6-10-1973

The Bedrock Geology of the Southwest Part of the Kachess Lake Quadrangle, Washington

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<https://doi.org/10.15760/etd.2184>

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AN ABSTRACT OF THE THESIS OF David Carl Lofgren for the
Master of Science in Geology presented June 10, 1973.

Title: The Bedrock Geology of the Southwest Part of the
Kachess Lake Quadrangle, Washington.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Paul E. Hammond

Gilbert T. Benson

Robert O. Van Atta

The southwestern part of the Kachess Lake quadrangle lies between Lakes Cle Elum and Kachess, on the east flank of the central Cascade Range of Washington. The region lies between the North and South Cascade petrologic provinces, and includes rocks typical of each. Pre-Tertiary Easton Schist (called the Shuksan Suite farther north), and the Late Cretaceous-Paleocene Swauk Formation occur widely in the North Cascades, while the Tertiary Silver Pass Volcanics and Teanaway Basalt are typical of South Cascade

volcanic sequences. Diabasic dikes of the Teanaway dike swarm occur throughout the vicinity.

The area is bounded on the west by a major fault, the Kachess, and both folding and faulting have occurred in the area proper. Folding is represented by southeast-plunging Thorp Mountain anticline, to the north, and Domerie Creek syncline to the south. Several faults have been recognized, the most important being northwest-southeast trending Thomas Mountain fault, which diagonally bisects the folds and complicates stratigraphic relationships.

The region has been geologically active during most of its history. Eugeosynclinal rocks were metamorphosed to blueschists and greenschists during a late Paleozoic-early Mesozoic orogeny, and folding, faulting, and unconformable relationships involving Tertiary strata indicate continued diastrophism during the Cenozoic.

THE BEDROCK GEOLOGY OF THE
SOUTHWESTERN PART OF THE KACHESS
LAKE QUADRANGLE, WASHINGTON

by

DAVID CARL LOFGREN

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University
1974

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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INTRODUCTION

Purpose of Report

The purpose of this report is to map and describe the bedrock geology of the southwestern part of the Kachess Lake quadrangle (15-min.), Washington, and to interpret the stratigraphic units, structural features, and geologic history of the area.

Location and Access

The Kachess Lake quadrangle is located on the eastern flank of the Cascade Range of Washington, near the geographical center of the state (Fig. 1). The area mapped embraces 42 square miles in the southwestern part of the quadrangle, between Lakes Cle Elum and Kachess. Commercial logging roads and U.S. Forest Service trails leading into the area can be reached from Cle Elum by State Road 2E, along the east shore of Cle Elum Lake, and from the Kachess Lake Road, near the town of Easton.

Regional Geologic Setting

The area lies astride the boundary between the older metamorphic and igneous petrologic province of the northern Cascade Range and the younger volcanic and sedimentary

Figure 1. Index map of Washington State showing location of thesis area (ruled).

province of the central and southern Cascades. Rocks and structural features characteristic of both provinces occur in the area and reveal a part of the Paleozoic, Mesozoic, and early Cenozoic geologic history of the Washington Cascade Range.

Geography and Climate

The area is characterized to the south by two nearly parallel northwest-southeast trending ridges (Kachess and Cle Elum). Intervening Silver Creek valley provides drainage south to Lake Easton. To the north, individual peaks (such as Thorp Mountain and French Cabin Mountain) prevail over ridges, and drainage is east to Cle Elum Lake by way of Thorp and French Cabin Creeks. Relief reaches a maximum of 3,649 feet between Thorp Mountain (5,854 feet) in the northwest corner of the area, and the Easton airstrip (2,205 feet) in the southwest corner. Average relief is about 2,500 feet.

Winters in the area are typically cold and wet, and summers are warm and dry. At Cle Elum, the average January temperature is 18 degrees and the average July temperature 64 degrees. Average annual precipitation ranges from approximately 25 inches on the east side of the area to approximately 40 inches on the west, much of which is in the form of snow; consequently, the field season is limited to early June through late October.

Due to the high annual precipitation, vegetation is moderately thick. Slopes are steep and heavily wooded, and the lack of continuous good outcrops considerably hampers geologic mapping.

Previous Work

Pioneer geology was done in the area by Russell (1893; 1899), Smith (1903), and Smith and Calkins (1906), who mapped the central Cascade Range on a reconnaissance scale. Virtually no further work was done in the region until Foster (1960) reinterpreted some of the earlier investigations in a geologic description of part of the central Cascades. The present work, though encompassing a relatively small area, resolves some of the problems encountered by earlier workers, and helps to relate the geology of the central Cascades to that of the northern Cascade Range.

Methods of Study

Geology was plotted at a scale of 1:24,000 on U.S. Geological Survey topographic base maps during 8 weeks of field work in the summers of 1971 and 1972. Field work was supplemented by information obtained from aerial photographs at the scales of 1:12,000 and 1:62,500 [supplied by Paul Hammond and by the Northern Pacific Railway Co. (now Burlington Northern)]. In the laboratory,

a petrographic microscope was used to examine thin sections of 45 rock samples. Plagioclase anorthite percentages were determined both by maximum extinction angles (method of Michel-Levy) and by the extinction of combined carlsbad-albite twins (method of F.E. Wright), and optic axial angles were measured from centered acute-bisectrix interference figures, using an ocular micrometer and the chart of A.C. Tobi (1956). A Swift automatic point counter was used to determine modal compositions of representative slides. The data obtained from petrographic examination of thin sections is presented in Appendices B-E, and the hand specimen descriptions and the locations of samples studied are presented in Appendix A and Figure 4.

Acknowledgements

The writer wishes to thank Professor Paul E. Hammond, advisor for the thesis, for his advice and guidance during the preparation of this report. He also wishes to thank Susan L. Tank for her assistance in typing the first draft of the manuscript, and Gretchen M. Azimzadeh for typing the final draft. Finally, thanks are extended to Paul Hammond and to Burlington Northern, Incorporated for the loan of air photographs used in this study.

DESCRIPTIVE GEOLOGY

Regional Geologic Relations

The thesis area is bounded on the west by Kachess fault (Pl. 1), a major structural feature trending north and south through Kachess Lake (Foster, 1960). This fault separates metamorphic, igneous, and sedimentary rocks east of Kachess Lake from a similar, although younger sequence of stratified rocks west of the lake. Foster named the sequence east of the fault the eastern stratigraphic section, and the sequence west of the fault the western stratigraphic section (Fig. 2). This report concerns only rocks of the eastern stratigraphic section (Fig. 3).

General Stratigraphic Relations

The area is divided by Thomas Mountain fault into a northern, anticlinal block and a southern, synclinal block (Pl. 1). Formations of the northern block include the Easton Schist and the North Peak Metavolcanics, which together constitute the pre-Tertiary basement rocks in the area, and the Swauk Formation and the Silver Pass Volcanics, both of early Tertiary age. Formations of the southern block include the Silver Pass Volcanics, the Teanaway Basalt, and the Roslyn Formation, all of early

Age	Western Stratigraphic Section		Eastern Stratigraphic Section	Rock Type
Pliocene			Howson	Andesite
			Yakima	Basalt
Miocene	Keechelus			Andesite
Oligocene				
Eocene	Naches		Roslyn	Arkose and Basalt
			Teanaway	
	Mount Catherine		Silver Pass	Volcanic rocks
Paleocene-Cretaceous	Guye		Swauk	Sedimentary rocks
Pre-Cretaceous			North Peak Metavolcanics	Metamorphosed andesite and welded tuff
			Easton Schist	Low grade metamorphic rocks

Figure 2. Eastern and western stratigraphic sections of Foster (1960), showing rock units of this report (in bold outline). After Foster (1960), and this report. Not to scale.

Age			Formation	Symbol	Tk	Brief Description
CENOZOIC	TERTIARY	PLIO-CENE L. EOCENE M. EOCENE E. EOCENE PALEO-CENE	Howson Andesite	Tha	100'	Porphyritic hornblende andesite
			Roslyn Formation	Tr	2275'	Arkosic sandstone
			Teanaway Basalt	Ttb	4400'	Basalt lava and pyroclastic rocks
			Diabase Dike Swarm	Tid	5-300'	Fine to coarse grained diabase dikes
			Silver Pass Volcanics	Tspv	5800'	Andesitic lava and pyroclastic rocks
			Swauk Formation	KTs	6600'	Arkosic sandstone and conglomerate
MESOZOIC	LATE CRET. ?		North Peak Metavolcanics	pTnp	600'	Weakly metamorphosed lava, limestone, and tuff
PALEOZOIC	LATE PERMIAN		Easton Schist	pTe	8000'	Blueschist, greenschist and graphite schist

Figure 3. Rock units of Foster's (1960) eastern stratigraphic section that are described in this report (not to scale). Hachure indicates hiatus. See also Figure 2.

Tertiary age. Strata of both blocks, with the exception of the Teanaway Basalt and the Roslyn Formation, are intruded by diabase dikes.

The recognition of the Thomas Mountain fault was a significant result of this study. Earlier workers, who mapped at smaller scales, failed to realize its existence, and this led to misinterpretations of certain contact relationships in the area. Smith and Calkins (1906) and Foster (1960) mapped the Swauk Formation - Teanaway Basalt contact as an unconformity, and Foster (1960) mapped the Silver Pass Volcanics - Teanaway Basalt contact as an unconformity, although he stated (1960, p. 106) that the relationship between the Silver Pass and Teanaway strata "may be more complex than the present mapping indicates." As shown in the map (Pl. 1), the Swauk Formation is in fault contact with the Teanaway Basalt, and, although the Teanaway Basalt does unconformably overlies the Silver Pass Volcanics regionally, the latter two units are also in local fault contact, complicating their relationship.

Easton Schist

Introduction

The Easton Schist, named by Smith (1903), consists of low-grade metamorphic rocks of pre-Tertiary age. It is the oldest formation exposed in the area, forming the basement rocks, and it crops out extensively to the north of French Cabin Mountain (Pl. 1), where it erodes to form gray, hummocky slopes and rounded peaks.

Lithology

The Easton Schist consists of complexly intercalated blueschist¹, greenschist, and graphite schist. Blueschist and greenschist are the most common rock-types, with blueschist being somewhat more abundant than greenschist; graphite schist is of lesser occurrence.

The rocks of the Easton Schist display a pronounced northwest-southeast trending foliation (Pl. 1). In general, the greatest schistosity has been developed in the graphite schist and the least in the greenschist,

¹The term "blueschist", as used in this report, refers to schistose metamorphic rocks containing the blue amphibole glaucophane, and should not be confused with the term "blueschist facies", which is defined (Bailey, in Hyndman, 1972) as those rocks forming within the stability field of the mineral lawsonite. Lawsonite is not found in blue amphibole-bearing rocks of the area.

while the blueschist is moderately schistose. No sharp contacts between the blueschist, greenschist, and the graphite schist were observed, and the transition from one rock type to another is gradational.

The blueschist is typically a fine-grained, dark blue rock with a satiny luster. Glaucophane and epidote are the predominant minerals, and occur as segregation layers developed parallel to the principal (S1) schistosity plane. Layers and lenses of quartz and plagioclase occur locally, and may parallel or cross the principal schistosity plane. Crossite, actinolite, and tremolite have been reported from blueschists of the Easton Schist (Foster, 1960; Stout, 1964), but were not identified in this study. Detailed petrographic data obtained from the thin section examination of three blueschist samples is presented in Appendix B of this report. Map locations of the samples studied are shown in Fig. 4.

The greenschist consists predominantly of clinozoisite, relict plagioclase, and metamorphic plagioclase, the latter mineral occurring as veins and irregular patches throughout the rock. Foster (1960) and Stout (1964) have reported epidote and actinolite as being the major constituents of both the greenschist and the blueschist, which, by comparison with the composition of rocks in the map area, suggests that the mineralogy of the Easton Schist is highly variable. Data obtained from the petrographic examination of two thin sections of the greenschist are presented

Figure 4. Location map of rock samples studied in thin section. For explanation of abbreviations, and hand sample and petrographic descriptions, see Tables I and II and Appendices A-E.

in Appendix C.

The graphite schist is dull gray in color and fine to medium-grained. Graphite and muscovite are complexly interlayered with lenticular pods of quartz and plagioclase (identified in hand specimen), and the rock is tightly folded. Foster reports the presence of minor amounts of chlorite, sericite, and stilpnomelane in the graphite schist.

Relict, unmetamorphosed parent rocks of the Easton Schist were not found. However, schists rich in epidote and a glaucophane mineral are generally believed to have been derived from basic igneous rocks, and the chemistry of most blueschists and greenschists is similar to that of unmetamorphosed eugeosynclinal rocks (Hyndman, 1972, p. 367). Carbonaceous sediments, from which graphite schist could be derived, might also be found in eugeosynclinal sequences, and the metamorphism of a eugeosynclinal assemblage seems a likely origin for the Easton schist.

Distribution and Thickness

The Easton Schist crops out in the core of Thorp Mountain anticline and is at least 8,000 feet thick (Pl. 1, Cross-section A-A'). The formation is exposed in a smaller fold north of Thorp Mountain anticline, and in an outcrop northwest of the town of Easton (Foster, 1960), as well as on the south side of the Yakima Valley (Stout, 1964). Its

thickness at these localities is unknown.

Age and Correlation

The Easton Schist is lithologically similar to, and on strike with, metamorphic rocks in the North Cascades known as the Shuksan Suite (Misch, 1966). Together the Easton Schist and the Shuksan Suite form a narrow, discontinuous zone of low-grade metamorphic rocks extending northward to near the Canadian border. Blueschists of the Shuksan Suite have recently been radiometrically dated at 218 and 259 million years (Misch, 1966). If the rocks of the Easton Schist and the Shuksan belt are correlative, and the radiometric dates represent the age of their metamorphism, they can be considered as being late Paleozoic to early Mesozoic in age.

North Peak Metavolcanics

Introduction

The north peak of French Cabin Mountain is capped by a sequence, approximately 600 feet in thickness (Pl. 1, cross-section A), of interlayered metavolcanic rocks and impure marble schist of probable Mesozoic age. These rocks have been described by Smith and Calkins (1906) and Foster (1960), but have never been formally named. Because their occurrence is restricted to North Peak, the rocks are referred to in this report as the North Peak Metavolcanics.

Lithology

The metavolcanic rocks consist predominantly of cataclastically deformed volcanic tuff and lithic lapilli tuff. The lithic lapilli tuff is most abundant, and consists of stretched and compacted lapilli size lithic fragments, as well as angular chips of unstrained quartz and altered, untwinned plagioclase. The lithic fragments have been almost completely altered to hematite and chlorite, imparting a mottled, reddish-green color to the rock in hand specimen. Relict pilotaxitic textures of some lithic fragments suggests their possible derivation from andesitic lavas. A point count of one thin section gave a modal composition for the lithic lapilli tuff of 95 percent lithic

fragments and 5 percent quartz and feldspar fragments, and chloritic matrix.

Of lesser abundance than the lapilli tuff, and inter-layered with it, is altered volcanic tuff. This rock is schistose, very fine grained, and light greenish gray in color. In thin section it is seen to be composed of broken and stretched plagioclase laths in a sheared, partially recrystallized matrix of quartz, calcite, magnetite, and chloritic material. Brownish streaks, visible in hand specimen, are believed to be hematite. Neither the altered lithic lapilli tuff nor the altered volcanic tuff can be assigned to a specific grade of metamorphism or metamorphic facies. However, both have suffered cataclastic metamorphism, and are best described as semischists (Turner, in Williams, Turner, and Gilbert, 1954, p. 205).

Intercalated with the metavolcanic rocks are several layers of impure marble schist. This rock is light gray on the fresh surface, has a sugary appearance, and possesses a slight foliation which is emphasized by streaks of red hematite and green chlorite aligned parallel to the direction of foliation. Calcite and clear quartz grains are visible in hand specimen, and Foster (1960) reports the occurrence of plagioclase in thin section examination.

All of the metamorphic rocks of North Peak have a northwesterly trending foliation. This foliation is parallel to, and believed to be associated with, the

northwest-southeast trending schistosity in the underlying Easton Schist.

Contact Relations

The contact of the North Peak Metavolcanics with the underlying Easton Schist is exposed in the saddle between North Peak and South Peak (Pl. 1), where it strikes northwesterly and appears to dip steeply to the northeast (Pl. 1, cross-section A-A'), and on the ridge on the northeast side of North Peak (Pl. 1), where it strikes northwesterly and is believed to dip steeply to the southwest (Pl. 1, cross-section A-A'). Both the northwesterly strike of the exposed contacts and the northwest-trending schistosity of the North Peak rocks (p. 16) are parallel to the trend of foliation in the Easton Schist, which suggests that the two units have been deformed simultaneously. Although the trend of the contacts between the two units is evident, it is not known what the nature of the contact is. The contact may be either depositional or tectonic.

Age and Correlation

The age of the North Peak Metavolcanics is uncertain. Lithologically, the rocks resemble neither the Silver Pass Volcanics on near-by West Peak (Pl. 1), nor the Teanaway Basalt, farther south on Cle Elum ridge. Smith and Calkins (1906) assigned them to the Hawkins Formation of Carbon-

iferous age, which crops out in the northeast part of the Snoqualmie Quadrangle, though they state that they are "unlike the typical Hawkins greenstone", and Foster (1960) attempts no correlation. Because they are younger than the Easton Schist, of late Paleozoic or early Mesozoic age (p. 14), and because they are more highly deformed than sandstone of the late Cretaceous-Paleocene Swauk Formation, which unconformably overlies Easton Schist on adjacent South Peak (Pl. 1), it seems best to consider the North Peak Metavolcanics as Mesozoic in age.

Swauk Formation

Introduction

The Swauk Formation, of Upper Cretaceous and Paleocene age, was first described by Russell (1893, 1899), who called it the Swauk Sandstone, and later by Smith (1904) and Smith and Calkins (1906), who introduced the name Swauk Formation. Recently, rocks of the Swauk Formation have been described by Foster (1960). Swauk sedimentary rocks occur in the northeast part of the map area (Pl. 1), where they form ridges with steep slopes and rounded crests.

Description

The Swauk Formation consists primarily of beds of well indurated, medium to coarse-grained arkosic sandstone, pebble conglomerate, and siltstone, of which sandstone is the predominant rock type. The sandstone strata are monotonous in character, being typically massive and lacking in distinctive units. The fresh surface is light gray in color, while weathered surfaces may be light yellow, brown, or gray. Quartz, feldspar, and mica are visible in hand specimen. The Swauk is fractured along a northeast and northwest trending rectangular joint system. Bedding planes are not easily distinguished from jointing planes in the massive sandstone, and the accurate determination

of bedding attitudes in the Swauk Formation is difficult. Leaf imprints, believed to be of a species of palm, were the only fossils found in the sandstone (Pl. 1).

Lenses of conglomerate (Fig. 5) and shale also occur in the formation, and are of lesser abundance than sandstone. The conglomerate consists of poorly-imbricated, rounded to sub-rounded pebbles of quartzite in a coarse-grained, arkosic matrix. The lenses vary in thickness from a few inches to several feet and can seldom be traced more than a few tens of feet. Siltstone occurs as fine-grained, dark gray to black layers averaging 5 to 20 feet in thickness and interlayered, light tan colored sandstone horizons averaging 1 to 3 inches in thickness. No fossils were found in these strata, though carbonaceous material is abundant.

Distribution and Thickness

In the map area, Swauk Formation crops out on the flanks of Thorp Mountain anticline and at two places along the east shore of Kachess Lake. The formation has a map thickness² of 2545 feet as measured between points D and D' in the area of South Peak (Pl. 1). The thickness is

²Map thickness, in this report, refers to thicknesses indirectly obtained by multiplying the map-width of the outcrop, measured perpendicular to the strike, by the sine of the dip angle of bedding in the outcrop. For further explanation of the method, see Ragan, 1968, p. 10.

Figure 5. Conglomeratic lens in southwesterly-dipping Swauk sandstone. Outcrop is in Swauk Formation, along west shore of Cle Elum Lake (SW 1/4 SW 1/4 Sec. 17, T. 21N, R. 14E.) Hammer for scale.

highly variable over short distances, however, and ranges from zero feet near the north base of West Peak (Pl. 1), where the sandstone thins and pinches out (Fig. 6), to about 6600 feet in the area southwest of South Peak (Pl. 1, cross-section B-B'). Regionally, the Swauk is recognized as one of the most extensive formations in the North Cascades (Foster, 1960). Northeast of Leavenworth, it reaches a thickness of 23,000 feet (McKee, 1972).

Depositional Environment

The sedimentary rocks of the Swauk Formation appear to be non-marine in origin. Fossil palm leaves were found in the area, and leaves representing ferns, conifers, and deciduous species have been reported elsewhere in the Swauk (McKee, 1972). Fluvial features such as cross-bedding and cut and fill structures occur locally, and these features, together with the relatively thin conglomeratic and silty horizons, and the occurrence of terrestrial leaf fossils, suggest that the deposition of the Swauk sediments may have taken place in a deltaic or flood plain environment. Misch (1966) states that the deposition of Swauk Formation sediments occurred on the surface of a rapidly subsiding tectonic trough. A possible source for arkosic sandstone of the Swauk is the granitic rock of the Mount Stuart Batholith, northeast of the area (Erikson, 1973).

Contact Relations

The Swauk Formation unconformably overlies a metamorphic basement of Easton Schist (Fig. 6). In the area, the basal rock is arkosic sandstone, similar to rocks elsewhere in the section. Foster (1960), however, states that the basal Swauk in most places is shale or siltstone that grades downward into iron-rich laterite, and in some places is conglomerate.

Age and Correlation

As previously noted, the Swauk Formation unconformably overlies the Easton Schist, of late Paleozoic or early Mesozoic age. It is overlain unconformably by the Silver Pass Volcanics, of probable early Eocene age. The formation is generally considered late Cretaceous and Paleocene in age (Foster, 1960; Misch, 1966; McKee, 1972), and in view of the fact that no fossils diagnostic of age were found during the present investigation, a late Cretaceous and Paleocene age is retained in this report.

The Swauk Formation is equivalent to the Chuckanut Formation, also of late Cretaceous and Paleocene age (Misch, 1966; McKee, 1972). The Chuckanut Formation crops out in the North Cascades and consists of strata of sandstone and conglomerate similar in lithology and thickness to the Swauk Formation (Misch, 1966).

Figure 6. Contact relations between the Swauk Formation (middle ground), the underlying Easton Schist (Knoll in right foreground) and the overlying Silver Pass Volcanics (cliffs in background), in the area of West Peak. Note how strata of the Swauk Formation "pinch out" between the Silver Pass Volcanics and the Easton Schist. View is to south-southwest from west side of North Peak.

Silver Pass Volcanics

Introduction

The Silver Pass Volcanics, of early Eocene age, were named by Foster (1960) for the sequence of andesitic volcanic and pyroclastic rocks exposed near Silver Pass, at the head of Silver Creek (Pl. 1). The rocks form steep, rugged cliffs at the north end of Kachess Ridge (Fig. 7), as well as the sharp, west peak of French Cabin Mountain (Fig. 6).

Lithology

The Silver Pass Volcanics consists of light-colored andesitic lava flows, tuff, tuff-breccia, and volcanic breccia. The rocks are light gray or brown in color and have been deeply weathered. At Silver Pass, the type locality, a well-stratified sequence, 3600 feet thick, of interlayered volcanic and pyroclastic rocks is exposed (Figs. 8 and 9; Pl. 1, cross-section A-A'). Three lithologies are predominant in this section; (1) dark-colored, fine-grained aphanitic flow rock, (2) darker, more coarsely-grained porphyritic flow rock, and (3) light colored, highly weathered and altered tuff, lapilli-tuff, and tuff-breccia. Together, the lava flows constitute 2125 feet, or 59 percent of the section, and the pyroclastic rocks 1475 feet, or 41

Figure 7. Steep, southwesterly dipping strata of Silver Pass Volcanics, at north end of Kachess Ridge. Peaks in middle background are of Teanaway Basalt, on south side of Thomas Mountain fault, which runs through deep saddle in the upper-left part of the picture. View is to south-southeast from north end of Kachess Ridge.

Figure 8. Sequence of stratified westerly-dipping Silver Pass Volcanics exposed in area of Silver Pass. Thickness of section is 3600 feet (Fig. 9). View is to north from south end of broad, upper Silver Creek Valley.

Figure 9. Generalized columnar section of upper 3600 feet of Silver Pass Volcanics shown in Fig. 8. Numbers refer to thin sections examined. For geographic locations of thin sections, see Fig. 4. For detailed petrography, see Table I and Appendix D. Except for SP5E - SP9E, column is to scale, 1 inch = 647 feet.

percent of the section. Petrographic descriptions of these rocks, and of specimens from the underlying, undifferentiated rocks (Pl. 1), are presented in Table 1 (p. 30), and the petrography of the formation as a whole is presented summarily in Appendix D (p. 70). Map locations of the samples examined are shown in Figure 4 (p. 12), and the locations by Section, Township, and Range are given in Appendix A (p. 64). A poorly exposed section of Silver Pass Volcanics occurs on the west side of Kachess Ridge, along the east shore of Kachess Lake (Pl. 1). These rocks were not examined in thin section, but consist primarily of beds of volcanic breccia several hundred feet thick. The breccia consists of poorly-sorted, angular lithic fragments ranging in size from a few inches to several feet. The fragments consist predominantly of light green or pink, porphyritic volcanic rock and light gray, medium to coarse grained sandstone, as well as occasional clasts of more finely grained sedimentary rock. Some outcrops contain fragments of dense, greenish-black, aphanitic basalt. Where the breccia is well exposed, as it is directly east of, and uphill from, the outcrop of Swauk Formation near the south end of Kachess Lake Road (Pl. 1), it grades upward to lapilli tuff, and finally to tuff that appears to have been water-deposited. Thus, the breccia of the Silver Pass Volcanics may be all, or

TABLE I

PETROGRAPHIC DESCRIPTIONS OF THIN SECTIONS REFERRED TO IN
TEXT AND IN FIGURES 4 AND 9. SEE ALSO APPENDIX D.

<u>T.S. Number</u>	<u>Description</u>
SP6W	Aphanitic andesite containing scattered phenocrysts of zoned, euhedral plagioclase and euhedral to subhedral pyroxene in a pilotaxitic groundmass.
SP5W	Porphyritic andesite containing altered plagioclase and pyroxene phenocrysts in a holocrystalline, intergranular groundmass.
SP4W	Crystal lithic lapilli tuff containing broken crystals of plagioclase and quartz, as well as angular lithic fragments containing plagioclase, pyroxene, and hornblende in a pilotaxitic groundmass.
SP3W	Porphyritic aphanitic andesite containing phenocrysts of plagioclase and orthopyroxene in a cryptocrystalline groundmass of quartz and plagioclase.
SP2W (U)	Porphyritic, vesicular andesite containing phenocrysts of plagioclase and orthoclase (?), as well as glass, calcite, quartz, orthoclase (?), and clay (?) - filled vesicles in a cryptocrystalline matrix.
SP2W (L)	Aphanitic andesite containing altered phenocrysts of plagioclase and hornblende in a cryptofelsitic groundmass.
SP1W (U)	Aphanitic andesite containing euhedral hornblende phenocrysts and subhedral augite phenocrysts in a trachytic groundmass.
SP1W (M)	Porphyritic andesite containing phenocrysts of fresh, subhedral to euhedral twinned augite and altered plagioclase in a brownish-colored, cryptofelsitic groundmass.
SP1W (L)	Porphyritic pyroxene andesite containing phenocrysts of subhedral to euhedral augite and hypersthene, plus euhedral, normally zoned, slightly altered phenocrysts of

TABLE I (CONTINUED)

<u>T.S. Number</u>	<u>Description</u>
	plagioclase in a pilotaxitic groundmass.
SP0 (G)	Light green crystal vitric lithic lapilli tuff containing broken, subhedral to euhedral plagioclase phenocrysts, clear, arcuate glass shards, and lithic fragments having pilotaxitic, subophitic, and cryptofelsitic textures.
SP0 (W)	White crystal lithic lapilli tuff containing broken plagioclase crystals and stretched and compacted, holocrystalline, pilotaxitic aphanitic lithic fragments in a cryptofelsitic matrix.
SP1E (U)	Porphyritic andesite containing altered phenocrysts of plagioclase and hornblende in a cryptofelsitic matrix.
SP1E (L)	Aphanitic andesite containing partially altered phenocrysts of hornblende and no plagioclase in a cryptofelsitic groundmass.
SP2E	Lithic lapilli tuff containing rounded, calcite-cemented lithic fragments and quartz chips in a green, cryptocrystalline matrix.
SP3E	Vitric crystal lithic tuff containing rounded quartz chips and lithic fragments, plus partially deritrified glass fragments, in a matrix of calcite and hematite.
SP4E	Amygdaloidal lava flow containing numerous, elongate amygdales filled with calcite, quartz, and an unidentified, yellow to yellow-brown fibrous material.
SP5E	Crystal tuff containing scattered, broken plagioclase crystals in a green, cryptocrystalline matrix.
SP6E	Porphyritic andesite containing numerous phenocrysts of plagioclase and scattered hornblende phenocrysts in a light green, cryptofelsitic matrix.

TABLE I (CONTINUED)

<u>T.S. Number</u>	<u>Description</u>
SP7E	Aphanitic andesite containing flow-oriented plagioclase laths in a light green, trachytic matrix.
SP8E	Aphanitic andesite containing flow-oriented plagioclase laths in a black, magnetite-rich, trachytic matrix.
SP9E (U)	Aphanitic andesite containing flow-oriented plagioclase laths with occasional larger phenocrysts of plagioclase and hornblende in a green, trachytic groundmass.
SP9 (L)	Water-lain crystal tuff or volcanic sandstone containing well-sorted, broken, sub-rounded quartz and plagioclase crystals in a green, cryptocrystalline matrix.

part, sedimentary in origin.

Distribution and Thickness

Silver Pass Volcanics occur on the southwest flank of Thorp Mountain, the west side of Kachess Ridge, the east side of Cle Elum Ridge, and along the south side of Easton Ridge. The thickness of the strata is variable. A thickness of 5800 feet was determined for the strata exposed between the north end of Kachess Ridge and the area east of West Peak (Pl. 1, cross-sections A-A' and B-B'), and a range in thickness of 3100 feet (Pl. 1, F-F') to 7990 feet (Pl. 1, E-E') was determined for rocks exposed on the west side of Kachess Ridge. The latter determinations are map thicknesses and assume a constant dip angle in the Silver Pass Volcanics of 70 degrees, the attitude of bedding near the south end of the ridge (Pl. 1).

Contact Relations

The Silver Pass Volcanics lie stratigraphically between the underlying Swauk Formation and the overlying Teanaway Basalt. At Silver Pass, the rocks unconformably overlie Easton Schist (Pl. 1), and the basal lithology is andesite. To the east, between the south and west peaks of French Cabin Mountain, and on the east side of Cle Elum Ridge (Pl. 1), they overlie Swauk sedimentary rocks with

an angular discordance of about 10 degrees. Here the basal Silver Pass Volcanics consists of medium-grained sandstone. Examination of a single thin-section of this rock shows it to be composed of subangular to subrounded grains of quartz and plagioclase in a matrix of calcite and a greenish material, possibly clay. Quartz and plagioclase grains are approximately equal in abundance, vary in size from .2 to .6 mm, and account for 50 to 60 percent of the rock. Matrix composes the remaining 40 to 50 percent. The thickness of the sandstone, and the nature of the transition to the more typical volcanic and pyroclastic lithology of the Silver Pass Volcanics, is not known.

Age and Correlation

No fossils have been found in the Silver Pass Volcanics. They unconformably overlies the Swauk Formation of Upper Cretaceous and Paleocene age (p. 23), and are themselves overlain unconformably by the Teanaway Basalt, of early to middle Eocene age (p. 46); thus, the formation is probably of Paleocene or early Eocene age.

Diabase Dike Swarm

Introduction

A system of north to northeast-trending diabase dikes intrudes rocks of pre-Teanaway basalt age in the map area. The dikes are most numerous in the north-central and northeast area of the map (Pl. 1), and are most conspicuous where they intrude light-colored rocks of the Swauk Formation (Figs. 10, 12). They vary in thickness from a few feet to about 300 feet, are vertical or steeply dipping, and generally strike in a northeasterly direction. The dikes are best exposed on ridge-crests and slopes, which they tend to bisect, and can seldom be traced farther than the width of the ridge. An exception is the dike exposed along the northeast shore of Cle Elum Lake (Pl. 1), which can be traced for nearly a mile.

Lithology

The dike rock is typically dark, greenish gray on the fresh surface and weathers to reddish-brown. Textures, in hand specimen, range from fine-grained aphanitic in the outer zones of the dikes to coarse-grained phaneritic in their cores. One sample, taken from the center of a dike 300 feet in thickness (Fig. 4, no. DD1) was examined in thin section. The rock is holocrystalline and contains 53 percent euhedral labradorite (An 46-71), 28 percent

Figure 10. Diabase dike intruding light-colored Swauk sedimentary rocks on Cle Elum Ridge (NE 1/4 NW 1/4 Sec. 13, T21N, R13E). For scale, trees are 30 ft. high.

clear, subophitic augite ($2v=60$ degrees), and 18 percent chlorite, magnetite, and micropegmatite. Scattered, irregular patches of calcite and a fibrous, weakly birefringent material believed to be serpentine occur, and may indicate hydrothermal alteration, possibly of olivine.

Foster (1958) describes a typical, aphanitic dike rock as having intersertal texture and containing 50 percent plagioclase (An 33-50), 30 percent pyroxene (both pigeonite and augite), 15 percent glass, mineraloids, and chloritic material, and 5 percent opaques.

Contact Relations and Alteration

The dikes intrude rocks of the Easton Schist, the North Peak Metavolcanics, the Swauk Formation, and the Silver Pass Volcanics. Contacts of the dikes with rocks of the Easton Schist and Silver Pass Volcanics were not examined closely, but alteration of the host rocks appears to be minimal. Where the contact with sandstone of the Swauk Formation is observed, it is sharp (Fig. 11), and the sandstone immediately adjacent to the dike has been slightly silicified. On Cle Elum Ridge, large blocks of Swauk Formation have been entirely surrounded by dike rock (Fig. 12), but have been little altered. The most extensive alteration of rocks intruded by the dikes occurs

Figure 12. Large block of unaltered Swauk sandstone (lower right-center) enveloped by dike rock. Dike is same as that shown in Fig. 10.

in the metavolcanic rocks on North Peak. These rocks include metatuffs which consist of red and green-colored lithic fragments that give the rock a mottled, reddish-green appearance. Where dikes are seen to intrude the metatuff, as along the logging road on the west side of North Peak (Pl. 1), the mottled appearance of the host rock completely vanishes within a few inches of the contact with the dike, and the reddish-green color of the metatuff becomes black. None of the tuffaceous texture remains, and the dense, hornfelsed rock contains numerous veins of garnet and hematite.

Age and Correlation

The youngest rocks intruded by the dikes are those of the Silver Pass Volcanics, of Paleocene or early Eocene age, which suggests an early Eocene age for emplacement of the dikes. Smith and Calkins (1906) mapped dikes similar in trend and lithology to those described here as far eastward as Wenatchee. Foster (1958, 1960) described these dikes and named them the "Teanaway dike swarm". The diabase dikes occurring in the map area are believed to represent the westernmost end of the Teanaway dike swarm.

Teanaway Basalt

Introduction

The Teanaway Basalt, of early or middle Eocene age, was named by Smith (1903) for a sequence of basalt lava flows and interbedded pyroclastics exposed along the middle fork of the Teanaway River, east of the map area. Rocks of the formation are highly resistant, forming prominent, steep-sided ridges, and are best exposed at the south end of Kachess Ridge, in a bluff overlooking the town of Easton (Fig. 13).

Lithology

The Teanaway Basalt consists of flows of dense, black, very fine-grained aphanitic basalt, and pyroclastic rocks composed predominantly of highly altered, poorly sorted fragments of pumice and lava. Both flow rocks and pyroclastics weather reddish-brown, and the strata are contrasted with the gray color of the underlying Silver Pass Volcanics. Bedding in the Teanaway Basalt is thinner and more clearly defined than in the Silver Pass Volcanics or Swauk Formation. The bottom and middle zones of the flows, which average 50 to 100 feet in thickness, consist of greenish or bluish black, aphanitic basalt with few phenocrysts. The upper part of most flows contains a zone of

Figure 13. Strata of the Teanaway Basalt exposed at the south end of Kachess Ridge, in bluff overlooking town of Easton. View is to north, from south end of Kachess Lake Road.

breccia which varies in thickness from a few feet to over 20 feet. The breccia consists of fragments ranging in size from 1/2 inch to 8 inches, which have been cemented together by quartz, and which may be black, green, or red in color. The breccia zones contain 50-70 percent breccia-size fragments, 30-50 percent lapilli, and 10-30 percent tuff-size fragments (visual estimate). Some of the lava flows, such as the one exposed along the crest at the south end of Kachess Ridge, are amygdaloidal, and contain spherical amygdales of quartz and calcite varying in diameter from one to four inches. The lava flows are highly jointed, and break into rectangular blocks of varying size. Columnar jointing (Fig. 14) and ellipsoidal weathering structures are also present.

Samples of four lava flows and three pyroclastic units were studied in thin section. The thin section descriptions are presented in Table 2 (p. 44), and the petrography of the formation as a whole is summarily described in Appendix E. Sample locations are indicated in Figure 4 (p. 12).

Distribution and Thickness

Teanaway Basalt crops out in the southern half of the map area in the flanks of Cle Elum and Kachess Ridges, which form the limbs of south-plunging Domerie Creek syncline (Pl. 1). The thickest sequence of Teanaway strata

TABLE II

PETROGRAPHIC DESCRIPTIONS OF THIN SECTIONS REFERRED TO
IN TEXT AND IN FIGURE 4. SEE ALSO APPENDIX E.

<u>T.S. Number</u>	<u>Description</u>
TB1	Dense, black, aphanitic basalt containing fresh plagioclase, altered pyroxene, spherulites, and pools of brown glass, in part devitrified, in a pilotaxitic or felted groundmass.
TB4	Dark gray, aphanitic, vesicular basalt containing altered plagioclase microlites and abundant magnetite in a cryptocrystalline matrix of quartz, feldspar, and devitrified glass.
TB5	Dense, black, aphanitic basalt containing subhedral plagioclase microlites, sub-calcic augite, and magnetite in an intergranular groundmass.
TB6	Green lithic vitric lapilli tuff containing a chaotic assemblage of shattered and altered glass and pumice fragments, as well as highly vesicular, volcanic lithic fragments in a cryptocrystalline matrix of quartz, feldspar and clay.
TB7	Dense, black, aphanitic basalt flow containing plagioclase, pyroxene, magnetite, and glass in an intersertal groundmass.
TBDPK	Red-green, crystal lithic tuff, possibly water-lain, containing abundant, severely altered volcanic lithic fragments as well as broken, poorly-sorted crystal fragments of quartz and plagioclase in an opaque groundmass of green clay (?).
TBMT	Light green pumice tuff containing altered and compacted pumice fragments in a matrix of partially to completely devitrified glass and green clay (?).

Figure 14. Columnar jointing in lava flow of the Teanaway Basalt. Exposure is along Kachess Ridge Trail (SW 1/4 SW 1/4 Sec. 25, T.21N., R.13E.)

(4,400 feet, measured in cross-section C, Pl. 1) occurs on the west flank of the syncline. Regionally, the Teanaway Basalt crops out in an arcuate band, up to 4 miles in width, that extends from Kachess Lake eastward some 28 miles to Table Mountain, and ranges in thickness from 1,000 to 5,000 feet (Foster, 1960).

Contact Relations

The Teanaway Basalt overlies the Silver Pass Volcanics with an angular unconformity of 30-35 degrees. The contact with the underlying rocks occurs in a deep, thickly vegetated ravine on the west side of Kachess Ridge (Pl. 1), but is not exposed. On Cle Elum Ridge, north of Thomas Mountain (Pl. 1), the Teanaway Basalt has been brought into contact with both the Silver Pass Volcanics and the Swauk Formation by the steeply southwest-dipping Thomas Mountain Fault (Pl. 1). The relationships in this area are obscured by vegetation, and, as noted earlier (p. 9), this contact had previously been interpreted as an unconformity (Foster, 1960).

Age and Correlation

The Teanaway Basalt unconformably overlies the Silver Pass Volcanics, of early Eocene age (p. 34). Outside the area, it is overlain concordantly by strata of the Roslyn Formation (Foster, 1960), which contains an Eocene flora

(Smith and Calkins, 1906) and middle or upper Eocene fauna (Wheeler, 1955). The Teanaway Basalt is, therefore, considered to be early to middle Eocene in age. The Teanaway Basalt has not been correlated with volcanic strata of other formations, though Weaver (1937) believed that the rocks had been deposited during the same time interval as the Metchosin Volcanics of Western Washington.

Roslyn Formation

Introduction

The Roslyn Formation, of middle or upper Eocene age, was named by Russell (1899) for the Roslyn coal-mining district near Roslyn, Washington. Approximately one square mile of rocks believed to be part of the Roslyn Formation is exposed in the extreme southeast corner of the map area (Pl. 1), where it underlies the low, thickly wooded south end of Cle Elum Ridge.

Lithology

The strata of the Roslyn Formation consist of yellowish, coarse-grained, friable sandstone and interbedded reddish-orange siltstone and claystone. Rocks of these strata were not examined in thin section. In hand sample, the sandstone contains abundant quartz and feldspar, and is arkose. The siltstone and claystone are identified as such on the basis of their very fine grain-size, lack of fissility, and clayey odor when moistened. The layers of arkosic sandstone show both graded-bedding and cross-bedding, contain pebbles and carbonaceous debris at their base, and range from a few inches to several feet in thickness. The upper zones of the arkosic strata have been stained to a reddish color by overlying layers of siltstone and claystone. These layers are generally less than one foot in

thickness.

Distribution and Thickness

The Roslyn Formation crops out along the southwest shore of Cle Elum Lake and forms the low, southern-most part of Cle Elum Ridge (Pl. 1). The western slope of the ridge is believed to be the top of the Roslyn Formation strata, and the map thickness of the section occurring between the ridge crest and the shore of the lake (Pl. 1, Line H-H') is 2,275 feet. Regionally, strata of the Roslyn Formation are best exposed along the forks of the Teanaway River, to the east of the map area (Foster, 1960), and attain a maximum thickness of 3,500 feet (Smith and Calkins, 1906).

Contact Relations

The Roslyn Formation, in the map area, is in fault-contact with strata of the Teanaway Basalt. The contact occurs in a stream-bed on the southwest shore of Cle Elum Lake (Pl. 1). It is not exposed, and is interpreted as a fault on the basis of the abrupt change in attitude between Roslyn and Teanaway strata on opposite sides of the stream, and because of the trend of the contact, which is nearly at right angles to the general strike of bedding in the two formations (Pl. 1). The fault strikes northeast-

southwest and has an estimated dip of 30-40 degrees southeast (Pl. 1). The northwest-southeast trending contact in the valley of Domerie Creek (Pl. 1) is also believed to be a fault (Foster, 1960). On a regional scale, the nature of the contact of the Roslyn Formation with the underlying Teanaway Basalt is described by Foster (1960) as "controversial", and may either be conformable or unconformable.

Age and Correlation

No fossils were found in the Roslyn Formation during this investigation. An age of middle Eocene has been suggested by Hesse (1936) on the basis of a fossil fish, and two fossil turtle carapaces, reported by Wheeler (1955), indicate a middle or upper Eocene age for the Roslyn strata. Weaver (1937) believed the rocks to be upper Eocene in age, and, on the basis of the foregoing discussion, an age of middle or upper Eocene is here assumed for the Roslyn Formation. These rocks have not been chronologically or lithologically correlated with rocks of other formations.

Howson Andesite

General Discussion

Several outcrops of gray porphyritic hornblende andesite occur on the west slope of North Peak, near the top (Pl. 1). The rocks appear to unconformably overlie the North Peak Metavolcanics, which are believed to be of Mesozoic age (p. 18), though the contact between the two units is obscured by talus. The andesite is unaltered and appears similar in hand specimen to samples of the Howson Andesite, which crops out approximately 4 miles to the northeast on Sasse Mountain. The Howson Andesite was named and described by Smith and Calkins (1906), but was not assigned an age. Foster (1960) stated that the Howson Andesite is "apparently the youngest formation in this and the surrounding area."

Lithology

The andesite is greenish gray on the fresh surface and weathers to light gray. Phenocrysts of hornblende up to 3 mm. in length are visible in hand specimen, as well as slightly smaller crystals of plagioclase. In thin section, the rock consists of 12 percent green, euhedral, zoned, and partially resorbed hornblende, 24 percent cloudy, complexly zoned plagioclase, and 64 percent matrix consisting of

felted plagioclase microlites, interstitial quartz, brownish chlorite, and granular magnetite. In the outcrop, the andesite breaks into angular blocks, averaging about a foot in diameter, from which extensive talus slopes have developed.

Age

The age of the Howson Andesite cannot be precisely determined from relationships in the area. Foster (1960, Pl. 1), however, shows the formation occurring stratigraphically above the Yakima Basalt of Mio-Pliocene age, and on this basis, a tentative Pliocene age is assumed in this report for the Howson Andesite.

STRUCTURAL GEOLOGY

General Relations

The most important structural feature in the map area is the north-northwest trending Thomas Mountain fault (Pl. 1), which approximately bisects the area and separates older, pre-Tertiary and Upper Cretaceous-Paleocene metamorphic and sedimentary rocks from younger Eocene volcanic and sedimentary rocks. Interlayered lava flows and pyroclastic rocks of the early Eocene Silver Pass Volcanics are exposed on both sides of the fault. North of Thomas Mountain fault, the structural trend is northwest, roughly paralleling the trends in Paleozoic and Mesozoic rocks of the North Cascades. The trend of the diabase dike swarm is northeasterly, nearly at right angles with that of the older rocks. South of Thomas Mountain fault, the older, northwesterly structural trend is reflected by Domerie Creek syncline, while the Silver Creek fault system (Pl. 1) is developed along a younger, northeasterly trend.

Folding

Two major folds occur in the area, Thorp Mountain anticline, to the north of Thomas Mountain fault, and Domerie Creek syncline, south of the fault. According to the classification of Straley (1935, in Badgley, 1965), these are open, cylindrical, inclined, asymmetrical folds

(see map and cross-sections, Pl. 1). A Beta diagram of 12 Easton Schist S_1 (schistosity) planes, constructed on a Schmidt stereographic net (Fig. 15), suggests that the axis of Thorp Mountain anticline trends south 31 degrees east, plunging 10 degrees. Domerie Creek syncline has a similar trend on the south side of the Silver Creek fault (Pl. 1). On the north side of the fault, the synclinal axis has a more northerly trend, and it is believed that rotational movement on the Silver Creek fault is responsible for the change in direction of the synclinal axis.

Faulting

The major fault in the area is the Thomas Mountain fault, which strikes north 63 degrees west and has an estimated dip of 70 degrees southwest. Movement on the fault has been predominantly vertical, the block on the south side having moved down with respect to the block on the north, although it is believed that some rotational movement, associated with movement on the Silver Creek fault, has also occurred. Evidence for rotational movement is provided by the structural block containing Thomas Mountain, which is bounded on the north by Thomas Mountain fault and on the south by Silver Creek fault (Pl. 1). The structural trend of this block is nearly north-south, while the structural trends of the adjoining north and south blocks are northwest-southeasterly, and nearly

Figure 15. Beta diagram constructed from 12 S1 (Schistosity) planes in the Easton Schist. Points indicate intersections of planes; "X" (visually located at maximum point density) indicates intersection of fold axis with lower hemisphere of projection. Direction of fold axis is S31° E, plunging 10°.

parallel. These relationships are difficult to explain without the inference of rotational movement.

The amount of displacement on the Thomas Mountain fault is not known. The significance of the fault in the interpretation of the contact relations between rocks of the Swauk Formation, Silver Pass Volcanics, and Teanaway Basalt, has been previously discussed (p. 9), and will not be repeated here. The fault has also complicated relationships at the north end of Kachess Ridge, where southwesterly dipping strata of the Silver Pass Volcanics on the south flank of Thorp Mountain anticline, have been brought into contact, along strike, with oppositely dipping Silver Pass strata on the west flank of Domerie Creek syncline (Pl. 1).

Three sub-parallel, northeast-trending faults occur to the south of Thomas Mountain fault. The most important of these is the Silver Creek fault which dips approximately 30 degrees to the southeast and which, as noted earlier in the discussions of Domerie Creek syncline and Thomas Mountain fault, is believed to have undergone predominantly rotational movement. The movement has shifted the synclinal axis (in map section) from a direction of north 52 degrees west on the south side of the fault to a direction of north 16 degrees west on the north side of the fault (Pl. 1). The two faults to the south of the Silver Creek fault also have dips of approximately 30 degrees to the southeast, but are apparently normal faults, the blocks on their south

sides having moved vertically downward with respect to the blocks on their north sides. To the north of Thomas Mountain fault, the Kachess Ridge fault (Pl. 1) truncates flows of the Silver Pass Volcanics. This fault, like the Silver Creek fault, strikes northeasterly and dips to the southeast, and may have developed contemporaneously with the Silver Creek and other northeasterly striking faults.

GEOLOGIC HISTORY

Introduction

Seven distinct rock units are recognized in the area. These, and the tectonic events associated with them, are summarized below, in order of decreasing age.

Summary of Rock Units and Tectonic Events

(1) The oldest rocks in the area are those of the Easton Schist. They form a basement of blueschist, green-schist, and graphite schist that was metamorphically derived from a eugeosynclinal assemblage of basaltic volcanic rocks and carbonaceous sedimentary rocks. The orogeny which produced the Easton Schist probably occurred in late Paleozoic or early Mesozoic time (p. 14), and marks the beginning of deformational history in the area.

(2) A sequence of pyroclastic rocks and limy sedimentary rocks was deposited upon the Easton Schist during the Mesozoic. Following their deposition, these rocks, along with the Easton Schist, were folded along a north-westerly trend, and the pyroclastic and sedimentary rocks were metamorphosed to marble and semischist, now recognized as the North Peak Metavolcanics. Most of these rocks were later removed by erosion, but a small mass, tightly folded with the Easton Schist (Pl. 1,

cross-section A-A'), is preserved at North Peak.

(3) During the late Cretaceous and Paleocene, arkosic sandstone of the Swauk Formation was deposited on the eroded surface of the Easton Schist. During or following this depositional phase, the Swauk Formation and underlying Easton Schist were folded along the northwesterly trend established in the Easton Schist during the Mesozoic. Folding was accompanied by erosion, during which a part of the Swauk Formation was removed, and the Easton Schist was re-exposed in the area of French Cabin Basin.

(4) The Silver Pass Volcanics, consisting of interlayered lava flows and pyroclastic rocks, were deposited nonconformably on the Easton Schist and unconformably on the Swauk Formation during the early Eocene. The differences in bedding altitude between strata of the Silver Pass Volcanics and Swauk Formation are not great (Pl. 1), and the attitudes suggest that strata on the flanks of Thorp Mountain anticline and Domerie Creek syncline probably dipped less than 20° prior to the deposition of the Silver Pass Volcanics. Folding along the northwesterly trend continued, however, and bedding on the flanks of these folds had probably attained dips of about 35° by the time the Silver Pass rocks had accumulated.

(5) Diabase dikes intruded the folded Easton Schist,

Swauk Formation, and Silver Pass Volcanics during the early or middle Eocene. The dikes were emplaced along a northeasterly trend, approximately at right-angles to the northwesterly fold trend. The northeasterly trend of dike emplacement may have been related to the stresses responsible for the folding of the Silver Pass and older rocks (Foster, 1960).

(6) Lava flows of the Teanaway Basalt were deposited unconformably on the Silver Pass Volcanics during the middle Eocene. The flows are exposed in the flanks of Domerie Creek syncline and have an average dip of 35° . The underlying Silver Pass strata, on the west flanks of both Domerie Creek syncline and Thorp Mountain anticline, have dips averaging about 70° , suggesting that folding along the northwesterly trend continued during, or following, the extrusion of the Teanaway Basalt. The present fold configuration was reached at some time following the deposition of the Roslyn Formation, of middle or late Eocene age. Strata of the Roslyn Formation are in fault contact with the Teanaway Basalt and older rocks.

(7) Faulting occurred during, or following, the final phase of middle or late Tertiary folding. Thomas Mountain fault, the main structural element in the area, nearly parallels the northwest-trending fold axes (Pl. 1), and reflects the northwesterly structural trend established in the basement rocks during the Mesozoic. The Silver

Creek fault, and the two faults to the south, have a northeasterly trend (Pl. 1). This trend may reflect the **direction in which shearing stresses**, associated with the formation of Thomas Mountain fault, occurred in the basement rocks.

(8) The final phase of volcanic activity in the region occurred during the Pliocene with the extrusion of the Howson Andesite. Most of these rocks were subsequently removed by erosion, and their original areal extent is not known.

(9) The youngest geological event recorded in the area is the formation of the deep basins now occupied by Lakes Cle Elum and Kachess. Glacial striations, such as those found on the west shore of Cle Elum Lake, suggest that these basins were carved by valley glaciers, probably during the most recent period of Pleistocene glaciation.

REFERENCES CITED

- Badgley, Peter C., 1965, Structural and tectonic principles: New York, Harper and Row, Publishers, 521 p.
- Erikson, E.H., 1973, Degranitization of the late Cretaceous Mt. Stuart Batholith, Central Cascades, Washington: Geol. Soc. America Abs. W. Programs, V. 5, no. 1, p. 39.
- Foster, R.J., 1958, Teanaway dike swarm, Central Washington: Am. Jour. Sci., v. 256, p. 644-653.
- _____, 1960, Tertiary geology of a portion of the Central Cascade Mountains, Washington: Geol. Soc. America Bull., v. 71, p. 99-126.
- Hesse, C.J., 1936, A new species of the genus *Priscarara* from the Eocene of Washington: Jour. Geology, v. 44, p. 745-750.
- Hyndman, Donald W., 1972, Petrology of igneous and metamorphic rocks: New York, McGraw-Hill, Inc., 533 p.
- McKee, Bates, 1972, Cascadia - The geologic evolution of the Pacific Northwest: New York, McGraw-Hill, Inc. 394 p.
- Misch, P., 1959, Sodic amphiboles and metamorphic facies in Mount Shuksan belt, Northern Cascades, Wash. (Abst.): Geol. Soc. America Bull., v. 70, p. 1736-1737.
- _____, 1966, Tectonic evolution of the Northern Cascades of Washington State - A west-cordilleran case history, in Gunning, H.C., ed., A symposium on the tectonic history and mineral deposits of the western cordillera in British Columbia and neighboring parts of the United States: Canadian Inst. Mining and Metallurgy Spec. v. 8, p. 101-148.
- Ragan, Donal M., 1968, Structural geology - An introduction to geometrical techniques: New York, John Wiley and Sons, Inc., 166 p.
- Russel, I.C., 1893, A geologic reconnaissance in Central Washington: U.S. Geol. Survey, Bull. 108, 108 p.

- _____, 1899, Geology of the Cascade Mountains in Northern Washington: U.S. Geol. Survey, 20th Ann. Rept., pt. 2, p. 83-310.
- Smith, G.O., 1903, Contributions to the geology of Washington: The geology and physiography of Central Washington: U.S. Geol. Survey Prof. Paper 19, p. 9-39.
- _____, 1904, Description of the Mount Stuart quadrangle [Wash.]: U.S. Geol. Survey, Geol. Atlas, Mount Stuart folio (no. 106), 10 p.
- _____, and Calkins, F.C., 1906, Description of the Snoqualmie quadrangle [Wash.]: U.S. Geol. Survey, Geol. Atlas, Snoqualmie folio (no. 139), 14 p.
- Stout, Martin L., 1964, Geology of a part of the South-Central Cascade Mountains, Washington: Geol. Soc. America Bull., v. 75, p. 317-334.
- Weaver, C.E., 1937, Tertiary stratigraphy of Western Washington and Northwestern Oregon: Univ. Wash. Publ. Geol., v. 4, p. 1-266.
- Wheeler, H.E., 1955, Dermatimidid turtle from the Roslyn Formation of Washington (Abst.): Geol. Soc. America Bull., v. 66, p. 1668.
- Williams, H., Turner, F.J. and Gilbert, C.M., 1954, Petrography: San Francisco, S.A. Freeman and Co., 406 p.

APPENDIX A

LOCATION AND HAND-SPECIMEN DESCRIPTION OF SAMPLES EXAMINED IN THIN SECTION. SEE ALSO LOCATION MAP, FIGURE 4, AND PETROGRAPHIC SUMMARIES, TABLES I AND II AND APPENDICES B-E.

<u>Formation</u>	<u>Description and Location</u>
Easton Schist	
ESB(1-3)	Glaucophane epidote blueschist, south side of French Cabin Creek Road, SE 1/4 SW 1/4 Sec. 2, T21N, R13E. Three thin sections.
ESG(1,2)	Clinozoisite chlorite greenschist, steep cliff 100 yards east of bridge across French Cabin Creek, NE 1/4 NE 1/4 Sec. 2, T21N, R13E. Two thin sections.
North Peak Metavolcanics	
NPK1	Welded lapilli tuff, peak of North Peak, French Cabin Mountain, S 1/2 SW 1/4 Sec. 1, T21N, R13E. One thin section.
NPK2(1,2)	Chloritic semischist, saddle between North and South Peaks, French Cabin Mountain, S 1/2, NW 1/4 Sec. 12, T21N, R13E. Two thin sections.
Silver Pass Volcanics	
SP6W	Black, aphanitic andesite, crestline of Kachess Ridge, SE 1/4 SW 1/4 Sec. 10, T21N, R13E. One thin section.
SP5W	Olive green, porphyritic andesite, 500 yd. NW of SP6W, along ridge crest. One thin section.
SP4W	Light gray green crystal lithic lapilli tuff, 300 yd. NW of SP5W, along ridge crest. One thin section.
SP3W	Highly altered, greenish black, porphyritic hornblende andesite, 200 yd. N. of SP4W, along ridge crest, Kachess Ridge. One thin section.

APPENDIX A (CONTINUED)

<u>Formation</u>	<u>Description and Location</u>
Silver Pass Volcanics	
SP2W(1,2)	Brownish white, highly weathered andesitic flow rock above reddish-brown hornblende andesite, on E. side of Kachess Ridge, 150 yd. NE and downhill from SP 3W. Two thin sections.
SP1W(1-3)	Upper hornblende andesite flow, middle aphanitic andesite flow, and lower hypersthene andesite flow, forming prominent peak to west of saddle at Silver Pass, French Cabin Creek Trail, NE 1/4 NW 1/4 Sec. 10, T21N, R13E. Three thin sections.
SP0W(1-5)	Upper green, crystal lithic lapilli tuff and lower white crystal lithic lapilli tuff, exposed west of trail at Silver Pass and east of sharp peak formed by SP1W. Five thin sections.
SP1E(1,2)	Upper porphyritic hornblende andesite flow and lower aphanitic hornblende andesite flow, forming peak directly east of trail at Silver Pass, NW 1/4 NE 1/4 Sec. 10, T21N, R13E. Two thin sections.
SP2E	Green, crystal lithic tuff, possibly water-lain, forming unit 120 ft. thick beneath flows of SP1E, 300 yd. E. of trail at Silver Pass. One thin section.
SP3E	Red, lithic lapilli tuff below SP2E. One thin section.
SP4E	Light yellow, highly amygdaloidal flow rock, NE side of Knob to NW of West Peak, NW 1/4 SW 1/4 Sec. 11, T21N, R13E. One thin section.
SP5E	Olive green crystal tuff, west side of West Peak on dip slope, SE 1/4 SW 1/4 Sec. 11, T21N, R13E. One thin section.

APPENDIX A (CONTINUED)

<u>Formation</u>	<u>Description and Location</u>
Silver Pass Volcanics	
SP6E	Similar to SP5E, from outcrops near peak of West Peak, French Cabin Mountain. One thin section.
SP7E	Bluish green aphanitic andesite, NE side of West Peak, probably below flows SP5E and SP6E. One thin section.
SP8E	Dense, black aphanitic flow rock, 100 yd. E. of SP7E, NE side of West Peak. One thin section.
SP9E(1,2)	Upper green, aphanitic andesite and lower, light green, water-lain crystal tuff or volcanic sandstone, N. side of Domerie Peak Trail, on ridge between West and South Peaks, NW 1/4 NW 1/4 Sec. 13, T21N, R13E. Two thin sections.
SP53	Highly weathered, rhyolitic andesite flow, W. shore of Cle Elum Lake, NW 1/4 SW 1/4 Sec. 20, T21N, R14E. One thin section.
SP32	Green, crystal lithic tuff identical to SP2E, 300 yd. S. of SP53, near mouth of creek, SW 1/4 SW 1/4 Sec. 20, T21N, R14E. One thin section.
Teanaway Basalt	
TB1	Dense, black aphanitic basalt, 300 yd. S.E. of beacon, S. end of Kachess Ridge, NW 1/4 SE 1/4 Sec. 26, T21N., R.13E.
TB4	Greenish-black, vesicular, aphanitic basalt, 400 yd. S. of TB1 at break in slope, S. end of Kachess Ridge.
TB5	Black, aphanitic basalt, 500 yd. S. of TB4, midway between top and bottom of Kachess Ridge.

APPENDIX A (CONTINUED)

<u>Formation</u>	<u>Description and Location</u>
Teanaway Basalt	
TB6	Green, vitric lithic lapilli tuff, 300 yd. S. of, and down-slope from, TB5, S. end of Kachess Ridge.
TB7	Black, aphanitic basalt, 400 yd. SW of, and downslope from, TB6, near base of Kachess Ridge, SW 1/4 NE 1/4 Sec. 35, T21N, R13E.
TBDPKP	Highly altered, vitric crystal lithic tuff, on Domerie Peak trail, 600 yd. NW of peak of Mt. Baldy, NW 1/4 NW 1/4 Sec. 31, T21N, R14E.
TBMT	Dark gray, glassy, vesicular flow rock, W. slope of Cle Elum Ridge, NE 1/4 SW 1/4 Sec. 24, T21N, R13E.
Diabase Dike Swarm	
DD1	Gray coarsely crystalline diabase dike, W. side of logging road, NE 1/4 Sec. 18, T21N, R14E.
Howson Andesite	
HA1	Porphyritic hornblende andesite, on ridge 500 yd. S. of top of North Peak, NW 1/4 NW 1/4 Sec. 12, T21N, R13E. One thin section.

Appendix B, Summary of Petrography of Easton Blueschist

Mineral	Glaucophane	Epidote	Chlorite	Quartz	Plagioclase
Modal %*	6-23	58-78	3-11	6-9	T
Pleochroism	strong; X = neutral, Y = violet, Z = blue	slight; shades of green, yellow-green	strong; neutral to green		
Optic Angle	(-) 45°	(-) 80	small		undetermined
Birefringence	undetermined	strong, .03	extremely weak		
Grain size	.1 mm	variable	variable	variable	variable
Occurrence	lenticular bands	segregation layers	veins; with epidote and glaucophane	veins; lenticular bands with pc	lenticular bands with quartz
Texture	nematoblastic	granoblastic	granoblastic	granoblastic	granoblastic, untwinned
Additional notes	Granular sphene and lesser amounts of partially oxidized magnetite are present as accessories.				

* Range of three thin sections, 500 points each

Appendix C, Summary of Petrography of Easton Greenschist

Mineral	Plagioclase (relict)	Clinozoisite	Plagioclase (metamorphic)	Chlorite	Epidote	Calcite
Average Modal %*	18	8	47	22	2	3
Pleochroism		slight; shades of pink and lt green		strong; shades of green, yellow- green	apple green to yellow- green	
Optic angle (-) 90°		(+) 60°		small	undeter- mined	(-) 0°
Mole % An	35		Undetermined			
Bire- fringence		weak, .015		very weak	strong .04	extreme
Occurrence	relict	porphyroblasts	veins; ma- trix	alteration of px	with clino- zoisite	veins
Texture	blasto- porphyritic	idioblastic	xenoblastic	xenoblastic	xenoblastic	xenoblastic
Average grain size (mm)	2-4	1-2	.1	very fine	variable	variable
Additional notes	relict plagioclase blastoporphs are partly enclosed in bladed porphyroblasts of clinozoisite and a lepidoblastic matrix of chlorite, clinozoisite, quartz, and plagioclase.					

* Point count of 1 thin section

Appendix D: Petrographic Summary of Silver Pass Volcanics, Part I

ROCK TYPE	APHANITES	PORPHYRITIC APHANITES	PYROCLASTIC ROCKS
Topographic Expression	sharp hogbacks and rims	steep slopes and cliffs	smooth, gentle slopes
Color Fresh Color Weathered	dark gray to black, light brown or gray	greenish gray, greenish brown, brown, yellow-brown	purple, red, green, light green, light gray
Grain Size	fine, .1 mm	fine matrix; 1-3 mm phenocrysts	tuffs, lapilli-tuffs, tuff-breccias
Crystallinity	merocrystalline to holocrystalline	holocrystalline	none
Textures	pilotaxitic, trachytic, felted, hyalopilitic; may be amygdaloidal, spherulitic, or axiolitic	pilotaxitic, trachytic, cryptocrystalline	poorly sorted, angular lithic fragments, usually with pilotaxitic or vitroclastic textures, and broken, euhedral crystals in a clay-like matrix

Appendix D, cont.: Petrographic Summary of Silver Pass Volcanics, Part II

ROCK TYPE	MINERALOGY and AVERAGE MODAL COMPOSITION
APHANITES	29-59%* fresh to highly weathered, subhedral to euhedral, twinned, zoned (An38-An64) plagioclase phenocrysts averaging .5 mm to 1 mm in length; 0-22% subhedral to euhedral phenocrysts of green or greenish-brown hornblende averaging .5 mm in length and altering in part to chlorite and magnetite; 0-35% calcite and epidote occurring in irregular patches in the matrix and as an alteration product of plagioclase and pyroxenes; 0-35% orthopyroxene microlites; 0-6% magnetite, and 13-97% matrix consisting of plagioclase microlites, granular pyroxene, and yellow to green, weakly to moderately birefringent material believed to be clay.
PORPHYRITIC APHANITES	6-22%** subhedral to euhedral, zoned (An32-An50) phenocrysts of plagioclase, highly corroded and embayed and altered entirely or in part to calcite and/or quartz, average length of phenocrysts 3 mm; 0-5% clinopyroxene phenocrysts averaging .25 mm to 1 mm in length, altered in some rocks to yellow-green, clay-like aggregates and bordered at grain edges in some rocks by orthopyroxene or magnetite; 0-12% twinned, weakly pleochroic orthopyroxene; 0-4% hornblende, in part resorbed or altered to magnetite and chlorite, occasionally oxidized; 0-1% calcite and epidote developed along cleavages and fractures in plagioclase crystals, and as patches, veins, and stringers; 0-1% magnetite, mostly secondary after hornblende and pyroxene, and 65-89% matrix, consisting of cryptocrystalline quartz, feldspar, and possibly clay minerals.
PYROCLASTIC ROCKS	14-17%*** lithic fragments, mostly volcanic and having vitroclastic or pilotaxitic textures, and containing plagioclase phenocrysts ranging from An36 to An54; 10-21% fresh, broken crystals of plagioclase ranging from An25 to An40; 0-2% broken, angular quartz fragments, and 60-76% unresolvable, greenish-colored, weakly birefringent matrix.

* Range of 4 thin sections point-counted 500 points each

** Range of 4 thin sections point-counted 500 points each

*** Range of 3 thin sections point-counted 500 points each

Appendix E, Part 1: Petrography of Teanaway Basalt Flow Rocks

Color	glassy black when fresh; shades of gray, brown, and red-brown when weathered	
Grain size	very fine, aphanitic; crystals average less than .25 mm in diameter	
Crystallinity	generally microcrystalline, but some flows are holocrystalline	
Matrix	intergranular or intersertal texture with pyroxene, plagioclase micro-lites, magnetite octahedra, and interstitial glass, clay minerals (?), and chlorophaeite (?)	
Mineralogy	Modal %*	Distinguishing Features
pyroxene	11-51	clear to very pale green, non-pleochroic, 2nd order interference colors
	35-54	zoned microlites (An39-An55) of random orientation
magnetite	3-17	corroded rods and euhedral octahedra
quartz	0-10	anhedral intergrowths with plagioclase
glass	0-18	interstitial and amygdaloidal; yellow, brown, brownish-green
hematite	T	blood-red borders around magnetite
calcite	0-5	random pools and veins throughout some flows
other	T	yellow, brown, or green materials believed to be clay minerals or chlorophaeite

* Range of 3 thin sections point-counted, 300-500 points each.

Appendix E, Part 2: Petrography of Teanaway Basalt Pyroclastics

Color	dull green to mottled red and green; fragments may be green, red, purple, or brown	
Fragment size	less than 1 mm to several centimeters, average about .5 centimeter	
Fragment nature	highly angular, poorly sorted lava fragments, vitric fragments, and broken crystals	
Matrix	optically unresolvable matrix believed to be a clay mineral (possibly halloysite) with minor amounts of calcite, hematite and quartz, often difficult to distinguish between matrix clastic materials	
Mineralogy	Modal %*	Distinguishing Features
Lithic	37-90	textures often obliterated by alteration, but where preserved appear to be cryptofelsitic, with minute feldspar micro-lites intergrown with quartz; mafic minerals not distinguishable; alteration products probably clay (smectite?)
Vitric	0-90	vitric fragments are pumicious with vesicles filled with green palagonite (?), growths of quartz and plagioclase, calcite, or opal; fragments usually stretched and flattened with arcuate shards trailing off into matrix
Crystal	0-4	crystal fragments, when present, consist of unaltered, poorly-sorted angular chips of quartz and untwinned plagioclase averaging .5 mm in length
Matrix	10-59	much of matrix consists of light, orange-brown, cryptocrystalline material which is dark gray, nearly isotropic under crossed-nicols, and is tentatively identified, on the basis of extremely weak birefringence (.001) and shatter-cracks, as halloysite.

* Range of 3 thin sections, 1 point-counted, 2 visually estimated