers pale yellowish-brown (10 YR 6/2); poorly sorted; coarse-grained; graded in beds 2-6 feet thick; abundant rock fragments.................	35	852
Unit 3.	Volcanic Sandstone (Tuff ?),		

Table 23. (Continued)

Unit	Description	Thickness(feet) Unit	Total
	Volcanic Breccia, and Keratophyric Flows: grayish-green (10 GY 5/2) and (5 G 5/2), weather pale yellowish-brown; graded sequence of volcanic breccia to sandstone (tuff ?); poorly sorted; recrystallized and silicified matrices; graded beds 5-50 feet thick; interbedded keratophyric flows of same composition as the volcaniclastic rocks; faulted near base so some beds may be repeated...........	530	817
Unit 2.	Quartz Keratophyre: yellowish-brown (10 YR 5/4), weathers grayish-orange (10 YR 7/4); porphyritic; phenocrysts of quartz and feldspar; may be intrusive....................	219	287
Unit 1.	Conglomerate: grayish-green (10 GY 5/2); weathers pale yellowish-brown; poorly sorted; clasts 0.5-6.0 cm in diameter; well-rounded; graded beds to volcanic siltstone; clast count shows 59 percent keratophyre, 7 percent spilite, and the remainder volcaniclastic rocks......	68	68
	Total Thickness		2367
	Base of section is not the base of the formation.		

Table 24. Reference Section, Hunsaker Creek Formation; Measured Along North Side of Ballard Creek Beginning at an Elevation of About 2,050 Feet. Top and Bottom of the Formation are not Exposed. Stratigraphic Studies Aided by 30 Thin Sections.

Unit	Description	Thickness(feet)	
		Unit	Total
Unit 48.	Volcanic Siltstone (Tuff ?): grayish-green (5 G 5/2), weathers pale yellowish-brown (10 YR 6/2); graded in beds 1-3 feet thick, from fine-grained sand to fine-grained silt sizes; poorly sorted; silicified	13	1898
Unit 47.	Volcanic Breccia and Volcanic Sandstone: pale-green (10 G 6/2), weather pale yellowish-brown (10 YR 6/2); graded from breccia to sandstone; poorly sorted; rock fragments are mostly chloritized mudstone (?) clasts; beds 1-10 feet thick; cut by narrow diabase dikes	38	1885
Unit 46.	Volcanic Sandstone (Tuff ?): dusky yellow-green (10 GY 3/2), weathers pale yellowish-brown (10 YR 6/2); graded beds 4-10 feet thick; last 10 feet volcanic siltstone; poorly sorted; medium to fine-grained; pebbly at some horizons; cut by diabase dikes	57	1847
Unit 45.	Volcanic Breccia and Volcanic Sandstone (Tuff ?): see Unit 47	28	1790
Unit 44.	Volcanic Siltstone (Silicified Tuff ?): pale-green (10 G 6/2), weathers light-brown (5 YR 6/4); sandy; fine grading; cut by diabase dikes	27	1762
Unit 43.	Volcanic Breccia and Volcanic Sandstone (Tuff ?): grayish-green (5 G 5/2), weather pale yellowish-brown (10 YR 6/2); graded beds 1-15 feet thick; poorly sorted; cut by several narrow dikes	108	1735

Table 24. (Continued)

Unit	Description	Thickness(feet) Unit	Total
Unit 42.	Spilite: greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); porphyritic; may be a sill	6	1627
Unit 41.	Volcanic Breccia (Tuff Breccia ?): pale-green (10 G 6/2), weathers light-brown (5 YR 6/4); poorly sorted; slight grading; matrix-rich; volcaniclastic rock fragments predominate	18	1621
Unit 40.	Volcanic Siltstone, Volcanic Sandstone, and Volcanic Breccia: dark greenish-gray (5 GY 4/1); graded beds 2-12 feet thick; spilitic breccia 35 feet above base; poorly sorted	60	1603
Unit 39.	Keratophyre: grayish-olive (10 Y 4/2), weathers pale yellowish-brown (10 YR 6/2); porphyritic; cliff-former; may be a sill	52	1543
Unit 38.	Volcanic Sandstone (Tuff ?): grayish-green (5 G 5/2), weathers pale-brown (5 YR 6/4); graded beds 1-3 feet thick; poorly sorted; angular fragments	41	1491
Unit 37.	Volcanic Breccia (Tuff Breccia ?): greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); spilitic; grades to sandstone (coarse tuff ?) in beds 3-8 feet thick; poorly sorted; calcareous; chlorite-rich; weathers to form grassy slopes	78	1450
Unit 36.	Spilite: greenish-black (5 GY 2/1); porphyritic; may be a diabase sill	7	1372
Unit 35.	Volcanic Sandstone and Volcanic Siltstone (Tuff ?): grayish-green (5 G 5/2), weather pale-brown (5 YR 6/4); graded; poorly sorted	10	1365

Table 24. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 34.	Spilite Tuff: greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); graded; weathers to form grassy slopes...............	16	1355
Unit 33.	Volcanic Sandstone (Coarse-Grained Tuff ?): pale-green (10 G 6/2), weathers light-brown (5 YR 6/4); graded to fine sandstone; crystal-rich................................	36	1339
Unit 32.	Volcanic Sandstone and Volcanic Siltstone: mixed pale-green and dusky-red; graded; poorly sorted; beds 0.5-1.0 foot thick......................	15	1303
Unit 31.	Volcanic Breccia (Tuff ?): grayish-green (5 G 5/2), weathers pale-brown (5 YR 6/4); graded; poorly sorted..............................	14	1288
Unit 30.	Volcanic Sandstone: grayish-green (5 G 5/2), weathers pale yellowish-brown (10 YR 6/2); graded; coarse to medium-grained; poorly sorted; some rounded grains......................	39	1274
Unit 29.	Volcanic Sandstone: dusky-red (5 R 3/4), weathers light-brown (5 YR 5/6); medium-grained; poorly sorted..............................	4	1235
Unit 28.	Spilite Tuff: greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); fine-grained; bedding 0.5-3.0 feet; graded........	10	1231
Unit 27.	Volcanic Breccia and Volcanic Sandstone (Tuff ?): grayish-green (5 G 5/2), weather light-brown (5 YR 5/6); graded beds 1-6 feet thick; angular clasts; poorly sorted.......	37	1221
Unit 26.	Volcanic Siltstone (Tuff ?): grayish-green (5 G 5/2), weathers		

Table 24. (Continued)

Unit	Description	Thickness(feet)	
		Unit	Total
	light-brown (5 YR 5/6); poorly sorted; sandy; fine grading in beds 0.4-1.0 foot thick..................	10	1184
Unit 25.	Volcanic Sandstone, Volcanic Siltstone, and Volcanic Breccia: pale-green (10 G 6/2), weather light-brown (5 YR 5/6); graded beds 3-8 feet; poorly sorted; tuffaceous; banded on weathered outcrops, cut by diabase dikes................................	73	1174
Unit 24.	Volcanic Siltstone: very dusky-red (10 R 2/2), weathers dark yellowish-brown (10 YR 4/2); fine-grained; 0.5-1.0 foot beds; faint grading....	11	1101
Unit 23.	Volcanic Sandstone and Volcanic Siltstone (Tuff ?): pale-green (10 G 6/2), weather pale brown; graded in beds 1-10 feet thick; poorly sorted; angular fragments; fine-grained beds are thickly laminated; cliff-former.	40	1090
Unit 22.	Spilite: greenish-black (5 GY 2/1); weathers dark yellowish-brown; porphyritic; diabase sill (?).......	4	1050
Unit 21.	Volcanic Siltstone (Fine Tuff ?): pale-green (10 G 6/2); fine-grained.	8	1046
Unit 20.	Volcanic Siltstone and Volcanic Sandstone (Tuff ?): pale-green (10 G 4/2), weather light-brown (5 YR 6/4); graded beds 1-8 feet thick; poorly sorted; angular grains.......	51	1038
Unit 19.	Volcanic Sandstone and Volcanic Siltstone (Tuff ?): pale-green (10 G 4/2), weather light-brown (5 YR 6/4); graded beds 1 inch-1 foot thick; poorly sorted; penecontemporaneous deformation common in finer grained beds. Sandstone is dominant........	35	987

Table 24. (Continued)

Unit	Description	Thickness(feet) Unit	Total
Unit 18.	Spilite: blackish-green (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); vesicular; cliff-former; flows (?) 10-15 feet thick..........	42	952
Unit 17.	Quartz Keratophyre Flows and Keratophyric Tuff: grayish-green (10 GY 5/2), weather light-brown (5 YR 6/4); porphyritic flows 5-10 feet thick interlayered with tuff of same composition; tuff is graded and crystal rich............................	93	910
Unit 16.	Volcanic Siltstone (Tuff ?): greenish-gray (5 G 6/1), weathers light-brown (5 YR 6/4); pebbly; abundant matrix; weakly graded..........	6	817
Unit 15.	Volcanic Sandstone and Volcanic Siltstone (Tuff ?): pale-green (10 G 6/2), weather light-brown (5 YR 6/4); graded beds 2-12 feet thick; poorly sorted; angular fragments; banding common in fine-grained beds; siltstone is highly silicified..........	49	811
Unit 14.	Spilite Tuff (?) Breccia: brownish-black (5 YR 2/1), weathers dusky yellowish-brown (10 YR 2/2); clasts measure 0.5-1.0 cm, largest up to 5 cm; graded units 2-15 feet thick; cut by diabase dikes................	148	762
Unit 13.	Volcanic Sandstone, Volcanic Siltstone, and Volcanic Breccia: pale-green (10 G 6/2), weather light-brown (5 YR 6/4); graded beds 1-10 feet thick; tuffaceous (?); poorly sorted; matrix-rich; large (5 mm) quartz and feldspar crystals....................	160	614
Unit 12.	Spilite: greenish-black (5 G 2/1), weathers dark yellowish-brown (10 YR 6/2); porphyritic; amygdaloidal; probably diabase sill...............	20	454

Table 24. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 11.	Volcanic Siltstone, Volcanic Sandstone, and Volcanic Breccia: pale-green (5 G 7/2); graded beds 3-15 feet thick; siltstone dominant; angular to rounded grains; tuffaceous.......	165	434
Unit 10.	Volcanic Siltstone: grayish-purple (5 P 4/2), weathers dark yellowish-brown (10 YR 4/2); pebbly; poorly sorted........................	1	269
Unit 9.	Spilite Breccia (Tuff ?): greenish-black (5 G 2/1); poorly sorted; clasts measure 2-4 cm; weakly graded................................	69	268
Unit 8.	Spilite: greenish-black (5 G 2/1); porphyritic; probably a sill..	2	199
Unit 7.	Volcanic Sandstone and Volcanic Siltstone (Tuff ?): grayish-green (10 GY 5/2), weather light-brown (5 YR 6/4); graded beds 1-8 feet thick; poorly sorted; angular fragments; some breccia..............................	37	197
Unit 6.	Volcanic Siltstone (Tuff ?): grayish-green (10 GY 5/2); poorly sorted; pebbly; graded..............	4	160
Unit 5.	Spilite Tuff: dark greenish-gray (5 G 4/1); graded beds 0.5-8.0 feet thick; poorly sorted; feldspar microlites are scattered in a chloritic matrix...............................	44	156
Unit 4.	Volcanic Sandstone (Tuff ?): grayish-green (5 G 5/2) and moderate-red (5 R 5/4); graded beds 0.5-9.0 feet thick; poorly sorted; crystal-rich..	81	112
Unit 3.	Spilite (Diabase ?): dark greenish-gray (5 G 5/2); porphyritic; amygdaloidal; probably a sill.......	16	31

Table 24. (Continued)

Unit	Description	Thickness(feet) Unit	Total
Unit 2.	Volcanic Siltstone and Volcanic Sandstone (Tuff ?): grayish-green (5 G 5/2); graded; load casts.......	8	15
Unit 1.	Spilite Tuff: dark maroonish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); coarse-grained; poorly sorted; spilitic rock fragments and feldspar crystals.........	7	7
	Total Thickness		1898
	End of section near power line road.		

Appendix B

Fossil Localities

Localities where fossil material was collected or noted are listed by formation. Triassic fossils were identified by Dr. N.J. Silberling, U.S. Geological Survey, and Permian fossils tentatively were identified by Dr. Francis G. Stehli of Western Reserve University. Their comments are added where appropriate. All identifications are from preliminary examinations and should not be quoted without permission from N.J. Silberling or Francis G. Stehli, as applicable.

Two types of locality numbers are used in this report. All localities have a number of the type F1, F2, or F3. The numbers that appear in parentheses are the field designations.

The date of the collection is given near the end of the explanation. Initials N.J.S. for N.J. Silberling and F.G.S. for Francis G. Stehli identify the quoted explanations.

Hunsaker Creek Formation (Phc)

F1 (TF-1). NW¼NW¼ sec. 27, T. 6 S., R. 46 E. Elevation 6,460 feet, approximately 2,000 feet northwest of the Fish Lake road-Trinity Creek intersection.

"Large Neospiriferoid-Pennsylvanian or Permian."

June, 1963. F.G.S., 1965.

F2 (TF-2). SE¼SE¼ sec. 21, T. 6 S., R. 46 E. Elevation 6,460 feet, approximately 2,000 feet northwest of the Fish Lake road-Trinity Creek intersection.

"Large Neospiriferoid-Pennsylvanian or Permian."

June, 1963. F.G.S., 1965.

F3 (TF-3). S½NE¼NW¼ sec. 15, T. 6 S., R. 46 E. Elevation approximately 6,500 feet, along east side of major outcrop.

"Clams, no help stratigraphically."

June, 1963. F.G.S., 1965.

F4 (TF-4). W. center, NE¼NE¼ sec. 22, T. 6 S., R. 46 E. Elevation 6,640 feet, approximately 200 feet south of road.

"Large Neospiriferoid-Pennsylvanian or Permian *Megousia* may be in here."

June, 1963. F.G.S., 1965.

F5 (TF-5). NW¼NW¼NE¼ sec. 22, T. 6 S., R. 46 E. Elevation approximately 6,600 feet, 400 feet south of the Fish Lake road on south side of ridge.

"Nothing worthwhile."

June, 1963. F.G.S., 1965.

F6 (TF-6). SE¼SW¼NE¼ sec. 21, T. 6 S., R. 46 E. Elevation 6,960 feet, 100 feet S. 15° E. of the old U.S. Forest Service guard tower.

"Some kind of Rhynchonellid.
Large Neospiriferoid. ...represented by a large number of species in the Leonard and Word of the Glass and Guadalupe Mountains."

July, 1963. F.G.S., 1965.

F7 (TF-7). W. center, SW¼NW¼ sec. 28, T. 6 S., R. 46 E. Elevation 5,960 feet, 500 feet east of East Pine Creek.

"Clams, no identification."

July, 1963. F.G.S., 1965.

F8 (TF-8). SW¼NE¼ sec. 21, T. 6 S., R. 46 E. Elevation 7,050 feet, about 200 yards east of old U.S. Forest Service guard tower.

"Crinoid columnals-Stoney Bryozoans, no help."

July, 1963. F.G.S., 1965.

F9 (TF-9). SW¼SW¼NW¼ sec. 22, T. 6 S., R. 46 E. Elevation 6,845 feet, about 500 feet south of old

U.S. Forest Service guard tower road.
"Pelecypods-probably generically identifiable by an expert."
July, 1963. F.G.S., 1965.

F10 (TF-10). NE¼SE¼SW¼ sec. 15, T. 6 S., R. 46 E. Elevation 6,600 feet along upper irrigation canal, about 40 feet below Fish Lake road.
"No help."
July, 1963. F.G.S., 1965.

F11 (TF-11). SW¼NE¼ sec. 22, T. 6 S., R. 46 E. Elevation 6,460 feet, about 100 feet west of Fish Lake road and 500 feet south of Fish Creek.
"All clams."
July, 1963. F.G.S., 1965.

F12 (TF-12). S. center, SE¼SW¼ sec. 27, T. 6 S., R. 46 E. Elevation about 5,060 feet, 50 feet north of Trinity Creek-West Trinity Creek confluence.
"Probably _Megousia_, but cannot be sure."
July, 1963. F.G.S., 1965.

F13 (TF-13). SE¼NE¼ sec. 3, T. 7 S., R. 46 E. Elevation 3,900 feet, about 150 feet west of East Pine Creek.
"_Megousia_."
July, 1963. F.G.S., 1965.

F14 (TSF-1). SE¼NW¼ sec. 21, T. 6 S., R. 48 E. Elevation 2,400 feet, from talus on crest of first ridge north of Irondyke Creek.
"Probably an Orthotetaceid of some kind. Indeterminate productids - possibly _Megousia_, but can't be sure."
August, 1963. F.G.S., 1965.

F15 (TSF-2). SW¼NW¼NW¼ sec. 21, T. 6 S., R. 48 E. Elevation 2,850 feet on crest of first ridge north of Irondyke Creek. Mostly productids.
August, 1963.

F16 (TSF-3). SW¼NW¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,610 feet, about 60 feet north of creek.
"Lingula, no help."
August, 1963. F.G.S., 1965.

F17 (TSF-4). SE¼SW¼SE¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,820 feet on first ridge west of road.
"_Megousia_."
August, 1963. F.G.S., 1965.

F18 (TSF-5). N. center, NE¼SW¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,650 feet on northeast side of north fork, Homestead Creek, about 200 yards N. 40° E. from the confluence of south and north forks, Homestead Creek.
"*Megousia*."
August, 1963. F.G.S., 1965.

F19 (TSF-6). N. center, NE¼SW¼ sec. 15, T. 6 S., R. 48 E. Elevation 2,230 feet along trail on south side of Herman Creek.
"Believe this is *Megousia* again, but specimens are not sufficiently complete to be sure."
August, 1963. F.G.S., 1965.

F20 (TSF-7). SE¼SW¼NW¼ sec. 2, T. 6 S., R. 48 E. Elevation 3,480 feet, about 100 feet north of Ashby Creek.
"A pectenoid clam
Possible *Megousia*, but can't be sure.
'Marginifera' - Mississippian to Permian."
August, 1963. F.G.S., 1965.

F24 (TSF-11). NE¼NW¼SE¼ sec. 33, T. 20 N., R. 4 W. Elevation 3,310 feet, about 20 feet north of small gulch.
"Indeterminate Spiriferoid."
September, 1963. F.G.S., 1965.

F25 (TSF-12). S. center, NE¼SW¼ sec. 33, T. 20 N., R. 4 W. Elevation 2,700 feet on south side of small ridge about 400 yards southeast of old homestead cabin.
"Nothing useful."
September, 1963. F.G.S., 1965.

F26 (TSF-13). SE¼SW¼ sec. 23, T. 20 N., R. 4 W. Elevation 2,560 feet along Kleinschmidt Grade.
"Indeterminate productid - possible *Megousia*, but I cannot be sure."
September, 1963. F.G.S., 1965.

F37 (LSF-6). N. center, NE¼SE¼ sec. 29, T. 21 N., R. 3 W. Elevation 3,610 feet, on crest of first ridge south of Allison Creek.
"Large Neospiriferoid-Pennsylvanian or Permian.
Possible (almost certain) *Megousia*."
July, 1964. F.G.S., 1965.

F38 (LSF-7). SE¼SW¼ sec. 29, T. 21 N., R. 3 W. Elevation 3,220 feet, crest of ridge south of creek that lies between Allison Creek and Eckels Creek.
"Large Neospiriferoid-Pennsylvanian or Permian."
July, 1964. F.G.S., 1965.

F40 (LSF-9). Section line between secs. 8 and 17, T. 21 N., R. 3 W. Elevation 1,700 feet, 50 feet above old road and approximately half a mile south of Squaw Creek rapids.
"Indeterminate productid."
August, 1964. F.G.S., 1965.

F41 (LSF-10). Section line between secs. 5 and 6, T. 7 S., R. 48 E. Elevation 2,790 feet, approximately 50 feet north of creek bed of Hunsaker Creek.
"Coral, apparently Lophophyllid type."
August, 1964. F.G.S., 1965.

F42 (LSF-11). SE¼SW¼ sec. 5, T. 7 S., R. 48 E. Elevation 2,350 feet, 50 feet north of Hunsaker Creek.
"Possible *Megousia*, but can't be sure.
Probably large Spiriferoid.
Large indeterminate productid."
August, 1964. F.G.S., 1965.

F44 (LSF-13). SE¼NE¼NW¼ sec. 21, T. 6 S., R. 48 E. Elevation 2,010 feet, north side of Homestead Creek, 100 feet from stream bed.
"Possible Rhynchonellid.
Possible Neospiriferoid."
September, 1964. F.G.S., 1965.

F46 (VSF-1). NW¼SW¼ sec. 15, T. 6 S., R. 48 E. Elevation 2,700 feet, north side of Whiskey Gulch, midway between the creek bed and the crest of the ridge.
Productids.
April, 1965.

F47 (VSF-2). NW¼NW¼NE¼ sec. 21, T. 6 S., R. 48 E. Elevation 2,580 feet, on crest of spur that points to Homestead, Oregon.
Productid reef.
April, 1965.

F52 (VSF-7). NE¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,630 feet, bearing N. 50° E. from

confluence of south and north forks of Homestead Creek.
Productids.
April, 1965.

F53 (VSF-8). SE¼NW¼NW¼ sec. 21, T. 6 S., R. 48 E. Elevation 2,320 feet, 150 feet south of Homestead Creek.
Productids.
April, 1965.

F57 NW¼NE¼ sec. 21, T. 21 N., R. 3 W. Elevation 2,520 feet, on north side of Kinney Creek, approximately 100 yards north of the creek bed.
Productids.
June, 1965.

F59 NE¼SW¼NW¼ sec. 2, T. 6 S., R. 48 E. Elevation 3,910 feet, about 200 feet north of Ashby Creek.
Productids.
June, 1965.

F60 NE¼NE¼ sec. 10, T. 21 N., R. 3 W. Elevation 4,720 feet, on south side of Schoolman's Gulch, approximately 40 feet from the creek bed.
Productids.
July, 1965.

F63 (VF-15). Center, T. 6 S., R. 47 E. Elevation 4,000 feet, on west side of Elk Creek, approximately 100 feet from the creek bed.
Productids.
August, 1965.

F64 (VF-16). Center, S. edge, T. 5 S., R. 47 E. Elevation 4,940 feet, approximately 600 yards west of Grave Creek and 400 yards north of Duck Creek.
Productids, Neospiriferoids (?).
September, 1965.

F65 (VF-17). SW¼SW¼ sec. 15, T. 6 S., R. 46 E. Elevation 7,080 feet, on crest of ridge south of Fish Lake.
Pelecypod reef.
September, 1965.

F67 (VF-19). Center, near west edge, T. 6 S., R. 47 E. Elevation 5,750 feet, on small nose,

approximately 75 yards south of Packsaddle Creek.
Reef of large pelecypods.
September, 1965.

Grassy Ridge Formation (Ꞧgr)

F39 (LSF-8). T. 5 S., R. 48 E. Elevation 1,940 feet, on crest of spur along the north side of McGraw Creek.
"Assigned USGS Mesozoic loc. M2673.
Daonella frami Kittl.
D. cf. *D. degeeri* Böhm.
These 'flat clams' occur singly or together at a number of places in Alaska and in the western and arctic parts of Canada. Wherever they have been dated by associated ammonite faunas, their age is Ladinian and older than latest Ladinian."
August, 1964. N.J.S., 1965.

F43 (LSF-12). SW¼SE¼SE¼ sec. 8, T. 21 N., R. 3 W. Elevation 1,780 feet, 150 feet above the old road, about 150 yards north of F40.
"Assigned USGS Mesozoic loc. M2674.
? *Daonella frami* Kittl.
D. cf. *D. indica*.
Preservation of these is not as good as in LSF-8 (F39), but the same age is suggested."
September, 1965. N.J.S., 1965.

F45 (LSF-14). S. center, sec. 16, T. 6 S., R. 48 E. Approximate elevation 3,000 feet, on ridge north of Homestead Creek. Exact location is unknown. This fauna was collected by Dr. David Bostwick and assigned a locality number of 0-408-59.
"Assigned USGS Mesozoic loc. M2675.
Daonella cf. *D. degeeri* Böhm.
Indet. phylloceratacid (?) ammonite.
More of the same; lithologically like LSF-8 (F39)."
1959. N.J.S., 1965.

F48 (VSF-3). SW¼SW¼NW¼SE¼ sec. 16, T. 6 S., R. 48 E. Elevation 3,350 feet on saddle of major ridge north of Homestead Creek.
"Assigned USGS Mesozoic loc. M4041.
Daonella frami Kittl.

D. cf. *D. degeeri* Böhm."
April, 1965. N.J.S., 1965.

F49 (VSF-4). SE¼NE¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 3,310 feet, south of saddle on major ridge north of Homestead Creek.
"Assigned USGS Mesozoic loc. M4042.
Daonella cf. *D. frami* Kittl.
(?) *D.* cf. *D. degeeri* Böhm."
April, 1965. N.J.S., 1965.

F50 (VSF-5). SE¼SE¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,420 feet, half-way up major ridge north of Homestead Creek on a small spur in brown argillite and sandstone.
"Assigned USGS Mesozoic loc. M4043.
Trachyceras ? (*Trachyceras* ?) sp.
Clionitites ? sp.
Fragment of the septal pattern of a large indet. ammonite with complex sutures.
Indet. pectenacid pelecypod." N.J.S., 5/3/65

"One ammonite fragment showing ventral ornamentation confirms the presence of *Trachyceras* (sensu stricto), tentatively recognized from this locality in my report to you of 5/3/65, and hence an earliest Late Triassic (lowest Karnian) age (in North American usage)."
N.J.S. 8/17/65.
April, 1965. N.J.S., 1965.

F51 (VSF-6). SW¼SW¼SW¼ sec. 16, T. 6 S., R. 48 E. Elevation 2,730 feet, on spur between south fork of Homestead Creek and main Homestead Creek.
"Assigned USGS Mesozoic loc. M4044.
Daonella cf. *D. frami* Kittl.
D. cf. *D. degeeri* Böhm.
April, 1965. N.J.S., 1965.

F56 (VSF-11). SE¼SE¼SE¼ sec. 8, T. 22 N., R. 3 W. Elevation 2,250 feet, above IPALCO road. Small limestone pod between tuffs.
"Assigned USGS Mesozoic loc. M4045.
Daonella similar to *D. degeeri* of LSF-8 (F39), LSF-14 (F45), VSF-3 (F48), VSF-4 (F49) and VSF-6 (F51) but consistently different in ribbing and better characterized as *Daonella* cf. *D. indica*. The age of *D. indica* is late Middle Triassic (mid

or late Ladinian)."
June, 1965. N.J.S., 1965.

F58 (VSF-12). SW¼SE¼SW¼ sec. 31, T. 21 N., R. 3 W. Elevation 2,900 feet, on south side of major spur that parallels Hibbles Gulch.
"(coll. discarded). Fragments of a finely-ribbed *Daonella* - possibly *D. degeeri*.
Age: Middle Triassic."
June, 1965. N.J.S., 1965.

F61 (VSF-13). NW¼SE¼NW¼ sec. 1, T. 20 N., R. 4 W. Elevation 2,530 feet, on north side of small gulch, bearing N. 73° E. from mouth of McGraw Creek.
"Assigned USGS Mesozoic loc. M4046.
Shelly hash - mainly of brachiopods.
Age: indet."
July, 1965. N.J.S., 1965.

F62 (VF-14). S. center T. 5 S., R. 47 E. Elevation 5,280 feet on northwest side of large rôche moutonnée along south side of the Imnaha River. Across river from "Hidden Campground" of U.S. Forest Service.
"Collection discarded. The scraps of halobiid pelecypods in this collection could be *Daonella*, but not enough is preserved to be certain."
August, 1965. N.J.S., 1965.

Imnaha Formation (TRir)

F66 (VF-18). Same as CW-FL-5 of Wetherell. NE¼SW¼SW¼ sec. 5, T. 6 S., R. 46 E. Elevation about 7,200 feet, southwest of Sugarloaf Reservoir about 250 yards.
"Assigned USGS Mesozoic loc. M3015.
Chlamys ? sp.
Minetrigonia ? sp.
Septocardia ? sp.
This assemblage of pelecypods, though not amenable to accurate identification, suggests an Upper Triassic stratigraphic assignment. Judging from the scraps of ornamentation preserved, all three species are in common with those from CW-FL-5 (USGS Mesozoic loc. M1443) in the Cornucopia quadrangle. The distinctive ribbing of the *Chlamys* ? also suggests comparison

with that in Ralph Cannon's collection F44 (USGS Mesozoic loc. M1730) up hill from Eagle Bar."
September, 1965. N.J.S., 1965.

Martin Bridge Formation (TRmb)

F27 (TSF-14). NW¼NE¼ sec. 31, T. 21 N., R. 3 W. Elevation 1,730 feet, probably the same as Cannon's F-36 and F-37.
"Collection discarded."
September, 1963. N.J.S., 1964.

F28 (FSF-15). NE¼SW¼NE¼ sec. 31, T. 21 N., R. 3 W. Elevation 1,890 feet, near Eckels Creek trail.
"Collection discarded."
September, 1963. N.J.S., 1964.

F29 (TSF-16), F30 (TSF-17), and F31 (TSF-18) all discarded.

F32 (LSF-1). T. 5 S., R. 48 E. Elevation 2,210 feet along the McGraw Creek trail.
"Collection discarded. Crinoid columnals of indefinite age."
June, 1964. N.J.S., 1965.

F33 (LSF-2). Southwest corner, T. 5 S., R. 49 E. Elevation 1,840 feet on north side of Kirby Creek.
"Collection discarded. Indet. pelecypod and crinoid debris. Nothing of age significance."
June, 1964. N.J.S., 1965.

F34 (LSF-3). T. 5 S., R. 48 E. Elevation 2,970 feet, along north side of McGraw Creek, approximately 200 feet above base of limestone.
"Assigned USGS Mesozoic loc. M2670.
Placunopsis sp.
These oyster-like pelecypods have no particular age significance, but are like forms known from the Upper Triassic. Apparently identical forms in the same kind of matrix occur in Ralph Cannon's collection F-36 (M1728) from a locality a couple of miles northeast and across the river from your locality."
June, 1964. N.J.S., 1965.

F35 (LSF-4). West edge, T. 5 S., R. 49 E. Elevation 3,360 feet along crest of the most northerly ridge between Leep Creek and Spring Creek.

"Assigned USGS Mesozoic loc. M2671.
Indet. spiriferid brachiopods.
Indet. pelecypod.
? *Juvavites* (sensu lato) sp.
The ammonite questionably referred to *Juvavites* and the spiriferid superficially resemble forms in LSF-5 (F36) and suggest correlation with it."

July, 1964. N.J.S., 1965.

F36 (LSF-5). West edge, T. 5 S., R. 49 E. Elevation 3,210 feet, on south side of ridge between Spring Creek and Leep Creek, in axis of syncline.

"Assigned USGS Mesozoic loc. M2672.

Ammonites:
- *Tropiceltites columbianus* (McLearn)
- *Juvavites* (sensu lato) sp.
- *Arcestes* sp.

Pelecypods:
- '*Chlamys*' cf. *C. mojsisovicsi* Kobayashi and Ichikawa
- Undet. pectenacids - 4 kinds
- *Lima* cf. *L. yataensis* Nakazawa and one or two other species
- *Avicula* sp.
- *Mysidia* sp.
- *Mysidioptera* cf. *M. spinigera* Bittner
- *M.* cf. *M. Williamsi* (McLearn)
- '*Ostrea*' sp.
- *Cassianella* sp.
- *Plicatula* ? sp.
- *Gervillia* cf. *G. angusta* Münster
- *Septocardia* ? sp.
- *Tutcheria* sp.
- trigoniids - 2 species
- *Parallelodon* cf. *P. monobensis* Nakazawa and several other undeter. pelecypods

Gastropods:
- 30+ different kinds including species of Eucyclus, Cirrus, Neritopsis, Delphinulopsis ?, and 'Loxonema'

Brachiopods:
- terebratulids - 2 species
- rhynchonellid - undeter.
- spiriferid - 6 species

Spongiomorphid coelenterates:
- *Spongiomorpha* sp.
- *Heptastylis* sp.

Scleractinian corals:
- *Thamnasteria* sp.
- *Elyastraea* sp.
- *Thecosmilia* sp.
- and at least 4 other kinds

Echinoderms:
- cidarid echinoid plates and spines
- crinoid columnals

This incomplete and provisional list of identifications is given only to indicate the size and diversity of this large silicified fauna that includes more than 70 kinds of marine invertebrates. ...the *Tropiceltites columbianum* (McLearn) ...is typical of the *Mojsisovicsites kerri* zone in northeastern British Columbia and is also present in this same zone in northwestern Nevada. The age of LSF-5 (F36) should thus be regarded as earliest Norian."

July, 1964. N.J.S., 1965.

Appendix C

Table 25. Type Section, Doyle Creek Formation; Measured Along the North Side of Doyle Creek From the Snake River to the Columbia River Basalt. Top and Bottom of Formation are not Exposed. Thicknesses were Hand-leveled and Estimated.

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 18.	Volcanic Conglomerate: dusky-red (5 R 4/3), weathers pale reddish-brown (10 R 5/4); interbedded sandstone and volcanic flow rocks; graded bedding; cross-bedding in some sandstone beds; poorly sorted; clast sizes 0.2-10 cm; clasts of flow rocks dominant, but clasts of volcaniclastic rocks and plutonic clasts also occur; this unit is part of the Ashby Creek Conglomerate..............................	275	1820
Unit 17.	Volcanic Breccia: dusky-red (5 R 3/4), weathers moderate yellowish-brown (10 YR 5/4); graded bedding; poorly sorted; reddish-brown volcanic clasts and yellow pumice fragments range in size from 0.1-8.0 cm; grades into volcanic sandstone and siltstone; mostly pyroclastic origin.............................	68	1545
Unit 16.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers to dusky-brown (5 YR 2/2); several flow units, both porphyritic and aphanitic; phenocrysts from 0.3-2.0 mm...	50	1477
Unit 15.	Dioritic Sill: phaneritic inequigranular; plagioclase, hornblende, and biotite are dominant minerals; jointed; thick; light gray; post-Triassic intrusive unit; not included in formation thickness.............	38	-
Unit 14.	Volcanic Flow (Spilite): very dusky-red (5 YR 2/2); several flows; porphyritic and aphanitic; feldspar		

Table 25. (Continued)

Unit	Description	Thickness(feet)	
		Unit	Total
	phenocrysts up to one cm in length	355	1427
Unit 13.	Volcanic Flow (Keratophyre ?): pale-green (5 G 7/2), weathers dusky-yellow (5 T 6/4); porphyritic; fractured	16	1072
Unit 12.	Volcanic Breccia: dusky-red (5 R 3/4), weathers pale reddish-brown (10 R 5/4); graded bedding; some interbedded flows; poorly sorted; clast diameters 0.1-10 cm; pumice, flow rock, and volcaniclastic clasts	218	1056
Unit 11.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); porphyritic, feldspar phenocrysts up to 3 mm in length; interbedded dusky-red breccia with abundant pumice, probably pyroclastic	70	838
Unit 10.	Dacite Sill: pale-green (5 G 7/2); porphyritic, phenocrysts of quartz and feldspar; post-Triassic intrusive unit; not included in formation thickness	15	-
Unit 9.	Volcanic Flow (Spilite): dusky-red (5 R 3/4) and grayish-black (N 2), weathers dark yellowish-brown (10 YR 4/2); mottled; intercalated thin beds of tuff breccia and tuff; poorly sorted; graded	65	768
Unit 8.	Volcanic Flow (Spilite): dark greenish-black (5 G 2/1), weathers moderate yellowish-brown (10 YR 5/4); aphanitic; interbedded dusky-red spilites; gradational unit	180	703
Unit 7.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); aphanitic; amygdaloidal	65	523

Table 25. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 6.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); vesicular; aphanitic....	10	458
Unit 5.	Volcanic Flow (Spilite): greenish-black (5 G 2/1), weathers dark yellowish-brown (10 YR 4/2); aphanitic; forms steep cliffs............	45	448
Unit 4.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); vesicular; amygdaloidal; aphanitic.........................	48	403
Unit 3.	Fine Tuff: dark greenish-gray (5 GY 4/1), weathers dark yellowish-brown (10 YR 4/2); graded; interbedded with greenish-black spilite flows; poorly sorted; mostly spilite clasts; top of Piedmont Point Member............................	80	355
Unit 2.	Tuff Breccia: grayish-black (N 2), weathers dark yellowish-brown (10 YR 4/2); black, greenish-black, and dark greenish-gray clasts; graded and massive beds up to 30 feet thick; clasts average 1-3 cm in diameter; poorly sorted; angular fragments; abundant matrix..........	220	275
Unit 1.	Volcanic Flow (Spilite): greenish-black (5 G 2/1), weathers dusky-brown (5 YR 2/2); aphanitic; amygdaloidal.............................	55	55
	Total Thickness		1820

Table 26. Reference Section, Doyle Creek Formation; Measured Along the North Side of the First Gulch North of Limepoint Creek, From the IPALCO Road to the Top of Hibbles Ridge. Thicknesses Hand-leveled and Estimated.

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 27.	Volcanic Conglomerate: dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); interlayered tuff and tuff breccia; poorly sorted; graded beds; clasts of volcanic flows predominate; all matrices are crystal rich............................	185	1301
Unit 26.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers dusky-brown (5 YR 2/2); aphanitic and porphyritic, some are glomerol porphyritic; flows up to 30 feet thick; interbedded tuffs and tuff breccias constitute up to 20 percent; deeply weathered outcrops; grassy slopes...	215	1116
Unit 25.	Volcanic Sandstone (Coarse Tuff ?): very dusky-red (5 R 2/2), weathers pale reddish-brown (10 R 5/4); graded to breccia; some volcanic conglomerate; this unit is part of the Ashby Creek Conglomerate........	35	901
Unit 24.	Volcanic Flow (Spilite): dark-gray (N 3) and dusky-red (5 R 3/4), mottled; weathers dusky-brown (5 YR 2/2); aphanitic; forms rounded outcrops............................	15	866
Unit 23.	Volcanic Conglomerate: dusky-red (5 R 3/4), weathers to pale reddish-brown (5 YR 2/2); interbedded volcanic breccia and volcanic sandstone; some flows; one glomerol porphyritic flow; graded beds from 2-12 feet thick; rounded outcrops; part of the Ashby Creek Conglomerate	135	851
Unit 22.	Volcanic Flow (Spilite): dark greenish-gray (5 G 4/1) and dusky-red (5 R 3/4), mottled; weathers		

Table 26. (Continued)

		Thickness(feet)	
Unit	Description	Unit	Total
	dusky-brown (5 YR 2/2); chalcedony-filled amygdules; cliff-forming outcrops; porphyritic with phenocrysts 3-4 mm in diameter; amygdules 3-8 mm in diameter	96	716
Unit 21.	Volcanic Sandstone (Tuff ?): dusky-red (5 R 3/4), weathers pale reddish-brown (10 R 5/4); graded beds 1-5 feet thick; some breccia in lower parts of beds; poorly sorted; fragments of spilite, some pumice, feldspar crystals, and abundant (20-30 percent) dusky-red matrix	20	620
Unit 20.	Volcanic Flow (Spilite): greenish-black (5 G 2/1), weathers dark yellowish-brown (10 YR 4/2); porphyritic; phenocrysts measure 0.8-1.3 cm in length, and constitute more than 50 percent of the rock; phenocrysts colored in light shades of pink and green; forms rounded outcrops	18	600
Unit 19.	Volcanic Sandstone: dusky-red (5 R 3/4), weathers pale reddish-brown; graded beds; poorly sorted; coarse-grained; angular fragments; feldspar rich, probably tuffaceous	19	582
Unit 18.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); porphyritic, interlayered greenish-black flows; forms cliffs	95	563
Unit 17.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); aphanitic; forms rounded outcrops	20	468
Unit 16.	Volcanic Flow (Spilite ?): grayish-red (5 R 4/2), weathers dusky-brown (5 YR 2/2); aphanitic; interlayered with 4-5 foot greenish-black flows; cliff-former; individual flows up to		

Table 26. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
	15 feet thick........................	68	448
Unit 15.	Coarse Tuff: pale-red (10 R 6/2), weathers pale yellowish-brown (10 YR 6/2); graded beds; poorly sorted except in some 3-5 cm beds; grain sizes up to 2 cm, but measures 1-2 mm; volcanic fragments of flows and clastics; feldspar crystal-rich; forms rounded outcrops..............................	20	380
Unit 14.	Volcanic Sandstone (Tuff ?): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); graded; poorly sorted; coarse grained, measure 1-2 mm; angular grains of rock fragments and feldspar crystals......................	8	360
Unit 13.	Volcanic Flow (Spilite): blackish-green (5 G 2/1), weathers moderate yellowish-brown (10 YR 5/4); aphanitic; forms rounded outcrops..............	7	352
Unit 12.	Volcanic Flow (Spilite): dark-gray (N 2), weathers dark yellowish-brown (10 YR 2/2); porphyritic; feldspar phenocrysts form more than 50 percent of rock; forms rounded outcrops..............................	58	345
Unit 11.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers pale reddish-brown (10 R 5/4); aphanitic, forms rounded outcrops....................	12	287
Unit 10.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2); weathers dark-brown; porphyritic, phenocrysts average 0.5-0.8 cm; cliff-former........	55	275
Unit 9.	Volcanic Sandstone (Tuff ?): dusky-red (5 R 3/4), weathers pale reddish-brown (10 R 5/4); graded; poorly sorted; coarse to fine-grained; rock fragments; feldspar crystals; pumice		

Table 26. (Continued)

		Thickness(feet)	
Unit	Description	Unit	Total
	(?); angular fragments; forms rounded outcrops	8	220
Unit 8.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2) and dark-gray (N 2); mottled; aphanitic; forms rugged cliffs	38	212
Unit 7.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers dusky-brown (5 YR 2/2); porphyritic; phenocrysts measure 0.5-0.7 cm in length; cliff-former	10	174
Unit 6.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2) and dark-gray (N 2), mottled; weathers dusky-brown (5 YR 2/2); rounded outcrops	15	164
Unit 5.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2); weathers brown; porphyritic; phenocrysts average 0.7-1.0 cm in length; cliff-former; individual flows are 10-15 feet thick.	48	149
Unit 4.	Volcanic Sandstone (Tuff ?): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); graded; poorly sorted; fine-grained; subangular to angular grains	10	101
Unit 3.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1), weathers dark yellowish-brown (10 YR 4/2); aphanitic; forms rounded outcrops	18	91
Unit 2.	Volcanic Breccia and Volcanic Sandstone (Tuff ?): dusky-red (5 R 3/4); weather dusky-brown; graded; poorly sorted; rock fragments are dominant clasts	43	73
Unit 1.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); aphanitic; cliff-former.	30	30
IPALCO Road	Total Thickness		1301

Table 27. Reference Section, Doyle Creek Formation; North Side of McGraw Creek, From Base of Formation at Elevation 2,150 Feet to McGraw Creek Fault at Elevation 3,210 Feet. Thicknesses Hand-leveled, Taped, and Estimated.

		Thickness(feet)	
Unit	Description	Unit	Total
Unit 15.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1) and dusky-red (5 R 3/4), mottled; weathers dark yellowish-brown (10 YR 4/2); aphanitic; top truncated by McGraw Creek Fault	20	972
Unit 14.	Volcanic Breccia (Tuff Breccia ?): dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); graded; poorly sorted; clasts of volcaniclastic (tuff ?) rocks	36	952
Unit 13.	Volcanic Breccia (Tuff Breccia ?): very dusky-red (5 R 2/2) with grayish red-purple (5 RP 4/2) clasts; poorly sorted; graded beds; angular fragments of volcanic flow rocks dominant	63	916
Unit 12.	Fine Tuff: pale-red (10 R 6/2) with dusky-red (5 R 3/4) bands; weathers brown; very fine-grained; rounded outcrops partly covered	20	853
Unit 11.	Volcanic Flow Breccia: dark-gray (N 2) and very dusky-red (5 R 2/2); mottled; weathers brown; swirled, monolithologic, clasts difficult to distinguish from matrix; some interlayered volcanic flows that are not brecciated	29	833
Unit 10.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers dusky-brown (5 YR 2/2); aphanitic; forms rounded outcrops	45	804
Unit 9.	Volcanic Breccia: dark-gray (N 2) with dark-gray and pale-green (5 G 7/2) clasts; mixed with beds of very		

Table 27. (Continued)

Unit	Description	Thickness(feet)	
		Unit	Total
	dusky-red breccias; graded; poorly sorted; clasts up to 8 cm in diameter	48	759
Unit 8.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), interbedded with dark-gray (N 2) flows; rare dusky-red breccia of 3-5 feet thicknesses (10 percent of unit)	245	711
Unit 7.	Volcanic Breccia and Volcanic Sandstone: very dusky-red (5 R 2/2) and dusky-red (5 R 3/4), weather dusky-brown (5 YR 2/2); with dusky-red, light-green, and grayish red-purple volcanic flow clasts; some pumice; graded; poorly sorted; crystal-rich; largest clast 4-5 cm, measure 1-2 cm; beds 1-5 feet thick	43	466
Unit 6.	Volcanic Flow (Spilite): grayish red-purple (5 RP 4/2), swirled flow banding; weathers pale reddish-brown (10 R 5/4); forms bold, jutting outcrops; aphanitic	26	423
Unit 5.	Volcanic Breccia: dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); with light-gray and very dusky-red volcanic flow clasts; interbedded volcanic sandstone; tuffaceous; poorly sorted; graded	28	397
Unit 4.	Volcanic Breccia: greenish-black (5 GY 2/1) with greenish-black and dusky-red clasts; graded; poorly sorted; interbedded volcanic sandstone; beds from 1-15 feet thick	135	369
Unit 3.	Volcanic Breccia and Volcanic Sandstone: dusky-red (5 R 3/4) and subordinate pale-green (5 G 7/2); weather brown; graded; poorly sorted; angular fragments; beds 1-10 feet thick	39	234

Table 27. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 2.	Volcanic Conglomerate: pale-red (10 R 6/2) with pale-green (5 G 7/2) and dusky-red (5 R 3/4) volcanic flow clasts; interbedded volcanic breccia; weak grading; largest clasts 10-12 cm; poorly sorted......	185	196
Unit 1.	Volcanic Breccia: dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); graded; some pumice; poorly sorted; overlies top bed of Grassy Ridge Formation.....................	11	11
	Total Thickness		972

Table 28. Reference Section, Doyle Creek Formation; Measured on the West Side of the McGraw Creek Fault in McGraw Creek. First 150 Feet is Covered. Thicknesses Chained and Estimated.

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 6.	Calcareous Siltstone: pale-green (5 G 7/2); bottom bed of Martin Bridge Formation; gradational contact; poorly sorted; angular grains..............	12	560
Unit 5.	Volcanic Breccia: dusky-red (5 R 3/4), with dusky-red, pale-green, and greenish-black volcanic flow clasts; weathers dusky-brown (5 YR 2/2); weakly graded; largest clasts 10 cm, measure 1-2 cm in diameter; angular fragments; 14 foot dacite sill cuts unit 100 feet above base..........................	240	548
Unit 4.	Volcanic Flow (Spilite): dusky-red (5 R 3/4), porphyritic; weathers dusky-brown (5 YR 2/2); phenocrysts 0.5-1.0 mm in diameter.......................	10	308
Unit 3.	Volcanic Breccia: dusky-red (5 R 3/4) and grayish-green (5 G 5/2); graded; clasts average about 2 cm in diameter; interbedded dusky-red flows up to 3 feet thick (20 percent).............	30	298
Unit 2.	Volcanic Flow (Spilite): dusky-red; porphyritic; weathers dusky-brown (5 YR 2/2)...........................	12	268
Unit 1.	Volcanic Flow (Spilite): dusky-red (5 R 3/4); aphanitic; partly volcanic flow breccia with dusky-red and pale-green clasts in a red and pale-green matrix........................	106	256
	Covered Slope: rock float shows breccia and flow rock mixed, all dusky-red.................................	150	150
	Total Thickness		560

Table 29. Type Section, Ashby Creek Conglomerate of the Doyle Creek Formation; Measured From 3,100 Feet to 3,680 Feet in SW¼NE¼ sec. 2, T. 6 S., R. 48 E., Second Gulch North of Ashby Creek.

Unit	Description	Thickness(feet) Unit	Total
Unit 11.	Volcanic Conglomerate: dusky-red (5 R 3/4) and grayish-red (5 R 4/2); graded beds 5-20 feet thick; poorly sorted; clasts from volcanic flow rocks; interbedded sandstone, probably tuffaceous; grassy slopes.......	240	602
Unit 10.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2); glomerol porphyritic; glomerols of 3-6 feldspar phenocrysts, 3-4 cm in diameter.....	10	362
Unit 9.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1); weathers dark yellowish-brown; aphanitic; forms rounded outcrops............................	62	352
Unit 8.	Volcanic Conglomerate and Volcanic Sandstone: dusky-red (5 R 3/4) with pale-red, pale-green, and greenish-black clasts; graded beds; poorly sorted; clasts of volcanic flow rocks; clasts subangular to well-rounded...	18	290
Unit 7.	Volcanic Flow (Spilite): greenish-black (5 GY 2/1) to dusky-red (5 R 3/4); porphyritic; mottled; feldspar phenocrysts 0.3-0.8 cm in diameter..	27	272
Unit 6.	Volcanic Conglomerate: dusky-red (5 R 3/4), weathers pale reddish-brown (10 R 5/4); graded to coarse volcanic sandstone (20 percent); poorly sorted; clasts from coarse sand size to 8 cm in diameter; subangular to well-rounded volcanic flow rock clasts...	55	245
Unit 5.	Volcanic Flow (Spilite): greenish-black (5 G 2/1), weathers yellowish-brown (10 YR 5/4); aphanitic; rounded outcrops; individual flows 8-15 feet thick............................	45	190

Table 29. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 4.	Volcanic Conglomerate: dusky-red (5 R 3/4); graded beds; poorly sorted; some angular clasts..................	5	145
Unit 3.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers dusky-brown (5 YR 2/2); porphyritic; amygdaloidal; phenocrysts 0.2-1.0 cm in diameter; amygdules filled with chlorite; individual flows 6-12 feet thick................................	40	140
Unit 2.	Volcanic Conglomerate: dusky-red (5 R 3/4), weathers dusky-brown (5 YR 2/2); graded to coarse volcanic sandstone; poorly sorted; clasts from 1-8 cm, average 2.5 cm in diameter; clasts from volcanic flow rocks............	25	100
Unit 1.	Volcanic Flow (Spilite): very dusky-red (5 R 2/2), weathers dusky-brown (5 YR 2/2); porphyritic; amygdaloidal; phenocrysts from 0.2-1.0 cm in diameter; amygdules filled with chlorite; individual flows from 5-15 feet thick..........................	75	75
	Total Thickness		602

Appendix D

Table 30. Reference Section, Martin Bridge Formation; Measured at Kinney Creek Near Big Bar, Idaho. Top of the Formation is not Present.

Unit	Description	Thickness(feet)	
		Unit	Total
Unit 7.	Limestone: dark-gray (N 3) to light brownish-gray (5 YR 6/1), weathers light-gray (N 7) to brownish-gray (5 YR 4/1); fine to medium-grained; mostly recrystallized; black and carbonaceous near base and top, light brownish-gray in center of unit; beds range in thickness from 0.5-2.0 feet near base to 3-8 feet towards top. Bottom units are somewhat dolomitic	652	1748
Unit 6.	Limestone: grayish-black (N 2) to dark-gray (N 3), weathers brownish-gray (5 YR 4/1); carbonaceous; fine to very coarse-grained; thinly laminated near base, thickening upwards to beds 30 feet thick; 8 foot thick limestone breccia 55 feet above base; becomes lighter gray above breccia, dolomitic in places	296	1096
Unit 5.	Limestone: dark-gray (N 3), weathers light-gray (N 7); medium to coarse-grained; cliff-forming unit; intercalated breccia; fossiliferous near base; bedding mostly absent and thick units are essentially structureless; 6 foot bed of cherty limestone 195 feet above base of unit; green sill cuts unit near base	397	800
Unit 4.	Limestone: grayish-black (N 2), weathers light-gray (N 7); fine to coarse-grained; frequently laminated; laminated beds alternate with medium-grained non-laminated beds of 1-2 feet thicknesses; coarser-grained beds are graded; green sills 80, 130, and 165 feet above base	185	403

Table 30. (Continued)

Unit	Description	Thickness(feet) Unit	Thickness(feet) Total
Unit 3.	Limestone: dark-gray (N 3) becoming grayish-black (N 2) near top; fine to coarse-grained; chert lenses about 95 feet above base; 2 foot thick fossil bed 127 feet above base, mostly pelecypods; beds measure 2-4 feet in thickness but range from 1-20 feet; some coarse-grained beds are dolomitic..........................	160	218
Unit 2.	Limestone: light-gray (N 6); fine-grained; thinly bedded; weak slaty cleavage; some pelecypod fragments..........................	42	58
Unit 1.	Volcanic Sandstone and Siltstone: grayish-green (5 G 6/1); calcareous, graded and cross-bedded, varies in thickness and character laterally...	16	16
	Total Thickness		1748

Table 31. Description of 24 Thin Sections From the Martin Bridge Formation, Kinney Creek Section, Adams County, Idaho. Description Proceeds From Base to Top of Section.

Specimen Number	Name (Folk, 1962)	Microscopic Description
LS8-2M	Biopelmicrite	Mostly microcrystalline calcite; 3% ovoid and round pellets, 7% fossils and fossil fragments; recognizable gastropod and pelecypod fragments.
LS8-3B	Fossil-Bearing Micrite	Mostly microcrystalline calcite, with some recrystallized fossil fragments; pronounced foliation approaches schistosity; fossil fragments not identifiable.
LS8-3M	Dolomitic Sparry-Micrite	Dark-colored; microcrystalline matrix, with dolomite euhedra; dolomite associated with microcrystalline quartz; replacive; quartz-rich; grain count shows 24% quartz.
LS8-3Fos	Biomicrite	Poorly sorted; angular fossil fragments in a micritic matrix; fossils partly replaced by dolomite and quartz, and partly recrystallized to sparry calcite; quartz in veins and stringers; matrix carbonaceous.
LS8-3T	Biosparite	Fine to medium-grained; recrystallized; originally a biomicrite; fossil fragments mostly pelecypods and brachiopods, most fossils not identifiable; carbonaceous material around periphery of some fossil fragments.
LS8-4B	Sparite	Thinly bedded; bedding defined by carbonaceous material; rare fossils recrystallized to sparry calcite; matrix fairly homogeneous.

Table 31. (Continued)

Specimen Number	Name (Folk, 1962)	Microscopic Description
LS8-4M	Sparite	Fine-grained; recrystallized micrite; abundant carbonaceous material; some allochem ghosts, probably fossils or pellets; bedding defined by oxidized iron possibly leached from carbonaceous material.
LS8-5B	Fossiliferous Sparite	Medium to coarse-grained; poorly sorted; angular to subangular fragments; very fossiliferous; fragments up to 2 mm in diameter; fossils mostly fragments of pelecypods, brachiopods, algae, and perhaps foraminifera; dolomite rhombs well-developed; quartz replacement common in some fossil fragments; large amount of brown carbonaceous material obscures relationships.
LS8-5M_1	Fossil-Bearing Sparite	Medium to coarse-grained; inequigranular; recrystallized biomicrite; veined; large amount of carbonaceous material; abundant quartz.
LS8-5M_z	Biosparite	Medium to coarse-grained; larger fragments approach 1 mm and average about 0.3 mm; fossil fragments recrystallized; sparry calcite is carbonaceous.
LS8-5T	Dolomitic Sparry-Micrite	Fine to medium-grained; sparry calcite mostly confined to replaced fossils and veins; small light-green, low birefringent, round aggregates showing radiating structures are probably chlorite; abundant carbonaceous material makes thin section brown.
LS8-6B	Micrite	Fine-grained; thinly laminated; well-indurated; with some venation; abundant quartz;

Table 31. (Continued)

Specimen Number	Name (Folk, 1962)	Microscopic Description
		carbonaceous material defines bedding planes.
LS8-6M$_1$	Dolomitic Intramicrite	Fine to coarse-grained; poorly sorted; very carbonaceous; some dolomite rhombs; intraclasts are fine-grained with well-defined boundaries.
LS8-6M$_2$	Dolomitic Biomicrite	Fine-grained with large fossil fragments; poorly sorted; sparry calcite veins and sparry calcite fossil pseudomorphs; fossils not identifiable; some dolomite rhombs.
LS8-6M$_3$	Fossiliferous Dolomite	Fine-grained with a few large fossil fragments; well-shaped dolomite euhedra; micritic material between some rhombs; faint fossil ghosts.
LS8-6T$_1$	Sparry Biomicrite	Fine-grained matrix with round and ovoid algal (?) fragments; some micrite recrystallized; fragments are now ghosts so original materials are not identifiable.
LS8-6T$_2$	Dolomitic Micrite	Fine to medium-grained; dolomite rhombs; some insoluble material; outlines of clasts indistinct.
LS8-7B	Intrasparite	Medium-grained; equigranular; fine-grained; carbonaceous; cemented by sparry calcite; intraclasts may be micritic lime or algal fragments.
LS8-7B$_2$	Sparry Intramicrite	Inequigranular, fine to medium-grained; mostly micrite with some sparry calcite disseminated through micritic matrix; some fossils fragments, mostly

Table 31. (Continued)

Specimen Number	Name (Folk, 1962)	Microscopic Description
		recrystallized; difficult to distinguish between pellets, intraclasts, and micritic matrix.
LS8-7B_3	Fossil-Bearing Intrasparite	Medium to coarse-grained, poorly sorted, some bedding; intraclasts may be algae, many appear rounded; fossils converted to sparry calcite with indistinct outlines; abundant carbonaceous material.
LS8-7M_1	Sparite	Mostly fine-grained, with some larger recrystallized sparry masses, probably recrystallized fossils; quartz abundant, mostly in veins but also disseminated throughout the section; probably a micrite originally.
LS8-7M_2	Sparite	Mostly fine-grained, some medium-grained; structureless; quartz is disseminated throughout section and also occurs in veins; probably a recrystallized micrite.
LS8-7M_3	Sparite	Fine-grained; sparry calcite veins; some micritic material; fossil outlines can be distinquished; some carbonaceous material.
LS8-7T	Micritic Intrasparite	Fine to medium-grained; blotchy; intraclasts both angular and ovoid; some quartz disseminated through section; some carbonaceous material; iron oxide (hematite) associated with the carbonaceous material.

Table 32. Results of Insoluble Residue, X-ray, and Optical Studies of Rocks From the Martin Bridge Formation, Kinney Creek Reference Section.

Sample Number	Weight Percent Insolubles	X-ray Percent Dolomite	Carbonaceous Material*
LS8-7T	4.98		A
LS8-$7M_3$	5.93		A
LS8-$7M_2$	4.81		T
LS8-$7M_1$	13.87		T
LS8-$7B_3$	6.55		A
LS8-$7B_2$	3.47		A
LS8-$7B_1$	2.80	Trace	U
LS8-$6T_2$	0.91	22.9	T
LS8-$6T_1$	5.34		U
LS8-$6M_3$	3.61	57.8	U
LS8-$6M_2$	5.69	15.1	U
LS8-$6M_1$	5.44	18.2	C
LS8-6B	6.71		C
LS8-5T	5.68	Trace	C
LS8-$5M_2$	6.30		C
LS8-$5M_1$	9.93		A
LS8-5B	2.84	95.1	A
LS8-4M	4.03		A
LS8-4B	7.24		C
LS8-3T	8.35		A
LS8-3M	20.54	Trace	A
LS8-3F	14.63	Trace	C
LS8-3B	3.81	Trace	T
LS8-2M	4.46	Trace	T

* Qualitative amounts from insoluble residue studies.
A = Abundant
C = Common
U = Uncommon
T = Trace